simulation of imagined realities

environmental design decision support tools in architecture

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Te Whare Wananga o te Upoko o te Ika a Maui

STATEMENT OF AUTHORSHIP

BY PHD CANDIDATE

Except where specific reference is made in the main text of the thesis, this thesis contains no material extracted in whole or in part from a thesis, dissertation, or research paper presented by me for another degree or diploma.

No other person's work (published or unpublished) has been used without due acknowledgment in the main text of the thesis.

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abstract

The spur for this research was a lack of use by architecture practitioners of the environmental design decision support tools (eddst's) they learn to use during their education. It was hypothesised that lessons for the improvement of eddst's could be found in a systematic examination of the problems encountered by design teams with a range of currently available eddst's.

The research plan was to establish through surveys and case studies how practising architects who have tried to use building eddst's assess the effectiveness of these tools. A range of different types of eddst was examined, each addressing a different aspect of the environment in buildings.

The research did not achieve its original goal of developing a formula for the generation of new eddst's for architects in the fields of building acoustics, lighting, thermal design and aerodynamics. What was found is a more fundamental common denominator underlying building design eddst's: the need for built-in Quality Assurance measures that assure not only the architect, but also the simulationist and the client of the reality of the ebuilding performance predictions.

It was found that contrary to their general reputation, designers do want detailed quantitative environmental information. They want to be able to discuss costs and benefits of decisions. However, they also want to be able to understand and trust this information. The output from eddst's must therefore also be qualitative in the sense that it communicates the quality of life resulting from a design decision.

What is proposed therefore for designers and simulationists is **Quality Assurance (QA) procedures** that are codified and incorporated into the design tools themselves. These are to ensure that the 'black box' of a digital simulation of building performance yields information that designers feel they can trust. The research demonstrates that to address the issues identified in the practitioner surveys, a **Quality Control (QC) reality test** is the single most important feature needed in any QA process. This would be a reality test that examines whether the ebuildings constructed with an eddst behave in a believable manner - like a 'real' building.

The proposed Simulation QA (SimQA) approach is an internet web service. It is a database of the databases available on the internet of Quality Assured performance data. Each time a person sets up a new Quality tested eddst input file or measures a building, it becomes another "data point" - another database listed in the SimQA metadata.

Also required in a robust QA process is the development of international norms for the simulation of building performance. www.aecsimqa.net is proposed as the venue for the development of an international documentation standard for simulation.

Finally, modern computer-based building performance simulation has not rid the design profession of its traditional problem with design tools: that they evaluate completed designs. The proposed database will make web-accessible a set of tested building designs and their associated performance measures. Placed at the designer's fingertips this will reveal insights into how their current building design should perform. It should be possible to generate initial design ideas based on systematic study of the successful precedents!

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acknowledgements

To do justice to the contributions of the people who have provided the inspiration that have enabled me to complete this thesis would require a novel. This page of notes will have to suffice.

First I must thank my supervisor Dr George Baird, for having the guile to give me the freedom to explore this topic and the wisdom to understand that hanging is not the only option selected when such 'ropes' are offered. I have gathered inspiration not only from observing George as researcher over our many years of contract research collaboration, but also from his invaluable skills in critical analysis of the text.

The core data that inspired the conclusions in this thesis is to be found in the New Zealand and USA surveys of digital thermal simulation computer program users. The New Zealand survey would not have been possible without the assistance of my good friend and colleague Nigel Isaacs. The thesis really came together when Dr Steve Selkowitz of Lawrence Berkeley National Laboratory gave me a home away from home in 'Building 90' during 1995/6 and facilitated the telephone surveys of the USA simulationists. I hope that the data collected and the new analysis contained here may be some small recompense for those kindnesses.

Over the years I have found great inspiration and energy from my Digital Craft and Building Science students. This thesis was inspired by that spirit. Successive classes for many more years than I have been working on this thesis have enthusiastically demonstrated that when they see an activity as worthwhile they will do whatever it takes to complete it. They have always taught me more than they learn with their open-hearted approach to learning new skills and new ideas. I would particularly like to acknowledge those who have successfully made the transition from undergrad 'pupil' to graduate colleague and friend. The list must start with Kathryn and Robert Amor. Kath's work during her MBSc as a Research Assistant on the aerodynamics and architects surveys was critical not only to the development of the thesis but also contributed to a refocusing of the Wellington City Ordinances. Robert, as a hybrid Computer Scientist and Building Scientist taught me an awful lot about computer representation of building information that eventually became a core part of my thinking during the analysis. Judith Becker, a committed green architecture student, interviewed two architect clients of the Centre for Building Performance Research. Research Assistants, Marie Fleming and Nick Warring contributed their own insights as analysts. Ben Masters as a Research Assistant and as a Building Science Honours student has developed the ideas about Quality Control reality tests into working prototypes. I am especially proud as I look at the alumni of the Bachelor of Building Science Honours classes which have under my care grown in numbers from 1 every two to three years to up to ten a year during the time of gestation of this thesis. Their achievements and more particularly their enthusiasm for the building performance simulation concepts explored in this thesis are a continued inspiration.

Innumerable colleagues deserve mention for the ideas and support they have provided. I must thank Grant Thomas who distracted me ultimately for nearly two years producing first on a book entitled ***Designing Comfortable Homes*** and then on the Standards New Zealand code of good insulation practice based on the book. The lessons learned illustrate the final chapter of the thesis. Werner Osterhaus and Robin Skinner and Peter Wood, my collaborators in research teaching have all provided insights that have helped shape the final edited form of the thesis.

I cannot write an entry like this without making particular mention of my friends and family. During the editing phases collaboration with Shayne, Bridgette, Peter and Peter in a million dollar self-financed construction project certainly delayed delivery by a couple of years, but I would not trade those years of fun and friendship (and hard financial lessons!) for anything.

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executive summary

> EVEN THOUGH WE NAVIGATE DAILY THROUGH A PERCEPTUAL WORLD OF THREE DIMENSIONS ...THE WORLD PROTRAYED ON OUR INFORMATION DISPLAYS IS CAUGHT UP IN THE TWO-DIMENSIONALITY OF THE ENDLESS FLATLANDS OF PAPER AND VIDEO SCREEN. ... ESCAPING THIS FLATLAND IS THE ESSENTIAL TASK OF ENVISIONING INFORMATION - FOR ALL THE INTERESTING WORLDS (PHYSICAL, BIOLOGICAL, IMAGINARY) THAT WE SEEK TO UNDERSTAND ARE INEVITABLY AND HAPPILY MULTIVARIATE IN NATURE. NOT FLATLANDS..
>
> ENVISIONING INFORMATION - EDWARD R TUFTE; GRAPHICS PRESS, 1990

The spur for this research was a lack of use by architecture practitioners of the environmental design decision support tools (eedst's) they learn to use during their education. It hypothesises that lessons for the improvement of eddst's can be found in a systematic examination of the problems encountered by design teams with a range of currently available eddst's.

The objective is to try to identify the types of edds questions that design teams wish to have answered and to obtain from them the desired form of that answer in situations where eddst's could be of assistance. “”

The research philosophy suggests that environmental quality will be improved in buildings if design teams have access to better eddst's. “” The majority of people interviewed are interested in how they might improve their abilities to create environments of thermal, visual and acoustic quality.

The research plan was to establish how practising architects who have tried to use building eddst's assess the effectiveness of these tools. This required a research plan containing the following items:

1. a classification system for eddst's.
2. case studies of designers' use of eddst's for at least two different types of environmental design issue.
3. analyses of the individual cases and a meta-analysis of the trends between cases.

Each eddst examined in the case studies is from a different category in the eddst classification and addresses a different aspect of the environment in buildings. Case study one - a text based design guide - addresses solar thermal performance of buildings; case study two - a computer and physical model simulation - addresses thermal performance and daylighting of two buildings; case study three - a physical model simulation - addresses the effect of buildings on the wind environment in the surrounding streets; case study four - a computer simulation - addresses the thermal performance of buildings; case study five - a physical model simulation - addresses daylighting performance of one building.

The research did not achieve its original goal of developing a formula for the generation of new eddst's for architects in the fields of building acoustics, lighting, thermal design and aerodynamics. What was found is a more fundamental common denominator underlying building design environmental decision support tools: the need for built-in Quality Assurance measures that assure the architect, the simulationist and the client of the reality of the buildings and the environments they are simulating (modelling).

Although designers want detailed environmental information there is no general format or pattern to the **type** of information they want. Rather, they want to be able to use it to persuade themselves and others of the **value** of their design decisions. This means normally that the information must first be quantitative, so that values such as costs and benefits can be attributed to it. However, they also want to be able to understand and trust it. It must therefore also be

qualitative in the sense that it communicates the quality of life that will result from the design decision.

The principal research conclusion is that in order to develop trust in digital simulation based eddst's amongst not only designers, but also simulationists **Quality Assurance procedures** need to be codified and incorporated into the design tools themselves. These will ensure that the 'black box' digital simulation eddst yields information that designers feel they can trust. Further, the research demonstrates that to address the issues identified in this research a **Quality Control reality test** is the single most important feature needed in any Quality Assurance process for building eddst's. A reality test examines whether the ebuildings constructed with the tool behave in a believable manner - like a 'real' building.

The field of digital simulation of building performance has reached a development plateau where the code developers have the luxury of being able to work on interface design rather than developing more calculation tricks to provide practical response times. There is a need for tools that don't just ease data entry but ones that aid understanding of the relationships between design factors and building performance. The designer requires an interface that is an expert advisor on the input and the output of each digital simulation. No amount of experience can create the intuition needed to spot the incorrect simulation through in the words of one simulationist surveyed ""eyeballing the data"" .

The final chapter of this thesis describes how a proposal for a Quality Assurance process for building environment simulation incorporating a Quality Control reality test might be implemented using internet technologies. The final chapter is therefore more in the nature of a hypothesis to be tested in future work.

It shows how elegantly the XML[1] system separates the **content** of a thermal simulation program input file from its **presentation** with the use of a **data model** expressed as metadata in XML syntax in a DTD[2] file. With this approach, and the naming conventions that already exist on the web, all that is needed at present to establish a QA lookup system for a digital thermal simulation eddst is a single working web site where such DTD metadata can be found and hence referenced by all computers that wish to "understand" the thermal simulation data in XML format.

The proposed Simulation QA (SimQA) approach uses Web Services via an agent running in each eddst simulation program. The SimQA web service is not a database. It is a database of the databases where tested examples of Quality performance data are held in web accessible format. Each time a person sets up a new Quality tested file or measures a new building, it can be put on the web as another "data point".

If each dataset is placed in Cyber space with its own built-in RDF[3] definitions, in an XML language document, then useful searches by a pre-processor could be constructed such as: '*find all the mild climate office buildings monitored in the past 10 years for which lighting measurement and energy consumption figures are available*'.

Another benefit of an XML based simulation QA process is stochastically valid risk analysis. In an XML system the weather data for a thermal or lighting simulation would contain the definitions of its terms. This would enable a different XML-aware simulation to translate / understand the weather information. It would also mean that each weather file could contain synoptic information on how typical it was. This could be used to construct risk analyses for certain given extreme weather events.

XML format data on the energy performance of real or simulated buildings would also contain data about the data (Metadata) in the file. This would describe the context for the measurements and hence permit the XML front end of the simulation package to *infer* how sensitive the simulation output is to variations in assumed usage patterns.

To create an appropriate and robust QA process requires more than the QC reality test. Also required is development of international norms for the simulation of building performance. These would specify the minimum content of an in-house database that documents the ebuilding construction and the digital simulation eddst modelling parameters. www.aecsimqa.net is proposed as the ideal venue for the support of an international effort focussed on the eventual development of this database into an international documentation standard for simulation.

Finally, the increased complexity of modern computer-based building performance simulation tools has not rid the design profession of its traditional problem with digital simulation based design tools: that they evaluate completed designs. The proposed web based database will make web accessible a dataset of tested building designs and their associated performance measures. Guidance about how to move forward in improving a design typically only comes only from the informed user looking backwards at how existing designs perform. An XML front end to a design process such as modelling a building in CAD would be able to look up Post Occupancy Evaluation (POE) contributions to the Internet database and would therefore place at the designer's fingertips a comprehensive set of data showing what might be expected of the current building design.

It might even be possible to generate initial design ideas based on systematic study of successful precedents!

PART A
RESEARCH DESIGN

table of contents

Part A sets the scene for the research. It outlines the rationale and background to the research, establishes a theoretical structure for the research and describes the research methodology.

1 . . . . . introduction

This chapter outlines the rationale for the research and the structure of the research itself.

2 . . . . . simulation: abstract reality

This chapter establishes the context for the thesis research. It reviews the historical development of building environment design decision support tools (eddst's).

3 . . . . . classifying simulation tools

This chapter continues the description of the context for the thesis research begun in the previous chapter's largely historical review. It classifies environmental design decision support tools (eddst's) in terms of their apparent function within architectural design practice and describes the broad research methodology within this context. The goal of the construction of this categorisation system for eddst's is to assist the analysis of the successes (and failures!) of these forms of "design tool" in the later parts of this thesis. The functional value of each category of tool is assessed in terms of its ability to provide environmental design decision support. This value is described in an hypothesised list of advantages and disadvantages for each category of eddst.

4 . . . . . research design

This chapter provides a general overview of the research design resulting from the research hypothesis stated in chapter 1 and the general philosophical approach to the research. It describes the relationship between the research goals and the surveys and case studies that form the principal technique used in this research. The research plan is simply to establish how practising architects assess the effectiveness of eddst's.

1

Introduction

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

introduction_2006_clean.wpd

THE SPACE WITHIN

THIRTY SPOKES SHARE THE WHEEL'S HUB;
IT IS THE CENTER HOLE THAT MAKES IT USEFUL.
SHAPE CLAY INTO A VESSEL;
IT IS THE SPACE WITHIN THAT MAKES IT USEFUL.
CUT DOORS AND WINDOWS FOR A ROOM;
IT IS THE HOLES THAT MAKE IT USEFUL.
THEREFORE PROFIT COMES FROM WHAT IS THERE;
USEFULNESS FROM WHAT IS NOT THERE.

LAO-TSE QUOTED BY BERNERS-LEE: WWW.W3.ORG:80/DESIGNISSUES/EVOLUTION.HTML

1-1 *the goal?*

The spur for this research was a personal observation based on many years teaching and researching building science issues in architecture: a lack of use by architecture practitioners of the environmental design decision support tools they have learned to use during their education. The consequent lack of quality sensory environments as buildings subject their occupants to unnecessary extremes of temperature, glare and noise due to the fundamental lack of connection between the building design and the environment it creates is my personal horror.

My broad hypothesis is that general lessons for the improvement of all building environment design decision support tools (eddst's) can be learned from the study of the practical application of those tools that are being used today. I assume there are common problems in the application of these tools that if identified can be used to define principles for the creation of new eddst's that do address the specific interests of architects and clients. Simply, design teams are presumed not to use currently available tools because the tools answer the wrong questions: "...there are serious doubts to assuming that more architects and engineers will *design buildings that exploit natural lighting* if only *they are provided with the requisite information and design aids ...*" [1].

The objective of this research is therefore to try to identify the types of questions that design teams wish to have answered where eddst's[2] could be of assistance. In the process it examines whether architects are really interested in creating environments of thermal, visual and acoustic quality, testing the common assumption amongst non-architects that they are not interested: "It is a telling commentary on the current situation that architects must now be convinced that it is no mean achievement to design buildings that function well.." [3].

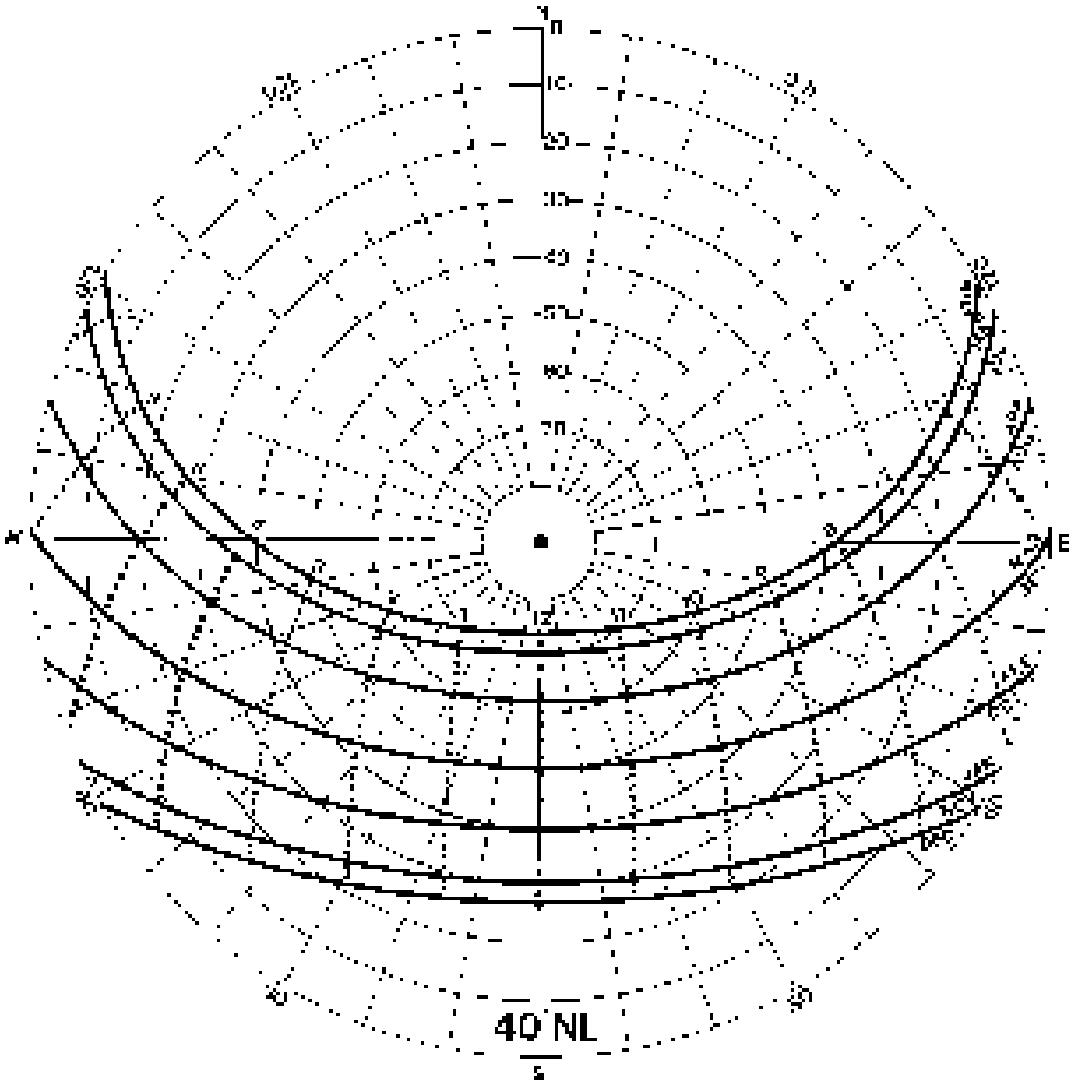

Figure 1 Example of a chart developed to assist building professionals to track the path of the sun without having to do multiple calculations using solar position algorithms.

It is not feasible to address this research question without also examining the single design tool serving multiple audiences - architects and engineers and builders, for example. It is common practice to develop a building performance assessment tool based on observations of correlations observed in the laboratory or in a practical survey, and then to offer the tool to the building design professions in general as a potential eddst. Sometimes, this performance assessment tool is used to derive simplified guidelines as an eddst purely 'for architects'.

For many years, design tools for building professionals have been developed from the basic building physics and psychophysics[4] equations into simplified charts, nomograms and simple calculator programs (see next chapter for a review of these types). This effort continues today. Developers of computer software for digital simulation of building performance are continually searching for improved Graphic User Interfaces (GUI's) - to my mind the modern day equivalent of the nomogram or chart.

The lack of acceptance of the current crop of eddst's in architecture appears to have several root causes:

1) the tools available today are often too simplistic. Researchers simplify a rigorous performance prediction equation or set of equations to the point where they judge they will be acceptable to architects who do little in design to predict or systematically document building performance[5]. This need for simplification is often suggested not only by individual architects expressing a desire to be told a 'rule of thumb' for a particular situation, but also by their professional associations[6]. Too often this process of simplification trivialises the issues. In an effort to encourage the use of a tool researchers make the input or output of information so simplistic that they often simplify the model of reality. Eventually, these simplifications make the performance model so remote from the complexity of reality that the designer sees the tool as irrelevant.

2) where a project is of sufficient size to have an expert design team, the environmental design experts in the design team often are ineffective in relating the environmental design issues to the interests and concerns of the architect. The causes of these problems are many. They include the oft-quoted lack of reading by architects of anything more complicated than a child's picture book[7]; individual environmental design analyst's inability to focus on the whole design rather than their one area of expertise; and the difficulty of establishing a good working relationship in a design team where the professional and financial rewards for team members may well conflict.

3) when reviewing lessons learned from the USA research programme involving practitioners using eddst's in (passive solar) commercial building design, experts concluded [8] that the design decisions made very early in the conceptualising phase of a project determine how well it is going to perform. This is a common mantra at conferences of eddst developers like the International Building Performance Simulation Association biennial conferences[9]. But, design tools are often most effective when the design is sufficiently complete that the detailed building specification required by the performance calculation is available. Architects unfortunately are trained[10] to look in this instance for the 'rule of thumb' which directs them towards the successful solution without requiring a great deal of thought. Nils Antoni[11], architect and then head of the National Swedish Institute of Building Research writing in the CIB journal in 1986 sums up the problems with this approach succinctly in writing about " *information which actually reaches the profession and is assimilated ... is highly selective and carefully pre-digested*" [into rules of thumb and guide books etc..]: "I am suspicious of selected, processed information. It is a last resort... One never knows what criteria lie behind the choice made and how competent those doing the processing are.."

4) the tools are not seen by designers to be in sync with their 'intuition'. It is likely that development of intuition to deal with the environmental design quality issues of interest to this thesis is impossible unless a practitioner produces standard houses of a standard size in a single climate for broadly similar clients. The USA passive solar commercial building research programme quoted above noted that the participants' 'intuition' was not sufficient[12]: "Repeatedly, highly skilled professionals found their intuitive grasp of a building's energy problems off-target when tested by even the most rudimentary energy

analysis techniques... ”

My research method studies how people use design tools created for use in practice. It was tempting to examine these tools in design studios in schools of architecture as this would have provided a much wider range of opportunities for comparative studies relating types of tool to the quality of the final product. However, these tools are often used more as a means of educating students in the principles. The tools are being used to try to develop their ‘intuition’ or understanding. I examine the use of environmental design tools in real design situations in order to draw general conclusions about:

5) **the types of questions the users want environmental design decision support tools to answer**;

6) **the nature of the input and output to these tools that is acceptable** (drawing lines on graphs; entering numbers in spreadsheets; automatically transferring data from the CAD drawing to the environmental calculation program?...)

7) **the types of quality control procedures adopted by the current small numbers of regular users of eddst’s that provide some guarantee of the reliability of their analyses**.

1-2 *background to the thesis*

I have been engaged in research in buildings at the Centre for Building Performance Research (CBPR) at Victoria University for over 20 years. Teaching building environmental science to architecture students at the Victoria University School of Architecture has helped develop a strong interest in the relationship between design expectations and actual performance. Unfortunately, most

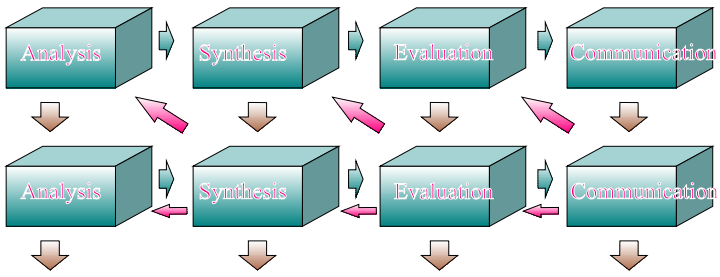

Figure 2 The cycle of design. Each step in the cycle may be repeated, any number of times. It assumes that eventually one progresses from mostly on the left side, **analysing** a design situation to mostly on the right **communicating** a design idea.

presently available design tools help us look ‘backwards’ to examine how well our building designs work. They do not work ‘forwards’ pointing out the types of design options that might be made to work. All who attempt to use such tools are constrained to adapt their design processes in some way so as to be able to move forward towards whatever ‘optimum’ fits the client’s needs.

Conventional models of the design process often[13,14] describe the design of a building as a "wicked problem in design"[15]. These are problems that are "without a definitive formulation" and "solutions that are proposed are not necessarily correct or incorrect." The 'solution' process for these 'problems' is seen as fours steps in a cycle: Analysis, Synthesis, Evaluation and Communication, each repeated as many times as are required for a design to be settled on. This process is envisaged as spiralling through these steps from the abstract to the concrete in design concept. Design performance assessment tools are viewed as having a primary role in the Evaluation[16] part of the cycle. In these models of the design process, there is an implied generate and test cycle. Within this, designers typically develop conceptual approaches that assist them to respond with new design concepts to the evaluations. Historically, when designers have sought evaluation data, researchers and engineers have used tools they have developed to analyse the building design. Often this data is produced too late in the progression from abstract to concrete design to have a great positive influence. The next logical step has been to attempt to provide designers with the assessment tool, or with a cut-down version they feel comfortable with. This thesis critiques these role(s) for performance assessment methods as environmental design tools in architectural design.

The approach to the thesis research has been determined by an early decision to examine practitioners' responses to environmental design tools and by access to primary data on practitioners' uses of such tools. As a consultant to the Wellington City Council, I had developed and audited a process of wind tunnel testing every new building in the Central Business District. We established a 'pre-design' qualitative wind tunnel test which would allow designers to examine their ideas relatively cheaply and simply. The goal was to allow designers to explore their design's impact on the pedestrian level wind environment. It was possible through this involvement to arrange to do a follow-up evaluation of the process with designers. I also had been closely involved with the setting up, running and evaluation of the first national series of seminars educating building professionals in passive solar design of houses in New Zealand. This data was readily available. As a result of evaluating these processes, and also after using thermal and daylighting software myself in design consultancy, I was aware that the environmental design tools that are available, and the problems they are used to solve are often not well matched.

This thesis project has taken a long time to gestate. As a result of my teaching and energy research at Victoria University I had long been interested in how to present environmental design information in a way that will engage architects in effective decision making on Environmental Control Systems (ECS) issues in buildings. This interest was pursued during my Research and Study Leave in 1985, when I had the opportunity to become involved in an examination of the presentation of ECS issues as design information to architects. I spent some six months in Zürich at the Swiss Federal Testing Laboratory (EMPA) in the building physics (KWH) section, where I compiled a paper on personal computer based software for solar house design and completed the analysis for a book aimed at architects: ***Design Guidelines : Passive Solar in New Zealand***.[17] In 1985 I also spent six months

based at SERI in Colorado gaining experience modelling commercial buildings with SUNCODE and DOE2.1C.

In the years leading up to the beginning of this current project in 1996, I had many opportunities to collect further data on practitioner interest in ECS information[18,19]. I also taught students to use environmental design computer software, and to design solar houses using my **Design Guidelines ..**[20] handbook. I have become increasingly convinced that computer based environmental performance simulation can provide the sorts of answers to the ECS design questions that architects ask. However, at present, that computer application may take too long to set up and run so that crucial design information is unavailable at the early design stage when the major building parameters are being established. What designer wishes to take the risk of designing a glazed atrium with natural ventilation when the computer based analysis of its economic feasibility is time-consuming and is not to be done until working drawings are underway, when their engineer, much earlier in the design process and on the basis only of previous experience has advised them that a reliable design solution should only have 10% of the surface glazed?

The barrier to the use of computer based simulation in architecture is the same problem that has plagued creators of environmental design tools that simulate building performance using hand calculations for the past 50 years: simulation of building performance, whether a computer or a hand calculation, currently evaluates buildings in a way that differs significantly from the way in which architects normally work. Therefore, the process by which ECS issues might be dealt with more effectively by architects is also examined in the practical studies of eddst use.

1-3 *why computer simulation?*

My experiences with the practical application of simulation have been highly influential in determining the direction of this thesis research. Computer based (digital) simulation projects where I have been involved directly have been daylight and heating energy use studies in a library[21], an office[22], a museum[23], an art gallery[24], a police station[25], and daylight studies in a tertiary institution library[26] and a large base hospital[27].

For the past twenty years I have also been observing and developing the practice of wind tunnel testing with physical models in Wellington City through my consultancy service to the Wellington City Council. I helped develop the purely performance based wind ordinance and provided expert audit of every wind tunnel test that analyses the pedestrian level wind effects of new building proposals. In addition to this, due to a change in the curriculum at the School of Architecture, I was required after 1995 to develop three new courses based on digital simulation: a new course[28] for between 20 and 30 students per year instructing them in the basics of thermal simulation; a module in a course for a further 30 students per year to learn the basics of lighting simulation[29]; and a course

where over 50 students each year simulate daylight in large museum buildings and report their output in web page format[30]. These contributions to design analyses in consultancy and in teaching have provided an insight into the range of questions that designers wish to ask of computer based eddst's and the acceptable formats for the answers they seek.

The most difficult issue facing the writer of a digital simulation program is deciding what questions

Figure 3 Computer generated picture of atrium in a university building

the program is designed to 'answer'. At present, many programs are designed to produce accurate physical representations of the performance of the building. For example, the physics of the radiation exchange in a lighting environment can be modelled in such a way that the computer can produce an output which is a picture showing what the building might look like (**Figure 3**) given particular light sources. The designer in this case wants a mixture of quantitative information (light levels in lux to compare with the specification for the job) and the qualitative information in the picture.

Often the qualitative information will be most helpful if it can also be made quantitative. For example, in an exercise examining the use of daylighting in a refurbishment of a building as an art gallery[31], it was found that applying daylight factor contours and numeric values of illuminance to the picture were unhelpful to the client and the designer. What did prove of assistance, was the introduction of a single spotlight illuminating a surface in the gallery to 150 lux. This gave the pictures, which had been produced to illustrate the lighting conditions, their own internal scale no matter what the external daylight conditions. (**Figure 4**).

Similarly, in an exercise examining the energy performance of a public library[32], the principal concern of the librarian - the question the designer needed to have answered by a simulation - was the potential for overheating. Energy use was secondary to comfort for the library workers and their clients. For the level of confidence that this client sought, and with a natural ventilation cooling system, what was really required was an analysis of the likelihood of high external temperatures occurring when the local sea breezes were not blowing. The question reduced to the frequency of occurrence of hot still days and the likely internal temperatures on these days.

For yet another project, the client was planning a major museum development[33]. Having elected to bring sun and day light into the major public circulation areas the designers were concerned to check the amount of light likely to spill into adjacent galleries. In museums the duration as well as the intensity of exposure to light is important as it can destroy some organic exhibits rapidly. Again, while the pictures from a ray-trace program were convincing as to the likely light intensities and the depth of penetration at particular times, nothing short of an animation could have shown the client how brief or long some exposures might be. (**Figure 5**)

In an office and studio development for a university[34], (**Figure 3**) we used thermal and sunlight modelling to examine the likely performance of a central atrium/light well. While the ray-traced pictures provided some credibility to the analysis, and the graphs of internal temperatures some reassurance that the analysis was rigorous, the architects sought reassurance mostly about the degree of change likely in the analysis with variations in the design. What was most needed was the accumulated experience of a simulationist, familiar with the program and familiar with the type of simulation being done. Such sensitivity questions are at the heart of designers' decision making.

Figure 4 Spotlight circle on wall with daylight spilling over screen walls

In a regional police station[35] of some 4000 m^2 daylighting, natural ventilation and passive solar space heating were investigated. Here, the biggest problem was developing a system of modelling at an appropriate level of detail. At the start of the design process answers were needed quickly and in multiple sessions. Simple but accurate models requiring little input information were needed. Later in the design process a much higher level of complexity was required in the modelling in order to answer the design team's questions. It required careful planning to use digital simulation efficiently throughout the design process.

In each of the above situations the essential requirement for effective use of simulation in design was for an expert in simulation sitting at the shoulder of the person using the information from the simulation program. Such an expert has many roles to play:

1. First they must be able to translate the data from the daylighting simulation so that it is available and consistent with the data entry requirements of the heating energy simulation which will switch off lighting if the daylight has been determined to be sufficient.
2. Second they must keep a record of the level of sophistication of the building model at each stage of the design process and maintain consistency between these levels or 'versions'.
3. Third, they must provide advice on the interpretation of the many thousands of lines of data that the program can produce.

The conclusion I reached from these experiences was that the environmental design decision support tools (eddst's) being developed for use by architects and building designers are largely being developed following a false paradigm about how designers work. With most such tools the designer

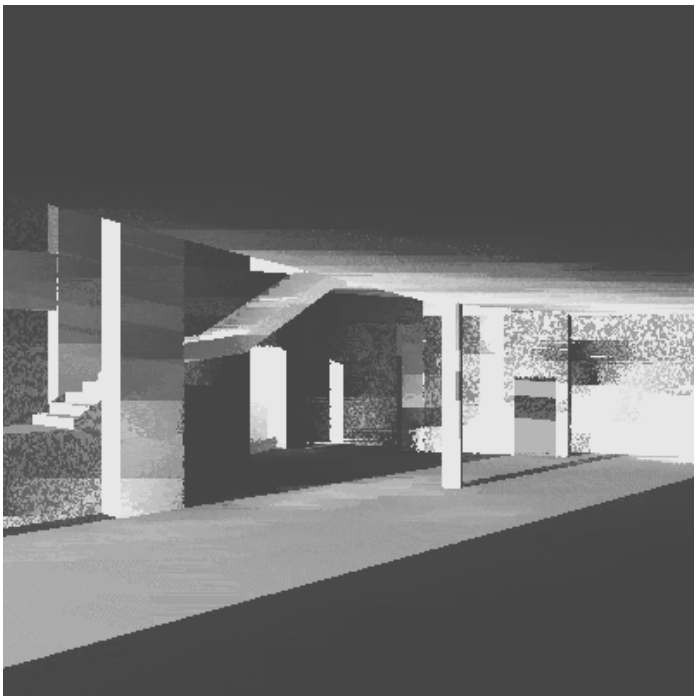

Figure 5 Sunlight in museum circulation zone

has to work within the model of design offered by the authors of the tool. If they do not do this, the information may not be of much help in improving the building design. While this applies equally to the use of physical models in wind tunnels and to digital simulation, it is most easily addressed in the translation of digital simulation programs into design decision support tools. If eddst's are to be of use to architects in their design processes then they will most likely be based on digital simulation because digital simulation programs offer the most adaptability of any eddst. Computer programs can have their interaction with the user much more readily altered than any other eddst. For example, the underlying calculation engine in the lighting simulation program Radiance has remained largely unchanged for many years, whilst its interaction with the user has changed radically[36].

At their most banal, current development plans for digital simulation tools only address the appearance of the user interface. The set a target of making an existing calculation program more 'user friendly' merely by adding the standard range of WIMPS[a] that we find in all windowing computer programs. The nature of the interaction between designer / user and the program is not addressed. An appearance consistent with the operating systems windowing environment is the principal goal.

Having taught courses in the use of SUNCODE[37] annually to small groups of senior level architecture and building science students for over ten years, and to large groups for the past five, I can sympathise with this goal. These students were typically keen to explore solar design issues, but found the text-based interface to the SUNCODE program a significant barrier to its use. A WIMPS interface was a very useful first start in making this particular simulation program usable outside an academic environment. The introduction to my undergraduate classes in 1998 of SuNREL[38], a version of SUNCODE with all the 'user-friendliness' of the familiar Windows interface, brought about a huge change in their acceptance and use of this analytical tool and hence of their view of the potential of design simulation.

But, as my experience with SUNCODE/SuNREL has also shown very well, merely improving the user-interface is not sufficient. The output of digital environmental simulation programs is also obscure. Users may get the results back more quickly but they still take quite some time to learn how to use the calculations to critique a design. In fact, the output of almost all environmental simulation models (tables of data, calculation formulae, nomograms, design 'handbooks') is couched in obscure terms for most users. What is normally required with this output is a set of interpreters and data analysis tools. The most obvious example of this interpretation issue is one that has dogged people writing manuals for the use of calculation for design analysis of energy use. It is most obvious in books describing digital simulation that have been published since the early 1980's[39]. How does one assess the output from a simulation? What does one measure it against? The typical suggestion in manuals on low energy design at present is to run the same simulation on a 'standard' building as well

[i]Computer jargon from **W**indows, **I**cons, **M**ice and **P**ointing device**S**

as on the design you are assessing, and to measure the output of one against the other. This always raises the question of how to establish reliable 'standards' for measurement.

My premises in this thesis are that :

1. despite common assumptions to the contrary, and the lack of evidence in the performance of many of their buildings, architects are interested in environmental design quality;
2. the most effective way to ensure that the design decisions made by architects reflect the environmental needs and concerns of the users is to provide them with digital simulation tools which inform them reliably of the consequences of their design decisions;
3. there is no future in relying on the conventional wisdom that simplification of these tools will improve their usefulness to and ease of use by designers; and
4. that sophisticated simulation based design tools can be used reliably by people other than those who make their careers out of simulation.

At heart, I am concerned that the 'simplification' that is normally undertaken to translate the hard science and research on which simulation programs are based into design tools too often trivialises the issues to the point where the designer sees no relevance in the remote or abstract information produced.

1-4 *research philosophy*

The research philosophy is founded on the assumption that environmental quality will be improved in buildings if design teams have access to better eddst's. "" It hypothesises that lessons for the improvement of eddst's can be found in a systematic examination of the problems encountered by design teams with a range of currently available eddst's. Identification of the problems common to the applications of several different eddst's should enable broad lessons to be drawn about the types and format of eddst likely to be best suited to architectural design. Throughout, the research questions its assumption that architects are interested in creating environments of thermal, visual and acoustic quality. As my own experience with consultancy on the design of real buildings has been so much more revealing than any laboratory or classroom situation could ever be, the basic approach of the research design for this thesis was that interviews and surveys of practitioners who use environmental design tools would be the most fruitful approach.

There is a basic dichotomy to be admitted at the outset: inherently the process of design needs to be long when human comfort and building environmental performance are studied, yet designers are under huge pressure to complete projects faster. During the 6 year development of this thesis, the role of digital building performance evaluation tools has expanded remarkably. From initially asking how can we create design tools that architects will use, this thesis has developed to the point where it asks how digital performance evaluation tools might be written to enhance architectural quality without increasing the time required for design, or for learning new concepts and theories.

1-5 *structure of the thesis*

This thesis is organised into three main Parts plus a set of appendices:

Part A, the broad overview of why and how the research was undertaken, comprising four chapters;

Part B, three surveys and two case studies each devoted to a different aspect of environmental science and different technique for design decision support;

and a final **Part C** comprising three chapters in which the lessons of the surveys and case studies are drawn together and a proposal for an improved design decision support tool is developed.

The following paragraphs provide a synopsis of the content and structure of the whole thesis.

1-5.1 part A

1.	introduction	This chapter: the rationale for the research and the structure of the research itself.
2.	simulation - abstract reality	This chapter establishes the context for the thesis research. It reviews the historical development of building environment design decision support tools (eddst's).
3.	classifying simulation tools	This chapter continues the description of the context for the thesis research begun in the previous chapter's largely historical review. It classifies environmental design decision support tools (eddst's) in terms of their apparent function within architectural design practice and describes the broad research methodology within this context. The goal of the construction of this categorisation system for eddst's is to assist the analysis of the successes (and failures!) of these forms of "design tool" in the later parts of this thesis. The functional value of each category of tool is assessed in terms of its ability to provide environmental design decision support. This value is described in an hypothesised list of advantages and disadvantages for each category of eddst.
4.	research design	This chapter provides a general overview of the research design resulting from the research hypothesis stated in chapter 1 and the general philosophical approach to the research. It describes the relationship between the research goals and the surveys and case studies that form the principal technique used in this research. The research plan is simply to establish how practising architects assess the effectiveness of eddst's.

1-5.2 part B

The overall goal of this thesis was to establish what common threads there might be between architecture design teams use of different eddst's. The result is five sets of interviews exploring eddst use in real situations. The surveys and case studies are:

5.	solar house design guide	Examination of reactions of users of a text based design guide focussing on solar house design at a series of seminars on the use of the guide - **survey**.
6.	computer simulation	Survey of Centre for Building Performance Research clients and research assistants on the use of computer simulation in **lighting** and **thermal** performance assessment - **individual case study**.
7.	computer (thermal) simulation	USA and NZ interviews by telephone and in person with users of eddst's in building performance evaluation. The USA participants were exclusively users of thermal simulation computer programs - **survey**.
8.	physical (wind) model studies	interviews with architects in Wellington City on their understanding and use of information produced for or by them on the aerodynamics of their buildings focusing in particular on their use and understanding of wind tunnel test data - **survey**.
9.	physical (lighting) model studies	interviews with the architect & lighting designer for the San Francisco Museum of Modern Art (SFMoMA) - **individual case study**.

1-5.3 part C

The final part of the thesis aims to put some pattern into the analysis. Evidence is presented for the advantages and disadvantages of the disparate approaches to environmental design analysis observed in the surveys and case studies. The goal, as outlined in the initial part of the thesis is still "'to analyse these forms of "design guidance" to establish how a systematic approach might be taken to examination of the role of environmental design tools in architecture."' The three chapters of this final part of the thesis comprise:

10.	research goals & case studies	**analysis** of the overall lessons from the surveys and case studies one level above the detailed advantages and disadvantages listed in each case study chapter; the analysis is looking for the common factors in all the users' uses of and reactions to these environmental design decision support tools.
11.	nature of design simulation	examination of these analytical **conclusions** with a view to identifying the principal features of an environmental design decision support tool (eddst) to be used by building designers early in the design process which guarantee that its predictions will be convincing.
12.	simulation tool agents	a hypothesis is presented as to what might be a **reality test** in digital simulation that would be sufficient to

convince users that the results of their own simulation represented an accurate picture of future building performance.

1-5.4 appendices

The thesis concludes with a concordance cross-reference index, a bibliography and Appendices A through K - reference material as a matter of record.

1

Notes & References

1. XML *Short for **Ex**tensible **M**arkup **L**anguage, a specification developed by the W3C. XML is a pared-down version of SGML, designed especially for Web documents. It allows designers to create their own customized tags, enabling the definition, transmission, validation, and interpretation of data between applications and between organizations.* From http://www.webopedia.com/TERM/X/XML.html (Last accessed, May 2003)

2. DTD *Short for document type definition. A DTD states what tags and attributes are used to describe content in an SGML, XML or HTML document, where each tag is allowed, and which tags can appear within other tags. For example, in a DTD one could say that LIST tags can contain ITEM tags, but ITEM tags cannot contain LIST tags. In some editors, when authors are inputting information, they can place tags only where the DTD allows. This ensures that all the documentation is formatted the same way. Applications will use a document's DTD to properly read and display a document's contents. Changes in the format of the document can be easily made by modifying the DTD.* From http://www.webopedia.com/TERM/D/DTD.html (Last accessed, May 2003)

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3. Jackson, Anthony **Reconstructing Architecture for the 21st Century - an inquiry into the architect's world.** Univ. of Toronto Press, p197, 1995.

4. Psychophysics is used in the building industry to imply that the responses to heat, light and sound we design for are human responses, not the interaction of thermal, light and acoustic energy with building materials. It is a term that has far more proscribed meanings in Psychology. (See web page for Department of Psychophysics, Max Planck Institute for Biological Cybernetics Tuebingen, Germany: http://www.kyb.tuebingen.mpg.de/bu/projects/

5. Mackinder, Margaret and Heather Marvin **Design decision-making in architectural practice** BRE Information Paper IP11/82, BRE Garston, 1982: *"'The designers studied seemed to believe that experience is best picked up through the practice of design although the majority of offices did not consciously collect feedback from their completed projects....'"*

6. Personal communication from Ian Cooper: pointing me to the following quotes from RIBA: *"The want of a proper knowledge on the part of the architect, combined as it is with the want of information on the part of the public, leads to many of the anomalies which are now so frequently observable in the practice of the profession, and to the presence in its ranks of many who have not the will to uphold its credit"* A. Bailey **Discussion on a Diploma in Architecture**, in papers read to the Royal Institute of British Architects, 1856. AND *"'Science has made such progress that, without theoretical training, office routine is utterly unable to keep up with it, and the five orders no longer suffice for the architect's wants.'" cited by Kaye Barrington in **Development of the architectural profession in Britain** Allen and Unwin, 1960.*

7. Marvin, Heather **Using experience and publications in building design**. BRE Information paper IP13/85, BRE, Garston 1985. AND: **Meeting building designers' needs for trade information** BRE Information paper IP14/85, BRE, Garston 1985.

8. *The three broad and most important lessons to emerge from this program are:*
   - *consider energy conscious design alternatives as early as possible in the design process*
   - *support all design decisions with thorough analysis that addresses building efficiency in its broadest sense, which includes economics.*
   - *think of passive solar design as an architectural, mechanical and electrical integration issue, not an "add-on" exercise.* Burt Hill Kosar Rittelman Assocs. and Min Kantrowitz Assocs. **Commercial Building Design: Integrating climate, comfort and cost.** Van Nostrand Reinhold Co., New York, p 12, 1987.

9. Personal observation from the 2001 (Rio de Janeiro), 1999(Kyoto), 1997(Prague), 1995(Madison), 1993(Adelaide) IBPSA (http://www.ibpsa.org - Last accessed March 2004)Conferences.

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14. An internet search on the phrase 'wicked problem in design' readily returns 500 references like this: Carol Ann Ogdin@deepwoods.com writes on a listserver maintained by learning-org@world.std.com:
I promised, in LO2351, to summarize the responses to by plea
...cites to the issue of "wicked problems"...:

K.C. Burgess Yakemovic (kcby @ gpsi.com):

> I just remembered a book with the title Wicked Problems, Righteous Solutions (Peter DeGrace, Leslie Hulet Stahl)... let's see...
> He says.... (page 82)
> "... we are now encountering problems of a different nature
> where the computer is no longer at the center of things --
> the human is -- and the machine is now acting to provide
> or organize information the humans need to produce results.
> These are called "wicked problems", described by
> Horst Rittel and Melvin Webber[1973]":

> Rittel, H., and M. Webber, 1973 "Dilemmas in a General Theory of Planning" pp 155-169, _Policy Sciences_, Vol. 4, Elsevier Scientific Publishing Company, Inc. Amsterdam. N.B.: This paper seems to be the "classical reference," ...
> There is a good description of wicked problems in "Challenging Strategic Planning Assumptions," by Mason and Mitroff. They also refer in there to a paper by Horst Rittel, On the Planning Crisis: Systems Analysis of the 'First and Second Generations', Bedriftsokonomen, NR8, 390-396, 1972.
> SIMON, H.A. (1969). "Sciences of the Artificial." Cambridge, MA: MIT Press.
> Team Tools for Wicked Problems Pacanowsky, M. In: Organizational dynamics. Wint 1995 v 23 n 3 pp 36-51
> Lindblom (1952), "The Science of 'Muddling Through'", Public Admin. Review. This is about how policy makers "muddle through" rather than
rationally solve (wicked) policy decisions.
>Buchanan, Richard Wicked Problems in Design Thinking. In: Design issues. Sprg 1992 v 8 n 2 pp 5+

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29. Donn, Michael. BBSC 231 Building Science. http://www.arch.vuw.ac.nz/papers/bbsc231 (Last accessed December 2003)

30. Donn, Michael. BBSC 303 Computer Applications http://www.arch.vuw.ac.nz/papers/bbsc303 (Last accessed December 2003)

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36. The basic, script based, Radiance calculation engine running on the Unix Operating System can be found at http://www.radsite.lbl.gov (Last accessed December 2003). There are a number of interfaces to the program available: ADELINE, produced by the International Energy Agency Solar Heating and Cooling Programme (http://www.iea-shc.org) (Last accessed December 2003); RAYFRONT produced by Georg Mischler (http://www.schorsch.com) (Last accessed December 2003); CONRAD 2.0 (http://www.openentry.com) produced by Ole Lemming (Last accessed January 2002).

37. Palmiter, Larry. **SUNCODE Users Manual**, ECOTOPE, Seattle, Washington, 1985

38. Deru, Michael. **SuNREL Users Manual.** Beta release obtained from National Renewable Energy Laboratory, Golden, Colorado, 2000.

39. Gordon, Harry, Justin Estoque and Min Kantrowitz **Commercial Building Design - integrating climate, comfort and cost** Van Nostrand Reinhold Company, New York, 1987.

2

Simulation: abstract reality

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

design_analysis_2006_a_clean.wpd

PREDICTION IS VERY DIFFICULT, ESPECIALLY ABOUT THE FUTURE.

NIELS BOHR (1885 - 1962)

This chapter establishes the context for the thesis research. It reviews the historical development of building **environment design decision support tools (eddst's)**.

2-1 *rationale for the research*

In the discussion of the pros and cons of different approaches to the development of eddst's that is the major part of the next chapter it is too limiting to follow the current trend to reserve the label "simulation" for those computer programs which model say the hour by hour heat losses and gains in a building. Rather, any simulation device is included whether it be a chart, formula, nomogram or computer program, or even a book whose purpose is to describe the performance to be expected of a particular design. The only limitation imposed is that described by my colleagues in "Task VIII" of the IEA Solar Heating and Cooling Agreement Research Programme: "...the term 'design tool' will be used to refer to tools that help make design decisions which ... are used in the design of ... buildings not *engineering tools which are used to size ... equipment...*" [1]. Each tool is seen as a device that permits the designer to model a building's environmental behaviour, and hence to operate as a simulation tool.

For the analysis in this thesis, the classification of design tools is based on the world view that each design tool creates. That gestalt[2] is a more accurate descriptor of the distinction that I am trying to draw with this classification. It was my hypothesis at the start of this research that it is the mis-match between the particular gestalt created by a design tool and the architect-user's own gestalt that creates the tension between the intentions of environmental design decision support tool (eddst) creators and educators and the application of their tools by practitioners. At its simplest it is the tension between the often iterative nature of design and the often linear, input precedes output, nature of tool use. In broader terms, it seems possible that eddst's may not provide the answers to the questions that designers ask. This tension is exemplified by the following exchange on the SBSE[b] internet listserver:

```
INITIAL QUERY:
From: "Brown, GZ (Charlie)" <gzbrown@aaa.uoregon.edu
 Subject: ecs framewk and concepts
 To: "sbse newsgroup" <sbse@uidaho.edu
 X-Mailer: Mail*Link SMTP-MS 3.0.2
 Sender: owner-sbse@uidaho.edu
 Content-Length: 687

I've been teaching at Oregon since '77 and I'm starting to run across
former students (now practising) in my energy consulting work. I've
been disappointed  in how little some of these students have retained
```

[ii] **S**ociety of **B**uilding **S**cience **E**ducators - a North American association of Environmental Control Systems (ecs) teachers in Schools of Architecture

from the ecs class. it makes me think i haven't been teaching them the right things in the right way. my guess too much detail and not enough on a framework for understanding and thinking about ecs and key concepts that are memorable so they can get their bldgs. designed correctly the first time around and use their consultants for detail and unusual problems.

 have any of you had similar experiences?

 anybody got a framework?

 what are the 10 most important concepts in ecs?

==========
Date: Tue, 4 Jun 1996 13:15:21 -0600 (MDT)
From: Tang Lee <lee@evds.ucalgary.ca>
To: "Brown, GZ (Charlie)" <gzbrown@aaa.uoregon.edu>
Cc: sbse newsgroup <sbse@uidaho.edu>
Subject: Re: ecs framework and concepts

The problem with ecs and simliar building science type courses is that it is taken as a course, and not integrated in studios. Students need to apply their knowledge about ecs principles as part of the design process before they acquire a true understanding. Architecture is essentially a series of compromises in order to achieve the optimal combination of technical, aesthetics, etc., issues. Students need to learn about these compromises in school if they are to become competent practitioners. The studio is the vehicle that they can explore the frustrations and successes with integrating ecs, structural, building code, etc., into the design.

As teachers, our role is not only to convey knowledge, but to stimulate interest, enthusiasm, and instil attitude towards architecture.

Our aesthetic design colleagues have been very good at instilling their attitude. The building science educator have traditionally convey only the facts. We need to impart attitude to our students as this will guide them much farther in their career.

Hope this helps.

Tang Lee
The University of Calgary.

==========
Date: Tue, 04 Jun 1996 16:26:59 -0500 (EST)
From: David Lee Smith <david.smith@uc.edu>
To: "Brown, GZ (Charlie)" <gzbrown@aaa.uoregon.edu>,
     sbse newsgroup <sbse@uidaho.edu>
Subject: Re: ecs framewk and concepts

CHARLIE:

Of course I've had similar experiences, but I don't have to wait until my students have moved on to professional life. They often demonstrate that they apparently have not grasped the essential intentions when they come across me again in upper level courses. But then, there are also the positive examples of those students who not only have understood what I was trying to convey, but have even taken it further.

I sometimes wonder if it is as much what we are doing (or not doing) but what students expect (or don't expect) from their education. It seems that students today (and recently, but not long ago when we were students) are focused on learning facts rather than principles. And these facts are not retained since they are not used in other courses, especially in design studios. There are also the premises that seem

> to infect much of design education today: a.) that the experienced spatial qualities of built form are not as important as the designer's intentions, and b.) that pragmatic issues are not serious architectural concerns, and if they need be addressed there are experts that will do it.
>
> Perhaps the most important concepts in ECS are that the experienced spatial qualities ARE what's important and effective architects ARE the individuals who are responsible for establishing these qualities. Architecture is a performing art, and architects must be capable of controlling the architectural performance.
>
> David Lee
>
> ```
> ************************************************
> *  David Lee Smith              Professor of Architecture
> *  Telephone:  (513) 556 5291   SAID, DAAP
> *  Fax:  (513) 556 3288         University of Cincinnati
> *  david.smith@uc.edu          Cincinnati, Ohio 45221-0016
> ============================================================
> ```

The motivation for the research reported in this thesis is contained in the above debate. The research goal is to address the disjunction that apparently exists between the knowledge that architects and clients want of the effect of buildings on human environments and their lack of desire to understand this effect at anything but the most trivial of levels. It addresses the debate that has continued over many years[3] in design methodology studies about the roles of analysis and synthesis in the design process.

2-2 *architects and simulation*

As this thesis is about the application of eddst's in architecture, and as Jean Baudrillard is often quoted in papers[4] concerning hypertext, virtual reality and "simulation" it seemed essential to at least distinguish my definition of simulation from that of the author of Simulacra and Simulation[5]. My reading of the passages I have found, and of secondary texts on the web have proven quite confusing. Although this confusion and the personal creative act of interpretation might be seen as a positive advantage by the authors of these texts, it has left the following two quotes as the most relevant outcome. These personal acts of interpretation are passed on, as the author of the second quote would desire, to the reader of this thesis:

> One Jean Baudrillard has made quite a stir by claiming that reality no longer exists, if it ever did, and all that is left are "hyper-real" simulacra, "copies of copies without originals." I am unaware of any arguments in favor of this, which I suppose is fitting. His stunningly atrocious articles saying that the Gulf War could not take place, and then that it hadn't taken place, deserve an honored place in the Museum of Intellectual Rubbish.[6]

And in a web page by Erica Seidel:

> The point Baudrillard is trying to make is that simulations have devoured reality, and that models have taken "precedence over things." Too much reality has resulted in saturation and explosion. Now, we are looking at an implosion -- reality and meaning are melting into a nebulous mass of self-reproducing simulation. So there is an odd chain reaction,

> whereby simulations have taken over for reality, but now generate nothing but more simulations: This "fall" into simulations is exacerbated by the masses and media. The public prefer spectacles to reality. We would rather go to Disney World than to work. When we watch the news, we would rather be entertained than informed. The consequence of this preference is that reality loses its status, and that the effectiveness of simulation is greater than the potency of reality.[7]

There is a suggestion that the growing tendency of people to be unable to distinguish reality from its simulacrum[8] places our social structures in danger. Examination in this thesis of one of the technologies by which simulations of people's experience of building performance might be created is not inconsistent with either of these views. Much of the discussion around Baudrillard's work centres on the use of simulation, or its role in people's lives. I suspect that in the terminology of those writing around the themes in Baudrillard's work, I am adopting a rather old-fashioned functionalist approach. By examining the relationship between the simulation tool and its user and not the social and power structures within which its use is placed, I am working within a paradigm that in their view inherently can only address some of the needs of designers for environmental design information. This is intentional. Dealing with just these "technical" issues of the response of people like architects to the technology of simulation is difficult enough. Later research can address the social structures within which environmental design analysis of buildings is conducted. First we need to document the social microcosm that is the world of the building design practitioner. What they do and how they describe their "use" of the environmental analysis data is the focus of this thesis. The social structures within which they practice are for others, with different skills and knowledge than I possess.

What I have therefore elected to deal with in this thesis is environmental design analysis as a design decision support tool. I am interested in the ways in which we simulate the world experienced by our senses - the world defined by Rasmussen[9] in **Experiencing Architecture**. The only distinction I have added beyond Rasmussen's definition of the sensed, haptic[c] environment is that his description is rather light on the temperature conditioning role of buildings.

This chapter is structured to place this research hypothesis into an historical and contemporary design tool context. In the next few pages, a brief review of the history of building environment design decision support tools provides the broad basis for the work of design tool classification which forms the body of this chapter. The purpose of the classification system is to provide a foundation for the introduction to the research philosophy and methodology that conclude the chapter and introduce the detailed research methodology in the next chapter.

[iii] *haptic* a. Of, pertaining to, or relating to the sense of touch or tactile sensations. b. Having a greater dependence on sensations of touch than on sight, esp. as a means of psychological orientation. Also absol., a haptic person. **Oxford English Dictionary Online**: http://dictionary.oed.com/ (Last accessed 2001) "1939 Mind XLVIII. 360 There is the notion of pure 'touch', and there are 'kinæsthetic experiences', and we can have the one without the other; but when we speak of 'the world of touch', or 'tactile æsthetics', we are referring to the data provided by an intimate combination of them both and for this sense Prof. Révész uses the adjective 'haptic'." Used in this thesis to include the visual and aural senses as well as those senses with which we 'feel' warmth and its opposite - a loss of heat - which I have heard some describe as coolth.

2-3 *historical overview*

Given that my thesis goal was to establish what are the common problems in the application of environmental design decision support tools (eddst's), I began the construction of the research methodology described in the next chapter by documenting what eddst's contribute to building design. Later sections of this chapter classify the various tools. This section examines the history of the application of eddst's in architecture.

2-3.1 simulation models

For centuries designers have devised means of organising the world according to models of how it is thought to work. As Wittkower notes[10] (quoting Palladio's Libri IV) in his description of the principles on which the architecture of the Renaissance was based:

> "..when Palladio wants churches to be built 'in such a manner and with such proportions, that all the parts together may convey a sweet harmony (una soave armonia) to the eyes of the beholder' he did not think of a vague indefinable appeal to the eye but of the spatial consonances produced by the interrelation of universally valid ratios (p115).... the Renaissance analogy of audible and visual proportions was no mere theoretical speculation; it testifies to the solemn belief in the harmonic mathematical structure of all creation. (p117)"

This trust in a higher order which could be modelled or simulated using mathematics follows ...

> "...an unbroken tradition coming down from antiquity according to which arithmetic, the study of numbers, geometry, the study of spatial relationships, astronomy, the study of the motion of celestial bodies, and music, the study of motions apprehended by the ear, formed the quadrivium of the mathematical 'arts'. By contrast to these 'liberal arts', painting, sculpture, and architecture were regarded as manual occupations. In order to raise them from the level of the mechanical to that of the liberal arts, they had to be given a firm theoretical, that is to say, mathematical foundation.. "

Wittkower points to the precedents in classical antiquity where Vitrivius requested musical training for the architect and notes Palladio's musical education, concluding: ... "a familiarity with musical theory became [during the Renaissance] a sine qua non of artistic education..." The world itself had been modelled in what was already acknowledged to be an abstract manner in such devices as the orrery that Archimedes is reputed to have constructed[11].

In **The Ascent of Man**[12], Bronowski writes a very persuasive description of what he sees as the first step in "the beginning of theoretical science" . In writing about the cliff dwellings in Canyon de Chelly in Arizona, he contrasts the process of moulding clay with splitting wood. The Anasazi Indian pit house ...

> "...reflects the shaping action of man (sic). Nothing has been discovered about nature herself when man imposes these warm, rounded, feminine, artistic shapes on her. The only thing that you reflect is the shape of your own hand..."
>
> But there is another action of the human hand which is different and opposite.. That is the splitting of wood or stone; for by that action the hand (armed with a tool) probes and explores beneath the surface, and thereby becomes an instrument of discovery. There is a great intellectual

> step forward when man splits a piece of wood, or a piece of stone, and lays bare the print that nature had put there before he split it. The Pueblo people found that step in the red sandstone cliffs that rise a thousand feet over the Arizona settlements. The tabular strata were there for the cutting; and the blocks were laid in courses along the same bedding planes in which they had lain in the cliffs of the Canyon de Chelly...
>
> ... from that simple beginning man prises open the nature of things and uncovers the laws that the structure dictates and reveals. Now the hand no longer imposes itself on the shape of things. Instead it becomes an instrument of discovery and pleasure together, in which the tool transcends its immediate use and enters into and reveals the qualities and forms that lie hidden in the material. Like a man cutting a crystal, we find in the form within the secret laws of nature.

The notion of discovering an underlying order in matter is man's basic concept for exploring nature. The architecture of things reveals a structure below the surface, a hidden grain which, when it is laid bare, makes it possible to take natural formations apart and assemble them in new arrangements. For me this is the step in the ascent of man at which theoretical science begins.

According to Bronowski this first step in developing models of the world based on an empirical understanding of its structure began in places like Canyon de Chelly around AD 1000. He argues that the designers of the Gothic cathedrals of the past are the people who created a structure out of the analysis of nature; and he argues that scientists are the same people who are "interested in the architecture of nature today..." His is a strong science-based counter to the cliche position adopted by some theorists in architecture even today: that "science is pure analysis or reductionism, like taking the rainbow to pieces; and art is pure synthesis, putting the rainbow together " (Perez-Gomez[13]).
It is only possible to speculate about the degree to which the modelling of the world described by Bronowski permeated consideration of environmental comfort and performance in building design. It would appear that the use of models of the environment as design guidance for building environmental quality did not appear until the nineteenth century.

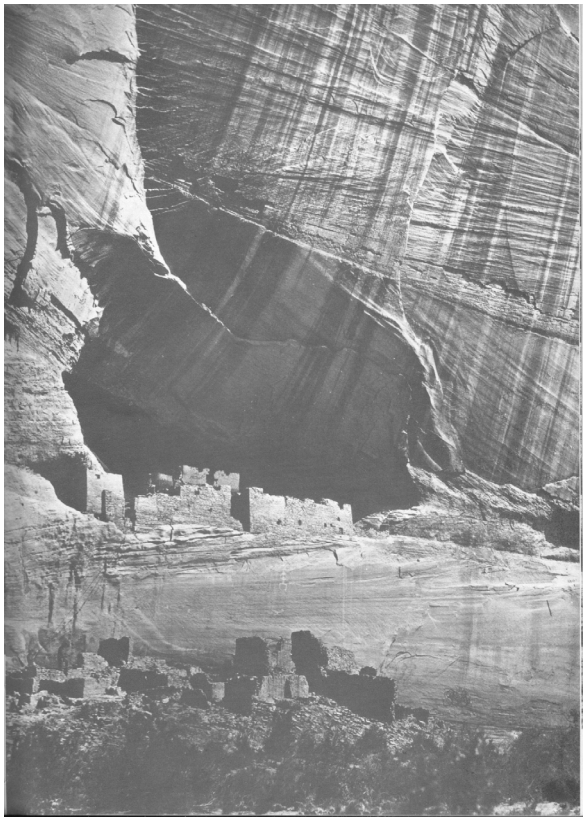

Figure 6 Bronowski illustration: *T H O'Sullivan 1873 photograph of the White House at Canyon de Chelly*

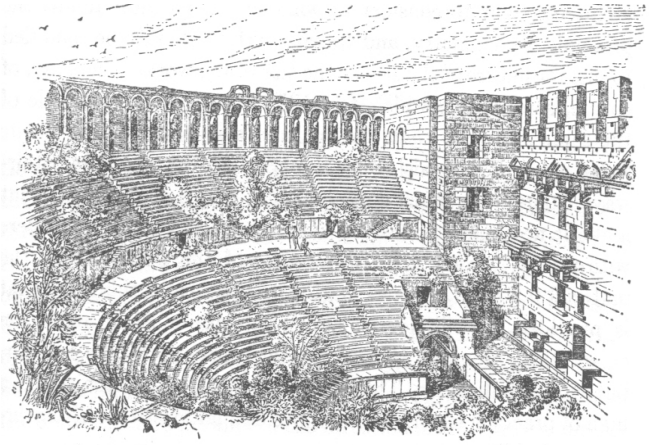

Figure 7 Theatre at Aspendos from Vitrivius' 'Ten Books'

2-3.2 early simulation models

Even when modelling was undertaken in the past, it is interesting to discover how little was understood of human perception and what we would today call building physics: Elliott's account[14] of the development of acoustics is a most intriguing demonstration of this. For example, Vitruvius' brief descriptions from the First Century BC of acoustic principles of Greek and Roman theatres present a description of harmonics as a science albeit "an obscure and difficult branch of musical science" . He advocates the placement of sounding vessels of varying resonant sizes in masonry theatres. "...by giving heed to these theories, one can easily bring a theatre to perfection, from the point of view of the nature of the voice, so as to give pleasure to the audience" . His descriptions of the "acoustics of the site of a theatre" in Book V, Chapter VIII do nothing for the architect wishing to follow them towards a theatre design with a good 'acoustic'. They describe the results of doing things wrong acoustically. These descriptions are quite clear and imaginable. But the only "solution" offered is:

> "...if there has been careful attention in the selection of the site, the effect of the voice will, through this precaution, be perfectly selected suited to the purposes of a theatre. The drawings of the plans may be distinguished from each other by this difference, that theatres designed from squares are meant to be used by Greeks, while Roman theatres are designed from equilateral triangles. Whoever is willing to follow these directions will be able to construct perfectly correct theatres."

Even more intriguing is Elliott's description of "an inexplicable belief that wire strung overhead across a hall would counteract undesirable acoustical conditions that were due to reverberation or would vibrate in sympathy with a speaker's voice, thus strengthening the sound. Wires were to be seen in many English churches at the turn of the century [1900].."

Vitruvius is the most often quoted source for environmental design decision support in antiquity. However, the most important thing to remember about Vitruvius is (from Kruft[15]) that he...

> ... was of virtually no consequence to Classical Rome, and his meteoric rise to fame began only in the fifteenth century.... Vitruvius had no influence on the architectural practice or thinking of the early Imperial era; only Pliny the Elder quotes Vitruvius as a source reference for the thirty-fifth

> and thirty-sixth books of his **Naturalis historia**; this, however, only in connection with his statements on painting and types of stone. To the later Imperial era belongs the **Compendium** of Faventius, and borrowings by Cassiodorus Senator © 490-583 AD);[d] but these references are in a rhetorical context. We know nothing about the dissemination of Vitruvius's text in Antiquity. ... The peculiar fate of Vitruvius's treatise has been aptly characterised as follows: 'In the history or art there is probably no other example of a systematic textbook aiming at contemporary influence, missing its target, and yet achieving such overwhelming success centuries after it appearance.'[e]

It is difficult therefore to read his descriptions of the principles of building performance - his simulations of environmental performance - as other than historical curiosities. They do of course appear to have influenced architects since the fifteenth century. The following are relevant (simulation) models of building environmental performance: **Book VI, Chapter I (of Vitrivius) "On climate as determining the style of the house"**:

> "If our designs for private houses are to be correct, we must at the outset take note of the countries and climates in which they are built. ...This is because one part of the earth is directly under the sun's course, another is far away from it, while another lies midway between these two...Thus we may amend by art what nature, if left to herself, would mar."

After a fairly jingoistic discussion of the attributes of the races from the various climes to which he refers, Vitruvius goes on to lay out preferred dimensions and exposures for rooms in different places and climates.

Under the "Farmhouse" he has this discussion of light:

> We must take care that all buildings are well lighted, but this is obviously an easier matter with those which are on country estates, because there can be no neighbour's wall to interfere, whereas in town high party walls or limited space obstruct the light and make them dark. Hence we must apply the following test in this matter. On the side from which light should be obtained let a line be stretched from the top of the wall that seems to obstruct the light to the point at which it ought to be introduced, and if a considerable... [NOTE the imprecision again!] ...space of open sky can be seen when one looks up above that line, there will be no obstruction to the light in that situation.
>
> But if there are timbers in the way, or lintels, or upper stories, then, make the opening higher up and introduce the light in this way. And as a general rule, we must arrange so as to leave places for windows on all sides on which a clear view of the sky can be had, for this will make our buildings light...

This could have been taken from a modern text on daylight. It does not provide a means of simulating any reality. Rather it presents a common-sense description or simulation of an approach - a reality - that works.

In order to understand early use of simulation it is instructive to look at Johnson's[16] description of the origin of the label architect:

> ...originating in the Greek architekton (archos, chief, and tecton, builder thus 'masterbuilder'), the word first entered the English language with a publication by John Shute in 1563[17].. Joseph Gwilt[18] claims that 'architect' was rarely used in the Middle Ages and prompts that 'ingeniator' was its equivalent in the twelfth century, and that 'supervisor', translated as 'surveyor' and 'overseer', was used frequently from the Norman Conquest. [19] Rykwert, Leach and Tavernor are then quoted in their translation of Alberti as defining a medieval usage derived from the Latin archus and

---

[iv] Koch, Herbert, **Vom Nachleben des Vitruv,** Baden-Baden 1951, p 9. Cited by Kruft.

[v] Ibid; p. 10. Again cited by Kruft.

> tectum and offering Alberti's definition of an architect as someone "who by sure and wonderful reason and method, knows both how to devise through his [sic] own mind and energy, and to realise by construction, whatever can be most beautifully fitted out for the noble needs of man, by the movement of weights and the joining and massing of bodies. To this he must have an understanding and knowledge of all the highest and most noble disciplines.." .

Note that word "method": apparently the only "modelling" of the world that would be undertaken by these architects would be interactions between structure and gravity.

Butti and Perlin[20] argue that solar principles were well known to "the Greeks" of antiquity. They quote Socrates: "In houses that look toward the south, the sun penetrates the portico in winter, while in summer the path of the sun is right over our heads and above the roof so that there is shade..." Aristotle apparently noted that this southerly orientation also kept out cold winds from the north. Butti and Perlin attribute this design approach to the "Greek's use of sundials. " Here we have an early example of the use of an eddst to predict building performance in may different situations. Examples are presented from Olynthus in Greece and from Priene and Delos in Asia Minor or Turkey. Apparently "even homes belonging to the poorer citizenry could enjoy the warmth of the sun in winter and be spared its heat in summer."

They make a brief case that Chinese architecture and urban planning followed similar solar lines. "Whenever the site permitted, the preferred house plan bore a striking resemblance to the Olynthian homes in that its principal apartments were built on the north side of a courtyard that opened to the south. " To what extent this reliance on the benefit of the sun can be attributed to good design or necessity brought about by a lack of fuel wood for heating is unknown. Discussion of the design principles of a well-insulated house that retains the heat collected during the day is not apparent.

> By the time of Christ, it was common for wealthy Romans to have central heating in their expansive villas. Their hypocausts burned wood or charcoal in furnaces and circulated the hot air through hollow bricks in the floors and walls. A hypocaust system could devour as much as 280 pounds (125kg) of wood per hour...

Local wood supplies in such circumstances became very scarce. In fact, hypocaust heating systems were in use in Ephes[os] 1000 years before this. One presumes that the builders had some rules to follow in their construction, but the question of what model or rationale they used to justify these rules is open to the same debate that rages over the amount of "glazing" that was really used in solar oriented buildings of antiquity[21].

Pliny is quoted by Butti and Perlman as naming one of his rooms a heliocaminus - literally *solar furnace*. "A thriving window industry existed in Rome at the time. Transparent coverings made of thin stone such as mica or selenite were produced by splitting the stone into plates as thin as desired. "

> "It was not until the First Century AD that an anonymous Roman thought of using transparent materials to make windows that would let light in but keep out rain, snow and cold. The philosopher Seneca noted the newness of this idea in a letter written in AD 65, "Certain inventions have come about within our own memory - the use of window panes which admit light through a transparent material for example."

Around the First Century the Romans appear to have discovered the benefit of the sun in their architecture to a great degree. Early public baths appear to have had small apertures high in the walls through which little shafts of light could penetrate. The later baths have large south facing windows. Apparently the baths were the only places where the poor felt the benefit of solar heating. Their homes did not gain from the solar design principles propounded by Vitruvius and his later colleagues. M. Cetius Faventinus (third century) and Palladius (Late imperial) both added solar refinements to their "direct or indirect compilations from Vitruvius" [22]. Most ingenious amongst the refinements was the solar storage floor which was finished black for better heat collection.

As with most other phenomena, there seems little to be gleaned about building performance from the records of history after the Greeks and Romans until the end of the Dark Ages. Throughout the Dark Ages: "again and again, from the fifth to the eleventh century, we read of monks complaining that their hands are too cold in winter" [23] for the paper work to continue, even though "the average temperatures of northern Europe were several degrees higher than they are today." Around the eleventh century temperatures started to cool and by the thirteenth, a two hundred year long little ice age set in. In England this change brought about a change in Manor house living. Instead of taking smoke from a central fire in a room full of people out through a hole in the roof, the chimney was introduced. The understanding of the technology of the design of the draught for the chimney "probably came from the craftsmen " who ran the iron and glass furnaces.

As it became economically and practically possible to heat separate rooms so the nature of buildings changed in the cold climate of England. Heated bedrooms and "the concept of privacy" arrived. A change in clothing (knitwear and buttons allowed tighter fitting clothes) and improved sanitation brought about big changes in the planning of the services of a building. Burke even suggests: "The understanding of draught physics may have been improved by the arrival of Tartar slaves into Italy in the fifteenth century, bringing with them air turbines with which to power fireplace spits." The final direction in which this change headed was the "prolific use of glass in the new buildings in England... Although there had been an active glass industry before this time it had in the main been confined to cathedrals and palaces, and as the surge in cathedral building waned in the fifteenth century, so had the industry. " Little is written in these descriptions of the means by which equipment was matched to the building design or the building itself was designed to match the environmental needs of its users.

Europe's first greenhouses were apparently[24] constructed in Holland in the 1500's. By the eighteenth century it was very fashionable to have a greenhouse. The fuel wood shortages and crudity of the blown glass methods of glass making had been replaced by coal fired techniques and the French developed plate glass process which "was strikingly similar to the Roman method." [25] By this time the Galilean revolution[26] was well under way, so scientists were systematically studying the ways in which they could improve the performance of the greenhouse or its cousin the conservatory attached to the house.

"Adanson wrote the first systematic treatise on the theory and construction of greenhouses. He presented rules, tables and diagrams to be followed for building the most functional greenhouses in every possible location, from the poles to the equator." [27] There are strong parallels between the success and demise of the conservatory as a means of heating today and one hundred years ago. As the conservatory became more popular people appear to have bought the icon, the symbol of warmth and light without thinking through how best to attach it to their house. At the turn of the century in England "artificial heating systems now provided warmth for the garden houses..." setting the scene for the "demise of the conservatory in England ...[with] .. the institution of fuel rationing during World War I." [28]

The nineteenth and early twentieth century saw other systematic attempts at the study of the sensed environment and the representation or modelling of the results in some predictive tool. It is useful to contrast the fields of "heating", "lighting" and "acoustics" during this period. Even these common names express a fundamental difference in the content and manner of the early development of the fields. The first two are about the technology of appliances placed in buildings, whereas the latter is fundamentally about building design. Sabine's systematic studies of the lecture hall at the Fogg Museum in New York are legendary. They established a quantitative science of architectural acoustics. They therefore form the major starting point of any book on the acoustic environment in architecture.

In lighting, the norm in architectural lighting texts is to present information on the light sources. Daylight design information is presented well, but after the lamp technology is described. It is telling that a study of the **Development of Materials and Systems for Buildings**[29] presents much heating and ventilating equipment and lamp developments not window technology. Hawkes' **History of models of the environment in buildings**[30] is actually about building design. It concentrates mostly on the development of predictive tools for the study of direct sun and daylight in buildings. The "design tools" described by Hawkes and their effect on building design are not dealt with at all under the "lighting", "heating and ventilation" or "air conditioning" chapters. Perhaps this concentration on the technology of these functions is where architects' lack of interest begins?

Cole and Cooper[31] report instances from the RIBA records over the past 150 years which indicate a strong interest by architects in coming to terms with an " ever-growing volume of scientific and technological information" . Two quotes summarise the search for environmental design principles well. First from a paper read to the RIBA in 1856: "The want of proper knowledge on the part of the architect, combined as it is with the want of information on the part of the public, leads to many of the anomalies which are now so frequently observable in the practice of the profession, and to the presence in its ranks of many who have not the will to uphold its credit." [32] And from a participant in the General Conference of Architects held in London in 1871: "So long as it is in the experimental stage, let the specialist keep it to himself, but as soon as it has passed this stage and reached the practical, then the architect should always be ready to avail himself of it" .[33]

2-3.3 architects and environmental performance simulation

No matter what the rhetoric of the environmental design theorist, architects still seems to see dealing with the flows of light and heat energy in a building as merely problems which will have a technological device thrown at them. Banham's comments about Frank Lloyd Wright's architecture[34] reveal Wright's interest in, one might even say a fascination with, the technology of environmental control. But there is apparently little clear understanding of the interaction of the building and its environment. Banham makes a convincing case that the Prairie Houses were technologically innovative. The association of extensive hot water heating radiators with the principal heat loss elements in the houses - the windows - made it possible to make those windows larger and hence provide greater and more extensive provision for one of Wright's fixations: ventilation. Even in this account celebrating the "first peak" ... in the .. "architecture of the well-tempered house... " there are some problems: the Robie house " has a reputation for being hard to heat." Not quite as bad as the present day closing of Wright's own house at Taliesin in Wisconsin every winter because it is so hard to heat[35].

Quinan's study of **The Larkin Building**[36] is a great illustration of how this technological innovation affected the design of Wright's buildings. However, even here, where evidence is presented of one of the first uses of air-conditioning (including Carrier's requirement of humidity control) the clear picture is of someone who perceived and acted as though there is a very strong separation between the rhetoric and the practice of environmental design.

Paulos writes[37] ":Rousseau's disparagement of the English as "a nation of shopkeepers" persists as a belief that a concern with numbers and details numbs one to the big questions, to the grandeur of nature" . One might see this as a caricature of the twentieth century architect's view of the role of building science in architecture. "Mathematics is often taken to be mechanical, the work of low-level technicians who will report to the rest of us anything we absolutely must know..."

This attitude can be seen to pervade the whole of the twentieth century's development of design guidance for environmental performance. The Renaissance adoption of Classical models for architecture, saw Palladio, Alberti and other authors' revisiting Vitruvius. However, by the nineteenth century, architects were copying the forms of the ancient buildings but not bothering to understand the principles on which they were based.

> "They failed to orient buildings properly, missing an opportunity to heat them with the sun. Humphrey Repton, one of the few English architects to recognize the irony of this misuse of Classical solar architecture, remarked: "I have frequently smiled at the incongruity of Grecian architecture applied to buildings in this country whenever I have passed the beautiful Corinthian portico to the north of the mansion house ... such a portico towards the north is a striking instance of the false application of a beautiful model." Thus northern Europe's wealthy classes often had to heat their cold mansions artificially, while their prized peaches basked in the solar

heat inside glass greenhouses" .[38]

Even more curious is the example of the Zeilenbau (row house) plan in Germany in the late 1920's:

> "The rows of four-storey buildings were erected far enough apart so that no apartment blocked another's sunlight. The majority of rows ran north-south and were only two rooms deep. The living room and a balcony usually faced west and a bedroom looked toward the east; theoretically, half the main rooms received the morning sun and the other half got the evening sun. The Zeilenbau plan described as "heliotropic" by many, excited the international architectural community. Critics like Lewis Mumford reflected this enthusiasm: " Above all Zeilenbau permits the orientation of the whole community for a maximum amount of sunlight... " The better architects recognised the need for shading from low angle rising and setting sun.

But, a scientist who studied the performance of the buildings noted that "the streets collected more solar heat than the apartments!"

By this time, as Hawkes[39] points out, Waldram's "design tool for architects " which predicted the natural illumination in a room given window size and orientation had been published for 5-7 years. Similar work of Molesworth had been published in 1902. There seems little reason for Mumford to uncritically endorse the "heliotropic" aspects of the design.

30 years later the non-uniform distribution of the overcast sky was published by the CIE in 1955. A further 10 years after that the Waldram diagrams were updated to account for this sky luminance distribution. It is interesting to note that, within five years of the development of this improved sky luminance version of the Waldram diagrams, the computer began to make it possible for architects like Hawkes to write: "A computer system which would help the architect to make decisions within the design process is a logical development of all the "models" described above." Hawkes then develops a "basic specification which should be satisfied by any computer system which is designed to act as a design aid." Since 1970 many of these early models of building performance have been used in research laboratories to construct computer programs which simulate the real environmental qualities of the world. Indeed, the "classical" thermal simulation programs , like the US Department of Energy DOE program originated in the 1960's.[40]

This thesis acknowledges that simulation is the creation of any kind of model of a building that permits its performance to be predicted. Environmental design decision support tools (eddst) typically use simulation to predict the environment that will result from particular design decisions. What has happened over the 30 years since 1970 is that computer simulation of some aspect of reality has become seen increasingly as the ideal tool for building design decision support. However, up until very recently, computer simulation programs have been too slow or have run on very expensive computers. They have therefore not been used directly in design applications. Rather they have been used in the laboratory to derive more and more sophisticated graphical design aids and rules of thumb for use as design tools.

In a recent review paper Papamichael writes:

> A major prerequisite in decision making is the ability to predict performance, which, in building design, is only [my emphasis] "possible through simulation. Up to a few years ago, simulation methods were limited to manual procedures, such as drafting, drawing, building of physical scale models, and performing manual calculations. Research and development efforts during the last two decades have produced a large variety of computer-based simulations that offer significant advantages when compared to manual methods. Almost all of the architectural and engineering firms currently enjoy the benefits of Computer-Aided Drafting (CAD) software, while a significant number of applications on structural, lighting, energy, economic, etc. analyses are now used regularly on large projects that can afford the higher associated costs." [41]

2-3.4 deconstruction of the programme?

The deconstructionists or their cousins the deconstructivists argue for "...'deconstructing' of the architectural 'programme'... " [42]. One might expect that theirs would be an interpretation which challenged and undermined the need for the types of analytical techniques - the types of design tools - that I am studying in this thesis. An eddst is after all merely being used to provide a performance prediction whose value is interpreted against a set of criteria normally derived from the architectural programme or brief. Perhaps there is a rationale here, in architects' writings on architecture, for the lack of engagement with environmental design principles in much modern architecture that was referred to in the early paragraphs of this chapter.

Peter Eisenman, for example, argues that recent developments in technology, philosophy and psychoanalysis render irrelevant the tradition of the relationship between the proportions of the human body and architecture. He is quoted in A+U August Extra 1988 as stating "the grand abstraction of man as the measure of all things, as an ordinary presence, can no longer be sustained." In relation to his University Museum for Long Beach, California he rationalises the design features he adds as 'traces' of some imagined past:

> "...because the traditional role of architecture has been not only to realise a sheltering function, but to represent and symbolise it as well. But whilst its function is to shelter art, it does not follow that the museum as a building must symbolise that fact. It could represent instead the relationship of art to society; it might raise questions about the museum as a social institution; it might even display a new way of representing the solution."

Perez-Gomez in his **Architecture and the Crisis of Modern Science** argues an even more extreme view of the role of science, and hence of simulation of building performance based on scientific principles. He suggests first that use of or reliance on scientific principles is"scientism" - interpreted here to mean a belief that the whole world is determined and determinable by scientific "laws" written as equations.

> "In Medieval and Renaissance Europe, the order of things and the social hierarchy were prescribed through revelation. The Galilean revolution represented the end of an understanding by which man had always held a privileged position, while at the same time being subordinated to the discipline of the cosmos as a whole. After the seventeenth century, the notion of system, or a whole made of coordinated parts (**the prototype of all rationality**),[my emphasis] was taken from astronomy and utilised as the model for the science and philosophy of the sublunar world." [43]

> "... Modern physics thus originated in the application of exact, immutable notions of an abstract

> order (mathemata) to the sphere of reality...The epistemological revolution he (Galileo) ushered in would one day wear the mantle of positivism[44] and, later, scientism[45]."
>
> ".. Galileo presupposed that the laws of nature were mathematical. Believing that the real incarnated the mathematical, he was incapable of recognising the distance between geometrical theories and experience. This illusion lay at the heart of all modern quantitative science, particularly of mechanics, which became almost immediately the model for all intellectual endeavours.[46]"

As noted earlier, simulation of the behaviour of the architectural world was apparently well-established at the time of Galileo. Although we now have a very different understanding of the mathematics and of the behaviour of buildings that they model, our basic trust in the ability of a model to replicate some aspect of reality remains firm. We trust that a physical model of a building in combination with a spotlight will show us sun penetration and in combination with a wind tunnel will show us wind flows. Mathematical models of the sun building interaction are also implicitly trusted. Perez-Gomez continues[47]:

> The Royal Academy of Architecture was founded in 1671 to elucidate the beauty of buildings and to provide a means for the instruction of young architects.[48] The best architects in France would convene once a week to discuss their ideas, and the rules emerging from these discussions would be taught in public courses two days a week.
>
> ... André Felibien, Pierre Boullet, and Antoine Desgodetz also presented a great number of papers on technical problems to the academy during the early eighteenth century... In 1730 Abbé Camus, also a member of the Royal Academy of Sciences, began to teach mathematics to the architects at their academy.

According to Perez-Gomez, after 1750 architects' interest in mathematics and geometrical methods apparently generally flagged, while their concerns with the more specifically technical problems heightened. He notes interest centred on modern materials and techniques:

> ...in the preface of the first edition of the **Critique of Pure Reason** (1781) Kant wrote that human reason was overwhelmed by questions it could not solve. In the name of experimental philosophy, he condemned speculative metaphysics. The philosophy of the future had to respond to a different model of truth based on geometry and mathematics... The main thrust of positivistic philosophy was the notion that phenomena were subjected to invariable natural laws. All intellectual enterprises were to have as their objective the precise determination of such laws and their reduction to the least possible number in each discipline.[49]

Perez-Gomez's position is at variance with the position adopted in this thesis and described by Bronowski in ther early paragraphs of this chapter. His critique as described by the following quote appears to be based on the assumption that those who use and work to improve our ability to simulate the performance of the built environment have this positivistic view of simulation:

> According to Saint-Simon, the aristocracy of the nineteenth century was to be composed of specialised scientists and technicians; applied science would determine the future of humanity[50]... The first few years of the nineteenth century also witnessed the emergence of a new intellectual leader: the arrogant and self-sufficient technical specialist. Such individuals received their education at the École Polytechnique in Paris, an institution founded by the revolutionary Convention that became a model of progressive education around the world. The technical unquestionably (NOTE) has been the most influential figure in Western culture for the last two centuries. With an infinite faith in mathematical reason and believing himself educated because he had passed through difficult schools, he had little or no knowledge of society, its history and problems, and despised the humanities because their content was always ambiguous and practically impossible to formulate with mathematical certainty.[51]
>
> According to Fourcy, who wrote the first history of the École Polytechnique in 1828, more than half of the members of the physics, chemistry and mathematics sections of the Institut, as well as

> the best engineers in the country, were graduates from the school....The École Polytechnique prepared equally scientists and technicians, both of whom were obsessed (NOTE!) with the illusion of a technological utopia.
>
> ...The tenth chapter of Rondelet's Art de Batir was devoted to the quantitative evaluation of buildings.... Rondelet ... was exclusively concerned with the technological values of efficiency and economy. He criticised Renaissance and Baroque architects for having disregarded these values and for spending their time imagining "capricious, sumptuous, or gigantic projects" [52]

Durand in the following quote is apparently "terrifying" to Perez-Gomez because he suggests that "architecture had no other objective than private and public usefulness, the conservation and happiness of individuals, families and society" . A rather lengthy leap is made. It seems somehow that "meaningful" architecture inflicts pain, or is oblivious of the people who inhabit it?

> In contrast to previous architectural theory, Durand stressed the irrelevance of any transcendental justification. .. Durand summarised the basic precepts of his value system: In all times and all places, the totality of man's thoughts and actions were generated by two principles: love of well-being and aversion to pain.[53] This materialistic premise became the basis of the ethics and aesthetics of technology, and it still underlies the popular historical and ideological conceptions inherited from the nineteenth century. Only after Durand would it become important for architecture to provide "pleasure" or that it would be "nice" rather than truly meaningful.

It is more than a little curious to discover this antagonism between art and science in a modern text (see below). Writings such as this thesis that describe ecs models for the simulation of building performance clearly focus on the human person and their responses to the environmental stimuli. This core focus of the research and development must acknowledge that the measurable physical stimuli and their associated human responses are but a part of the human interaction with the built environment. However, in construction of this thesis it seemed necessary to acknowledge that the perverse other view argued by Perez-Gomez and others exists:

> "... certain basic contradictions in the theory of architecture emerged during the nineteenth and twentieth centuries. There has been an acute and unprecedented division between art and science, reason and poetry, architecture and engineering. Architects have opted for the extreme expressions of rationalism or romanticism, formulating design decisions from either positivistic reason or intuition. For the last two centuries, a reconciliation of the spheres of logos and mythos has been, explicitly or implicitly, deemed impossible. Ultimately, these contradictions must be seen as a result of the technological world view, the condition described in the introduction (after Husserl) as the crisis of European science, with its consecration of the Cartesian split between objective truth and subjective opinion, between mind and body, and its rejection of myth, poetry, and art as legitimate and primary forms of knowledge." [54]

This (unproven) polemic raises a lot of questions for another thesis. Most significantly, the causal relationship between what Perez-Gomez describes as the "technological world view" and the split between art and science is apparently an article of faith.

The concluding quote is an apparent promotion of a split between design for the individual's physical welfare and design for their spiritual well-being:

> "The ever present enigma of the human condition is only denied by the foolish. And it is this mystery that architecture must address. Part of our human condition is the inevitable yearning to capture reality through metaphors. Such is true knowledge, ambiguous yet ultimately more relevant than scientific truth. And architecture, no matter how much it resists the idea, cannot renounce its origin in intuition. While construction as a technological process is prosaic - deriving directly from a mathematical equation, a functional diagram, or a rule of formal combinations - architecture is poetic, necessarily as abstract order but in itself a metaphor emerging from a vision

of the world and Being."

Probably the most easily read refutation of this philosophical position is contained in an essay by Stephen Hawking:

> The people who ought to study and argue about such questions, the philosophers, have mostly not had enough mathematical background to keep up with modern developments ... They are still arguing about the scientific theories of the early years of this century ... My approach has been described as naive and simpleminded. ...The technique appears to be refutation by denigration ... A theory is a good theory if it is an elegant model, if it describes a wide class of observations, and if it predicts the results of new observations. Beyond that it makes no sense to ask if it corresponds to reality, because we do not know what reality is independent of a theory. ...[55]

Inhabitation' - the 'function' of human occupation of a building - is of undeniable importance in architecture. It is clearly a central dilemma when architectural theory and criticism addresses a real building. A critic like Jencks[56] when reviewing Peter Eisenman's addition to Cincinnati University reinterprets the building through his Cosmogenic Architecture paradigm to remark: "... it cries out for ... greenery, light from above, a view to the outside from the central atrium."

Broadbent argues[57] that Frank Gehry has been deconstructing the architectural programme without the associated word games of the 'Derridean' Deconstructionist thought. He quotes Gehry: "Unlike most architects, all these guys (his artist friends) call my work into question. Just think ... for God's sake. Think of Gordon Matta Clark! He called everything into question didn't he? And architects have never done that! "

But, in 1996 at the opening of an exhibition of Gehry's work on the Disney concert hall for Los Angeles in Arata Isozaki's Museum of Contemporary Art in downtown Los Angeles I found another paradigm in operation. What was most striking about the opening was the central importance of the Tokyo based acoustic consultant Minoru Nagata in the ceremonial and also in the design development expressed by the models and drawings on display. Those in attendance had a clear demonstration of the central position of "function" - or at least acoustic function - in a design process that produced what a tourist guide to LA[58] calls: a "...controversial design, which will look out to the street through waves of glass, ..." [and] "...resembles a sculpture of curving and folding

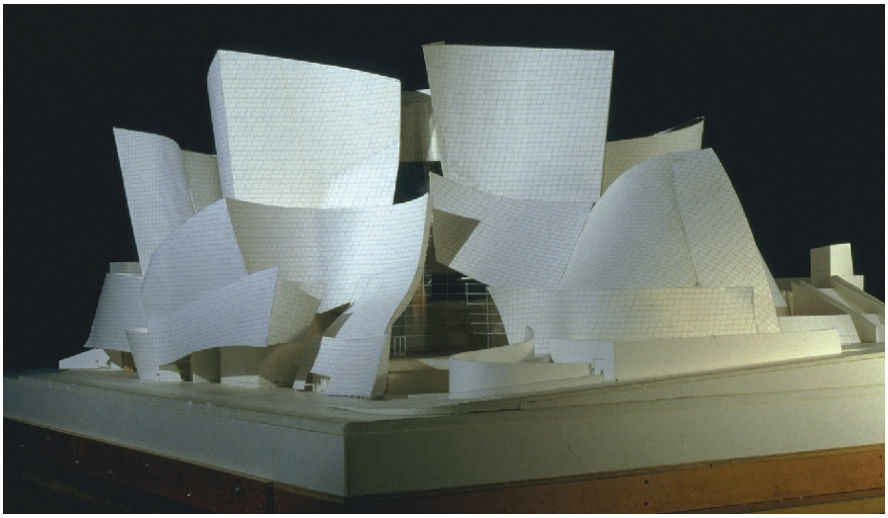

Figure 8 Model of Disney Concert Hall, Los Angeles. Architect: F. Gehry

French limestone, with a concave copper roof and inward tilting walls. "

Despite the deconstruction of the programme, there appears to be a strong thread of function in all this architecture. This challenge to the programme is apparently reserved for some 'aesthetic level', much in the same way as Kruft in his seminal **History of Architectural Theory**[59] restricts his definition of architectural theory to "any written system of architecture, ... that is based on aesthetic categories." The challenge of a "new aesthetic" based on the ideas of thermal comfort and performance[60] is not addressed. Rather, the conventions of the performance paradigm are accepted[61]. The building appears to be a conventional acoustic/lighting/heating environment merely clothed in an unconventionally shaped skin. The environmental performance of the components - the walls, roof, floors, windows - is conventionally defined. The design opportunities that are provided by the assessment of the quantifiable aspects of building performance are ignored.

Lebbeus Woods, in a lecture on his (paper) architecture at the San Francisco Museum of Modern Art in 1995 described how he is responding to a situation where "the existing languages of architecture are not serving us well." He is seeking to create an architecture with "useless and meaningless spaces; spaces which are difficult to occupy." In this drawn architecture, one perhaps does not have to address issues of inhabitation. However, the non-space created in some of his buildings on exhibition at the SF MOMA was at times difficult to occupy because it had a hostile light, sound or thermal environment. Even here, the conscientious designer (Woods) wishes to deliberately control the environment that is being created, and thus must understand the performance implications of their design decisions, even though their rhetoric is to reject this performance paradigm. To deliberately make an environment that is marginal for human habitation one must implicitly accept and understand what is necessary for human habitation. In fact to do this with any conviction requires quantification of building performance through some form of simulation.

2-3.5 a 'transcendent realm'?

Jencks[62] rejects the notion of scientific laws as 'social constructions' - "...mathematical models which just happen to be useful in describing regularities." He prefers to believe in a 'transcendent realm' along with, he suggests 'most scientists' [who] "...believe they are discovering something objectively real and that reality 'obeys' or is 'subject to' these laws" For him they become "...a standard for us-independent of us..." and "Because the laws illustrate this otherness..." he chooses "...to design them into and onto buildings, in both literal equations and performative figures."

The basic problem for the building scientist is persuading architects like Jencks, who are arguing for an architecture oriented to nature and culture - a green architecture - that it is their job to understand the applications of these 'laws' to the design of their buildings. It is the central dilemma on which this thesis is focussed. While it may probably never be possible to persuade the Perez-Gomez's of this world as to the value of eddst's it is essential that an architect of the (green) philosophical approach

of Jencks is persuaded to address carefully and systematically the implications of their design decisions. This requires moving beyond designing them "...into and onto buildings..." . It requires an understanding of what these laws mean for the interaction between the building design and the human, physical, cultural and natural environment it occupies.

There is no clearly preferred type of design tool suggested by the theoretical discussions of architecture at the turn of the millennium. In fact, disappointingly, there is very little written about the real environmental impact of design. There is a clue to a way forward in a book written by Steven Groák to mark the 60th anniversary of the British Building Centre Trust[63]. He argues that techniques of computer representation are likely to change the way we think about, and hence design buildings. He points out "...we are used to the idea that speech, writing, mathematical reasoning, carving and hand-crafting are all ways of thinking, not records after the event...it could be argued that if one is not drawing, or speaking or writing, or hand-crafting, certain thoughts are somehow 'unthinkable'. " The computer can alter the manner in which we design to the point where new realities might be imagined. Virtual representations in the computer will have such strong reliable physical analogues that designers will be able to imagine these new realities with a precision and accuracy previously unthinkable.

In the next chapter, I describe a means for systematically examining the role of eddst's in architecture. The goal was to review the range of eddst's that exist and that may at present be used in architectural design. The outcome of that review would be a classification of the different approaches to development of eddst's that have been tried in the past. Ultimately the aim was to develop a research plan that examined the practical application of those types of eddst within the classification that were judged of most general, practical application. That research plan is described in the chapter after next - the concluding chapter of this first Part of the thesis.

2

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   Etymology: L., f. simulare to make like, to simulate. See also simulacre.
   1 A material image, made as a representation of some deity, person, or thing.
   * 1599 Sandys Europμ Spec. (1632) 229 - The Heathen themselves call them every where the Effigies and Simulachra of other.
   ...
   2 a Something having merely the form or appearance of a certain thing, without possessing its substance or proper qualities.
   * 1805 Edin. Rev. VII. 183 - Does he mean..films, shadows, or simulacra proceeding from real external existences.
   b A mere image, a specious imitation or likeness, of something.
   * 1833 Edin. Rev. LVII. 334 - Some spirit of life breathed into their simulacrum of a faith.
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    Etymology: ? a. Fr. architecte or Ital. architetto, ad. L. architectus, f. Gr. arxitektwn, f. arxi- (see archi-) + tektwn builder, craftsman. Several of the derivatives are formed as if on L. tect-us from tegere; e.g. architective, -tor, -ture.

    c.f.: *tegere, texi, tectum:* to cover; to bury; to conceal; to shield, protect in my Latin English Dictionary. And thence *tectum* a roof or ceiling; a shelter, dwelling. Cassell's New Compact Latin Dictionary, D.P. Simpson, 1967.

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44. OED Definition: **positivism 'pozItIvIz(<e>)m.**

Etymology: ad. Fr. positivisme (Comte), f. positif, -ive, positive: see -ism; la philosophie positive being Comte's name for his system. [La philosophie positive occurs first in St. Simon Introd. aux Trav. Scientif., Oeuvres I. 198. Comte's Philosophie positive vol. I was published in 1830.]

1 A system of philosophy elaborated by Auguste Comte from 1830 onwards, which recognizes only positive facts and observable phenomena, with the objective relations of these and the laws that determine them, abandoning all inquiry into causes or ultimate origins, as belonging to the theological and metaphysical stages of thought, held to be now superseded; also a religious system founded upon this philosophy, in which the object of worship is Humanity considered as a single corporate being. Also, the name given generally nowadays to the view, held by Bacon and Hume amongst others (including Comte), that every rationally justifiable assertion can be scientifically verified or is capable of logical or mathematical proof; that philosophy can do no more than attest to the logical and exact use of language through which such observation or verification can be expressed.
Also ellipt. for logical positivism (see logical a. (and sb.) 7).
...
* 1868 (Nov. 8) Huxley Phys. Basis Life Lay Serm. (1883) 140 - In fact M. Comte's philosophy in practice might be compendiously described as Catholicism minus Christianity. [Often referred to as `Huxley's well-known description' or `definition of Positivism'].
...

2 a Definiteness, peremptoriness. b Certainty, assurance: = positiveness 2.
...
* 1874 P. Smyth Our Inher. v. xxi. 415 - The Doctor..adopts that with positivism.
...
3 Law. A term derived from positive law (cf. positive a. 1) and applied to theories concerned with the enactment of law, the reaching of legal decisions, the binding nature of legal rules and the study of existing law; which postulate that legal rules are valid because they are enacted by the `sovereign' or derive logically from existing decisions, and deny that ideal or moral considerations (such as those of natural law, or that a rule is unjust) should in any way limit the operation or scope of the law.
* 1927 M. R. Cohen in Proc. 6th Internat. Congr. Philos., 1926 469 (title) - Positivism and the limits of idealism in the law.
...

45. OED Definition: **scientism 'saI<e>ntIz(<e>)m.**

Etymology: f. scient- (see scientist) + -ism.
1 The habit and mode of expression of a man of science. ...

2 A term applied (freq. in a derogatory manner) to a belief in the omnipotence of scientific knowledge and techniques; also to the view that the methods of study appropriate to physical science can replace those used in other fields such as philosophy and, esp., human behaviour and the social sciences.
* 1921 G. B. Shaw Back to Methuselah p. lxxviii, - The iconography and hagiology of Scientism are as copious as they are mostly squalid.
* 1937 J. Laver French Painting in Nineteenth Cent. i. 73 - It really appeared to many educated people that at last all the secrets of the universe would be discovered and all the problems of human life solved. This superstition..we may call `Scientism'

....
* 1969 Encounter Jan. 23/2 - There is an aberration of science..which has come to be known as `scientism'... It stands for the belief that science knows or will soon know all the answers.
* 1972 K. R. Popper Objective Knowl. iv. 185 - The term `scientism' meant originally `the slavish imitation of the method and language of (natural) science', especially by social scientists.
* 1972 K. R. Popper Objective Knowl. 186 - But I would go even further and accuse at least some professional historians of `scientism'.
...etc

46. Gusdorf, G, **La Révolution Galileénne**, Vol. 1, chapter 3. *In* Perez-Gomez (1983).

47. Gusdorf, G, **La Révolution Galileénne**, Vol. 1, chapter 3. *In* Perez-Gomez (1983), p195.

48. Blondel, F. **Cours d'Architecture**, Paris 1698, pp2-4. *In* Perez-Gomez (1983).

49. Comte, A. **Cours de Philosophie Positive** Paris, 1864, first lecture. *In* Perez-Gomez (1983) p276.

50. Renan, E. "L'Instruction Supérieure en France", in **Questions Contemporaines** , 1868, p71. *In* Perez-Gomez (1983).

51. Hayek, F.A. **The Counter-Revolution of Science** pp 105-116. *In* Perez-Gomez (1983).

52. Rondelet, J. **Traité**, chapter 10, p273. *In* Perez-Gomez (1983), p289.

53. Durand, J.N.L. **Précis des Leçons d"Architecture Donneés à l'École Royale Polytechnique**, Paris, 1819, 2 vols. Vol 1, p. 6. *In* Perez-Gommez (1983), p299.

54. Perez-Gomez, *op. cit.* 1983. p314.

55. Hawking, Stephen. **Black Holes and Baby Universes.** Bantam Press, London pp 41-44. (1993)

56. Jencks, Charles. **The Architecture of the Jumping Universe** Academy Editions, London, 1997

57. *In:* Glusberg, Jorge. **Deconstruction - a student guide.** Academy Editions, London, 1996

58. Wurman, Richard Saul. **Los Angeles Access** Access Press, Harper Collins, Dunmore, PA. 1994

59. Kruft, Hanno-Walter. 1994. *op. cit.*

60. **Green Dialogues - Talk about sustainability: Architecture - how do we make responsive buildings?** Metropolismag.com: Special Supplement to the October 2001 issue: *A report on the proceedings of the Metropolis West Conference,* February 7+8, 2001, Yerba Buena Center for the Arts, San Francisco, *Finding the Thread of Sustainability.* http://www.metropolismag.com/html/content_1001/sup/index_h.html (Last accessed May 2003) [Updating the discussion developed in Progressive Architecture April issues in the late 1980's].

61. Groák, S. **The Idea of Building - thought and action in the design and production of buildings** E&FN Spon, London, 1992 p141:
It has become the convention that we invoke six principal characteristics of the performance approach to ensure that all those bidding will do so on a common basis, so that in principle we can 'compare like with like' at the level of performance:
- *we must define the terminology to be used (e.g. as in specified standards)...;*
- *we have to list performance requirements ... in assessable terms;*
- *we have to define the service conditions or environment in which the building or elements are placed;*
- *we have to define what criteria will be used to determine acceptance or rejection of proposals, in ways which relate to the performance requirements;*
- *We must evaluate in terms of agreed data - nature, units, format and timing;*
- *We must identify what will be the methods of assessment and verification.*

62. Jencks, Charles. **The Architecture of the Jumping Universe** Academy Editions, London, 1997

63. Groák, Steven. **The Idea of Building - thought and action in the design and production of buildings** E& FN Spon, London, 1992.

3

classifying simulation tools

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

design_analysis_2006_b2_clean.wpd

THE NEXT GREAT AWAKENING OF HUMAN INTELLECT MAY WELL PRODUCE A METHOD OF UNDERSTANDING THE QUALITATIVE CONTENT OF EQUATIONS. TODAY WE CANNOT. TODAY WE CANNOT SEE THAT THE WATER-FLOW EQUATIONS CONTAIN SUCH THINGS AS THE BARBER POLE STRUCTURE OF TURBULENCE THAT ONE SEES BETWEEN ROTATING CYLINDERS. TODAY WE CANNOT SEE WHETHER SCHRÖDINGER'S EQUATION CONTAINS FROGS, MUSICAL COMPOSERS, OR MORALITY --- OR WHETHER IT DOES NOT.

RICHARD FEYNMAN

This chapter continues the description of the context for the thesis research begun in the previous chapter's largely historical review. It classifies environmental design decision support tools (eddst's) in terms of their apparent function within architectural design practice and describes the broad research methodology within this context. The goal is to analyse these forms of "design guidance" to establish how a systematic approach might be taken to examination of the role of environmental design tools in architecture.

3-1 *categorisation systems*

The following pages describe a categorisation system for the books, computer programs, formulae, graphical aids and the many other paraphernalia that have been created over time to assist architects with the task of matching the environment created by their buildings to the needs of the people who are to use or occupy them. The goal of the construction of this categorisation system for eddst's is to assist the analysis of the successes (and failures!) of these forms of "design tool" in the later parts of this thesis. The functional value of each category of tool is assessed in terms of its ability to provide environmental design decision support. This value is described in an hypothesised list of advantages and disadvantages for each category of eddst.

The hypotheses as to the advantages and disadvantages of each category of eddst are returned to at the end of each survey or case study chapter in the main body of the thesis as criteria for their dissection. Evidence or otherwise is presented for the advantages and disadvantages of these disparate approaches to environmental design.

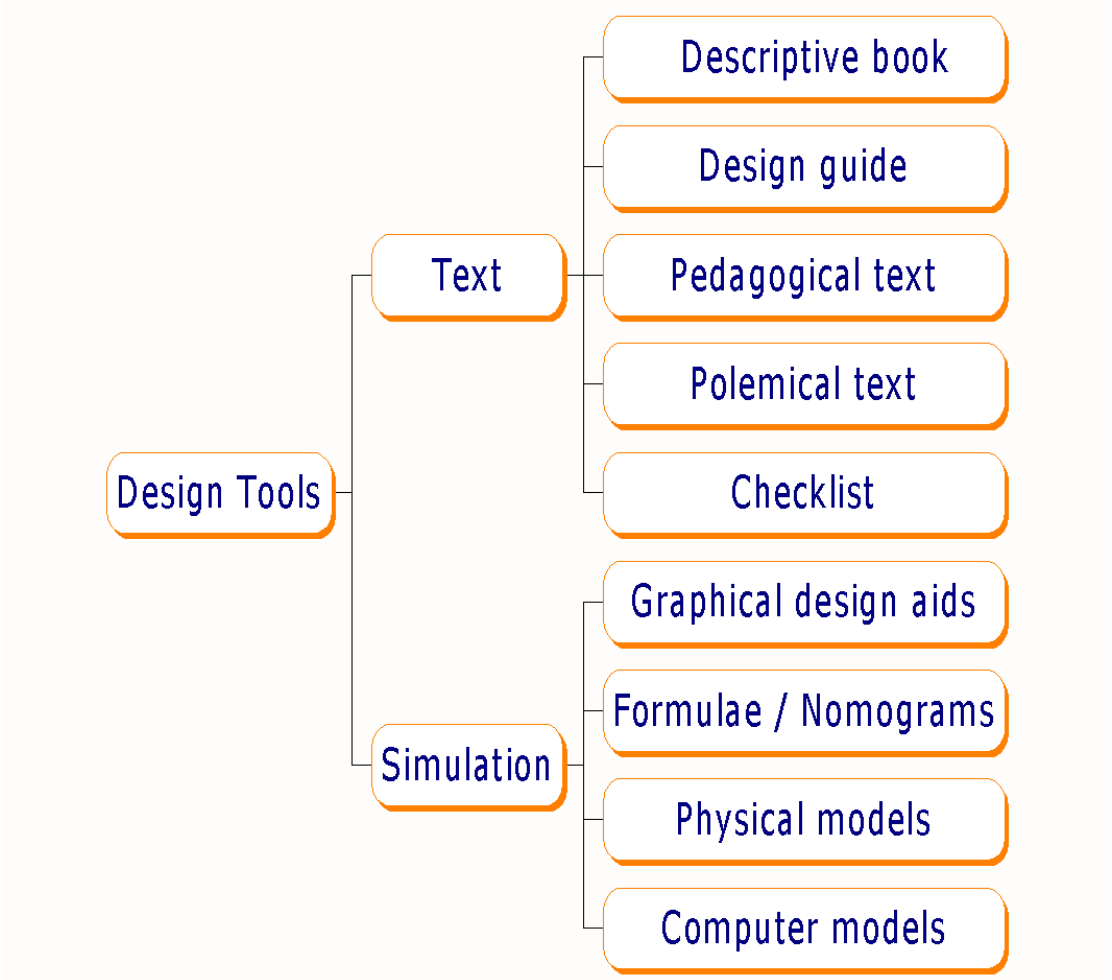

Figure 9 Design Tool Classification Created for this thesis

The categorisation system developed for this thesis is derived from a structure implied in the earlier quote from Papamichael: Functional Categories[1]. The categories derive from the functions required of the user. Thus one might categorise as a **Descriptive Book**, Vitruvius' Ten Books[2] in which we find admonitions like: "If our designs for private houses are to be correct, we must at the outset take notion of the countries and *climates* ..." (my emphasis) "...in which they are built. " As **Design Guide** we would have Jacques Gandemer and André Guyot's Intégration du Phénomène vent dans la conception du milieu bati[3] (my literal translation is: Integration of wind phenomena into the design of the built environment) - subtitled 'Guide to methodology and practical advice'. An **Educative/pedagogical text** would be a document like: Brown et. al.'s Inside Out - design procedures for passive environmental technologies.[4] At the **Polemical text** edge of the spectrum, we find Victor Papanek's The Green Imperative.[5] Within many other text books we could find many other forms or formats of design guidance: **Checklists** of good design practice (e.g. 'Responding to Pollutants' or ' The sound-healthy home' or many other lists in Pearson's The Natural House Book[6]; **Graphical Design Aids** such as the sun-path diagrams in Victor and Aladar Olgyay's Solar Control and Shading Devices[7]; **Formulae** for estimating the environmental impact of a design decision (e.g. Reverberation Time for auditoria[8]); **Nomograms** for performing a calculation with formulae; **Physical simulation models** for use in testing equipment like artificial

skies and wind tunnels; **Computer simulation models** which allow one to model an aspect of environmental reality (e.g. Radiance[9]).

Other researchers have found eight categories in the literature - the texts - alone[10]: research reports; research papers; text books; handbooks; design guides; checklists; journal articles; trade literature. These seem less useful than the functional categories listed above in the context where the discussion is focussed on what designers might do with the information.

In 1970 Professor Dean Hawkes of the Martin Centre at Cambridge University wrote a Working Paper[11] examining the "history of models of the environment in buildings" . He suggested three categories for historical models:

Design aids.
Design assistance by example.
Legislative tools.

He defined his sphere of interest to be "thermal, visual and acoustic properties of buildings." And he placed emphasis "upon the quantifiable aspects of building performance within this definition." It is a fascinating aspect of this particular history that despite this overt focus it actually concentrates on the daylight and sunlight access tools developed particularly in the UK from 1865 (the earliest example presented) onwards. The first section labelled design aids is exclusively about these tools. Little else is covered. Nothing is dealt with to the same depth as daylight and sunlight in any part of the report. This seems to reflect a bias in architectural design where lighting design decision support tools of this type are seen as more architectural than acoustic, aerodynamic or energy efficiency tools.

The section in Hawkes' paper on design assistance examples, and the section on legislation similarly concentrate on sun and light. Reference is made in the latter section to a study by Ford[12] identifying "the main determinants of building bulk as follows:"

"Sunlight and light"
"Traffic congestion and skyscrapers"
"Safety in skyscrapers."
"Dust, Gases and Noises"
"Wind and air among tall buildings."
"Outlook among skyscrapers."

> ....Perhaps the major contribution made by this study was the attempt it made to quantify the value attached to sunlight, light, air, privacy, outlook and freedom of movement....

There seems little of use to Hawkes' analysis in this three category (Design Aids; Design Examples; Legislation) breakdown which concentrates on the use to which the analytical data is put rather than the type of information it provides. What is adopted in this research is his emphasis on eddst's that enable assessment of the quantifiable aspects of environmental performance.

While much of the content of Cecil Elliott's book **Technics and Architecture** is about the technology, there is one section which describes building design. The section on Acoustics spends most of its 24 pages describing the development of models of the acoustics of buildings. One reads

here of a slow but steady progression from a past where design principles were largely analogic: they were based on a hope or belief that the harmonies in music might be reflected in the harmonies of proportion in the buildings in which it was to be performed.

Much is made by Elliott of the scientific research backing the developments leading up to the present day understanding of acoustics: "Sir Christopher Wren, scientist and geometer as well as architect... Sometime before 1829 the Reverend John Blackburn, finding it difficult to make himself heard in his church, had erected behind the pulpit, "a sounding board like a hood...Apparently Blackburn's scheme fulfilled its purpose... Blackburn published his design in a small pamphlet that was circulated to scientific groups..." [about Girard College in Philadelphia:] "J.B Upham, a Boston physician who wrote on architectural acoustics, visited the college in 1847 ..." [and] "*found that the reverberation of a sound in these rooms lasted 6 seconds...A physicist at Johns Hopkins University in 1878 published results of an experiment ...John Scott Russell, a young professor of natural philosophy and geometry at the University of Edinburgh, ...delivered an address " [in 1847]* ""*On the Arrangement of Buildings with Reference to Sound" to the assembled membership of the Royal Institute of British Architects...in 1835.. David Boswell Reid, a British scientist better known for his study of ventilation.. recommended auditoriums be built with low walls high pitched ceilings, and floors covered to absorb sound...*" [and of course the doyenne of Acousticians] "Wallace C. Sabine [was] *a 27 year old instructor in physics* " [when he conducted the experiment that] "would establish the quantitative science of architectural acoustics..."

The building acoustic analysis system is labelled "scientific" but it suffers from a lack of a clear definition of what might be other categories: "unscientific"? I have not been able to find a clear precedent for the categorisation of environmental design decision support tools. The rest of this chapter therefore develops my own categorisation system. It presents it in a standard format which describes the chief characteristics of the category; presents examples of the category and then attempts to describe the likely advantages and disadvantages of the category as an environmental design decision support tool for architecture.

These advantages and disadvantages reflect a set of values - a measure of usefulness - derived from the analysis of design tool histories. Each is compared against an ideal eddst which will enable a design team to be aware at all times of the impact of their design decisions on the environmental performance of the building they are creating.

3-2 *text based design tools*

3-2.1 descriptive book

Books like Elliott's **Technics in Architecture**[13] and Hopkinson and Collins' **The Ergonomics of Lighting**[14] provide a survey of the field of environmental design. In the former the survey is organised by topic (Heating, Acoustics, Structure, etc) and chronology; in the latter the organisation is by theory, experiment and application. In each case, there is very useful design advice contained in the body of the text. In Hopkinson and Collins' preface to **Ergonomics...** they write: "*"*

> The purpose of this book is to give consultants and environmental designers a summary of studies on the frontiers of lighting technology, particularly those aspects relating the physical environment to the subjective responses of the individual.

Descriptions such as Elliott's (in **Technics...**) of the belief systems that have brought us the buildings we have today provide a very useful insight into the ways in which clients believe buildings "behave". It would be difficult to find a person today who would defend strongly the "belief ... that wires" [strung overhead] "could augment or clarify sounds in an auditorium" or that an auditorium would sound better if built to "*the dimensions ... (6:3:2) "the three proportionate numbers of musical harmony"*" However, it would not be difficult to find a person who would swear "that only wood could produce the desired resonance, and here the recurrent analogy of the violin is evidenced." There is no strong evidence to support any of these claims. What is interesting is that one can imagine people still believing this last claim.

Advantages

- Comprehensive discussion of all the principles.
- Given the time, the designer can mine from the book a rationale for a design as well as the design idea(s).
- The general applicability of the information presented enables the observant designer to develop their own heuristics or "rules of thumb".
- Applying the understanding provided by the information in the text, the designer can observe the performance of buildings they have designed and apply these lessons to future designs.

Disadvantages

- Finding the design advice in the midst of the discussion is difficult.
- The time needed to mine information from the book can be a significant barrier to continued use of the book in a design office.[15]
- The text can be far more general than the average designer wants when looking for advice about a particular design issue. The author seeks to make the text as widely applicable as possible. In developing this thorough description they "hide" the specific data deep in the chapter or paragraph structure.
- Conducting systematic observation of previous designs is apparently not a valued activity for many designers. The craft of Post Occupancy Evaluation was developed to combat this. But, very few designers are encouraged by their education or the professional fee structure to use POE or

any other technique systematically to observe the performance of their completed designs.

3-2.2 design guide

The best environmental design guides explain the principles and provide practical design advice. **The Passive Solar Energy Book** by Ed Mazria[16] adopted what I have found in a teaching environment to be one of the most accessible structures for a design guide. It presents a set of *Patterns* after the fashion of Christopher Alexander's book **A Pattern Language** :

> ...each pattern has the same format. First, there is a picture which shows an archetypal example ... Second, ...each pattern has an introductory paragraph... [a] *headline gives the essence of the problem..* [then] "comes the body of the problem " [then] "the solution - the heart of the pattern.. " [17]

The following parallel description is from Mazria's chapter describing his "Design Patterns": "All acts of building no matter how large or small, are based on rules of thumb... We call these rules of thumb "patterns". ..To be useful in a design process, rules of thumb must be specific, yet not overly restrictive...This chapter contains twenty-seven patterns for the application of passive solar energy systems to building design...Each pattern is connected to other patterns which relate to it...Each pattern has the same format...Together the patterns form a coherent picture of a step-by-step process for the design of a passive solar heated building... The patterns can also be used to analyze or critique existing buildings or proposed designs...However not all patterns apply to each project... Select patterns most useful to your project, more or less in the sequence presented here...Remember that these patterns are evolving and will change over time...This means that the patterns should not be taken too literally... Finally the reader must realize that the extent to which any or all of the patterns are realized in practice depends in large measure on the extent to which the designer succeeds in understanding and applying the patterns..." [18]

This last point of Mazria's identifies a fundamental difference between his and Alexander's book. Alexander believed "...that this language which is printed here is something more than a manual, or a teacher, or a version of a possible pattern language. Many of the patterns here are archetypal - so deep, so deeply rooted in the nature of things, that it seems likely that they will be a part of human nature, and human action, as much in five hundred years, as they are today..." However, the sequencing of patterns, their interconnectedness and the graphic and textual integration of their presentation is very close in style. Inevitably, the Alexander text covers some of the same issues as Mazria, but from a less rigorous viewpoint: where Alexander writes: "If the right rooms are facing south, a house is bright and sunny and cheerful; if the wrong rooms are facing south, the house is dark and gloomy..." [19] Mazria writes: "When deciding on the rough shape of a building, it is necessary to think about admitting sunlight into the building. A building elongated along the east-west axis will expose more surface area to the south during winter for the collection of solar

radiation. This is the most efficient shape, in all climates, for MINIMIZING heating requirements in the winter and cooling in the summer..." [20]

Advantages

- The rule of thumb approach makes for efficient design. An interconnected set of design decisions is prescribed in a simple-to-use format.
- Standardised checklists and rules of thumb are easy to remember and thus can be readily internalised into the subconscious design process. All the designer's buildings then become 'solar' or 'environmentally aware' without that designer spending much time or work in achieving this.
- As also noted by Mazria, a checklist or rule based system permits ready evaluation of the suitability of a design or of an existing building.
- In well-presented formats the explanations of the "rules" or "patterns" assist the user to make intelligent deductions about non-standard situations. They teach the user about the dependencies between design and environment.

Disadvantages

- As Mazria points out in the quote above, patterns in Design Guides *"should not be taken too literally."* They present a simplified view of the world which must be understood to be used effectively. In solar design for example, the approach to developing 'rules' or 'patterns' is to systematically study a single family home [21]. The rules derived from this study are presented as generally applicable, and often the basis for them is ignored by the user. In the classic text, the Los Alamos **Passive Solar Design Handbook** [22], the recommendations are based on a very few buildings and measurements. As Eclipse consultants[23] note: *"what is offered is based on very little built experience. Even those"* [..14 passive test rooms, a few test boxes and 15 actual buildings which have been monitored..[24] *"are likely to be based on atypical preferences, expectations and patterns of living..."*
- The problem with standardised solutions is well-described by Eclipse Consultants in a paper to the BRE in which they review Mazria's book: *"Bases of design guidance not necessarily disclosed...without recourse to the originals, no judgement can be made about the soundness or validity of these offerings"* [25]
- No matter how well-constructed, a checklist is normally too restrictive. It contains sections that are not applicable to the current design or recommendations that conflict with other design imperatives. It normally is presented in such a way that each individual item is accounted for but not the interactions between the items. No-one can determine from the rules or checklists just what the consequences on the other recommendations will be if say, rule 3 of 10 is not adopted because it conflicts with other requirements in the brief.
- The explanations can often interfere with the accessibility of the design information. The wind tunnel design and atmospheric aerodynamics theory presented at the start of the two most accessible wind environment design guides in the world[26] is a distraction and a confusing element in the presentation of the design advice they offer.
- The biggest single factor weighing against checklists and design guides is the

complexity of the subject they are trying to simplify. At times this means the issue is trivialised. At other times the recommendation or rule of thumb becomes extremely convoluted: "*A solar collection area of (R1)% to (R2)% of the floor area can be expected to reduce the annual heating load of a building in (location) by (S1)% to (S2)%, or, if R9 night insulation is used, by (S3)% to (S4)% where the values of R1 ... (etc) are selected from Table D-1 for the location of interest*" [27]

- With design guides more than with any other design tool, one has to share the model of design offered by the authors. If one does not share that model, then the information can be less than useless. Eclipse consultants[28] reviewing the Los Alamos **Passive Solar Design Handbook Volume 3**[29] for the IEA remark: " ... *the whole handbook (all three volumes) is predicated on the notion of design as fundamentally an analytical (from first principles) and predictive (using quantitative methods) activity.*"

3-2.3 educative/pedagogical text

The educative text assumes a readership with a very low level of knowledge on the subject. It offers a comprehensive education in the techniques and theory. While it may contain rules of thumb, it sees its primary purpose as educating the reader in the principles of the subject. Mazria's **Passive Solar Energy Book** does function as an educative text. However, its primary purpose is as a design guide. It is intended to offer the user at the drawing board a readily accessible compendium of relevant design ideas. Hopkinson and Kay's **The Lighting of Buildings**[30] is a good example of an educative text. While it contains information that would guide design, its primary purpose is to educate the reader in the concepts and practice of lighting.

Commercial Building Design[31] although written as a summary for designers of the lessons learned from the construction and monitoring of the performance of large commercial passive solar buildings in the United States, also falls into this category. It has a high ratio of discussions of theory to descriptions of practical steps to undertake. For example, the section on 'Key Design issues' from page 199 to 236 uses very detailed monitoring data to illustrate the principles and explain the design recommendations. It does not contain a simple reference list comparing design situation and recommended action.

It should be noted that the authors of **Commercial Building Design** have organised the chapters "according to the traditional phases of the design process... " They note that "Good energy-conscious design requires more than intuition..." because they found their own pre-conceptions and

those of the design teams they studied were constantly being destroyed during the design analysis for their case study buildings. The dense information presentation is apparently a reaction against the creation of a *"how to"* book.

The most self-consciously educative text is Brown, Reynolds and Ubbelohde's **Inside out**[32]. It claims an audience of students, teachers and practitioners, but is clearly full of large sections of instructional material for students to do as exercises in class.

Advantages

- The practitioner has available not just the design recommendations, but the theoretical foundations for them. It is possible not just to follow the recommendations, but to understand what they are intended to achieve and therefore to be able to make variations from them intelligently.
- The calculation methods are easy to apply because they are backed up with many tables of standard values and comprehensive reference lists for further "input" data.
- The best of these texts, because they are grounded in the theory, never lose their relevance over time.

Disadvantages

- The practitioner looking to scan the pages for a few practical recommendations has to wade through a considerable body of theory and practice to find them. In the case of Hopkinson's book, the chapter structure, with later chapters devoted to practical applications to different building types is somewhat better than might at first be expected in this.
- Often the book is dependent on other companion volumes in the assumed pedagogical model. For example, *Inside out* assumes all readers (students) have access to McGuinness, Stein and Reynold's **Mechanical and Electrical Equipment for Buildings** and Balcomb et al's **Passive Solar Design Handbook.**
- The instructional exercises and assumed methods of working in them do not allow for easy adaptation of the material in the book for other modes of working.
- The most comprehensive approach to this type of text is Hasting's **Passive Solar Commercial Buildings**[33] - it presents the results of a major International Energy Agency research programme. The results of extensive theoretical analysis and empirical measurement are presented. The result is a book that always rewards those who delve into its depths with new snippets. However, it is very difficult to use it as a guide to design one particular new building.

3-2.4 polemical text

The recent spate of publication of 'green design' books [34] fit this description most aptly. They are intended to persuade to a particular point of view. In the process, they offer a collection of design guidance and checklists of how to comply with their view of the world. Other books in this class are texts like Vitruvius' **Ten Books on Architecture**[35] and Rybczynski's **The Most Beautiful House in the World**[36]. Even Victor and Aladar Olgyay's **Design with Climate**[37] which normally is

classified as the quintessential instructional text in bioclimatic or environmental design, is more polemical than instructional.

The primary intention of this type of text is to persuade the reader to a particular view of the world. A philosophy of life or a philosophy of approach to building design is proposed. Clearly implied is the notion that the approach suggested will produce better architecture and a better life for its inhabitants.

Hawkes[38] writes about a section of a paper on "dwelling houses, factories and offices .... A Warning was sounded about the problems which might arise as a result of "over-enthusiasm for insolation". This is one of the few references to the problem of solar heat gain and it is surprising that the Committee's study of Atkinson's work did not indicate to them that simple avoidance of highly glazed southerly facades was not enough to cope with this... The polemical nature of the majority of the manifestos issued by the many schools and individuals, " [of the modern movement] "upon whom most academic historians have concentrated their attention, almost necessarily excluded any research of the kind which concerns us... "

On the positive side, these texts persuade the reader to take more care in the design of the built environment. They suggest rationales for adopting their methodologies. In books like that of Rybczynski the methodologies are sparse. All the reasons for designing well are provided, but little of the means.

The most dangerous are the polemical texts from "master" architects: "Today, the construction of façades in which soft stone is used in large blocks leads to this absurd result - that the windows, originally intended to introduce light, are flanked by deep embrasures which completely thwart the intention. .. A house is a machine for living in...An armchair is a machine for sitting on..." [39] Le Corbusier seems entirely unaware or uninterested in the point that these embrasures, if properly designed, make the interior more pleasant under all lighting conditions. They create a lighting quality that is almost universally appreciated.

In another polemic, this time Ruskin's **Seven Lamps of Architecture**[40], we read (referring to the "young architect"): "let him design with the sense of cold and heat upon him; let him cut out the shadows, as men dig wells in unwatered plains; and lead along the lights, as a founder does his hot metal." However, Ruskin is referring to the appearance of building exteriors, not their performance as shelter for people. Elsewhere he writes "... architecture is only the association of ..." (...sculpture and painting, the only two fine arts possible) "... in noble masses, or the placing of them in fit places.... All architecture other than this is, in fact, mere building..." He makes quite plain that he sees architectural concerns centring on the play of light and shade on a building's form, not the quality of light for the users' functional enjoyment - say for reading.

This type of focus encourages the complete elimination of environmental concerns from architectural practice such as Jackson[41] describes in the following: ""

> The essential characteristics of the art world still persist. It [architecture] remains a self-indulgent activity for a very small minority. It continues to justify its practices by the pretensions of its claims. It doggedly holds on to the myth that it is the only authoritative producer of culture for society as a whole. And it continues its long-standing tradition of ignoring, deriding or excluding everybody else who does not share its interests.
>
> ... for most architects, the information received from scientists has been either too general to add much to their common experience, or too specific to be readily applicable in other circumstances.[42]... the belief that design affects human behaviour continued to influence the way architects considered and justified their choices. This belief peaked with their endorsement of Le Corbusier's vision that his radiant city plan would usher in a better way of life, a claim that raised architects, at least in their own eyes, to the powerful position of social engineers.[43]
>
> The extraordinary achievement of Le Corbusier was to combine all these transcendental propositions into a convincing fiction, and to attach them to the image of his own architectural style. ...

A visit to Frank Lloyd Wright's own homes at Taliesin or Taliesin West is to be disappointed that the imagery of the "organic architecture" in harmony with the site and context is flawed. Taliesin is so cold in winter it is closed. Taliesin West has large cooling towers for its air conditioning system hiding behind stone walls. These user modifications to the buildings and their use have been made necessary by their design.

Advantages

- It is in the nature of this type of text to encourage the reader to be enthusiastic about the topic, and therefore about the ideas promulgated.
- There is a certain cachet in following the style of a famous architect, which somehow legitimises the work of the architect emulating it and thus encourages the reader to use the principles more often.

Disadvantages

- Calculation methods for estimating the performance of a new building are often left out of the polemical text. The authors are working to capture the reader's imagination, not explicitly to provide building performance assessment tools.
- Because so little is explained about the relationship between building design and building performance, none of the ideas presented is readily adapted for other circumstances.

3-2.5 checklists

Every designer apparently has a checklist of some type. It may not be a formal document on which ticks are placed. It will be an order in which design activities are normally conducted so as to avoid duplication of effort or to avoid missing of vital steps in the process. Checklists seem to be most commonly produced by professional institutes[44] or as supplemental chapters in larger texts[45].

These are normally the most overtly useful of the text based design tools. They are intended to sit on the wall or table beside the drawing board and to operate as aids to the drawing / design process. Often they do. They are inevitably limited because they represent a generic building type and cannot therefore approach the flexibility of match between type, size and location that real projects inevitably impose. Generic guidelines about "commercial" solar buildings for example, struggle to deal with the

diversity of building types (shop, office, bank, gymnasium...) which constitute the genre. That these buildings might also be of widely varying scale and location in the city or suburbs is tricky to include in any simple checklist format.

Advantages

- The material acts as an aide-memoire to many other sources of information and thus significantly enriches the design quality of a project
- The material is instantly accessible because it is often written in the nature of simple aphorisms.
- The inter-relationships between the various issues are more obvious in a short one or two page list than they are in most other formats.
- By its very generic nature a checklist can encourage designers to apply it to their project because it is so simple. For example, an exhortation to consider daylight as an option for lighting offices is far easier to apply than a specific sizing tool or formula.

Disadvantages

- The very simplicity of the material acts as a deterrent to its use. Unless there is a cross reference to a lot of further data or calculation tools, the exact behaviour expected of the designer who has, say, "thought about" daylight in offices is unclear.
- The brevity of the checklist tends to trivialise the whole topic in the mind of the user. If it can be reduced to such a short list, then it is obviously of low significance and hence can be left to a final checking process, after the design is completed, rather than being integrated into the design process. This after-the-fact check then becomes an exercise in justification: selecting those list items that support the design, and justifying why other items are not important in this design.
- Often the presentation of the information as generic makes its application to a particular project problematic in the eyes of the designer. For example, in solar house design guides it is common to list the various solar systems with a simple cross section graphic showing the collector, storage, insulation mix in a simplistic mono-pitch one room view.[46] This is as a means to reveal clearly the major influences on the performance. In fact, for many potential users the image is of a requirement that solar houses must be mono-pitch, ugly "machines for living".

3-3 *simulation tools*

The following paragraphs rate my perceptions of the advantages and disadvantages of the various types of simulation tool that are available to today's building designer. The all-inclusive definition of simulation means that the range of design decision support tool categories dealt with here is broader than might conventionally be expected: Graphical Design Aids; Formulae and Nomograms; Model Simulations; and Computer Simulations. Each of these is defined more precisely under the appropriate heading. In each case, the rationale for selecting the category for consideration is that it is a type of design decision support tool that permits the building designer to predict how a building or a building element is likely to perform.

In this sense, even the calculation of an R-value for a wall is a simulation. It is a prediction of the thermal performance of the wall. One does not require the use of the R-value in a degree day calculation to have simulated the wall's thermal performance. Simulation of the thermal performance of a wall element merely requires reporting in a standard manner the heat flow through it: the R-value is a standardised manner of reporting heat flow. The standardising or normalising factors are area and temperature: an R-value is a heat flow per square metre for a temperature difference of one degree Celsius in the metric (S.I.) system.

3-3.1 graphical design aids

The most obvious examples of this type of Design Tool are:

1) The Psychrometric Chart with applied comfort zone such as is found in Victor Olgyay's **Design with Climate**[47] and in Vivienne Loftness's book on climate analysis for the WHO[48]. These are not simplistic psychrometric charts relating temperature and humidity but action tools which describe the relationship between human comfort, building design and the temperature/humidity measures of climate. Building performance predictions are derived from the imposition onto these charts of a climate record.

2) The many solar building design guides that publish graphs showing effect on performance of varying building parameters: e.g. *GJ/yr plotted against South Glazing area as a percentage of Floor Area* in The IEA Solar Heating and Cooling Programme's **Design Guidelines: an International Summary**[49], and *Effect of passive solar design on annual energy use* in **Design Guidelines: Passive solar in New Zealand.**[50]

3) The **Annual Loss Factor**[51] method for calculating the energy performance of houses in New Zealand taking account of the orientation of the building elements to the sun was a paper-based graphical method. Now, a computer program looks up the graphs and reports the results. It is still like many other computerisations of charts and tables, a graphical method. It does not calculate the energy performance from first principles, it looks up the tables for some cumulative result of particular design features selected by the user of the software.

The better forms of graphical analysis are based on many hundreds of studies of buildings and their variations and the graphs represent the trends across all these situations.

Advantages

- These graphical methods enable a designer to assess quickly the likely impact of a design decision. In the example graph in **Figure 10**, energy use is shown for each choice of passive solar system attached to 25%, 50% or 100% of the length of the side of the house facing the sun. In ALF3 a designer selects a focus (Building Performance Index[52] or total annual energy use) then watches the figure vary as one switches from one construction option to the next - a simple and effective feedback to the user on the relative importance of

Disadvantages

- These graphs are generated typically by running hundreds of computer simulation runs, using a standard building and a set of standard operating parameters. They can also be a summary of a series of measurements of one or more real building's performance. For many people, making the link from the standard building to lessons for their own situation or design is quite difficult. The graphs do not assist this interpretation.
- In many cases the information is presented in a standardised format such as the

each factor.

- Energy and temperature and many other performance criteria can be represented in this form in the graphs. They can therefore establish a clear and robust multi-criteria decision support system for the designer.
- Through interpolation and interpretation the user can adjust the graphs to suit their own design in a relatively simple manner. They are therefore readily adapted to different buildings and situations.
- They aid "intuition". Observation of the trends in graphs of this type when using them can develop the users' understanding to the point where the graphs are only needed when a degree of precision is required. For general design work, the intuitive response, educated by use of the graphs, will contribute to the development of environmentally responsive design.

example above where energy use in a standard building is presented in terms of square metres of window area per square metre of floor area of the building. This implies a scalability that often is not real. For example, in the **Design Guidelines** publication from which the above graph was taken, the effect of varying the size and the plan shape of the standard 100 square metre building was examined: a building of 120 square metres floor area consumed 60% less in Auckland, but 10% more in Christchurch if it was two storeys in height! Doubling the area of the building does not normally mean doubling the length of one wall - the building typically gets deeper in plan as well. Therefore there is not normally enough area to double the glass on the north side. In Auckland, we calculated that increasing each side of a house in length by a factor of 1.4 (so the total area was increased by 2 = 1.4x1.4) increased the energy use by a factor of 1.4. However, in Christchurch the energy use increased by a factor of 2.2!

- The design "rules" or design advice graphics are presented factor by factor making it difficult to assess what the effect might be of changing two things at once: e.g. what if, in **Figure 10**, we also increased the amount of concrete used for solar heat storage? The calculations can only realistically be performed parameter by parameter. There are just too many combinations and permutations of window area, wall, roof and floor R-value, heat storage etc, to make it feasible for the author of the graphs to contemplate calculating the effects of varying more than one design parameter at a time. They cannot anticipate which combination of factors will be taken up by each designer. The problem for the designer trying to use this data is that they cannot assume that all the effects will add together.

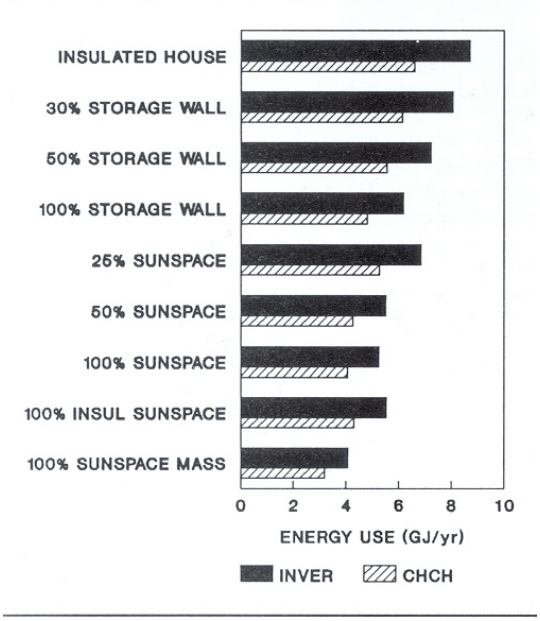

Figure 10 Effect of Passive Solar Design on annual energy use in Invercargill and Christchurch: from **Design Guidelines: passive solar in New Zealand**

3-3.2 formulae and nomograms

The Sabine Reverberation Time[53] calculation formula, or its Eyring variant, is a simple empirically-derived formula which enables the building designer to predict the acoustic performance of a space in a building. There are many formulae like this in Building Science. The R-value formula[54] for heat loss through building elements, or the Lumen Method formula[55] for illuminance on a flat plane beneath a flat grid of lights are examples from the thermal and lighting fields respectively. All have been computerised for ease of repetitive use. All simulate an aspect of building performance. What is normally excellent about these formulae is that they express in an elegant manner the interrelationships between the significant influences on performance. This elegant expression is of course only visible to those who wish to examine the algebra critically. My experience with architecture students is that they focus on the whole formula and what the output number is, rather than on the form of the equation and what that implies about the relationship between building design and performance. It would appear that practitioners are worse than students. They do not wish even to do the calculation because they might end up liable for the recommendations emanating from its use.

A nomogram is simply a manual or graphical means of performing a complex calculation. They tend to have been generated by researchers who have graphed a series of measurements or other calculations[56] and wish to translate into design performance prediction formulae the mathematical relationships shown in the graphs. Often the mathematical relationship shown in the graphs is in terms of some quite complex mathematics requiring a scientific calculator (sines, cosines, cubes etc...). Wary of requiring apparently maths-phobic designers to perform the calculations on a calculator, researchers have attempted to provide the data in a graphical form. The goal is accessibility of data.

Advantages

- The simplicity and directness of the relationship between input and output is, in the hands of the intelligent user, an educative experience.
- The formulae are all typically public domain relationships published by researchers. It is therefore possible to enter them into a spreadsheet and to run them iteratively. The spreadsheet can show the input and output cells in the same screen because of the simplicity of many of the formulae, so the reaction of the building to a change in design can be seen almost instantaneously.

Disadvantages

- The simplicity and directness of the relationships expressed in a formula often hide the complexity and interrelatedness of much of building operation and performance. Many formulae, like the lumen method formula apply in particular restricted circumstances, when simplifying assumptions can be made. Often, when the formula is applied by the unthinking, it can result in a one dimensional, low quality design. For example, using the lumen method to calculate the performance of a grid lighting system in an office can lead to a very boring lighting scheme. Colour, contrast, glare and delight are mostly ignored by the simple formula.
- The simplicity of the relationship can suggest to the user that the issue is trivial. As mentioned earlier, if a designer views an issue as trivial because the formula is trivial, then they tend not to take seriously the issue for which the design tool has been generated.
- With nomograms the problem is often that the simplicity of the relationships between building design feature and building performance is lost in the graphical presentation.

3-3.3 physical model simulations

There is a long tradition of architects testing building designs through models. The use of models to test the effects of the wind on buildings (and vice versa) dates from the 1750's, though reliable prediction techniques were really only developed in the 1970's[57]. Physical models are still commonly used in artificial skies to test daylighting and sun penetration[58]. The benefit of these tests is that they are instantly comprehensible by the client. However, despite the fact that most architecture firms use

models in the design process, particularly for large commissions as well as presentation models for "selling" the scheme to a client, they seldom seem to use these models for environmental assessment.

There are rare exceptions: in 20 years, a minimum of 25 students per year, and latterly 60 per year, have been trained at Victoria University in the use of a heliodon for sun penetration studies, an artificial sky for daylighting studies and a wind tunnel for pedestrian wind environment studies. Of those who have graduated and still practise in Wellington, on average 1 per year might seek to use the heliodon; 3 in 20 years have used the wind tunnel; and no-one has done any daylight studies. The most recent wind tunnel test is the closest to a true design analysis. The previous two had been designers seeking a cheaper venue to perform the wind tunnel test required for all buildings over 4 storeys in height in the CBD. The 1999 wind tunnel test examined a school design on an extremely windy site where the client had rejected the original design concept partly because of concerns about wind.

Advantages

- The simplicity and directness of the relationship between the environmental factors and the display of their effects provides immediate and readily understandable feedback on the environmental performance of the building.
- Clients find the model and the environmental effects very easy to understand. Flow visualisation techniques such as erosion of sand, or cork granules or polystyrene beads from around a wind tunnel model immediately show people where the high and low wind speeds occur. Shadows from the sun inside and outside a model are very graphic demonstrations of the likely effect of the building on its environment. Photographs of the light and the sun inside a building can be very realistic and convincing representations of what quality of light will be experienced in the proposed building once it is completed.
- The test is often very simple to set up. Even though a wind tunnel and its instrumentation can be expensive, a lot can be learned about the effect of a building on the wind environment through observation of the movement of lightweight grains of cork or styrene around the model while the tunnel is running. No instrumentation is needed for this - merely an ability to watch and document systematically. A solar penetration or daylight study can be conducted by simply taking a model outside and putting oneself inside it, perhaps with the aid of a camera.

Disadvantages

- Models for wind tunnel and lighting studies can take a very long time to construct and designers therefore are often reluctant to use them in a relatively harsh environment where they may be carved up by the investigators as they try different design options to solve issues revealed by the test(s).
- Model-making is a painstaking process even in the physical scaling of objects. Therefore modelling variations to a design, truly designing with the model, can be a time consuming and tedious process. Continuity of design development can often be disturbed by such modelling delays. They mitigate against designers making more than one or two changes to explore the options they have for improving the design of the building.

- The calibration of a model to reality is often very simple. In a wind tunnel it is clear: geometrical scaling is simple and "intuitive". Dynamic scaling (the relative speed of the wind) is understandable. Fortunately, in wind environment studies it is seldom necessary to be concerned about the modelling of the viscous properties of air. Flow around hard edge models is the same as flow around their full-scale counterparts. It is only aerodynamic shapes that might require further careful attention to the relationship between the model and reality - calibration. In a similar manner, modelling the physical shape of a building for daylight or sunlight studies is "common-sense". Window reveals are important. Orientation is important. Modelling accurately the light loss through a piece of glass of the type that will eventually be placed in the window opening can be achieved by applying a factor to the results from study of a model with holes where the windows will be. The factor is the transmissivity of the glass and it can be simply obtained from manufacturer's literature. Even modelling the reflectivity of the finishes can be easily achieved: use samples of the materials that will eventually be used in the real building.
- Models have no "standard" shape and few norms to comply with for the sake of the accuracy of the analytical technique. The freedom to examine almost any design is much wider than with many other design tools.
- The biggest problem for designers using physical models to study environmental quality in buildings is that they have to have a completed design before they can conduct the test. This tends to force the test to be the last thing that is done in the design process. In such circumstances the designer can be reluctant to make the changes necessary to achieve the environmental goals. Compromises are made so that a) the project can continue; or b) there is minimal loss of fees through re-design; or c) the economic or aesthetic goals used to generate the original design and agreed with the client/planning authority/ design team can be achieved.

3-3.4 computer simulations

Placing computer simulations at the end of this chapter implies a hierarchy. This is a hierarchy from less to more complete. Typically, computer simulation is the most comprehensive item in the hierarchy of design tools. It uses the power of the computer to automate the mathematics and therefore has less need of the simplifications, standardised buildings and normalised reporting of results of other methods. It is therefore the most flexible in its coverage of what can and cannot be studied.

The corollary of this comprehensive coverage is complexity. Typically, computer simulation has required something akin to a priesthood to run it: people who have specific training in the complexity of the mathematic solution techniques used, in the limitations imposed by those mathematical techniques and in the building science field covered by the simulation. This priesthood has also

required sufficient practical experience under the watchful eye of other simulation experts before they can be trusted to produce useful and relevant predictions of building performance.

Computer programs that simulate "virtual" realities are now available for the creation of apparently realistic digital representations of the interaction between the environment and the human senses: space definition through sound, light, air movement and temperature. Cyber reality can be generated by the expert "simulationists" who write and use the programs. These simulationists validate their programs thoroughly. In the right hands therefore one can:

1) virtually sit in the front row of an unbuilt auditorium, and compare the sound quality of a piece of orchestral music played on stage with the sound quality one can hear 20 rows back in a side aisle[59];

2) virtually read a computer screen in a room sidelit by windows whose image, along with one's own reflection are visible as distractions in the glass front of the monitor[60];

3) plot the temperature[61,62,63] movement overnight in a room in midwinter after the sun has set, taking into account the heaters are only on from 7pm to 11pm, the floor is carpet over concrete and the windows in the room are large and faced the setting sun.

4) pictorially represent the flow of air[64] through a room with one window open to a downtown street in a windy city and a door opening onto a balcony around the second floor of a four storey naturally vented atrium.

The major unanswered question with computer based simulation is: will it ever be used by anyone other than a member of the well-trained priesthood? If the other, less complicated design tools are infrequently used as intended, will the added flexibility and richness of information that full computer simulation can produce provide sufficient incentive for designers to integrate it into the design process?

Increasingly computer modelling is becoming easier than physical modelling and its output is at least as intuitive and hence as informative. The advantages of computer modelling over physical modelling are that: a) making changes and testing a myriad of design options is far easier and hence quicker and cheaper with computer models; b) copies of the one computer model can be used in a pared down form in a thermal analysis and in a more finished form in a lighting study without compromising the quality of either analysis; c) electronic data produced by the simulation is far easier to process into reports and to analyse further with graphical interpretation tools.

Advantages

- (As with physical models) The simplicity and directness of the relationship between the environmental factors and the display of their effects provides immediate and readily understandable feedback on the environmental behaviour of the building. It looks real.
- (As with a physical model) Clients find the model and the environmental effects very easy to understand. Flow visualisation techniques such as the coloured cross

Disadvantages

- (As with physical models) The biggest problem for designers using computer models to study environmental quality in buildings is that they have to have a completed design before they can conduct the test. This tends to force the test to be the last thing that is done in the design process. In such circumstances the designer can be reluctant to make the changes necessary to achieve the environmental goals. Compromises are made so that a) the

sections overlaid with wind direction vector arrows immediately show people where high and low wind speeds occur in a room. Shadows from the sun inside and outside a model are very graphic demonstrations of the likely effect of the building on its environment. Digital "photographs" of the light and the sun inside a building can be very realistic and convincing representations of what quality of light will be experienced in the proposed building once it is completed.

- (As with physical models) Computer models normally have no "standard" shape and few norms to comply with for the sake of the accuracy of the analytical technique. The freedom to examine almost any design is much wider than with many other design tools. The building analysis produced is going to seem more real and hence relevant the less compromise there is in the "input of the data" to the analysis.
- Although computer building models take a long time to construct, the process of construction of the model is increasingly part of the routine of design using CAD. Developments are in hand to take the relevant data from the CAD model and make it available for the lighting, structural thermal or any other analysis designers may want to undertake [65].
- Model making is a painstaking process whether it is physical or computer based. However once the computer model is constructed, modelling variations to a design, truly designing with the model, can be a simple process. Designers can be encouraged to make several changes and try many variations because ultimately each change in the model produces still the same "original" quality printed plans when the design documentation phase begins.
- The ability of the computer to post-process data from performance calculations makes computer-based simulation potentially a far richer medium than any of the other simulation or even text based design decision support tools. The patterns revealed by this post-calculation analysis could be measured against a Mazria style pattern language. The software authors can design the post-processor as an educative as well as performance assessment tool.

project can continue; or b) there is minimal loss of fees through re-design; or c) the economic or aesthetic goals used to generate the original design and agreed with the client/planning authority/ design team can be achieved.

- The calibration of a model to reality is often very difficult. The question always has to be posed to the simulationist making recommendations based on a computer simulation: "how can you tell that these results are genuine predictions of what is likely to happen in the proposed building?"

3-4 *philosophical approach to the research*

It is apparent that the whole of this thesis adopts and is situated within a philosophical tradition which is labelled (often pejoratively) as an *analytical* approach. The pejorative usage in my experience of architectural critiques in schools of architecture often accompanies a polemic in which analysis is confused with some positivist world view. Johnson's **The Theory of Architecture**[66] has a rather neat discussion of science which summarises the approach taken in this thesis:

> Certainly "to think of science as motivated ultimately by practical goals, as judged or justified by bridges and bombs and the control of nature, is to confuse science with technology. Science seeks knowledge without regard to practical consequences, and is concerned with prediction not as a guide for behaviour but as a test of truth"[f] But the science of architecture does seek the truths of scientific understanding in its research and development, and then it finds architectural applications for them, just as the results of pure science are utilised in applied science. To hold steadfastly to such a hard definition as Goodman's suggests that there is something called science; in fact there are many things called science.[67] I am inclined to Paul Feyerabend's 'definition' that "science is what I am doing and what my colleagues are doing and what my and their peers and the public at large regard as 'scientific' Given this situation it does not surprise us at all that there is 'scientific' wrestling and 'scientific' dogfood".[g] Likewise, there is 'scientific' architecture.
>
> So, armed with this soft definition of science, it is not difficult to see that much of the structure, fabric, and servicing of modern architecture (whether as the machine aesthetic or not), both internally and externally, involves strict obedience [note the word use here] to physical laws, and that it is impossible not to see it as science. The science of architecture has determined the truth of why foundations settle, membranes fail, artificial lighting affects colours, thermal comfort varies, corrosion among differing metals occurs, acoustic conditions aid or hinder speech, thermal fatigue fractures glass, friction coefficients are important in flooring, glare creates discomfort, refrigerants affect the ozone layer, plastic fabrics and coatings affect health, and on and on. As Alan Colquhoun remarked, "with the development of modern science, the word "art" was progressively restricted to the case of artefacts that did not depend on the general laws of physical science, but continued to be based on tradition and the ideal of the final form of the work as a fixed ideal"[h] Nonetheless, art may still be the ideal and inspirational edge of architecture, but only science and its instrumental arm, technology, can keep it there. Moreover, without the science of architecture, design could only proceed by tradition, yet even this would not develop were there not some intrinsic fit, the **truth** of which is **proved** over time.
>
> "The issue for theory concerning the science of architecture is allied with what Paul Feyerabend says of the scientist: "the task of the scientist ... is no longer to 'search for the truth', or 'to praise god', or 'to systematise observations', or 'to improve predictions'. These are but side effects of an activity to which his attention is now mainly directed and which is 'to make the weaker case the stronger' as the sophists said, and thereby to sustain the motion of the whole"[i]. If the architect is the scientist in the science of architecture, then it is also the task of the architect to make the weaker case the stronger and technology the means of mediation. It seems we have no other

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vi Goodman, Nelson, 1972 in **Modern Art and Modernism : A Critical Anthology,** ed. Francis Frascina and Charles Harrison, Paul Chapman Publishing, with Open University, London, 1988. Quoted by Johnson.

vii Feyerabend, Paul. **Against Method**, revised edition, Verso, London, 1988, p257. Quoted in Johnson's The Theory of Architecture. .

viii Colquhoun, Alan. **Essays in Architectural Criticism: Modern Architecture and Historical Change**, Oppositions Books/MIT Press, Cambridge, Mass, 1986. Quoted by Johnson.

ix Feyerabend, Paul. **Against Method**, revised edition, Verso, London, 1988, p21. Quoted in Johnson's The Theory of Architecture.

choice. ”

This issue of there being “many things called science” relies heavily on Kuhn's “definition” of science:

> We have.. Already noted that once the reception of a common paradigm has freed the scientific community from the need constantly to re-examine its first principles, the members of that community can concentrate exclusively upon the subtlest and most esoteric of the phenomena that concern it. Inevitably, that does increase both the effectiveness and the efficiency with which the group as a whole solves new problems. ...
>
> ... there are no other professional communities in which individual creative work is so exclusively addressed to and evaluated by other members of the profession. (Except the "texts" of deconstructivist architecture?) .... Just because he is working only for an audience of colleagues, an audience that shares his own values and beliefs, the scientist can take a single set of standards for granted. ... Even more important, the insulation of the scientific community from society permits the individual scientist to concentrate his attention upon problems that he has good reason to believe he will be able to solve.....
>
> The effects of insulation from the larger society are greatly intensified by another characteristic of the professional scientific community, the nature of its educational initiation. In music, the graphic arts, and literature, the practitioner gains his education by exposure to the works of other artists, principally earlier artists. Textbooks, except compendia of or handbooks to original creations, have only a secondary role. In history, philosophy, and the social sciences, textbook literature has a greater significance. But even in these fields the elementary college course employs parallel readings in original sources, some of them the "classics" of the field, others the contemporary research reports that practitioners write for each other. As a result, the student in any one of these disciplines is constantly made aware of the immense variety of problems that the members of his future group have, in the course of time, attempted to solve. Even more important, he has constantly before him a number of competing and incommensurable solutions to these problems, solutions that he must ultimately evaluate for himself.
>
> Contrast this situation with that in at least the contemporary natural sciences. In these fields the student relies mainly on textbooks until, in his third or fourth year of graduate work, he begins his own research. Many science curricula do not ask even graduate students to read in works not written specially for students. ... Until the very last stages in the education of a scientist, textbooks are systematically substituted for the creative scientific literature that made them possible. ...

Without wishing to defend the excessive lengths to which this type of education has occasionally been carried, one cannot help but notice that in general it has been immensely effective. The research in this thesis does not therefore attempt to place a value on simulation. It is neither good nor bad. Rather, I have presumed that if architects are interested in the effect of their design decisions on the environmental qualities of heat, light and sound experienced by people in their buildings, then they need reliable design tools that assist with this decision making. The thesis then attempts to answer the question of why those architects who are interested do not currently use the environmental design decision support tools that have been created for them. It looks for the answer in a study of the ways in which a range of different types of eddst do and do not match the needs of the practitioners who are using them at present. The hypothesis underpinning this research philosophy is that common lessons will be able to be drawn across this range of types of eddst as to the types of information need identified by these practitioners.

3-4.1 research methodology

Using the classification system outlined above, the research analyses a series of surveys and case studies of designers' use of building environmental performance assessment tools. The research methodology is systematically to examine the use in real buildings of eddst's. The analysis focuses on the responses of the design team to the tool and its use. A series of different types of design decision support tool - alternative means of simulation of reality during design - is examined in different architectural contexts with a view to analysing the common threads in the users' reactions to them. The result is a collection of interviews with practitioners who use environmental design decision support tools in real situations. These are collated in a series of five chapters comprising three surveys and two case studies:

- the direct value to designers of a **text based design guide** containing **graphical design aids** for the creation and appropriate sizing of the elements of a solar house. . . . . SURVEY: Solar House Design Guide.
- the value to designers of information provided by expert simulationists on building performance based on **computer simulation** of **lighting** and **thermal** performance. . . . . CASE STUDY: CBPR project review
- the value to simulationists of information provided by current state of the art **computer (thermal) simulation** packages. . . . . SURVEY: USA and NZ simulationist interviews
- the value to designers of information from **physical model studies** of pedestrian **wind** environments. . . . . SURVEY: architects and wind tunnel use in Wellington City
- the value to designers of information from **physical model studies** of art gallery **daylighting** . . . . CASE STUDY: architects and lighting designers San Francisco MoMA

Figure 11 repeats the diagram at the start of this chapter, highlighting the coverage of the surveys and case studies. As can be seen, the emphasis in the coverage has been largely on simulation. In reviewing the advantages and disadvantages of these eddst categories it became clear that while text based tools may be a necessary part of understanding how simulation tools work, simulation is really the only approach that offers the user the ability to quantify the performance of individual building designs.

Even for the focus group for this research - architecture design teams and clients who want to know the effect of buildings on human environments - simulation eddst's therefore offer a design analysis potential that text based tools do not. The research focuses on the application of simulation to quantification of building performance in building design. It is presumed that each design team studied understands the issues explored in text based environmental design decision support tools and is seeking to apply these principles in design.

It can be seen that there are two exceptions to this general research focus: one text-based tool - a design guide - is studied; and one simulation tool - formulae and nomograms - is not studied. The former is examined because this is the traditional approach to eddst delivery: construct a book explaining the principles and providing practical design advice. The latter is excluded because it is seen as an outmoded and increasingly irrelevant form of simulation. Increasingly, what was previously

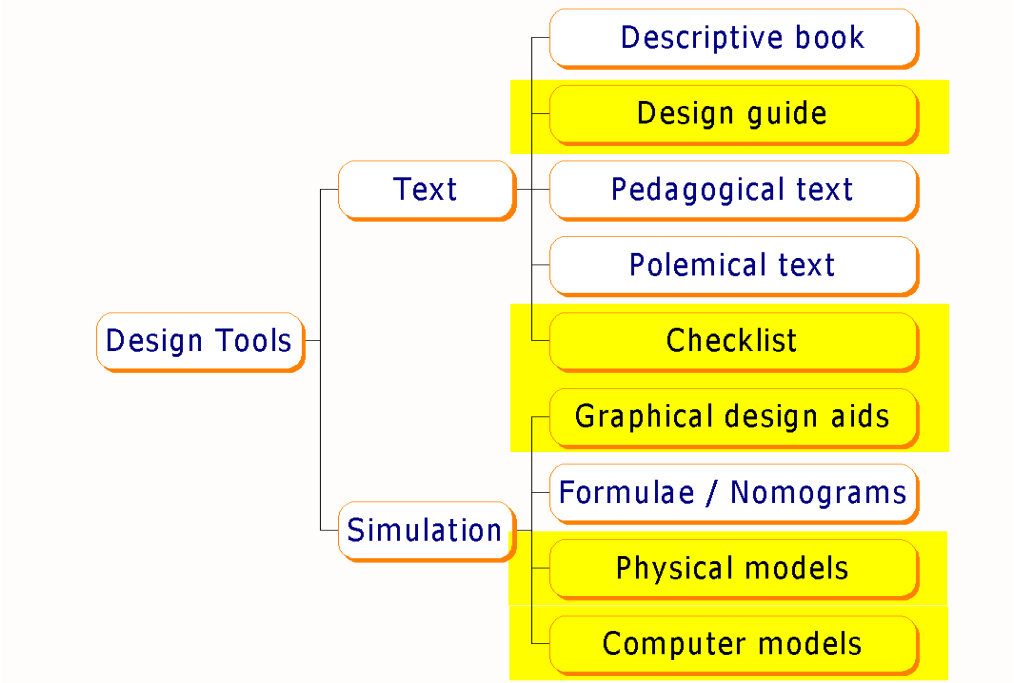

Figure 11 Shading indicates which classes of eddst are studied in this thesis

packaged as a nomogram to make it easier for design teams to use the complex formulae that predict building performance is being packaged as a computer program which has an interface that is far simpler to use. The research in this thesis has therefore focused on the means of simulation - physical and computer models - that offer a significantly greater number of advantages than disadvantages in the functional assessments listed earlier in this chapter.

The next chapter of this thesis describes the approach adopted to examination of these surveys and case studies. The research plan considered not only the various ways in which the functions and contributions of environmental design decision support tools can be classified but also how the use of these building performance analysis tools might be studied in real consultants' practices. The succeeding chapters report the five surveys and case studies individually, describing the consultants' views of the various categories of eddst and analysing the evidence for the hypothesised advantages and disadvantages.

3

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4

Research Design

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

research_plan_2006.wpd

IT SEEMS CLEAR..THAT THE DILEMMA WHICH AFFLICTS THE PROFESSIONS HINGES NOT ON SCIENCE PER SE BUT ON THE POSITIVIST VIEW OF SCIENCE. FROM THIS PERSPECTIVE, WE TEND TO SEE SCIENCE, AFTER THE FACT, AS A BODY OF ESTABLISHED PROPOSITIONS DERIVED FROM RESEARCH. WHEN WE RECOGNIZE THEIR LIMITED UTILITY IN PRACTICE, WE EXPERIENCE THE DILEMMA OF RIGOR OR RELEVANCE. BUT WE MAY ALSO CONSIDER SCIENCE BEFORE THE FACT AS A PROCESS IN WHICH SCIENTISTS GRAPPLE WITH UNCERTAINTIES AND DISPLAY ARTS OF INQUIRY AKIN TO THE UNCERTAINTIES AND ARTS OF PRACTICE...

DONALD A. SCHÖN, IN "THE REFLECTIVE PRACTITIONER"

4-1 *research plan*

This chapter provides a general overview of the research design resulting from the research hypothesis stated in chapter 1 and the general philosophical approach to the research outlined in the last chapter. It describes the relationship between the research goals and the surveys and case studies that form the principal technique used in this research. The introduction to this thesis stated: *My broad hypothesis is that general lessons for the improvement of all building environment design decision support tools (eddst's) can be learned from the study of practical application of those tools that are being used today. I assume there are common problems in the application of these tools that if identified can be used to define principles for the creation of new eddst's that do address the specific interests of architects and clients.*

The research plan is simply to establish how practising architects, who have tried to use building environmental design tools, assess their effectiveness. Systematic analysis of building design practitioners' assessment of building environmental design decision support tools required a research plan containing the following items:

1. a classification system for the types of environmental design tools in use.
2. particular design tools that were being used by more than 10 and preferably 20-30 different architects so that statistically valid generalisations of these responses could be produced.
3. design tools that address at least two different types of environmental design issue from amongst the broad range of typical thermal, visual, acoustic, and external environmental design issues.

The first item is described in the previous chapter. The other two are the core of the research design described in this chapter.

4-2 *rationale for the research*

The design decision support tools examined in this thesis are based in what I regard as the discipline of Building Environmental Science or Building Physics. This is the systematic study of the Thermal, Visual and Acoustic environment in and around buildings. It is necessary at this point to clarify my approach to (building) science: I am taking what I understand is a positivist position in relation to the subject ". ..a theory ... is just a mathematical model that we use to describe the results of

observations. A theory is a good theory if it is an elegant model, if it describes a wide class of observations and if it predicts the results of new observations. Beyond that, it makes no sense to ask if it corresponds to reality, because we do not know what reality is independent of a theory. " [1]

The rationale for this research then is **to address the disjunction that apparently exists between the knowledge that architects and clients want of the effect of buildings on human environments and their desire to understand this effect at anything but the most trivial of levels.** To do this, I have adopted an approach of interviewing practising designers and analysts about their use of environmental information and their approach to environmental design. This has required the development of user surveys and case studies examining the application of environmental design information in one or other of the categories of design tool that are described in Chapter 3.

Each eddst examined in the surveys and case studies is from a different design tool category and addresses a different aspect of the environment in buildings. 1(Survey): - a text based design guide - addresses solar thermal performance of buildings; 2 (Case Study): - a computer and physical model simulation - addresses thermal performance and daylighting of two buildings; 3: (Survey) - a physical model simulation - addresses the effect of buildings on the wind environment in the surrounding streets; 4 (Survey): - a computer simulation - addresses the thermal performance of buildings; 5 (Case Study): - a physical model simulation - addresses daylighting performance of one building. Overall, the aim of selecting more than one eddst and comparing the different ways in which they are used is to determine whether there is any commonality in the ideas or types of information presentation that work for designers in the very different branches of building environmental science: solar design, daylight design, thermal simulation in design and building aerodynamics.

The eddst's selected for examination are however all of the type classified in the previous chapter that overtly provide quantitative as opposed to qualitative information on the consequences of design decisions. This choice was dictated by my experience over the past 20 years teaching students of architecture that purely qualitative information is of little use in design studio. Designers need some idea of the importance of their decision other than the recommendation that "option X" is better (in thermal, lighting or acoustic terms) than "option Y". They essentially want a benchmark, typically a number or index, against which to compare the calculated benefit of their design decisions. Without this benchmark the qualitative decisions they want to make are impossible.

The realm of the calculated environmental performance is the realm of the virtual. Each of the design tools examined in the surveys and case studies in this thesis addresses a different mode of developing a representation of the influence of the built environment on our haptic senses. They produce virtual environments - abstractions of reality. Each tries to describe what the thermal or visual nature of that virtual reality might be if the design decisions are followed through.

While the original intention of the research was to concentrate on the question of what design decision support tools are suited to architects and the architectural design process, the reality of the research and of architectural practice is that this neat separation never happens. Unlike students in architectural design studio, architects work in design teams some of which include specialists in these aspects of building environmental science. At best it was thought that asking the question would identify the role that design decision support tools play in the design team and the characteristics that best suit this mode of operation. It was acknowledged that it might be impossible to identify particular characteristics of design tools that make them more suitable for architects than they are at present. Overall, it was assumed that it would be possible to identify amongst the design decision support tools studied one(s) that is(are) better for producing quality architectural environments.

4-3 *research approach*

Given that the goal of the thesis was to investigate the practical application in design consultancies of environmental design decision support tools, there seemed little option but to approach the topic using a survey and case study methodology. The methodology developed was to survey groups of design team members. The plan was to assemble groups large enough that general lessons could be drawn from summative analysis of the observations. The common thread of experience being investigated in each survey was the individual's experience with a particular design decision support tool. Ultimately, this plan was supplemented by two case studies examining particular projects which were illustrative of the principles and which assisted in broadening the range of environmental analysis technique examined.

Some initial thought in an earlier abortive research project had been put into observing students' applications of these tools in design studios over a number of years. This had never been fully implemented as a methodology as it had very real problems with the degree to which the results might be generalised to design and to design practice. First, students will have been educated in the application of these design decision support tools by the person (me) who is conducting the survey. There is a huge potential problem of confounding the research with my own expectations in the choice of lecture content. This would be no reasonable test of the application of the tool to design decision support.

In a student design studio, projects that have been constructed to teach the principles of application of a design tool will also significantly simplify other aspects of the design situation in order to permit clear focus on the application of the tool to the design goals. In real design projects this simplification does not necessarily happen. The goal was to study application of design tools to the complexities, the messiness, of real designs with real site and budget constraints and real client desires. Observing the application of design decision support tools in real consultancies was the only method available for getting this close to the reality of design.

Observation of the application by a third party of a decision support tool is fraught with complexities. One could sit and observe in an office for a period of time and record the decisions. One would record the nuances of use. The day-to-day frustrations and the ease of application could be readily noted. However, this would require extremely long periods of time spent observing the design process. It would therefore be limited to a very few sets of observations and hence a limited range of buildings and practices could be studied. It would also require extreme care on the part of the observer not to influence the observed practice in an unrecorded manner. The nature of the research data gathering would make the researcher a "participant observer"[i]. If one were to be a participant in this manner then the richness and depth of the observations would be increased, but the number and range of types of situation needed to provide data for a comparative study would be difficult to achieve.

The results of participant observation would be highly detailed studies of the interactions of a few designers with a design tool on one or two different buildings.

The focus of this thesis is on the nature of the information sought by the designer from an eddst, not the nature of the interaction with the tool. While it is likely that this interaction may affect the accessibility of the design information the tool produces, it seemed more worthwhile to conduct a broader study to characterise the issues better. Detailed case studies could then be conducted to tease out the issues identified as critical.

Surveys of the user are the conventional, objective, scientific rational approach to determining the nature of response of a broad range of people to a "stimulus". This thesis research focuses on the stimulus provided by eddst's and in particular on architecture design teams' perceptions of the resulting design quality.

Even surveys that are conducted with standard survey forms by mail or by telephone require a significant amount of effort in the development of the survey tools: the combination of survey form and analytical technique. In the five detailed studies that form the core of the research it was therefore possible only to develop survey examinations of three different categories of eddst: a text based design guide, and simulation through physical models and through digital simulation. These three surveys have been supplemented by two case studies of individual building design teams: one

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[x] M. Dereshiwsky http://jan.ucc.nau.edu/~mid/edr725/class/observation/observer (Last accessed 2001):

* "The "participant part" implies an immersive experience in a real-world, "field-based" setting. As such it implies that the researcher is holistically committing his/her feelings, thoughts, emotions, etc. to that setting.

* On the other hand, the "observer part" is characterized by the scientific approach to knowledge. That implies objective, scientific, neutral, scholarly recording of these data or observations. At first glance, it seems like a rather precarious balancing act, doesn't it?

* Go too far in the "participant" extreme and the researcher runs the risk of, as Miles and Huberman characterize it, "going native." He/she can in essence become "co-opted" by the situation, setting, key players, etc., to such a degree that scientific objectivity is lost. ...

* Go too far in the "observer" direction and you run the risk of doing what I call "overly sterile qualitative research!" By that I mean skimping on the "rich, thick, vivid description" that we have learned is the hallmark of qualitative research. "

examines the particular application of digital simulation to heating and lighting in two buildings and the other the application of physical model simulation to lighting of a single museum building. The broader questions identified by the surveys can be examined in the "rich thick vivid" [2] manner of the participant observer in the first of the individual case studies, and through detailed interviews with the major design participants in the other case.

4-4 *case study overview*

Each of the five detailed studies examines critically a different type of environmental design tool. These types are representative of the different categories of eddst defined in the previous chapter. The five case studies are:

1. a **text based design guide** containing **graphical design aids**
   . . . . . Solar House Design Guide - **survey**.
2. **computer simulation** of **lighting** and **thermal** performance.
   . . . . . CBPR client reaction - **individual case study**.
3. **computer (thermal) simulation** packages. USA and NZ interviews - **survey**.
4. **physical model studies** of pedestrian **wind** environments.
   . . . . . interviews with architects in Wellington City - **survey**.
5. **physical model studies** of art gallery **daylighting**
   . . . . . architect & lighting designer interviews SFMoMA- **individual case study**.

The three surveys were planned for two very different areas of environmental design: thermal design of buildings (text based design guide and digital simulation) and the effect of the design of buildings on pedestrian level winds (physical models in a wind tunnel). The goal was to establish what common threads there might be between these three situations in the ways architecture design teams use the design information produced by current eddst's.

Selection of thermal design and wind environment as the specific areas to study was based on my research and practice experience in these areas. I already had sufficient knowledge of the basics of thermal and wind environment design that I could devise realistic survey instruments and speak the language of the consultants.

The two Individual Case Studies were selected because the data was fortuitously available: 1) the evaluation of the Victoria University CBPR involvement in the environmental design of two buildings; and 2) the evaluation of the relationship between the daylight design firm analyses and the form of the San Francisco MoMA building. Unlike the three surveys they examine the design of single buildings. However, they fit neatly into the coverage of the rest. They are included because they provide illustrations of the lessons from the broader surveys' investigation of the role of environmental design tools in architectural design.

The First Detailed Study was a Survey evaluation of reactions to the thermal design information presented at seminars on passive solar design of houses in New Zealand. The design information presented in the seminars and the associated "design manual" fitted three eddst categories: re-presentation of textbook material on the thermal properties of buildings, rules of thumb sizing guides and a performance estimation calculation. While technically it therefore contains elements of the text book, the design guide, the checklist, and the formulae/ nomogram categories, it has been classified as principally a *design guide*. The participants in the seminars and the associated design workshops rated the design guidance material on the basis of their use of it to design a solar house in the seminar workshop sessions.

The Second Detailed Study was a Survey of thermal simulation tool users. This survey was applied first on architects, engineers and builders in New Zealand. It asked what they sought in a design tool. It sought usage statistics on what tools of the wide range available people used routinely. Then the same survey instrument was made specific to computer programs that simulate the thermal performance of buildings and applied in the Western States of the USA. It was therefore seen as addressing specifically the *digital simulation* classification of eddst. The survey targeted people who were experienced users of digital simulation. The survey sought users' views on the programs they were using. It sought evaluations of the current functionality and expressions of interest in possible future developments of the computer programs. It also examined from the simulationists' point of view the roles of building industry players - architects, engineers, simulationists - in building thermal design. Interestingly, even in the areas of the USA where the codes have required use of tools like this in design for many years, no architects were among the experienced user group.

The Third Detailed Study was a Survey of architects who had been involved in the design of buildings to comply with the Wind Ordinance that I had helped the Wellington City Council develop. The Ordinance requires developers of large buildings in the Wellington Central Business District to examine the performance of their proposed buildings in a wind tunnel. The survey was therefore seen as addressing specifically the *physical model simulation* classification of eddst. The Ordinance was written to encourage architects to use a simplified wind tunnel test procedure early in the design process when design changes should be easier to make. In interview, architects who had experience of wind tunnel tests and the reports they produce were asked their assessment of the Ordinance and the Pre-Design Wind Tunnel Test and they were also evaluated on the degree to which they appeared to have understood the effects buildings have on the wind.

The table below summarises the principal features of the Surveys and the individual Case Studies:

Study		Number people	Res-ponse	Scale and type of Building	Topic
1	Passive Solar Seminars	47	36%	House	Thermal Design
2	Simulation Tool Usage	80 (NZ)	NA	Large and small Commercial	Thermal Design
		44 (USA)	11%		
3	WCC Wind Ordinance	16	70%	Large Commercial	Design for Wind
4	CBPR Design Examples	2	NA	Large Institutional	Thermal & Daylight Design
5	SF MOMA Daylight	3	NA	Large Institutional	Daylight Design

Table 1 Principal features of each of the Surveys and Case Studies in this thesis

The first three studies involve administration of a survey instrument to as large a body of people as possible. The response column rates the number of participants against the potential number who might have been surveyed if that whole "population" were approached. Thus, of the 130 people who attended the Passive Solar Seminars 36% responded to the questionnaire. The nationwide survey of New Zealand simulation based design decision support tool usage selected representative numbers of architects, engineers, builders and Territorial Authority officials. Particular numbers of each group were found to reach a certain representation of each type of user and sufficient people were approached to find this number to respond, so a response rate of the type reported for the other surveys is not applicable.

In chronological terms, the detailed studies were performed in the order 1, 3, 4, 2, 5. Although the development of the use of the computer over the time frame of all these surveys is huge, very few of the questions addressed in case study 2 would have been different if the survey was administered ten years earlier, when the first study was completed. For example, the general principles[3] for the creation and development of a useful computer based design tool expounded in a Survey of Computer Programs published by the EMPA in Switzerland in 1985[4] have not changed in the intervening years. Neither would one change the definitions of computer program capability listed by Dean Hawkes[5]. What has changed is the capacity of software to meet these definitions.

4-5 *analysis*

The dissection of the surveys and case studies is "analytical" because it is systematic and because it uses a categorisation approach to sort out the similarities and differences between the observed attitudes and behaviours of the architects involved. It is statistical to the extent that it counts occurrences of common responses to the same question when it is asked. However, it also borrows from the fields of social science in order to handle the large number of open-ended questions asked in the questionnaires and interviews. Many responses are reproduced in verbatim quotes in order that the language of the respondent is used to summarise the answer(s) to these questions. The goal is to develop a picture in the mind of the reader of the rich variety of responses to the application of design decision support tools in practice.

The approach to the analysis of the data collected is described in more detail in the chapter on each survey or case study. This approach relies primarily on descriptive statistics (e.g. *"x% of the respondents concluded ...."*). There was no perceived necessity to develop a deterministic relationship between the type of eddst and designers' behaviour. Rather, what was sought was descriptive analyses. The intention was to identify the parameters that describe tools which in the view of the user are more suited to decision support in architecture. The overall analysis in the conclusions section of the thesis draws all the parameters identified in the individual analyses together into a comprehensive prescription for an environmental design decision support tool for use in architecture.

In order to put some pattern into this potentially chaotic, subjective analysis, the design tool classification outlined in the previous chapter and the associated hypotheses as to their individual advantages and disadvantages are used to provide a consistent means to dissect each case. The evidence or otherwise for the advantages and disadvantages of these disparate approaches to environmental design is presented. The summary analysis for these in the final section of this thesis then tries to step back one level above the detailed advantages and disadvantages and look for the common factors in all the users' uses of and reactions to these environmental design decision support tools.

4

Notes & References

1. Hawking, Stephen. **Black Holes and Baby Universes.** Bantam Press, London, 1993.

2. Dereshiwsky, M. http://jan.ucc.nau.edu/~mid/edr725/class/observation/observer (Last accessed May 2003)

3. Donn, Michael R. **Design tool survey**, EMPA, Zuerich, 1985

4. Donn, Michael R. 1985, op. cit.

5. Hawkes, Dean **A History of Models of the Environment in Buildings** Working Paper 34 of the Centre for land Use and Built Form Studies in the University of Cambridge, September 1970.

PART B

SURVEYS AND CASE STUDIES

table of contents

Part B contains five chapters describing detailed studies of the application in architectural design of environmental design decision support tools (eddst's). They are:

5 . . . . . text based (solar) design guide

Exploration of the application of a **text based design guide** containing **graphical design aids** . . . . . **a survey**.

6 . digital (thermal & lighting) simulation

Exploration of the application of **computer simulation** of **lighting and thermal performance -** interviews with CBOR analysts and clients . . . . . **individual case study**.

7 . . . . . digital (thermal) simulation

Exploration of the application of **computer (thermal) simulation packages** by New Zealand and USA design teams.. . . . . **telephone and mail 'interviews'- survey.**

8 physical (wind tunnel) model simulation

Exploration of the application of **physical models** in studies of pedestrian **wind** environments. . . . . interviews with architects in Wellington City **- survey**.

9 . . . physical (lighting) model simulation

Exploration of the application of physical models in studies of art gallery daylighting - architect and lighting designer interviews - SanFrancisco MoMA . . . . . **individual case study.**

The overall goal of this thesis was to establish what common threads there might be between these studies in the ways architecture design teams use current eddst's. The result is five sets of interviews exploring eddst use in real situations. The design tool classification hypotheses from Volume A as to the advantages and disadvantages of different eddst's are presented at the end of each study as a means of analysing their suitability to the task. A summary of these five detailed analyses is presented

in the analysis chapter of Volume C of this thesis. There, the analysis looks explicitly for the common factors in all the users' uses of and reactions to these environmental design decision support tools.

5

text based (solar) design guide

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

thsolcas_2006.wpd

IN HOUSES THAT LOOK TOWARD THE SOUTH, THE SUN PENETRATES THE PORTICO IN WINTER, WHILE IN SUMMER THE PATH OF THE SUN IS RIGHT OVER OUR HEADS AND ABOVE THE ROOF SO THAT THERE IS SHADE

SOCRATES, AS QUOTED BY XENOPHON, CITED BY BUTTI AND PERLMAN[1]

This is the first in a series of five detailed studies of the application in architectural design of environmental design decision support tools (eddst's). The five studies are:

1. a **text based design guide** containing **graphical design aids** . . . . . Solar House Design Guide - **survey**.
2. **computer simulation** of **lighting** and **thermal** performance. . . . . CBPR client reaction - **individual case study**.
3. **computer (thermal) simulation** packages. . . . . USA and NZ interviews - **survey**.
4. **physical model studies** of pedestrian **wind** environments. . . . . interviews with architects in Wellington City - **survey**.
5. **physical model studies** of art gallery **daylighting** . . . . . architect & lighting designer interviews SFMoMA- **individual case study**.

This study is one of the three in this thesis that reports reactions to the use of an eddst gleaned from surveys of experienced practitioners. It examines the use of an eddst that applies ***a text based design guide*** to the simulation of the likely environmental performance of a building. Specifically, solar house design proposals are developed following guidelines in a text, and then their performance is assessed following the procedures also outlined in the text.

5-1 *background*

In November 1984, I participated in the planning and presentation of a series of seminars on passive solar design of houses which was run with the sponsorship of the then Ministry of Energy. The seminars were run in Auckland, Hamilton, Wellington and Christchurch. These were my first opportunity to examine the relationship between ECS theory and its use by practising designers. Participants in the seminars were asked to complete a questionnaire after they had returned home. The goal was to give people time to assess in practice what they had experienced in the workshop sessions of the seminar.

The seminars used the draft **Design for the Sun** residential design guidelines for New Zealand[2]. They had two ostensible purposes:

1. to "give designers experience and knowledge in passive solar design" and
2. to assist in the "refinement" of the **Design for the Sun**[3] reference manual and form the associated working document.

Participants were advised of these dual purposes. They were also given a specific set of objectives that they were to achieve through participation. The aims and objectives communicated to the seminar participants are listed in **Figure 1**.

The seminars ran over two days. Participants attended lectures for short periods of time, interspersed between a series of workshops progressively applying the lecture ideas to the design of a small solar house on a site with some tricky solar shading and wind exposure aspects. In the workshops the participants were required to document their design decisions on large A1 sheets of bond paper. These were retained for subsequent analysis. The participants formed groups on day one and with that group developed the design for the full two days. I a final day plenary each group presented its design and its design thinking. As session facilitator, I summarised the energy performance of each building on a chart showing the principal heat losses and gains.

The design process was somewhat pre-determined by the order and nature of these individual workshops. A typical design process for a workshop group is illustrated in the series of photographs in **Figure 2** through **Figure 7** for Group F at Wellington. They show that group's design process.

SEMINAR/WORKSHOP AIMS AND OBJECTIVES

The aims of the Passive Solar and Energy Efficient House Design seminar/workshop are to:

8. *Give designers experience and knowledge in passive solar design, and*
9. *Refine the "Design for the Sun" reference manual and associated working document.*

The objectives for the two days are to enable the participants to be able to:

1. *Inform and advise clients on the suitability and implications of energy efficient and passive solar design,*
2. *Advise clients on the selection of specific energy efficient, passive solar design strategies which best suit their needs, with an understanding how climate guides the design process,*
3. *Use the design rules of thumb successfully,*
4. *Understand when rules of thumb, detailed design calculations, and / or computer simulations are appropriate.*

Figure 1 Aims and Objectives for the *Design for the Sun* Seminars

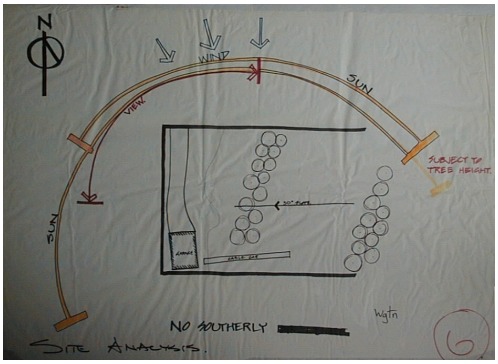

Figure 2 Wellington Group F Site Analysis

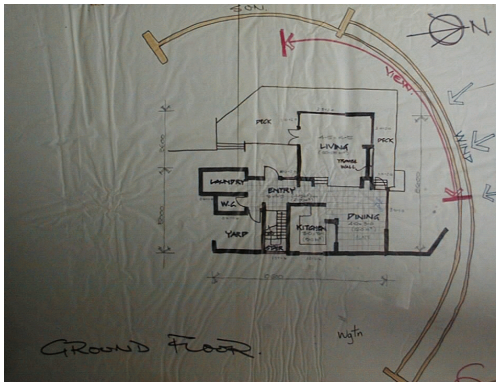

Figure 3 Wellington Group F Plan

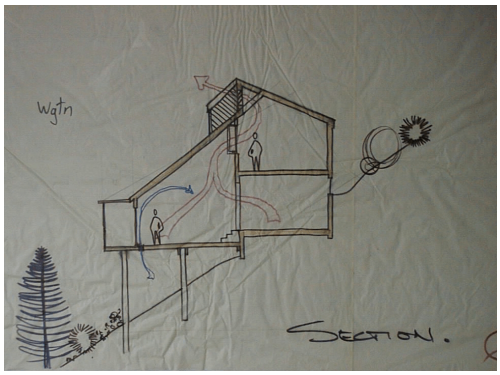

Figure 4 Wellington Gp F Solar Section

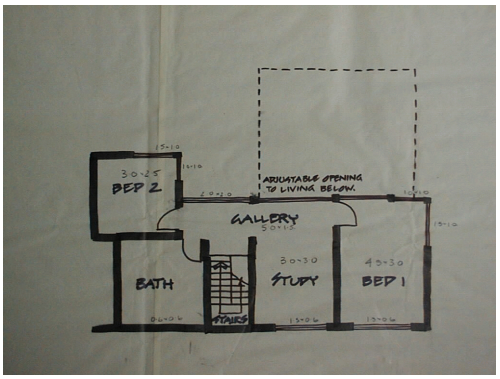

Figure 5 Wellington Gp F Upper Level Plan

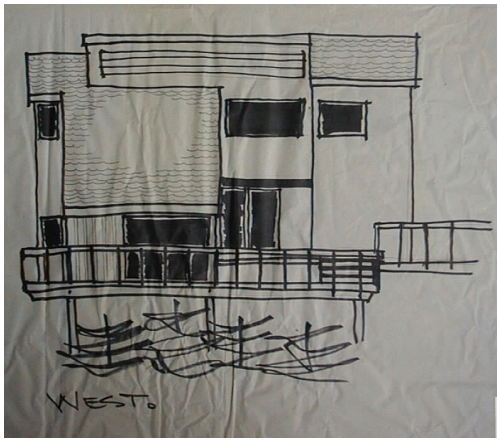

Figure 6 Wellington Gp F West Elevation

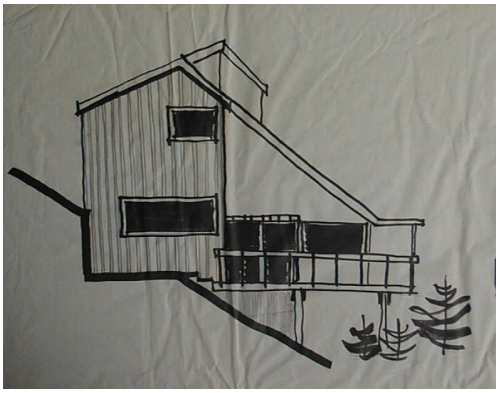

Figure 7 Wellington Gp F North Elevation

The next pages show some typical outcomes from various groups in various cities at the conclusion of the two day solar design seminars.

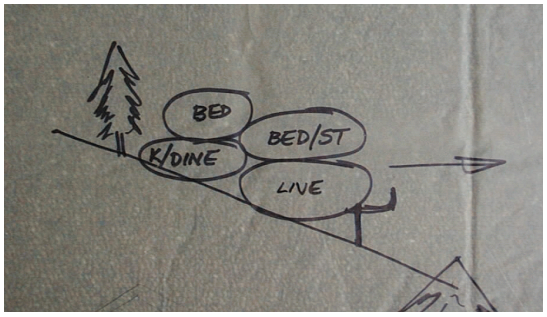

Figure 8 Wellington Gp D 'bubble' section

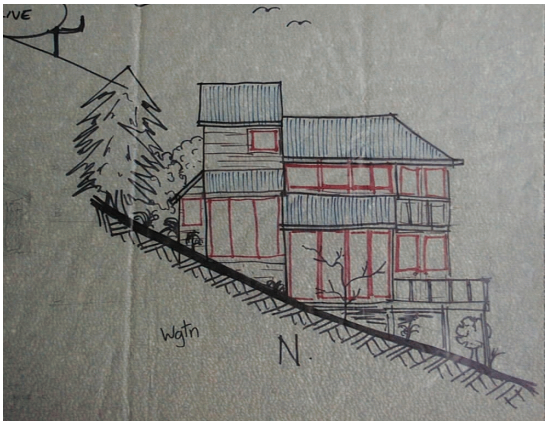

Figure 9 Wellington Gp D North Elevation

Figure 10 Auckland Gp A sketch

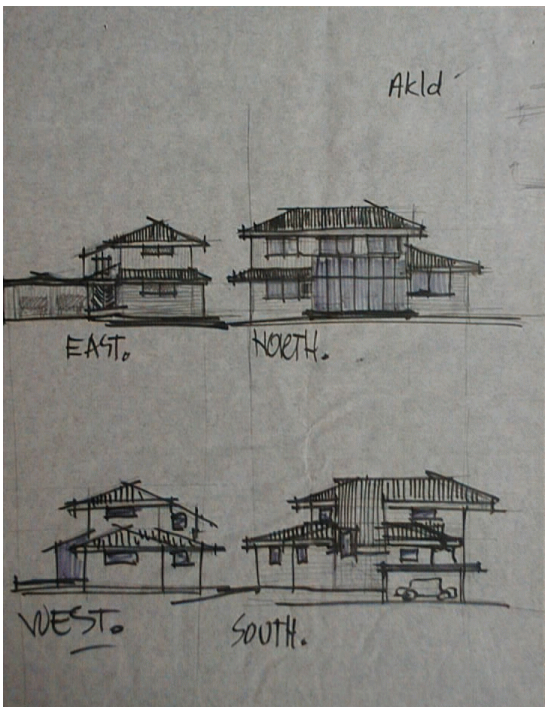

Figure 11 Auckland Gp E Elevations

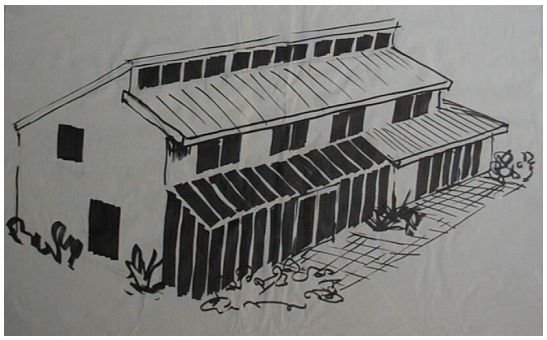

Figure 12 Christchurch Gp C Sketch

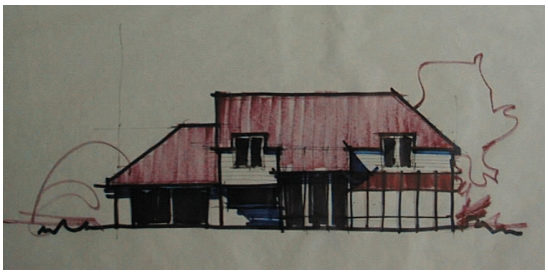

Figure 13 Christchurch Gp F Elevation

To illustrate the range of activities undertaken by the groups, the next set of photographs contains

photographs showing the "workings" of Group D from Auckland. This group produced display charts of all their work, not just sketches of the building design.

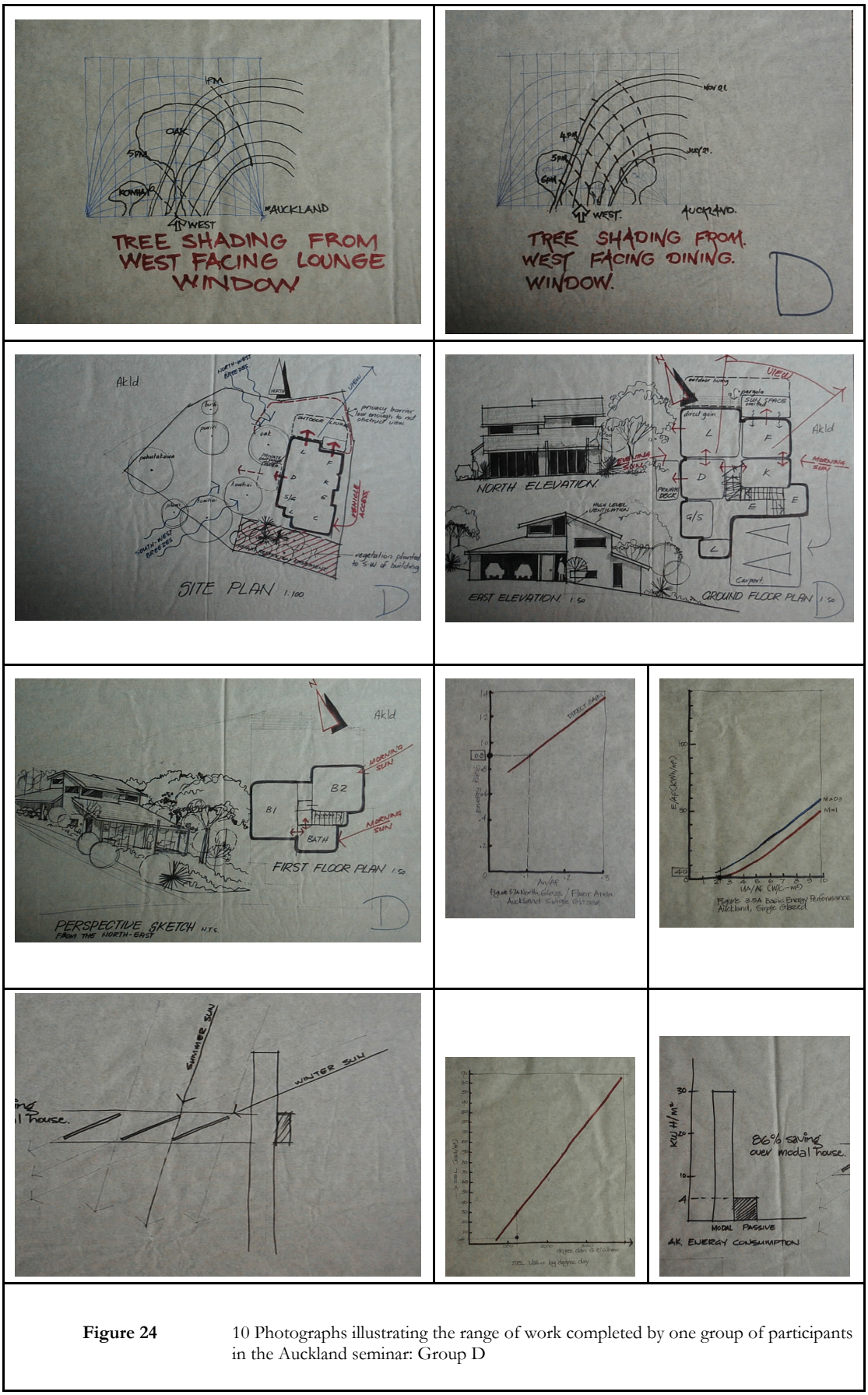

Figure 24 10 Photographs illustrating the range of work completed by one group of participants in the Auckland seminar: Group D

5-2 *seminar participants' evaluations*

Like the seminars, the survey of the seminar participants had two purposes:

1. first, as a tool to assist development of a work book to accompany the **Design for the Sun** manual.
2. second, I wished to examine reactions of building designers to ECS material.

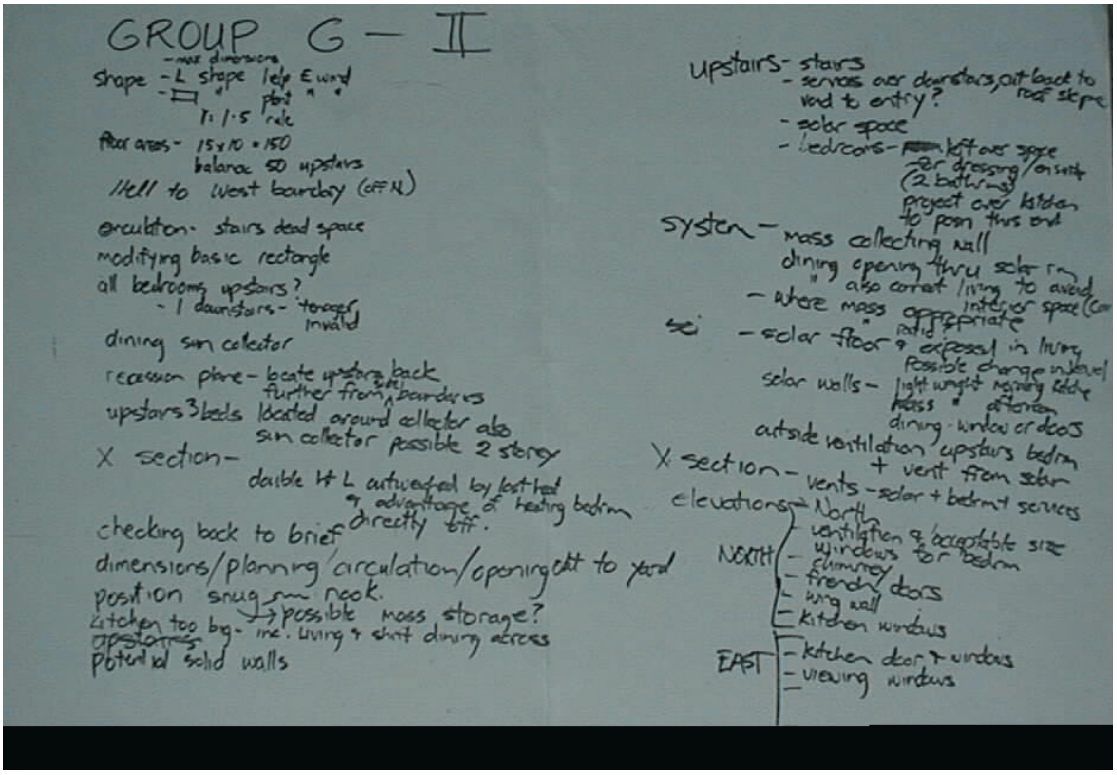

Figure 25 Typical calculation sheet (number 2 of 5) for Group G at Christchurch Seminar

The questionnaire responses were mostly better suited to the first than the second purpose. The

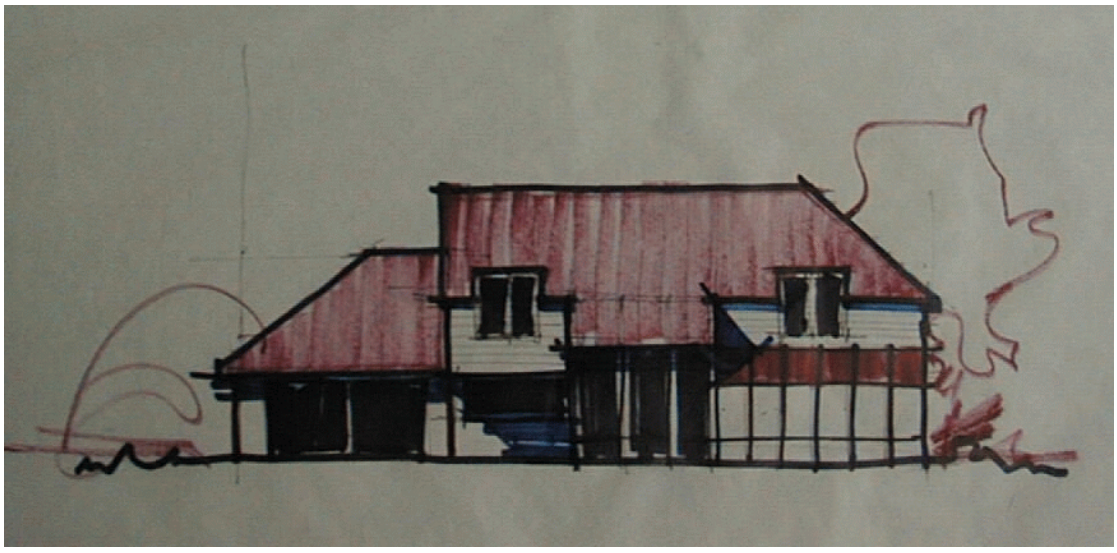

Figure 26 Elevation of solar house design by Group F at Christchurch Seminar

respondents saw this as its prime purpose and answered the questions with this in mind. However, they were enthusiastic participants, completing calculations willingly and producing quality "presentation sketches" for the end of seminar critiques, as can be seen in **Figure 25** and **Figure 26**.

Name.....PROFESSION.....

Has this seminar been of use to you?
What areas have been most useful? Why?
What areas have been least useful? Why?

Please record the sections of the manual used by you during the workshop sessions.

What was your response to each of these sections of the design manual? Did you find it clear or difficult? Enter C or D (or '-' for those sections you have no response to) in the two columns below.

Section		*When first read*	*After the seminars*
1.1	*Introduction / A Perspective*		
1.2	*Heat Flows*		
1.3	....		

Which Rules-of-Thumb did you
(A) Understand; (B) Use in the Workshop?

		A	*B*
2.12.5	*Building Shape & Orientation*		
2.12.6	*Design Direct Gain*		
	A Basic Choices		
	B Windows		
...			

Which Performance Prediction Worksheets (Chapter 3.1) did you:
(A) Understand; (B) Use in the Workshops?
Worksheet 1
Worksheet 2
...

Was the format of this workshop successful? Could it be improved? How?

Is the Design Manual useful?
What other information would you like to see included?
What information do you think could be removed?

Do you feel that you can now undertake the tasks outlined in the seminar's objectives?

Thank you.

Figure 27 Questionnaire for *Design for the Sun* Seminar Participants

5-2.1 questionnaire

The questionnaire asked only eight questions. However, it filled four pages because it sought reactions to each of the sections of the design manual. **Figure 27** lists the eight questions asked but excludes all except a few example section references in Questions 3, 4 and 5 whereas the full questionnaire lists all of the relevant sections of the design manual.

Of the 42 Auckland participants, 6 are builders, 7 represent manufacturers, a further 3-4 are in education or engineering, and the remaining 25-26 are architects or architectural designers. In Hamilton, of 23 participants, 18 were architects or architectural designers; one was a builder; the other 4 were engineers and a building inspector.

From the only comprehensive list of attendees (for Christchurch) it is possible to infer the following: of the 39 at the Christchurch seminar: 10 were definitely architects or architectural designers; 7 were engineers, building inspectors or educators; 3 were definitely builders; the remainder (19) were most likely either builders or designers.

The proportions of architects and architectural designers to others attending the seminars is shown in **Figure 28**. The responses appear to be representative of the seminar participants.

Question 1 was the most comprehensively answered of the whole questionnaire. It would seem that the energy and enthusiasm slowly waned as people proceeded through the questions. Most respondents answered the questionnaire as an assessment mostly of the seminars themselves. They had very specific comments on their organisation. The following were typical:

1. people felt that they were unable to tackle the workshop design tasks as well as they wanted because they just had insufficient time in the brief workshop sessions to absorb all the ideas or to understand the issues, especially the arithmetic and the data lookup required for the worksheets;
2. many felt that the 75-100 mm thick manual lacked organisation - they felt that the accessibility of the information was compromised;
3. the late mailing of the manual to participants so they had no time to go through it prior

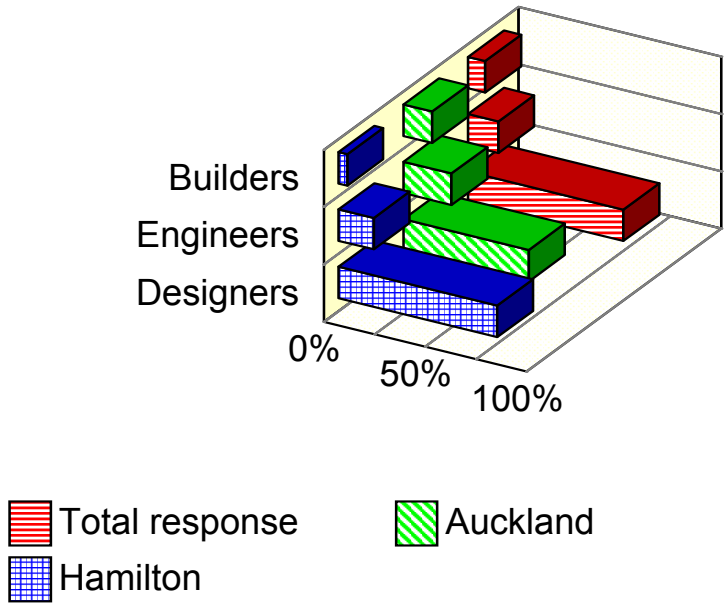

Figure 28 Breakdown of "Responses" to questionnaire compared to Auckland & Hamilton seminar participation

to the seminars also hindered participants' ability to absorb the material in it.

question 1 - architects' and architectural designers' responses

1	Has this seminar been of use to you? *1. What areas have been most useful? Why?* *2. What areas have been least useful? Why?*

Figure 29 Solar House Seminar Question 1 - Has this seminar been of use?

The answers to the question ***what areas of the seminars have been most or least useful*** fell into four categories: Calculations/Workshops, Rules-of-Thumb, Theory/Principles, and Miscellaneous. The responses are shown in graphical format in **Figure 31**. Contrary to my expectations, the responses were more in favour of the ***calculations*** aspect (as shown in the example in **Figure 30**) than the ***Rules-of-Thumb***. I had expected that the architects in particular would be biassed against anything mathematical. This is not to deny the expected popularity of "Rules-of-Thumb". These were also mathematical in nature. However their usefulness or perhaps the conventional expectations aroused by their label made them acceptable to eight users, and unacceptable to no-one.

Of equal interest was the ambivalence about the Principles section of the seminars. The split in opinion over the Theory is easy to explain by reference to some of the negative comments themselves: *Basic site planning, orientation, climate etc is already fairly well understood; Basic climate factors ... adequately studied previously.* Many of those attending were passive solar enthusiasts and thus found that they knew the basic concepts being explained in the theory sessions. Their principal purpose in attending the seminars was to find out "the numbers" for New Zealand, as all the literature they had read to that point was about the USA. From the "least useful" count it would appear that this group of informed participants represent approximately one-sixth of all participants.

The Economics section of the seminars was the least well liked. Few people even bothered to mention them. The two who did, only commented unfavourably. Essentially, the "formulae" approach presented by the tutors was universally seen as irrelevant to practitioners in New Zealand.

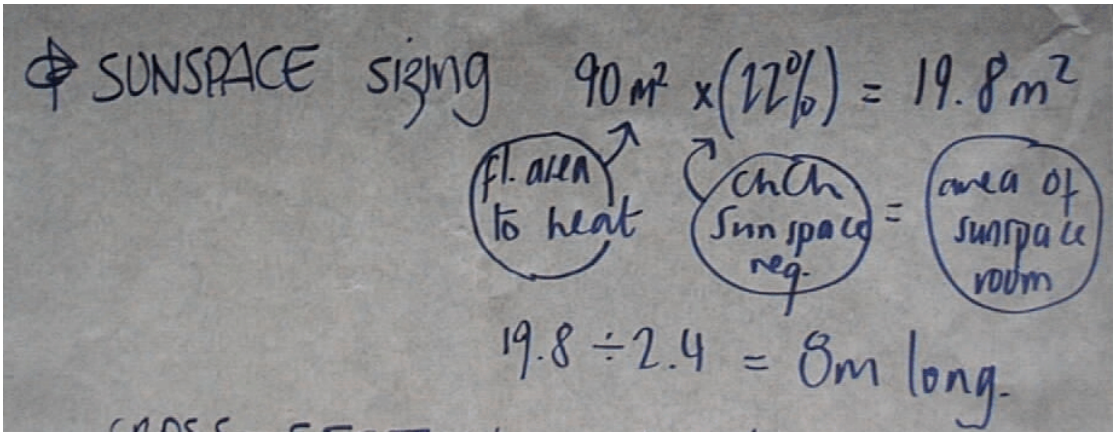

Figure 30 Notes from one of Christchurch workshop participant's worksheets

It is informative to examine the "Miscellaneous" category for the "Least Useful" respondents a little closer: of the 19 who are grouped here, 11 responses were, in the words of one respondent *None of it is not useful.* The remaining 8 were genuinely miscellaneous. At least in response to this question, the answers were significantly more positive than negative.

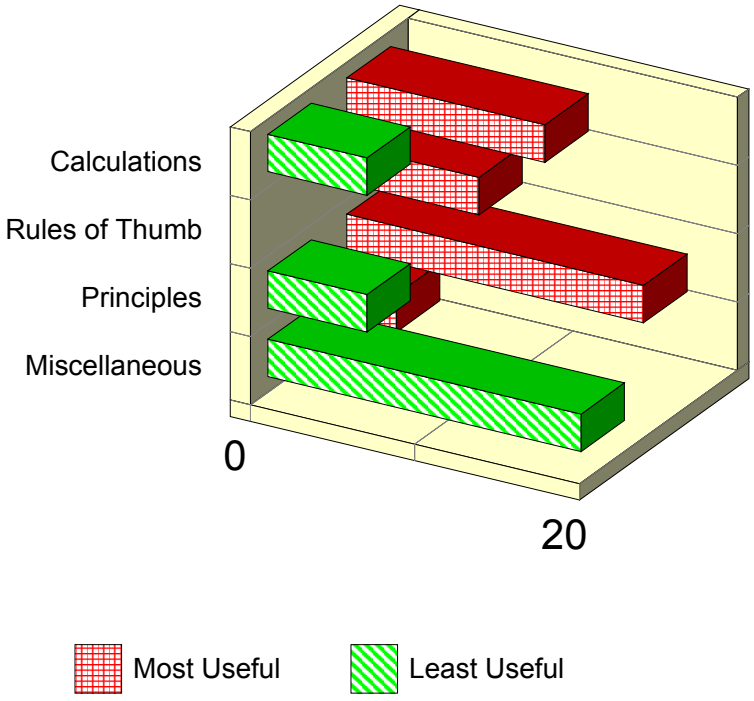

Figure 31 Responses to Question 1: "What areas of seminars were most / least useful?"

question 2 - architects' and architectural designers' responses

2	Please record the sections of the manual used by you during the workshop sessions.

Figure 32 Solar House Seminar Question 2 - Record the sections of the manual used during the workshop?

This was **the** most comprehensively filled in section of the whole questionnaire. After reviewing the range of responses I have divided them into three main categories: Calculations, Theory, and Rules-of-Thumb. The full contents list for the Design to the Sun Manual is listed in **Figure 33**. Sections 3.1-3.3 and Section 5 of the manual were labelled "Calculations"; "Theory" was in Sections 1.1-1.12, 2.1-2.11 and 4.1-4.8; and "Rules-of-Thumb" were Sections 2.12-2.15. People obviously entered more

1.1 Introduction / A Perspective
1.2 Heat Flows
1.3 Energy Criteria
1.4 Comfort Criteria
1.5 Design with Climate
1.6 Climate Information
1.7 Design with Insulation / Glass / Mass
1.8 Material Properties
1.9 Sun
1.10 Windows
1.11 Heat Loss Calculations
1.12 Mass
2.1 Design Procedures
2.2 Programming / Brief
2.3 Siting / Land Planning
2.4 Conservation / Solar
2.5 Insulation
2.6 Infiltration / Condensation / Ventilation
2.7 Floor Plan
2.8 Heating Levels
2.9 Internal Gains
2.10 Lighting
2.11 Types of Passive System
2.12 Rules-of-Thumb
2.13 Overheating Control
2.14 Night Insulation
2.15 Priorities / Design Checklist
3.1 Performance Prediction
3.2 Solar Control Design
3.3 Shadow Analysis
3.4 Computer Analysis
4.1 Introduction
4.2 Insulation
4.3 Infiltration / Vapour Control
4.4 Direct Gain
4.5 Sunspace
4.6 Thermal Wall
4.7 Solar Control
4.8 Night Insulation
5.1 Economics & Non-Economics
5.2 Cost Levels

Figure 33 Complete Table of Contents for the *Design for the Sun* Manual

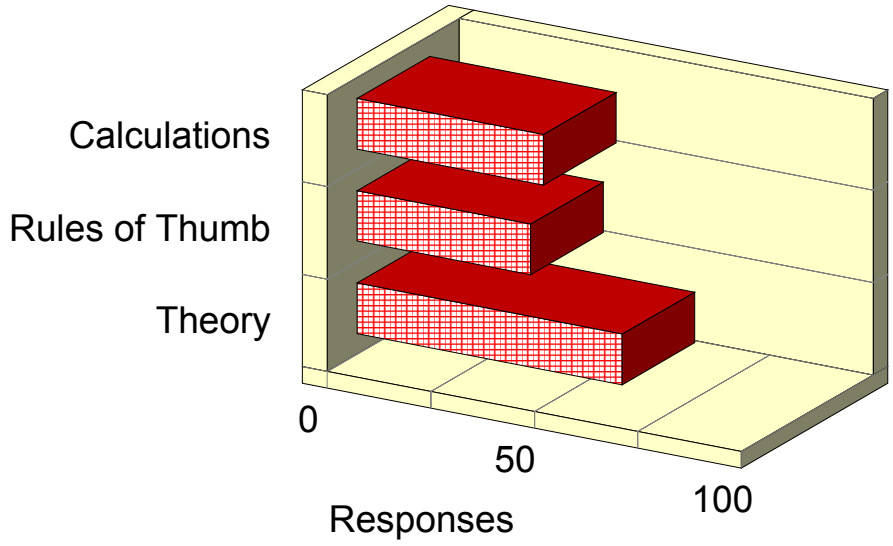

Figure 34 Designers' responses to question 2: "Sections used during workshops" ordered by category in the Manual.

than one section number here. The average number of sections referred to was 3.3. There were two who wrote down large numbers (10 and 11) of sections. There were also 8 who wrote nothing. Within this range, the significant numbers are the 27 people who noted use of Section 2.12 "Rules-of-Thumb" and 21 Section 3.1 "Performance Prediction". Thus 27 of the 42 (64%) count for the Rules of Thumb category and 21 of 45 (47%) for the Calculations category are represented by these two key sections of the manual.

These two sections are the most mathematical in the manual apart from the Economics section. The result illustrated in **Figure 34** and **Figure 35** suggests that the participants used the performance prediction parts of the manual in the design exercises set in the workshops. Whether or not they liked to, the designers used these performance prediction calculations and rules-of-thumb when required by the workshops to demonstrate that their designs could work. It is difficult to say that the seminar participants freely chose to use the calculation-oriented sections of the design manual. However, it is possible to conclude that, when required by the workshop format to prove that their design would work, they reverted to the calculations.

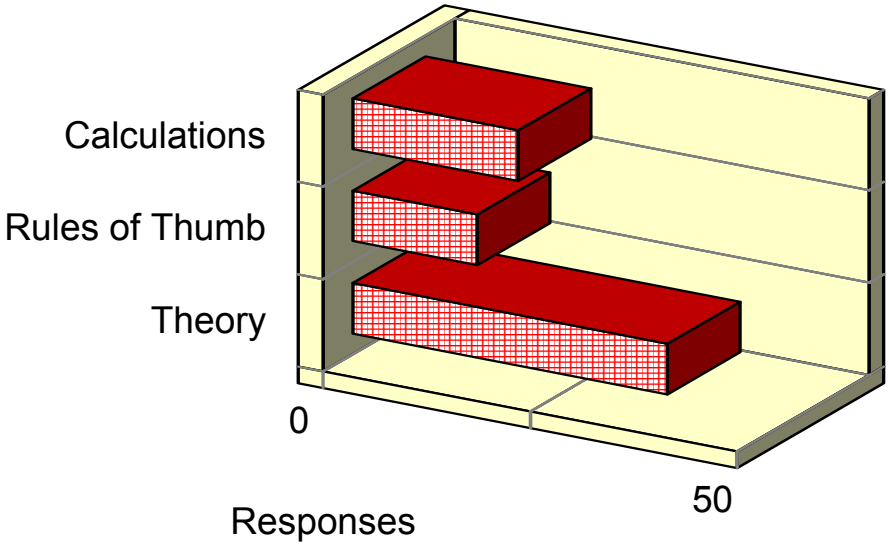

Figure 35 Non-designers' responses to Question 2: "Sections used during Workshops" ordered category in the Manual

For comparative purposes, **Figure 35** shows the responses from the non-designer participants in the seminars. It is clear comparing **Figure 34** with **Figure 35** that the non-designers placed far less emphasis on the use of calculations.

questions 3 and 5 - architects' and architectural designers' responses

3 What was your response to each of these sections of the design manual? Did you find it clear or difficult? Enter C or D (or '-' for those sections you have no response to) in the two columns below.

Section		When first read	After the seminars
1.1	Introduction / A Perspective		
1.2	Heat Flows		
1.3	....		

5 Which Performance Prediction Worksheets (Chapter 3.1) did you:

(A) Understand; (B) Use in the Workshops?

Worksheet 1
Worksheet 2
...

Figure 36 Solar House Seminar Questions 3&5 - Record responses to and use of sections of the design manual used during the workshop?

The responses to Question 3 were the biggest disappointment of the whole exercise. The question listed each section of the manual and sought responses on whether they were ***'C'lear*** or ***'D'ifficult*** in two categories: ***On first reading*** and ***After the seminar***. This question in particular clearly focussed on the overall goal of the thesis. It aimed at finding which of the forms of presentation that

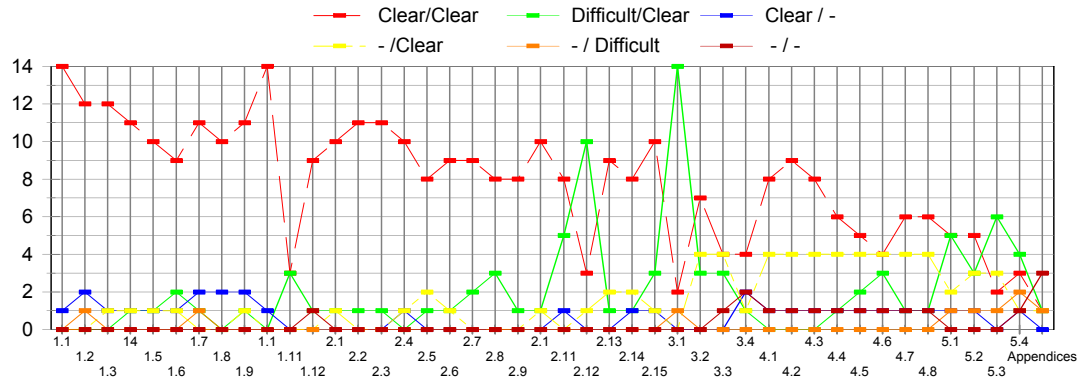

Figure 37 Responses to Question 3 on Whether the numbered Sections of the Manual listed on the X axis were 'C'lear or 'D'ifficult on first read/After seminar

are used in this large text-based eddst are preferred. The responses either were not answered clearly or were completely filled with 'C's. Question 5 about which Performance Prediction Worksheets were 'understood' or 'used in workshop' was mostly answered in the affirmative to both options.

Only Question 3 has been quantitatively analysed. Except for one or two obvious dips in the graph, **Figure 37** shows the evenness of the responses from those who did bother to fill in the page and a half page long list of individual sections of the manual. The count of responses in **Figure 37** is divided into categories of Clear/Clear or Difficult/Clear and so on. Clear/Clear (Clear on first read/Clear after the seminar) was the most common response by far. The drift of this response from early to later parts of the manual seems to indicate from the comments on the forms (e.g. *Have not fully studied these sections*) that the respondents have not read all the way through it. Higher numbered sections are later in the manual.

The only other two categories with a significant number of responses are the ***Difficult/Clear*** and ***no-***

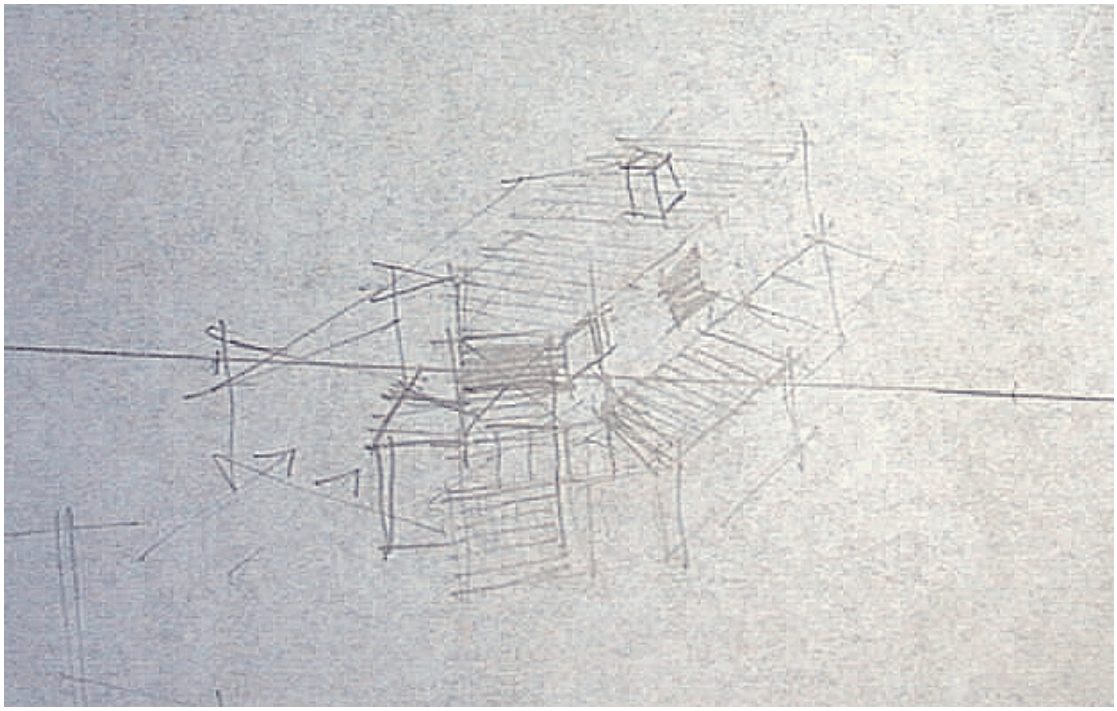

Figure 38 Solar house development sketch from Group C in Auckland Workshop

response/Difficult categories. ***The no-response/Difficult replies*** are just four people who have found the detail of Sections 4 and 5 Difficult.

Of far more interest is the contrast between the ***Clear/Clear*** and ***Difficult/Clear*** traces in **Figure 37**. When the ***Clear on first read/ Clear after seminar*** trace reaches Section 1.11 "Heat Loss Calculations"; Section 2.12 "Rules-of-Thumb"; and Section 3.1 "Performance Prediction" the assessment dips. These are the principal arithmetical sections of the manual. For two of these, Sections 2.12 and 3.1, the ***Difficult on first read/ Clear after seminar*** trace takes a corresponding leap. A clear statement that the workshops have helped people understand and deal with these sections. The simple arithmetic of the R-value calculation in Section 1.11 was apparently not well explained in the seminars; both traces stay at a low count at this point.

question 4 - architects' and architectural designers' responses

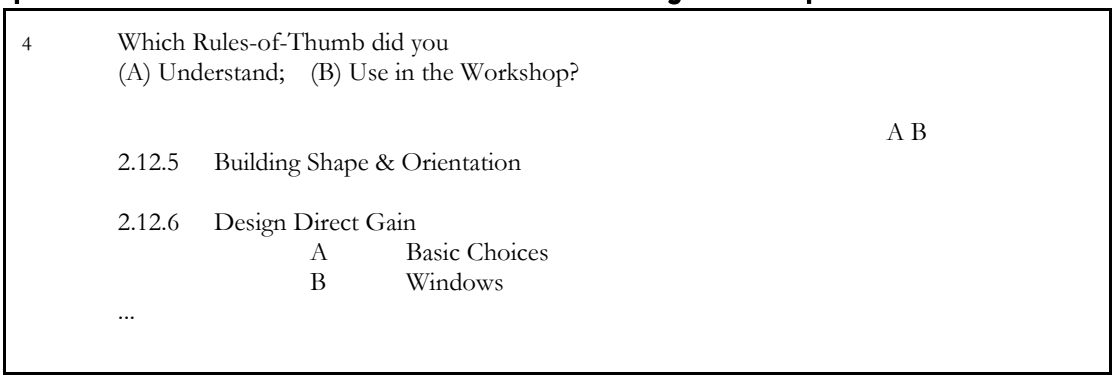

Figure 39 Solar House Seminar Question 4 - Record the use and understanding of the Rules of Thumb during the workshop?

This question sought to ascertain seminar participants' 'understanding' and 'use in the workshops' of the rules-of-thumb in Section 2.12. The responses were mostly in the affirmative, though seldom for more than half of the rules. In many cases, no answer at all was entered for this question. **Figure 40** shows the response count in three categories: Responses where the respondent just noted that the Rule was 'Understood'; Responses where the response was that the Rule was 'Used in the Workshops'; and Responses where the Rule was BOTH 'Understood' and 'Used in the Workshops'.

There were practically no responses in the category of just 'Used in the Workshops'. The other two categories naturally trace a complementary pattern. When one dips in number of responses, the other rises, because people ticked either one or both entries.

What we can see from these responses is that:

- the Rules-of-Thumb were generally understood (adding together Understood only and Understood and Used in Workshop traces);
- Direct Gain and Sunspace designs were far more used than Thermal wall designs in the Workshops.

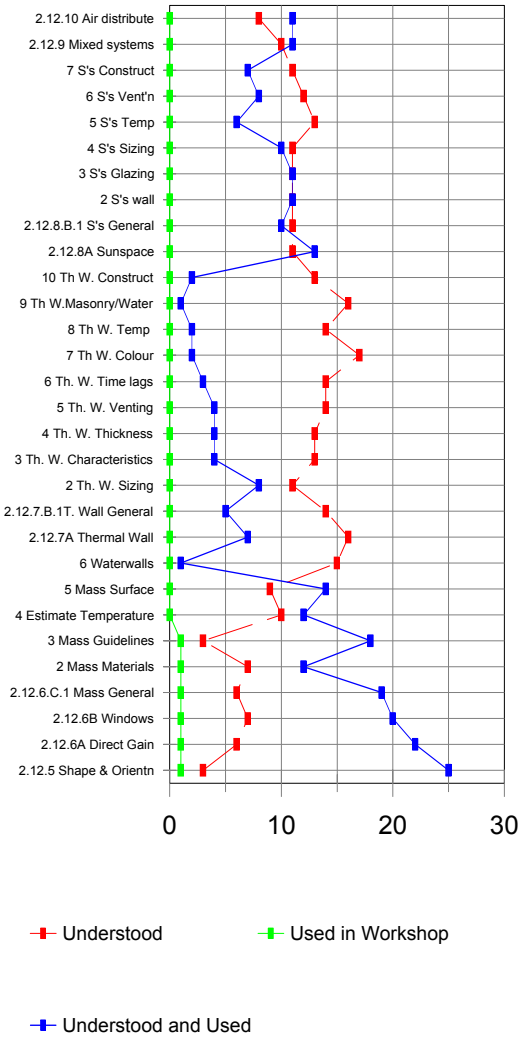

Figure 40 Question 4: Use and Understanding of Rules of Thumb

question 6 - architects' and designers' responses

6	Was the format of this workshop successful? Could it be improved? How?

Figure 41 Solar House Seminar Question 6 - Was the workshop successful? Could it be improved?

This question asked ***Was the format of this workshop successful? Could it be improved? How?***. Of the 36 respondents 21 said it was successful and 5 said it was not. However, 34 of these people indicated that the workshop could be improved - only 2 thought that it could not be improved. The suggested improvements can be grouped into four categories:

- There was too much material to be covered in just a two day full-time seminar. *Perhaps too crammed for information for one seminar. ..In my case four days would have been better ...Perhaps three days would be better...*
- More time should have been allotted to the workshops. *...the workshops were so rushed that I*

was a little frustrated... Format of lecture / workshop only reasonable method, but more time to resolve prediction worksheets would help

- The workshops themselves need reorganisation. *Group of six too many to work on problem ... would have saved a lot of unnecessary hassle if say a standard floor plan on a flat site had been given out for groups to work on ...The purpose of the seminar being to come to terms with the solar problems rather than aesthetics.*
- Miscellaneous: *tough site was excellent - problems could be met head on...perhaps actual costings of an existing house...specific life-like examples would be helpful..*

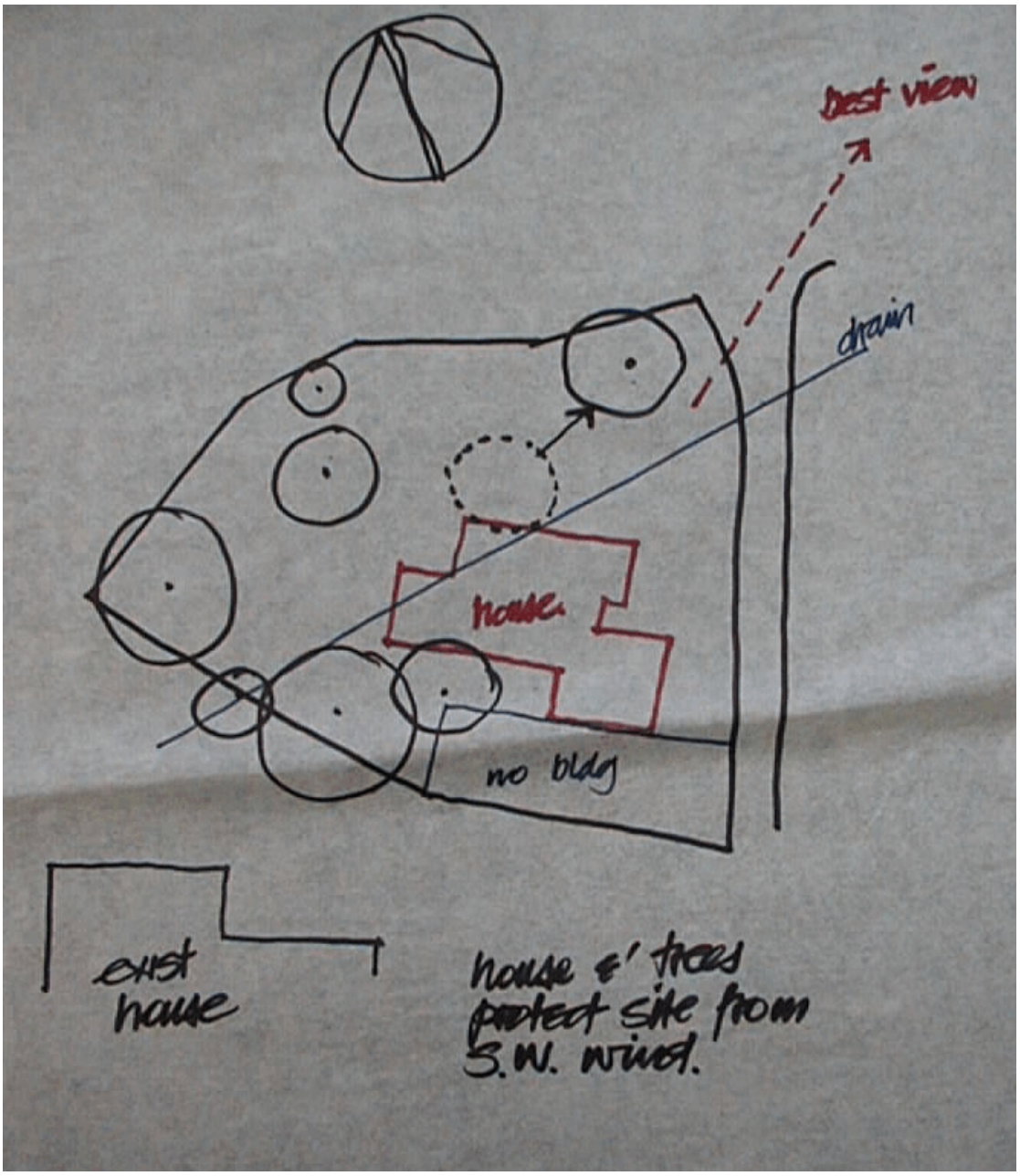

Figure 42 Summary of design exercise site conditions from Group B Auckland, illustrating "difficult" site contributing to some participants' frustration

question 7 - architects' and designers' responses

7 Is the Design Manual useful?

- What other information would you like to see included?
- What information do you think could be removed?

Figure 43 Solar House Seminar Question 7 - Was the Design Manual useful?

This question was also in three parts: Is the Design Manual Useful? What other information would you like to see included? And: What information do you think could be removed?

28 people thought the manual useful, and only 4 thought it was not.

The responses to what should be in the manual varied so much they were very difficult to summarise. After a couple of readings of all the responses, I tried dividing them into four categories:

- those who thought the manual would be improved by dividing it into a design workbook and a reference manual; *Condensation of main working material - e.g. 2.11, 2.12 in supplementary form...*
- those who thought insertion of indexes and cross-references would make it very much easier to use the manual and its worksheets; "*would appreciate more cross references to sections and figures which apply as one works through the worksheets...*"
- those who thought that insertion of example buildings would increase general understanding; "*more worked examples... Illustrations of successful houses and performance calculations...*"
- and miscellaneous comments. "*Specifics for other locations? A clearer definition of degree days... Still to read total therefore don't appreciate any (if any) shortcomings...*"

The responses were not divided into any clear pattern by this categorisation: there were 2 responses advocating a summary workbook; 5 advocating indices; 4 seeking examples; and 12 that fitted the Miscellaneous category.

A similar pattern emerges from examination of the pattern of responses to the question of whether there is anything that could be removed except that an overwhelmingly large number of respondents (16) replied that nothing should be removed. For half of these, responses like *none* and *All useful* were supplied; the other half just indicated with a simple dash. Those who left the response field blank have not been counted.

question 8 - architects' and designers' responses

8	Do you feel that you can now undertake the tasks outlined in the seminar's objectives?

Figure 44 Solar House Seminar Question 8 - Can you now undertake the tasks outlined in the seminar objectives?

The response was 32:1 in the affirmative to the question of whether the participants felt that they could "now undertake the tasks outlined in the seminar's objectives (see **Figure 1**)". The only common thread in the comments on this reply was that many people felt cautious about the degree of understanding they had. Twelve expressed the opinion that they needed practice before they would be fully confident of their abilities: "*acid test yet to come ... It still requires more study and practical exercise... Perhaps after doing calcs on further buildings ... Would like to work through an example on the boards ... Given practice. The general attitudes conveyed in the seminar affect our work daily - very worthwhile...*"

5-3 *survey conclusions*

The general behaviour of the participants in the passive solar seminars was to try the "simulation" formulae provided in the Design for the Sun manual[4] almost at random in order to try to sort out what worked. They did not behave as if they had any idea, even after the lectures, as to which building feature would have the greatest effect. What was the most disappointing aspect of this as a tutor was that there was little connection made between the "Rules of thumb" and the calculations. This is apparently a weakness of the rule of thumb approach. Rules of thumb typically specify what the size of a building feature (window, wall thickness, amount of thermal storage) "should" be. They do not normally specify why this size is recommended. The type of performance that should be expected if these features match the recommended sizes is implicit, not explicit. As a result, the cost of deviation from the "rule" cannot be intuited. They are hard to use in an intuitive, 'what-if' design situation.

In the concluding sessions of each seminar, participants were required to present their building in a standard format specifying the performance and certain critical parameters defined by the tutors. These concluding sessions became quite crucial because there the participants and the tutors compared the performance of all the group's houses. It was only in these comparisons of different design approaches to essentially the same design scenario that it became clear which were the important and which the unimportant features of the buildings from the point of view of energy performance.

At the same time as the Design to the Sun Seminars were being presented, I was completing a solar house research project in association with the International Energy Agency.[5] My immediate reaction

to this evaluation of the Design to the Sun manual was to complete development of the associated New Zealand Design Guidelines document in a way that presented the impact on building energy performance of choices of different building design features. **Figure 45** shows an example of how this information was presented.

However, there is still a major problem with this type of presentation. The problem is that each such diagram stands alone. There will be other similar diagrams showing the impact of glazing type (double, triple, single plus curtains etc.) or of orientation (North, East, West etc.). While a little more sophisticated than the rule of thumb, they are still very hard to combine. They are therefore very difficult to apply in general. What they show are the likely impacts of design decisions on building performance only for the building type studied, and only with the building operated in the standard manner assumed by the research team. It is hard to see diagrams like these as other than a

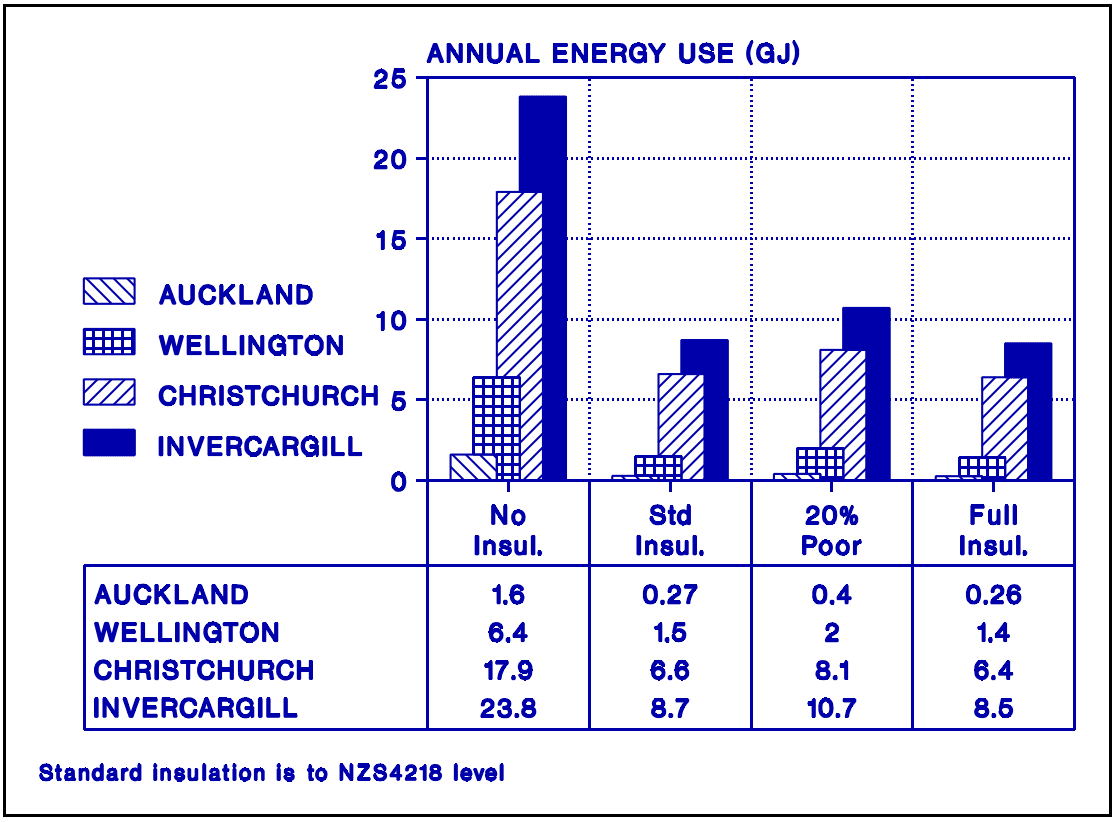

Figure 45 The effect of insulation on annual energy use in the standard solar building

systematised overview of the performance of one building. The benefit for the individual designer is to understand what was important in this building and to deduce from this what factors to be careful with in their own building.

5-3.1 analysis of advantages and disadvantages of text-based eddst

The *à priori* analysis of environmental design decision support tools in chapter 3 suggested the following advantages and disadvantages of text based design guides like the passive solar design manual used as the basis of the seminars studied in this survey:

Advantages

- The rule of thumb approach makes for efficient design.
- Standardised checklists and rules of thumb are easy to remember
- A checklist or rule based system permits ready evaluation of the suitability of a design.
- The explanations of the "rules" or "patterns" assist the user to make intelligent deductions about non-standard situations.

Disadvantages

- patterns in Design Guides "" present a simplified view of the world ""
- The problem with standardised solutions is "*no judgement can be made about the soundness or validity of these offerings*" [6]
- No matter how well-constructed, a checklist is normally too restrictive..
- The explanations can often interfere with the accessibility of the design information.
- The biggest single factor weighing against checklists and design guides is the complexity of the subject they are trying to simplify.
- With design guides more than with any other design tool, the designer has to share the model of design offered by the authors.

As a prelude to the summative analysis of all the cases in the first chapter of the final section of this thesis, the following paragraphs summarise the results of this survey within the context of this eddst classification.

Advantages

Quick efficient design: the designer participants apparently found the checklist and manual calculation approach very easy to work with. They were able quickly to complete reasonable house designs during the workshop even in spite of the 'design-by-committee' problems arising from working in groups and in spite of the workshop design scenario site complexity leading to increased time pressures.

Standardised checklists easy to remember: the designers commented about the difficulty of the manual calculation process. They wanted more time to practise this technique in the seminars, not more explanation of the steps in the checklist.

Checklists permit ready evaluation: everyone felt the process was easy to understand and apply. They saw the most problem in getting the opportunity to practise the skills on real buildings.

Explanations help understanding of the design principles: the designers' enthusiasm for mastering the calculations shows a desire to go beyond the basic instructions of the rules of thumb to try to understand their basis.

Disadvantages

Simplified view of design interactions: the presentation of design performance in charts related to window size or insulation level hid the complexity of the workshop designs.

Standardised checklists disguise impacts of design decisions: the popularity of the manual calculation "simulations" provided by the design workshops seemed to be a result of the lack of the seminar participants' understanding from the Rules of Thumb of which were the important solar design parameters.

Checklists normally limit the range of design options: the disparity between the user's understanding of the design rules of thumb and their actual use of them in the design workshops is ample evidence that they found this approach limiting when they had to apply them in a 'real' design situation.

Detailed explanations can make checklists confusing: there is a clear desire on the part of the workshop participants to have the material in the manual 'simplified'. They want to see the detailed explanations removed to clarify the design workbook. The more operationally efficient these checklists and Rules of Thumb become, the less explanatory material they can contain and the more likely will be the problems of understanding of principles demonstrated in these seminars.

Design guides require the designer to share the world view of the design tool developer: this concept was not evaluated in this research.

Overall, the disadvantages of the rule of thumb and design checklist were emphasised by this survey. A team of people produced the information, and presented it and the theory in the handbook and in the lectures as well as providing guidance on the use of the simple performance calculation (simulation) tool. Despite this, the workshop participants had very little idea at the end of the seminars of what were the important design parameters. Nor did they appear to know how to use the "simulation" tool to determine which of these parameters was most important in a specific design.

Having looked at 47 people's responses to a text-based thermal eddst in this case, the next case examines the responses of two architects to the computer simulation thermal environment design decision support provided on two buildings.

5

Notes & References

1. Butti, Ken and John Perlin. **A Golden Thread - 2500 years of solar architecture and technology**. Van Nostrand Reinhold, New York, 1980

2. Breuer, David, Peter Sterios and Joel Swisher **Design for the Sun - residential design guidelines for New Zealand** Ministry of Energy, 1985

3. Breuer et al 1985, Op. Cit.

4. Breuer et al 1985, Op. Cit.

5. Holtz, Michael **Design Guidelines - an international summary**. IEA Solar Heating and Cooling Programme Task VIII publication, July 1990. US DoE: Technical Inquiry Service, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado 80401.

6. Eclipse Consultants. **Survey and review of existing handbooks** for IEA Passive Solar Handbook (UK version) - IEA Solar Heating and Cooling Programme, Task VIII, Subtask C internal document, March 1985.

6

digital (thermal & lighting) simulation

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

KNOWLEDGE IS OF TWO KINDS; WE KNOW A SUBJECT OURSELVES, OR WE KNOW WHERE WE CAN FIND INFORMATION UPON IT. --
S. JOHNSON, LETTER TO LORD CHESTERFIELD, FEBRUARY, 1755.

This is the second in a series of five detailed studies of the application in architectural design of environmental design decision support tools (eddst's). The five studies are:

1. a **text based design guide** containing **graphical design aids**
. . . . . Solar House Design Guide - **survey**.
2. **computer simulation** of **lighting** and **thermal** performance.
. . . . . CBPR client reaction - **individual case study**.
3. **computer (thermal) simulation** packages. USA and NZ interviews - **survey**.
4. **physical model studies** of pedestrian **wind** environments.
. . . . . interviews with architects in Wellington City - **survey**.
5. **physical model studies** of art gallery **daylighting**
. . . . . architect & lighting designer interviews SFMoMA- **individual case study**.

This case study is one of the two in this thesis that reports reactions to the use of an eddst gleaned from interviews with individual practitioners about their involvement in specific projects. It analyses the use of an eddst that applies ***digital models*** to the ***simulation*** of the building environmental performance. Specifically, computer models of the building are subjected to various climate influences in order to determine the likely impact of a proposed building design on the internal thermal and lighting environment.

6-1 *background and chapter structure*

This chapter analyses thermal and daylighting performance simulations undertaken by the Centre for Building Performance Research (CBPR) under my direction during the design phases of two buildings. The buildings are the Schools of Architecture and Design (UNIPOL[k]) in Vivian Street Wellington, and a regional police station in a town in the central North Island. The descriptions concentrate on reporting the design ideas which were explored in the early stages of the design process. Some of these ideas were included in the buildings' designs. The chapter examines the designers' responses to these eddst digital performance simulations through interviews with the designers of both buildings and the analysts who ran the simulations of the police station.

In each building the performance simulations were conducted in two distinct phases: Energy and Comfort investigations, using the computer simulation program Suncode[1]; and the Atrium

[xi] The project name was "Unipol" due to the University and Polytechnic collaboration in the construction of the building: this shorthand title is used in this Case Study.

Daylighting investigations, using the simulation program Radiance[2]. The chapter is divided into five major sections; the first two sections describe the results of the actual performance simulations for each building in turn; the third section describes the Police Station design analysts' views of the strengths and weaknesses of their involvement in the design process; the fourth section describes the architects' evaluation of the value of performance simulation in the design process; and the fifth and concluding section examines the lessons learned.

The design analysts' evaluation was initiated after the Police Station performance simulation was stopped abruptly. It had been recognised that further analysis was unlikely to effect any changes in the design. The comments are likely to be coloured by this hindsight. A verbatim report of these comments is contained in Appendix F.

In architects' evaluation, a graduate student interviewed the architects with two principal aims: to investigate their understanding of and preferences in presentation of eddst information based on CBPR performance simulation. A summary of the principal points reported independently by the student in her research report can be found in Appendix G.

6-2 *results of actual performance simulations*

In order to present the CBPR analysts' and the CBPR clients' views in context, the following two sections of this chapter describe the results of the Unipol and police station design analyses as they were presented to the clients.

6-2.1 ´unipol´ building energy and daylight analyses

This project saw the conversion of a warehouse in Central Wellington into offices, studios, workshops and lecture spaces for a School of Architecture and a School of Design. The CBPR design analyses were provided as environmental design decision support during the initial design phases. They relied principally on rapid development of digital building models - ebuildings - in SUNCODE and RADIANCE.

summary of the design recommendations

It was anticipated at the start of this work, that the preliminary investigations using Suncode would assist the design team to identify the "ballpark" size of the energy and thermal comfort performance of their design ideas. Simulations were conducted of the heat gains and losses hour by hour over a typical year, accounting for the storage of solar radiation in the construction, assuming fixed ventilation rates and evaluating the effects of window size, shading and glazing type on comfort in prototypical rooms. These results were supplemented by hand calculations of the likely daylighting conditions in these prototypical rooms on cloudy days.

It was originally proposed that the Suncode investigation would be followed by more detailed simulations of wind and thermal current driven natural ventilation, of solar heating and of the interaction between heating, ventilating and air conditioning equipment and the internal load management strategies. This was to use a computer model of the whole building. The opportunity to analyse alternative equipment strategies that the design team might wish to explore at this detailed level did not arise.

A spreadsheet for hand calculations of cloudy sky daylighting was developed to speed up the process of preliminary design daylight analysis. Examining the daylight role of the atrium under cloudy and sunny sky conditions in Radiance was left to a later analysis phase. That a spreadsheet calculation had to be developed to answer questions with the speed required by the design team was an important lesson learned from this analysis.

The final design has adopted only some of the measures identified by these analyses to have a performance advantage. The decisions were made by the design team weighing up the overall costs and benefits of these measures, rather than taking the narrow focus on energy and environmental performance that was the brief for the CBPR analyses.

unipol - energy and comfort investigations:

The first step in the *Suncode* energy performance simulation was to model the atrium and prototypical offices. The aim was to characterise for the design team the likely impact on the design of selections of types of glazing, shading device and ventilation strategies.[3]

The following principal parameters[4] were varied in the study: type of glass; configuration of roof glass; U-value of glass; area of north glass in atrium; ventilation rate. In each case a full year's calculation has been run, examining the total heat input through the windows and the resultant temperatures in the atrium and two adjacent spaces: a large studio, and a small office. The output of the simulation by the *Suncode* thermal simulation program yielded the maximum, minimum, mean, and range of temperatures in the spaces, plus the maximum energy loads (kW).

In order to place these issues in a broader context, daylight issues were investigated with simple hand calculations of the overall light level on all interior surfaces. These calculations were designed to assess the likely overall impact of changes to shading or the installation of a solar radiation absorbing glass. The precise exploration of the reflected daylight on work surfaces in the rooms was left to a later stage of the design process. The reason for performing these hand calculations using rough rule-of-thumb formulae was that the designers required information more quickly than could at the time be delivered by a RADIANCE analysis. The time problem with the RADIANCE analysis was in the model-making process. Creating a full three dimensional model of the whole building, and of the atrium required several weeks work, even with an experienced AutoCAD operator.

On overseas experience, naturally ventilating the spaces surrounding the atrium is clearly achievable. It was expected that use of the atrium in this way would require considerable computer modelling of the atrium airflow at the developed design stage. Some considerable time was invested in January 1993, at no cost to the project itself, preparing another three dimensional computer model of the building in which natural ventilation could be simulated using a newly acquired computer analysis program from the UK: ESP[5]. In the event, this model was not used because the necessary cooperation of the HVAC engineers was not available. They had "completed the design" of the HVAC system at this point. They declared that if CBPR "wished to do the design again" we were more than welcome.

The very obvious cost constraints under which the HVAC engineers laboured are clear in this action. With a very small fee, there was no incentive for them to do more than the bare minimum to deliver the simplest system that they thought would reliably deliver what the client asked for. There was obviously no room in their fee to consider design options.

The initial analysis reported to the architects that the more area there is in atrium roof glass, the higher the daylight levels in the atrium. It also noted the caveat that glass that is basically horizontal, lets in nearly twice as much daylight (but not sunlight) as vertical glass.[1]

unipol - detailed daylighting investigations:

This part of the study looked primarily at the impact of the proposed atrium on the daylighting of the new School of Architecture building on Vivian Street. It took many of the thermally based decisions on suitable maximum areas for glass in the atrium as given and worked on the daylighting and sunlighting potential of differing configurations of those areas.

The investigation was carried out in four stages

- comparing atrium roof design options
- testing atrium internal opening design options
- quantifying the effects of using light reflectors
- combined testing of the final configuration of the above options

The investigation involved the use of a 3 dimensional computer model of the building, constructed in AutoCAD and tested in RADIANCE Daylighting Simulation Software. The results produced were in the form of rendered images, which enable both qualitative and quantitative comparisons to be made between varying design options.

The early study of the thermal comfort and daylighting options in a building of this scale in this location provided some indications of likely light levels in the atrium given four initial atrium roof design options. These figures were provided as general estimates obtained from hand calculations

[1] In all cases, the light levels are calculated for clear glazing. If the evergreen glass is used, then the lighting levels will be 60% of those indicated.

based on glazed areas. Figures for the daylight potential in various external offices with different sunshade selections were also reported at that time.

Eventually models of each of the options were tested in RADIANCE to yield more accurate results for specific areas, under specific sky conditions. There were two reasons for this analysis. First, with Radiance, the effects of daylighting on sunny days could be investigated, something that could not be done with hand calculations; second, the interreflection model in Radiance allowed reflected light from light shelves and other shading devices to be estimated accurately.

This phase of the project stopped at the point where a model had been created to permit examination of the artificial lighting, and its combination with natural lighting. It had been intended that this model would be used to find a balance between natural and artificial light. Again, the speed of the project and lack of a budget from the client for the engineers to fully investigate these options, mitigated against this type of analysis.

Testing was carried out over varying sky conditions throughout a 1 year period, namely sunny and overcast sky, each at 10:00 am, 12:00 pm and 2:00 pm, in both summer (December) and winter (July), ie. 12 different conditions for each of the 4 design options. Given that each 'condition' took from 12-24 hours to "run" as a simulation, this test took a significant amount of time. Even the process of creating a roof glazing option in AutoCAD and translating it across to RADIANCE took more than half a day.

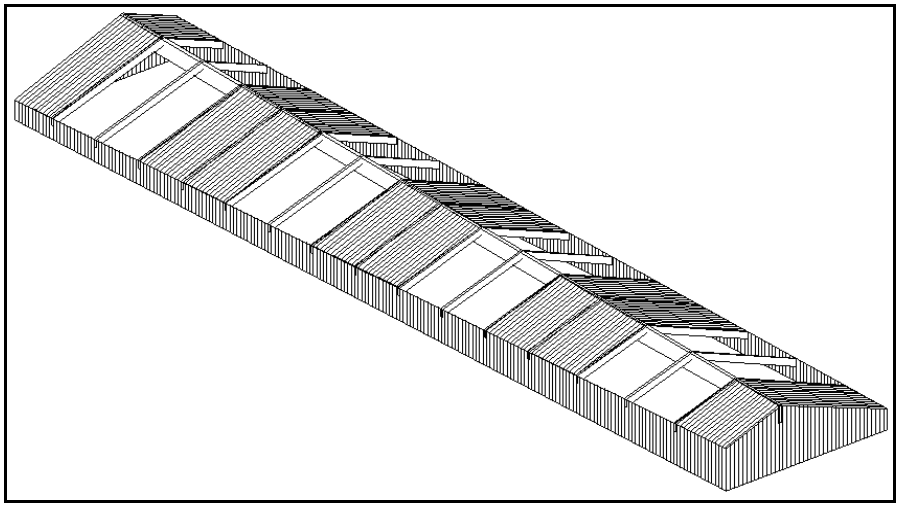

Figure 46 Diagram showing the skewed roof glazing on the Schools of Architecture and Design atrium

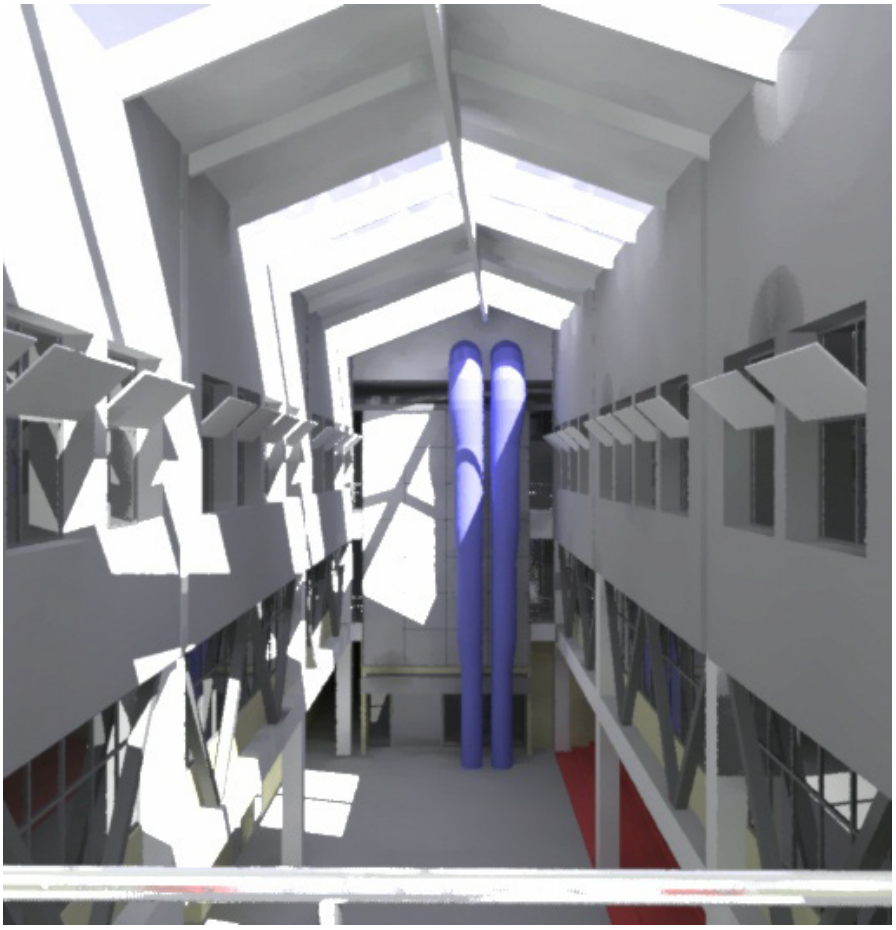

Figure 47 RADIANCE rendering of Schools or Architecture and Design atrium looking from bridge towards rear

Qualitative results were provided in the form of rendered images illustrating the relative daylighting quality in each of the spaces over the varying sky conditions. Quantitative results were also provided allowing direct numerical comparisons between the different design options for daylighting levels within the atrium space.

Annotated coloured printouts of the output from this stage of the investigation were presented to the design team to enable them to draw their own conclusions as to which of the four design options was more suitable.

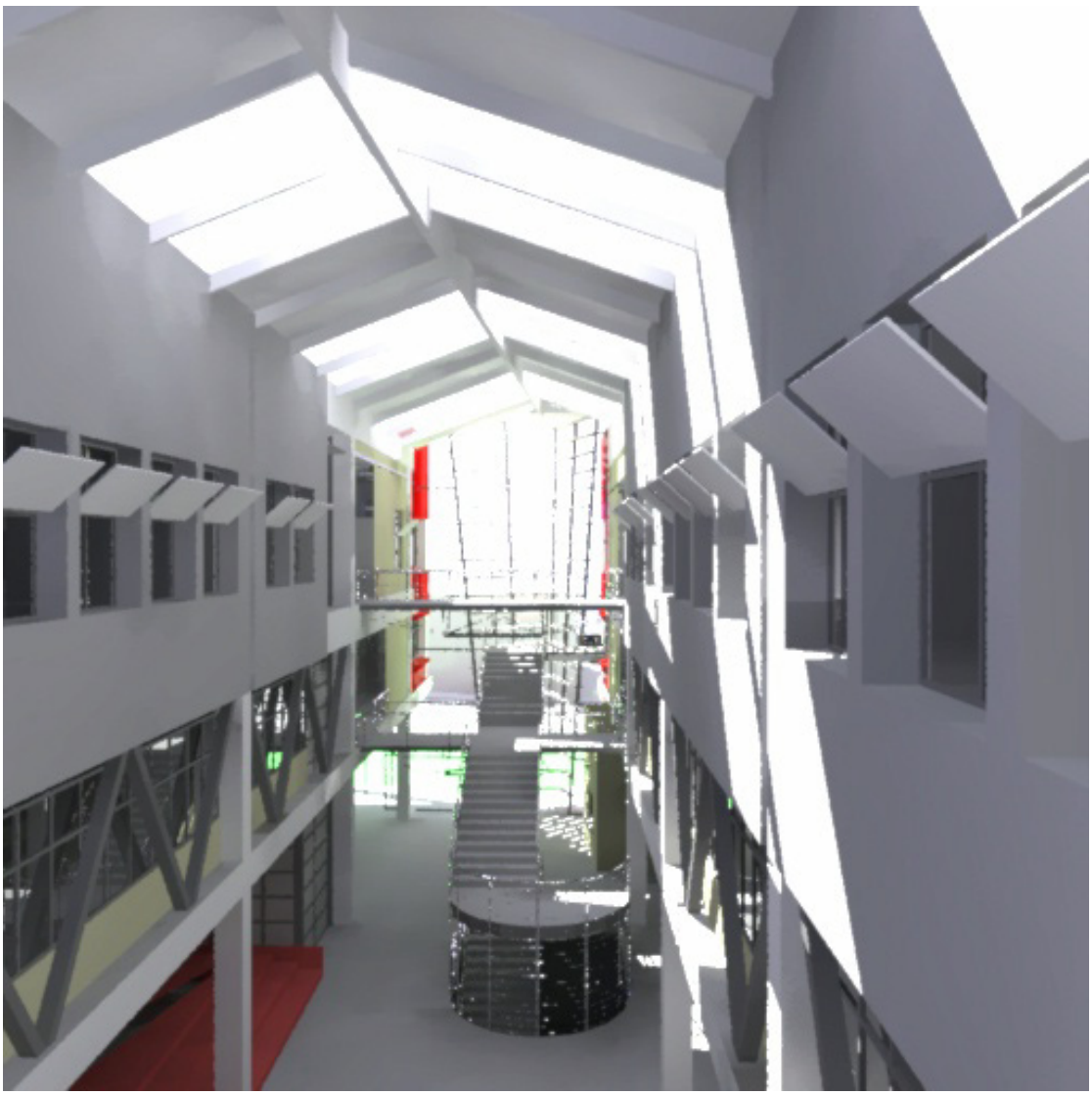

Figure 48 RADIANCE render of atrium in Schools of Architecture and Design; looking from rear to front

Acting on choices from the design team, the roof design was fixed and the investigation concentrated on the light levels within the office and studio spaces adjoining the atrium on level 2 and how these were affected by careful window and reflector design.

Six models were constructed and tested each trying a different size opening or varying angle of reflector ranging from 34° through to 55° to the horizontal.

Quantitative results from the testing indicated that light levels inside the office and studio increased the most when the light reflectors were used at an angle of 42° from the horizontal and placed at a height of 2 metres from the floor.

Finally, a "stage III" model was updated to include atrium design changes. The model now incorporated:

- structural bracing on the atrium interior

- accurately modelled interior wall panels inside the atrium space
- light shelf reflectors on levels 2 and 3, angled at 42° to horizontal
- louvred glass wall across the north facing side of the atrium
- atrium roof modelled as 'skewed' single north-south gable with glazing on the top face only (see diagram in **Figure 46**).

A detailed investigation into the benefits of the light reflectors on level 2 was undertaken by testing the updated model against a second model that included the same changes minus the light reflectors. Testing was again carried out over a 1 year period, using varying sky conditions, looking specifically at the office and studio spaces on level 2.

Figure 48 and **Figure 47** show the type of simulation pictures produced by RADIANCE simulation for these design analyses.

6-2.2 regional police station design analyses

This building analysis was undertaken as an experiment in digital simulation environmental design decision support (edds). A summary report was prepared to accompany the design drawings for a new regional Police Station project as a means of providing edds for the architect. It documented CBPR analysis of the thermal and lighting performance of the design proposal. The following paragraphs summarise the design recommendations.

summary of the design recommendations

Based on previous experience in this type of design, and on numerous surveys of buildings in operation, it was assumed that natural ventilation of as many of the interior spaces as possible was desirable from the users' perspective. Therefore the design analysis sought to demonstrate the applicability of passive solar technologies like daylighting and natural ventilation to the sketch design plans supplied by the architect.

The simulation analysis showed that the atrium space conditions are acceptable without specific heating or cooling so long as adequate natural ventilation is designed for. The atrium will get colder and hotter than the offices around it but not unacceptably so if it is used merely as a transition zone between rooms. To achieve the required natural ventilation would have required significant alteration of the building design.

The area of greatest potential for improvement in the sketch design from the point of view of daylight and natural ventilation was in the planning of the spaces around the atrium. Of the spaces adjoining the atrium the analysis indicated that very few needed daylight or direct outside air ventilation which was seen as one of the potential benefits of access to the outside through an atrium.

As a wholly internal space, the conference room on the first floor could not be used without artificial light. It was suggested that it would be far more pleasant and welcoming with inclusion of at least a skylight. There being a skylight already lighting the adjacent little-used kitchen, it was suggested that

it could be moved to light this space. The design report also used this room to illustrate the benefit of connection to the atrium through windows for daylight and natural ventilation.

In order to illustrate properly how well a particular feature of the design is performing, or to fully describe the alternative design options open at this point, a number of design ideas were analysed which were variations on the basic design. These ideas were offered as a commentary on what would be required to make the sketch design building into a low energy passive design. No more than cursory attention was paid to the significant design work already invested by the architect in maintaining associations between certain types of room and ensuring police security concerns were met. Rather, the ideas were put forward to illustrate the principles which could be exploited in using natural energies in the design and operation of a building.

Over 100 different views of the internal spaces were generated in colour by the Radiance ray-tracing package. Typically they showed the same spaces at 3 different times of the day in summer and in winter on a sunny day plus one view for midday in summer and winter for a cloudy or fully overcast day.

Two sets of runs were done. One produced histograms of the internal temperatures in 16 separate internal zones in the building with the building temperatures allowed to "float" without heating or cooling, but with natural ventilation. This was intended to highlight the intrinsic performance of the building itself. The other set of runs examined the energy consequences of setting heaters on if the internal temperatures dropped below 20 deg C and cooling on if the temperatures got above 27 deg C. Twelve design variations were evaluated. The SUNCODE computer thermal simulation produces 30-50 pages per run.

With better design of the windows and skylights so that they brought light into the interior as well as to the perimeter, and with most of the building being used only during the hours of daylight, reductions in energy use of 50-80% were identified as achievable in this building. This would amount to over $18,000 per year savings. These savings would obviously be lower if the energy use for lighting were lower due to the installation of high efficiency lighting systems.

We recommended that distributed heating appliances under adequate time clock and thermostat control but only in the locations likely to need heating, were likely to be the most energy efficient option. This question needed more work in the detailed design phase of this project, as the issue of comfort had not been investigated. For example, double glazing may well be justifiable on other grounds than energy savings. Also, all the energy savings were calculated on the basis of internal design temperatures of 20 °C. More realistic preference temperatures of 21-23 °C would provide much higher energy cost figures. Finally, the trade offs between size of window to maximise daylighting and the comfort of people sitting near the cold glass in winter were not evaluated.

6-3 *design analyst's and clients' evaluations*

The next two sections of this chapter summarise the evaluations of the CBPR design analysts and of the clients for the two buildings described above.

6-3.1 design analysts' comments on the police station design analysis process

As input to this thesis' evaluation of digital eddst's, the design analysts involved in the police station were requested to provide a personal evaluation of the process they had been involved in. Their comments were all written as suggestions as to what could be improved about the process. Given that they were requested to complete these evaluations immediately after the project had been cancelled prematurely by the project leader - me - this is understandable. It was viewed as a failure on our part to achieve all we had set out to. The evaluations can best be comprehended if we group them under three headings:

1.	Improved communication.	10 responses
2.	Accountability of the design team members.	9 responses
3.	Time constraints.	4 responses

Under ***improved communication***, Analyst 1, wanted *a clear brief made known to ourselves, the architect and the client.* Analyst 2 suggested *Regular meetings* and said *Simply, the design process was not two way. Nor was it interactive*. And Analyst 3 summed up with the comment *Regular meetings with all concerned may have helped as well as regular communication with those we were directly working with / against - ...*

Under ***accountability of the design team members*** the pithy statement *... role of CBPR not viewed as important in the process of completing the building at cost, and on time - minimal emphasis on quality...* sums up the analysts' reactions well. Another noted *the architect did not appear to be very interested in cooperating with us. His lack of interest seemed to directly influence everyone else...*

The four comments on ***time constraints*** were less critical of the other members of the design team: *Tightness of time schedule. Perhaps it was an impossible task....*

6-3.2 evaluation of CBPR design assistance by architect-clients

The architects of the two buildings described above were interviewed by Judith Becker for a research report[6] she completed under my supervision. My precis of her reporting of these interviews is contained in Appendix G. Judith's interest was in the acceptability or otherwise of low energy passive solar concepts in commercial building design. She termed this design "thick friendly walls" in her interviews. The principal issues relevant to the use of design tools raised by the architects were raised in the context of Judiths' questions assessing the utility of the CBPR's computer analyses of the buildings. These issues are discussed below under the headings of Time, Fees and Risk. But, first I summarise the architects' views, as expressed to Judith, on the impact of Climate and Cost on New Zealand commercial buildings.

climate and cost

One architect commented: *New Zealand is unusual because it has very little variations between seasons, so the environmental control problems don't arise to the same degree as in other countries.*

Our climate lets the developer get away with a lot, because of the benign climate. In other countries, these buildings would be uninhabitable. ... Since the 1972 oil crisis, energy hasn't been a problem ... overseas these energy issues have always been there, because of the extremes in climate.

The architects disagreed on the designs that would work in this benign climate. One said: *Glazing has had huge technological breakthroughs, so you can minimise the old* [environmental control] *problems by just using a sheet of glass.* While the other thought: *Architects ask too much of the glass and too much of the air conditioning* systems.

In most commercial developments, the occupant is not important, it is dollar driven. There seemed a general cynicism about the acceptability of any innovation in building design. One architect suggested a tax rebate as a solution: *Setting an energy consumption level for a certain size building and giving a rebate if the building comes in under that level.*

The example of a project budget being split up into discrete smaller budgets for one of the example buildings above was also offered as a barrier to acceptance of innovation. The quantity of glazing in the building was partially determined by the size of the glazing budget. The area of glazing could not have been increased by cost savings made elsewhere in the building.

Both architects identified economic changes in New Zealand as producing reductions in architects' fees to the point where architects can't afford the time required to experiment with low energy solar design.

One architect said that the number of jobs for which he is having to tender is increasing, and this is pushing fees down. [We] *had limited funds, therefore we had to produce a design quickly to come within the fees we were being paid. [Because of the] minimum fee we weren't interested in pursuing alternatives unless we were paid for it.*

time

Judith writes: "The computer modelling done by CBPR was considered useful, but the information was not available immediately enough, to keep pace with the required design speed. The architects indicated that the extra time required to fully consider the options put forward by the CBPR would have put them behind schedule and they couldn't afford to do that because the short design time was necessary to ensure the architects didn't lose money on the job."

Both architects apparently found the computer based testing of design options could be useful to architects, but thought that the CBPR service was not fulfilling their requirements. Essentially, the speed with which results could be produced was too slow for the tight building schedules they had to operate under. They felt information arrived too late to impact on the design.

fees

Again quoting Judith: "Low fees, resulting in limited design time, affected how advantageous both architects found the services of the Centre for Building Performance Research. ...Another problem with using CBPR to do computer modelling in the scenario of low architect's fees, was that there wasn't adequate money to pay for it. One architect felt that minimum fees are discouraging architects in New Zealand from experimenting with non-conventional ideas ..."

Quoting one of the architects: *Clients requirements dictate going in a certain direction.* The responses recorded in Judith's report note that both architects identify two basic types of client: the developer and the end user of the building. However, the rest of their recorded responses do not identify any behaviour that might be typical of one and not the other. We can infer that the developers are seen to be much less interested in the end users' comfort: [The developers*] know what they want and the cheapest way to get it.* Even when the client is the end user, the other architect expressed the opinion that the internal environment of the building is not something people worry about in New Zealand: *New Zealand people don't seem to care too much about their internal environments. Mostly now only Government employees get good internal environments .. because the user has more clout, but with the decline of the unions, this is less the case.*

risk

The architects are reported as saying that the computer modelling done by CBPR was useful, but the information was not available immediately enough to keep pace with the required design speed. One architect felt that although used overseas, "thick friendly walls" are still unusual in the New Zealand context and architects' unfamiliarity with them produces a situation of increased risk. *Architects already*

have one of the highest risk factors of all professionals in New Zealand and they would need to be paid a good fees before they were willing to experiment with ideas and technologies which were new to them.

Clients need to be shown. Often they only see as far as what they see elsewhere. Clients need to be taken beyond their experience. According to Judith " This architect thought that inexperienced clients don't fully appreciate how being aesthetically driven as well as cost driven can improve a building. " These clients apparently find it difficult to weigh up the risks and benefits of low energy design.

The final issue in terms of risk was apparently the notion that handing over the design to "scientists and researchers" who would perform this sophisticated computer based analysis ran the risk of *...buildings which look as though they have been designed around the environmental control issues. Thick walls are scientifically driven and science and aesthetics can be difficult to come together. You need to look at the macro and the micro - the overview. [How well this is done] depends on the skill of the architect to combine many different factors. At the end of the day you can't compromise the aesthetic quality or an engineer could have designed the building...* The other architect thought that *A good architect should be able to play within any system and make it look good..*

6-4 *analysis and conclusions*

The *à priori* analysis of design decision support tools in chapter 3 suggested the following advantages and disadvantages of computer simulation based environmental design decision support tools:

Advantages

- (As with physical models) Simple and direct relationship between the environmental factors and the performance of the building looks real.
- (As with a physical model) Clients find the model and the environmental effects very easy to understand.
- (As with physical models) The freedom to examine almost any design is much wider than with many other design tools.
- Although computer building models take a long time to construct the process of construction of the model is increasingly part of the routine of design using CAD[7].
- Once the computer model is constructed, modelling variations can be a simple process. Designers can be encouraged to try many variations.
- Post-processing data from performance calculations makes computer-based simulation potentially a far richer medium than any of the other design decision support tool.

Disadvantages

- (As with physical models) The biggest problem for designers using computer models to study environmental quality in buildings is that they have to have a completed design before they can conduct the test.
- The calibration of a model to reality is often very difficult.

The following paragraphs examine the CBPR analysis feedback in light of this analytical framework.

Advantages

Realistic feedback: the basis of the analyses in computer simulation not only produced realistic looking pictures, but gave the analysis an air of dependability.

Clients understand environmental effects: the CBPR reports were not to our knowledge delivered to the clients. They were largely seen as design advice for the designer.

Electronic models already exist: the simulation models took advantage of the existence of a 2D CAD model on which to build the 3D electronic models for the light visualisations. While in the eyes of the analysts this did not simplify the design analysis process, it did demonstrate the potential for re-use of electronic models created for other purposes.

Design variations easy with electronic models: the number of design variations studied was more a matter of interest expressed by the designer than any limit imposed by the modelling process. It was relatively easy to change the energy and the lighting models by changing only one or two parameters.

Performance data post-processing provides more data analysis potential: with the data already in electronic format, the presentation of the data in graphs and word processed reports was made very easy.

Disadvantages

Models time consuming to construct: the designers' complaints about timeliness of response were entirely due to the time taken to construct each model.

Designers must finish the design before a test can be constructed: the problems encountered with the studies of the natural ventilation potential of the atrium in the School of Architecture are clearly a result of the lack of availability of a simulation earlier in the design process when such an option might have been explored.

Calibration with reality can be difficult: this aspect was not evaluated during this particular case study.

Summarising the detailed information in this chapter leads to a specification of the characteristics sought by clients and designers in an ideal environmental performance design analysis service. Such a specification need not be just about the modes of CBPR use of computer based thermal and lighting design decision support tools studied. It may be that the service is merely a button on an architect's computer screen when they are drawing in CAD; it may be a service run by a specialist bureau; it may be an in-house environmental analysis service offered by a department of the architect's own firm. What is crucial is that the eddst service, however delivered, meets the following performance criteria:

timeliness: both the client and the analyst reported that design decision support was better if the performance analysis was able to keep pace with the design process itself. It seems that the decision support is likely to be more effective if it can answer designer's queries as soon as they are raised, rather than waiting for days for (computer or physical) models to be constructed. The problem is not that the designer cannot and does not at the moment wait. Rather, the problem is that the design continues to develop while the model is constructed so the answer that is returned is of lesser relevance to what has become the design by the time the analysis is complete.

reduction of risk by communication of cost and benefits in clients' (users') terms: timely analysis that helped clients understand better the actual environmental risk produced by the goals of the designer to produce a more aesthetically driven building as well as a better performing one.

low cost: the underlying implication of the speed of response issue was the reduction of cost. While admitting the intrinsic merit of the environmental design advice, the consensus seemed to be that it should not be more than a fraction of the costs of the other design services. There is a major marketing issue here for environmental design services: convincing the client and the designer that there is value in advice that may cost as much as the design work on the HVAC system in the building. With the latter there is a tangible product placed in the building. With the environmental design service, the product is some graphs and a report. Design decision support by definition is an intangible whose greatest success is to be an integrated (invisible?) support for the design team's decisions.

6

Notes & References

1. DeLaHunt, M.J. and Larry Palmiter. **Suncode-PC: A Microcomputer Version of SERI/RES.** Proceedings of Building Simulation Conference, Seattle, 1985: pp81-85.

2. Ward, G.J. **Radiance: A Tool for Computing Luminance and Synthetic Images**, Lighting Systems Research Group, Lawrence Berkeley Laboratories, California, USA. 1990 http://radsite.lbl.gov/radiance/HOME.html (Last accessed April 2004).

3. It should be noted that at an early meeting with the design team it was established that there were no funds for air-conditioning the whole building. It was noted at the meeting that some of the internal mechanically ventilated studio spaces if fully occupied at the height of summer could get to temperatures as high as 32°C at the target ventilation levels of 6 ACH once or twice a year at most.

4. No heat gain from internal sources such as people and lights was allowed for in these calculations, as the intention was to see how the building itself behaved. The simulation looked at maximum temperatures and daylight levels as well as the potential contribution of solar heat gain to the heating of the building.

5. **ESP-r**: -" "an integrated design tool for the simulation of the thermal, visual and acoustic performance of buildings and the assessment of energy use and gaseous emissions associated with the environmental control systems..." *http://www.esru.strath.ac.uk/Programs/ESP-r.htm* .(Last accessed March 2004).

6. Becker, Judith. **Thick Friendly Walls - why are the opportunities under-utilised?**. ARCH 389 Research Report, Victoria University School of Architecture, BArch degree report, Wellington, June, 1994.

7. Augenbroe, Godfried. *COMBINE Final report.* CEC- DGXII report (1995) cited in *Communicating Performance Assessments of Intermediate Building Design States* Godfried Augenbroe and Sten de Wit Proc. of 1997 IBPSA Conference, Prague **OR** Bazjanac, V., and S. Selkowitz. 1997. *The International Alliance for Interoperability: Its Mission and Its Method*, LBNL, August 1997. Cited in *The Implementation of Industry Foundation Classes in Simulation Tools for the Building Industry* Vladimir Bazjanac, Drury B. Crawley. Proc. of 1997 IBPSA Conference, Prague

7

digital (thermal) simulation

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

thsimcas_02_last_fixed.wpd

> ...OUR THERMAL RELATIONSHIP WITH A PLACE IS MORE LIKELY TO BE ESTABLISHED THROUGH CONVECTION, EVAPORATION, AND RADIANT EXCHANGE. WE MAY NOTE THESE PROCESSES IN THE EXTREME CASES: THE VERY HOT AIR OF THE SAUNA IS UNFORGETTABLE, AND THE RADIANT HEAT FROM A VERY HOT SOURCE SUCH AS A STOVE, A FIRE OR THE SUN IS CERTAINLY NOTICEABLE. BUT MORE OFTEN THESE PROCESSES OPERATE BELOW OUR CONSCIOUSLY SENSIBLE LEVEL. WE MAY STILL PERCEIVE A PLACE TO BE WARM AND COMFORTABLE, OR COOL AND RELAXING, BUT WITHOUT NECESSARILY NOTING EXACTLY WHY OR HOW. THE THERMAL INFORMATION IS NOT DIFFERENTIATED IN OUR MEMORY; RATHER, IT IS RETAINED AS A QUALITY, OR UNDERLYING TONE, ASSOCIATED WITH THE WHOLE EXPERIENCE OF THE PLACE. IT CONTRIBUTES TO OUR SENSE OF THE PARTICULAR PERSONALITY, OR SPIRIT, THAT WE IDENTIFY WITH THAT PLACE. IN REMEMBERING THE SPIRIT OF A PLACE, WE CAN ANTICIPATE THAT IF WE RETURN, WE WILL HAVE THE SAME SENSE OF COMFORT OR RELAXATION AS BEFORE.
>
> LISA HESCHONG IN THERMAL DELIGHT IN ARCHITECTURE[1]

This is the third in a series of five case studies of the application in architectural design of environmental design decision support tools (eddst's). The five case studies are:

1. a **text based design guide** containing **graphical design aids**
   . . . . . Solar House Design Guide - **survey**.
2. **computer simulation** of **lighting** and **thermal** performance.
   . . . . . CBPR client reaction - **individual case study**.
3. **computer (thermal) simulation** packages. USA and NZ interviews - **survey**.
4. **physical model studies** of pedestrian **wind** environments.
   . . . . . interviews with architects in Wellington City - **survey**.
5. **physical model studies** of art gallery **daylighting**
   . . . . . architect & lighting designer interviews SFMoMA- **individual case study**.

The overall goal of this thesis was to establish what common threads there might be between these cases in the ways architecture design teams use current eddst's. The result is five sets of interviews exploring eddst use in real situations. The 3 design tool classification hypotheses as to the advantages and disadvantages of different eedst's are presented at the end of each case as a means of analysing their suitability to the task. A summary of these five case study analyses is presented in the analysis chapter of the conclusions Part of this thesis. There, the analysis looks explicitly for the common factors in all the users' uses of and reactions to these environmental design decision support tools.

This case study is one of the three in this thesis that reports reactions to the use of an eddst gleaned from a survey of a range of experienced practitioners. It analyses the use of an eddst that applies ***digital models*** to the ***simulation*** of the building environmental performance. Specifically, computer models of the building are subjected to various climate influences in order to determine the likely impact of a proposed building design on the internal thermal environment.

7-1 *background*

Much of 1990's building simulation research and development[2] concentrated on improving user interfaces to thermal simulation engines. The short term goal was to make the software easier to use. The long term goal is to permit building designers to deal with issues of thermal comfort and building design in a more thorough manner than has been possible to date. This raises two questions: what interface will achieve this improved ease of use? And, by what criteria is software ease of use measured? This chapter reports surveys of users of simulation software which aimed to determine what they seek from improvements to the product they use regularly.

The survey examines the processes used by simulation practitioners ("simulationists") when they wish to maintain quality assurance in their office simulation routine. It also describes the priority placed by these practitioners on such usability features as Graphic User Interfaces, Default Values and "Prototypical" buildings.

There were two surveys. One conducted in New Zealand in conjunction with contract work to revise the Energy Efficiency Clause of the New Zealand Building Code[3] and the other conducted in the USA. For the New Zealand (NZ) Survey, the participants were approached in person and by telephone. The survey of USA users of simulation programs was conducted by telephone and mail. In this chapter the Building Code survey is referred to as the **NZ Survey**, and the survey of simulation program users as the **USA Survey**.

For the purposes of these surveys "design decision support tools" included (but were not solely limited to):

- technical tools - including nomographs (whether on paper or computerised), rules of thumb, handbooks, computer simulations, Standards, etc
- economic tools - calculation procedures, computer assistance, Standards etc.

7-1.1 the New Zealand survey

The New Zealand Survey formed part of the work programme for the revision of Clause H1 of the New Zealand Building Code. It was approved as *Contract No 7* in that programme. Appendix A contains an abridged version of the contract report prepared for the Building Industry Authority on the New Zealand Building Code work.

The Terms of Reference established that the required output was a two part report:

- Part 1 to describe existing practices; and
- Part 2 to describe in broad terms any additional support tools required. Part 2 was to be completed based on other BIA/EECA contracts presently under way.

Only that information from Part 1 which relates to design decision support tools is presented in this thesis.

The major issues that were explored in the design decision support tools part of the NZ Survey were:

- The sorts of analysis for which they use environmental design decision support tools and especially simulation.
- The degree of expertise the respondent had in the use of environmental design simulation packages as a tool to assist the design of buildings.
- The perceived roles of the various participants in a design team (architect, engineer, developer... etc) in environmental design analysis.

For each of these major "research questions" a number of specific questions for the participants was generated for inclusion in the NZ Survey.

7-1.2 the USA survey

Whilst in the USA in 1995/6, I designed, trialed and administered a survey of users of the major computer based energy simulation programs available there. I was based at Lawrence Berkeley Laboratories in Berkeley, California. The Laboratories are administered by the University of California at Berkeley (UC), and therefore I had available the services of the University's survey design centre. I also had to comply with the requirements of the UCB ethics committee in the design and administering of the survey itself.

The questionnaire format for the USA survey grew out of my experience with the analysis of the New Zealand survey. It was targeted at a more specialised audience. This was users of digital simulation models of the thermal performance of buildings.

The USA Survey sought to question users of the energy simulation programs BLAST, DOE2 and SUNCODE and was conducted in early 1996. The major issues explored in the User Survey were:

- The degree of expertise the respondent had in the use of simulation packages in the design of buildings.
- The amount of customisation of input or output or usage of the simulation package routinely undertaken by a firm or an individual
- How the simulation package might be improved
- What sorts of analysis do they use simulation for.
- The perceived roles of the various participants in a design team (architect, engineer, developer etc) in environmental design analysis.

For each of these major "research questions" a number of specific questions for the participants was generated. The wording of these were then discussed and developed over a period of a month with the UCB survey research centre. The principal changes were in the type of English that elicits responses that are reliable and simple to code.

The USA Survey sought to understand what are the expectations of the members of the design team for the roles they play in ECS design, and the potential involvement of computer thermal simulation in these roles. It critically examined the architects' role in simulation in light of general agreement amongst simulationists that "intuition is not sufficient for good decision making " and that "energy conscious design alternatives " (should be considered) " as early as possible in the design process." [4]

7-1.3 implementation of the NZ survey

The Energy Efficiency section of the New Zealand Building Code (NZBC) was revised during the years 1994 -1996. For proof of compliance with the performance statements in the Code, the new code required some kind of Verification Method or design decision support tool.

The goal of the whole NZ survey for the NZ Building Code (NZBC) was to ascertain the scope of the use of design decision support tools in the building industry and expectations of future developments. The study could not visit a statistically large sample of building industry people. Rather, the survey selected people who represented a range of extremes of types of practice, to ascertain the range of opinions and behaviours current in the industry.

Within this overall goal, the specific goal of the NZ Survey questions included in the NZBC survey and analysed in this Chapter was also to "ascertain the scope of the use of design decision support tools in the building industry and expectations of future developments." Members of the building design team within the group of people surveyed for the NZBC project, rather than the whole building industry, were the focus of the analysis. The survey sought to establish the type of environmental design decision support tools that might support the design processes of people interested in designing energy efficient buildings.

NZ Survey design

The NZ survey intention was to:

1. interview (in person and by telephone) the selected representative individuals; and
2. prepare an analysis of the interviews, to be available publicly, detailing by a suitable classification structure, the:
    - awareness of H1 and its requirements;
    - current use of support tools for H1 and perceived effectiveness;
    - usability of existing tools in the design environment;
    - use of other energy efficiency support tools (e.g. daylighting);
    - knowledge of other support tools
    - desired form of future support tools

The survey itself was carried out by C Watson Consultancy Ltd. An abridged form of the report can be found in Appendix A.

The first step in writing the NZ Survey was to establish the key issues where we required industry feedback. From this we created a list of issue categories for later analysis. Within each category individual questions were formulated which were designed to provide quantifiable answers. For clarity in the interview the individual questions were not strictly grouped by issue in the Questionnaire.

The questionnaire trial took two steps. First, three people were interviewed in person. These people fitted the desired participant profile, but the data collected was not used in the analysis. This step permitted us to establish where the questionnaire language needed work for clarity. It also permitted us to test the "flow" of the questions. After these interviews, identified problems were resolved. Next a pilot survey consisting of one personal and two telephone interviews was conducted.

In the pilot study it became apparent that there was an important distinction between actions taken in order to comply with Clause H1 - Energy efficiency - of the Building Code and those done for the sake of energy efficiency. Because the current H1 is simple and relatively easy to comply with, many people don't use tools to comply with the code. However they may use tools in order to further improve the energy efficiency of their buildings. Thus, for the survey itself, we separated out questions regarding design for code compliance, and design for more general energy efficiency. The answers to both sets of questions are of significance, as are the differences between them.

A copy of the NZ Survey questionnaire is included in Appendix B.

7-1.4 implementation of the USA survey

During Research and Study leave in 1995 and 1996, I interviewed as many people as possible about their use of computer simulation building "design decision support tools" to try to learn from them how they use these tools and what they used them for.

The development of computer analysis capabilities has been spectacular in architecture as in many other fields over the past 10 years. Following the NZ Survey, I was interested in the international state of the art in computer analysis of building performance. The West Coast of the USA has long been the place where by far the most advanced ECS computer based tools have been provided to assist the building industry to demonstrate compliance with the building code. Goldstein's estimate *"that 80% of houses use the computer methods, and only 5% use the prescriptive packages*[5] " suggested a major opportunity.

Therefore, the goal in the USA was to identify a group of experienced users of these types of design decision support tools and survey their experiences and attitudes. Ultimately their input would help to establish a specification for building environment design decision support tools. There seems little reason to think that the restriction of the survey to experienced thermal simulation program users in the Western United States makes the conclusions invalid in a broader international context. While

this geopolitical context may influence the rationale for doing a simulation, it is unlikely to make expert users' comments on the software usability and utility any less relevant.

USA survey design

The intention of this survey also was to:

1 interview (by telephone and by mail) a minimum of 30 individuals with expertise in the use of computer simulation in the analysis of building performance; and

2 prepare an analysis of the interviews detailing by a suitable classification structure:

- what it is that people are trying to do with building performance simulation on computer?
- whether any of these ways of using simulation are non-standard?
- what amount of customisation occurs of the input, output or general use of the software?
- whether there is any correlation between degree of expertise with the software and the amount of specialist use of it?
- what degree of standardisation of input is currently undertaken in the office, and to what extent they expect that this might be over with improved data integration between programs?
- to what degree the client is involved in any of the examination or analysis of the simulation output?
- how should our present education programs change to better serve these non-standard uses of the simulation software?
- a brief for undertaking improvement and development of simulation design decision support tools
- a report for users describing the lessons to be learned about how to do better simulations
- a brief for those designing education programs for simulationists.

The structure of the questionnaire (see Appendix C for a full copy of the questionnaire itself) follows very much the list above. Two additional sections were added that were not strictly part of the above analysis plan. These appeared prior to the questionnaire proper. They were screening questions establishing first which computer program(s) they used and second the size and nature of the work undertaken by their firm over the past 12 months. Responses to these permitted some comparison of these participants with those from New Zealand.

Discussion with the UCB survey research centre elicited the "Often, Sometimes, Rarely and Never" responses in the questionnaire. This was to assist with easier coding of the replies. Changes like reducing instructions from two sentences to one phrase were introduced to ensure these instructions did not interfere with the content of the questions themselves. The following is a typical question before and after the recommended changes:

> BEFORE:
> As I read out the following list of building types, please try to describe the degree of involvement of your firm in work on them on a scale from **Most** of our work is this, through **Some** of our work, to we do a **Few** buildings and **None** of our work is in this sector.

AFTER:
As I read each of the following building types, please try to describe the degree of involvement of your firm in work on them on a scale from **Most** of our work is this, through **Some** of our work, to we do a **Few** buildings and **None** of our work is in this sector. How about (EACH)? Would you say Most, Some a Few or None of your buildings were that type?

The reference to EACH in the later version is where the interviewer was to read out the list of building types saying in turn: "***How about small scale domestic? Would you say etc...***" Then "***How about Large scale domestic? Would you say etc.***." ...

7-1.5 questionnaires

The Figures on the next few pages contrast and compare the initial questions in the NZ and USA survey questionnaires. The essential difference over the first few pages for the two questionnaires was the addition of a set of screening questions (**Figure 54**) to the start of the USA survey. The reason was that, although I was gathering the list of participants from mailing lists for BLAST[6] and DOE2[7], the two more popular USA computer analysis packages, I was uncertain that all the people I contacted would have relevant experience. These screening questions avoided the waste of interviewer time or the potential participant's time by establishing their eligibility.

Introductory notes;
This is a small part of the **revision of the energy efficiency section** of the building code. The Building Industry Authority wants to find out about the **range of experience** in the building industry of energy efficiency of buildings.
This questionnaire refers to buildings your office/firm worked on in **last 12 months** which and are completed or are expected to be built. My notes from this interview will remain **confidential** to the Centre for Building Performance Research at Victoria University and C Watson Consultancy Ltd. An **anonymous summary and analysis** will be used for development of the Building Code and in a study of the usability of design tools/aids. If you do not understand something please ask for **clarification**.

1☐-telephone 2☐-personal consent to interview ..... (signed) 1994

Figure 49 Cover page of NZ Survey Questionnaire - Introductory notes

The early questions in both the NZ Survey and the USA Survey forms established the nature of the work undertaken by the interviewee's firm. Then, in the NZ Survey a series of questions addressed each firm's approaches to energy efficiency in buildings, and the types of design decision support tool used. These mid-section questions in the USA Survey sought feedback only on computer simulation program use. The final group of questions in each survey sought feedback on the roles expected of the different design team "players" (architect, engineer, analyst) in energy efficiency design analysis.

In language and presentation, the NZ Survey form had worked reasonably well as a set of notes for use by a single researcher administering a "quick and dirty" examination of the New Zealand building sector. It was changed in the USA Survey into a document that served not only as a set of notes for

telephone interviews, but also as a form that could be sent by mail to consultants in the expectation of obtaining reliable information. The reliability of response arose from the way in which the revised layout of the form improved its usability. For example, the wide spacing of individual responses in the USA Survey were designed to lessen the likelihood of a tick apparently covering two responses. In addition, this wide spacing and the trailing dot lines linking to the response numbers left plenty of room for additional notes of clarification to be added by the telephone interviewer or by the individual mail survey respondent.

Your Firm

1 Please advise if there are any errors in the contact details above.

2 What is your primary role in the firm?

1☐-Owner
2☐-Manager
3☐-Designer
4☐-Inspector
5☐-Solo
6☐-.....

3 How would you describe the activities of your firm?

1☐-Property Developer
2☐-Builder
3☐-Engineer
4☐-Architect
5☐-Designer
6☐-Inspector
7☐-.....

4 How many new buildings < 300 m^2 did your firm work on in the last 12 months?

.... 0m^2 - 300m^2

5 How many new buildings > 300 m^2 did your firm work on in the last 12 months?

.... 300m^2 +

6 On average how many full-time equivalent people were involved in your firm?

Figure 50 NZ Survey Questionnaire: Details of Participant's Firm

The NZ survey form contained 52 questions, including six of the total of nine questions about the nature of the participant's firm which were on the front page and are shown in **Figure 50**. The NZ Survey consisted of closely spaced type on seven A4 pages. The USA Survey contained 51 questions,

including the three screening questions shown in **Figure 54** and a final "question" which was really a request for volunteers for further assistance[m]. The form was 23 A5 pages (approximately[n]) in length including the two cover pages.

A further distinction between the surveys arose from a clear separation between identification and survey related information. In the NZ Survey the name address and firm name was printed above the introduction from a database of names using a spreadsheet merge operation. In the USA survey, the information was hand entered. It and the screening questions were on a cover sheet which was designed to be removed. This was to facilitate meeting the assurances about privacy of information given in the survey and its covering letter. The "code number" (**Figure 51**) was to be entered on this

This "interview" form is designed to elicit responses which will help us all understand better the role of simulation in design. It is planned to use the analysis of the responses to develop three products:

- better data for those undertaking improvement and development of simulation design tools
- a report for simulation program users describing quality control procedures in simulation
- a brief for improvement of education of new users' of simulation programs

Our questions refer to a particular building your office or firm has worked on which has been recommended as worthy of closer examination in a case study of the influence of simulation on design. The notes from this survey form will be held in confidence by the Centre for Building Performance Research at Victoria University and the Windows and Lighting Group at Lawrence Berkeley National Laboratory. As the case study will require publication of details of the design of the building, we ask your permission to publish information about it in the summary reports of the analysis. If you do not understand something please ask for **clarification** at any time of the author Michael Donn. Your individual responses to the survey, where they do not relate directly to the design of the building will only be published in anonymous form.

1☐-Permission to publish description of the building and impact of simulation on its design?

1 . . . . . (signed) ..... (date).....

---

1 Name . . . . . .

2 Address . . . . . .

3 Contact 'Phone number . . . . . .

4 Code Number . . . . . .

Figure 51 Cover page of USA Survey Questionnaire - Introductory notes and Identifier

[xiii] Question 51 read: *Do you have any current or recent projects which might be suitable material for a design case study of the use of dynamic simulation software?*

[xiv] The USA survey necessarily used the local standard letter size paper; the booklet style printing of the survey fitted two pages on each letter size sheet.

cover sheet, and on each page of the form, then the cover could be removed during all subsequent analysis phases to preserve the privacy of the participants.. The identification data linking names and code numbers was retained, but in locked storage only until the completion of the project.

Figure 52 lists a comparison of the section topics used to organise each questionnaire. Only 16 of the individual questions in each survey address the same issues. Of these, 9 are 'Scene setting"

NZ Survey	Q No's	USA Survey	Q No's
Your Firm	1-9	Screening	1-3
Approach to energy efficiency	10-13	Your Firm	4-13
Design tools to comply with NZBC Clause H1	14-30	Your use of simulation program x..	14-16
Other energy efficiency Design tools	31-36	Other energy efficiency design tools	17-19
Sustainable energy	37-39	The principal simulation program	20-43
Future Design of energy efficiency	40-48	Future design of energy efficiency	44-47
Users of energy efficiency design tools	49-52	Users of energy efficiency design tools	48-50

Figure 52 NZ and USA Surveys: Section headings and number of questions they contain

Your Firm
The next few questions help us establish the nature and character of your firm for comparison with those firms surveyed in the 'phone and mail surveys of simulationists earlier this year..

4) Would you describe your firm's role in the building industry as primarily HVAC Engineer, Architect, or Simulationist
HVAC Engineer . . . . . ☐-2
Architect . . . . . ☐-3
Simulationist . . . . . ☐-4
Utility support group . . . . . ☐-5

5) How would you characterise your own (primary) role in the firm - owner, manager, designer, a sole practitioner, or what?
Owner . . . . . ☐-6
Manager . . . . . ☐-7
Designer . . . . . ☐-8
Solo . . . . . ☐-9
Analyst . . . . . ☐-10
Other (SPECIFY_____) . . . . . ☐-11

6) As you read each of the following, please tell me whether your firm used a computer for that purpose during the past 12 months.
Word processing . . . . . ☐-12
Accounts . . . . . ☐-13
CAD (Computer Aided Drafting/Design) . . . . . ☐-14
Scheduling (Project management etc) . . . . . ☐-15
Design analysis (Structural, thermal, lighting calculations) . . . . . ☐-16
Any other way (SPECIFY_____) . . . . . ☐-17

Figure 53 USA Survey Questionnaire: Details of Participant's Firm

Screening questions

1. Did you use any of the following simulation programs as design aids/tools to help you with energy efficiency design choices? (READ ALL AND CHECK THOSE THAT APPLY)

DoE2 ..... ☐-2

a commercially available PC version of DoE ..... ☐-3

BLAST ..... ☐-4

a PC version of BLAST ..... ☐-5

TRACE or other TRANE product ..... ☐-6

HAP or other Carrier Product ..... ☐-7

ESP from APEC ..... ☐-8

Other (SPECIFY_____)..... ..... ☐-9

IF MORE THAN ONE SIMULATION PROGRAM IS IDENTIFIED AS BEING USED IN DESIGN, GO ON TO QUESTION 2, ELSE GO TO QUESTION 3.

2. Of the programs you listed, which would you say was most used for design of the building envelope as opposed to HVAC services design? THE REST OF THE QUESTIONS IN THIS INTERVIEW ARE ABOUT USE OF THIS PROGRAM.

..... ☐-10

3. Here are some situations where energy efficiency considerations might influence your design choices. I would like you to state how often they have influenced the design of buildings you have worked on in the past 12 months. Have (OPTION) Always, Frequently, Sometimes or Never influenced your choice?.

	Always	Frequently	Sometimes	Never
Building envelope alternatives	1	2	3	4
Specialist Solar features (sunspace, Trombe wall, ...)	1	2	3	4
Passive solar features (Orientation, mass, shading)	1	2	3	4
Selection of HVAC equipment	1	2	3	4

Figure 54 USA Survey Questionnaire: Screening Questions

questions designed to establish the size and type of the participant's firm. The rest of the questions in the NZ Survey are addressed to issues of specific application to the NZBC project which funded the bulk of the work. The questions in the USA Survey address the topics listed earlier related to the usability and individual approaches to the use of computer simulation programs in the design of buildings.

The USA Survey screening questions shown in **Figure 54** were of greatest use in the telephone survey. With two of the potential participants the "interview" stopped at Question 2[o].

Two of the 16 questions common to both surveys will be used in the next few paragraphs to illustrate the utility of the improvements in the USA Survey. Questions 8 and 49 in the NZ Survey, are

[xv] Strictly speaking Question 3 is not a screening question in the same sense. It has been used in the analysis to "screen" out some participants from some of the analyses, but it was not used to screen out participants from interview. It was placed here because it fitted the flow of the survey form language.

contrasted with the corresponding Questions 12 and 48 in the USA Survey. Their texts are contained in **Figure 32**, **Figure 43**, **Figure 44**, **Figure 55** through **Figure 58**.

Question 8/12 is one of the scene setting questions querying the participant about the nature of their firm's business. In this case what was sought was the likelihood of a correlation between the nature of the business undertaken and the use of design decision support tools for environmental design. It would be conventionally expected that those who principally design houses would have a lot less to do with sophisticated building performance analysis computer programs than those who routinely work on large scale complex buildings. This question permitted an analysis which tested this hypothesis.

8 What types of buildings was your firm involved with? *(NB: all these questions were related to last 12 months of* activity of the firm.

1□-Detached dwelling
2□-Multi-unit dwelling
3□-Group dwelling
4□-Communal residential
5□-Communal non-residential
6□-Commercial
7□-Industrial

Figure 55 NZ Survey Question 8 - What types of building was your firm involved with?

The differences in language and presentation are obvious in **Figure 32**, **Figure 43**, **Figure 44**, **Figure 55** and **Figure 56**. The question in **Figure 32**, **Figure 43**, **Figure 44**, **Figure 55** from the NZ Survey was conveniently brief for the researcher conducting the interviews. However, it was my experience that even the telephone interviews which I conducted ran faster with the lengthier question in the USA Survey **Figure 56**. The reason was that it was very much easier for me to read the question quickly as it followed a formula, and it seemed very much easier for the interviewee to understand because of this formulaic presentation.

The approach guaranteed a more reliable result because there was a reasonable guarantee that the participants were all responding to the same question. There was no potential for subtle differences in understanding arising from subtly different presentations of the question. There is of course no guarantee that the participants did not have subtly different understanding of the questions themselves.

A far more important aspect of the design of the questions was clarification of the type of response sought. With the addition of the *Most, Some, Few* or *None* response categories, it became possible for the responses to be quantified. This made it possible to summarise and to report the responses in a much more precise manner.

49 Who would be the primary users of energy efficiency design aids/ tools which affect building construction?
(E.g. tools/ aids which relate to thermal mass, air leakage, solar gain, insulation, double glazing)

Buildings < 300 m^2	Buildings > 300 m^2
1□- Architect, designer	1□- Architect, designer
2□- Engineer	2□- Engineer
3□- Energy Consultant	3□- Energy Consultant
4□- Builder	4□- Builder
5□-	5□- .....

Why?.....

Figure 57 NZ Survey Question 49: Who would be primary users of design tools?

Question 49 in the NZ Survey (**Figure 57**) was one of the questions at the end of the survey which was added to the core NZBC-related questions specifically addressing the issues examined in this thesis. It asks members of the design team what they think are theirs and others' roles in environmental design analysis. The aim is to compare the views mentioned in the introduction to this Chapter (page 3) emanating from the research community about who are the most influential decision makers in environmental design of buildings. These views suggest that the most effective way to design buildings with high quality internal environments is to ensure that the sketch design works well. This is seen as leading to a need for design decision support tools especially for the architect to assist them to create these sketch designs with good environmental performance.

Figure 57 and **Figure 58** show the same improvements as in the previous two figures. Again, the explanation in the USA Survey is more extensive, standardised and easy to comprehend than in the NZ Survey. The responses to the three USA Survey questions of this type from the postal survey

12 **As you read each of the following building types, please try to describe the degree of involvement of your firm in work on them. Would you say *Most, Some,* a *Few* or *None* of your firm's buildings is of this type?**

	Most	Some	Few	None	
Small scale domestic;	1	2	3	4	-1
Large scale domestic;	1	2	3	4	-2
Retail;	1	2	3	4	-3
Commercial office;	1	2	3	4	-4
Commercial accommodation;	1	2	3	4	-5
Industrial	1	2	3	4	-6

Figure 56 USA Survey: Question 12 - What types of building was your firm involved with?

were comprehensive and demonstrated a clear understanding of the issues. However, the question

was difficult to read out over the telephone. As originally planned, I was to read each question twice; once for small and once for large buildings. In reality, in order not to appear to take too long asking these questions, I resorted to asking for each in a standard form (e.g. whether the Architect, designer would be a Primary, Major, Occasional or Not a User of Simulation based energy efficiency design aids or tools) adding a footnote querying whether the response would be any different for small buildings (under 3000 m^2).

A further difference arose in the translation of this question from the NZ to the USA Survey: In addition to changing from Metric to Imperial measurements, I changed the size at which to separate "small" and "large" buildings. The NZ Survey was interested in the differences between responses from people involved with houses and commercial and institutional buildings. As the focus of the USA Survey was on users of simulation in design, I assumed that the consultants would be working principally on commercial and institutional buildings. Therefore, in the USA Survey, I made the size distinction between small and large commercial and institutional buildings. The 300 m^2 (3,000 square feet) separation point between small and large buildings in the NZ Survey became 30,000 square feet (3,000 m^2) in the USA Survey.

QUESTIONS 48-50 QUERY THE ROLES OF PEOPLE USING SIMULATION IN ASPECTS OF DESIGN. THEY LIST DIFFERENT PARTICIPANTS IN THE DESIGN TEAM. THEY ALSO ASK WHETHER YOUR ANSWER WOULD BE DIFFERENT FOR **LARGE** OR **SMALL** BUILDINGS.

48 **Please tell me whether you think that (EACH) is the *Primary* User, a *Major* User, An *Occasional* User, or *Not* a User of simulation based energy efficiency design aids/tools which affect building construction**

(E.g. such design tools/aids would relate energy use to thermal mass, air leakage*, solar gain, insulation, double glazing)*

A **For buildings under 30,000 square feet (3000 $m^{2)}$**

	Primary	Major	Occasional	Not
Architect, designer	1	2	3	4 . . . . . -1
HVAC Engineer	1	2	3	4 . . . . . -2
Energy consultant	1	2	3	4 . . . . . -3
Builder/contractor	1	2	3	4 . . . . . -4
Design/Build Contractor	1	2	3	4 . . . . . -5
Other (SPECIFY.....)				. . . . . -6

B **For buildings over 30,000 square feet (3000 $m^{2)}$**

	Primary	Major	Occasional	Not
Architect, designer	1	2	3	4 . . . . . -8
HVAC Engineer	1	2	3	4 . . . . . -9
Energy consultant	1	2	3	4 . . . . . -10
Builder/contractor	1	2	3	4 . . . . . -11
Design/Build Contractor	1	2	3	4 . . . . . -12
Other (SPECIFY.....)				. . . . . -13

Figure 58 USA Survey Question 48: Who are the users of design tools?

7-1.6 participants

In both surveys the target participants were users of building environmental design decision support tools. However, in the NZ Survey addressed a broad range of people involved in the building industry who might use environmental design decision support tools. The engineer, architect and architectural designer categories of participant amounted to 50% of the total number of people surveyed. The target population for the USA Survey was narrowed to users of computer based environmental performance simulation programs.

NZ Survey participants

Clause H1, the Energy Efficiency portion of the New Zealand Building Code, is used by a range of people involved in the creation of buildings. The following classes of users were identified for the NZ Survey:

- Architects: design the building whilst ensuring the requirements of H1 are met;
- Engineers: design energy using services (e.g. HVAC) to meet H1 requirements;
- Draughtspeople: draw and often design the building to meet H1 requirements;
- Builders: construct the building envelope to meet the requirements of H1;
- Developers: ensure investment meets the relevant legal requirements;
- Suppliers: demonstrate product(s) permit compliance with requirements of H1;
- Support organisations e.g. BRANZ in the development of Appraisal Certificates
- Energy efficiency consultants: assist in the design of energy efficient buildings.

Of this list, only suppliers were not surveyed. Support organisations or Quantity Surveyors were classified in the 'other' category . Draughtspeople are categorised with the designers who were not architects or engineers. The survey was designed to cover the range of users of Clause H1, and its present and possible future use of support tools. Names of members of each user group to survey were generated from listings by their respective professional organisation or trade group. CBPR had previously undertaken a telephone survey of a selection of major heating and ventilating engineers to determine their use of design decision support tools[8]. That survey group was selected based on the interest group information provided by the Association of Consulting Engineers of N.Z. (ACENZ), the Institute of Professional Engineers (IPENZ) and the Institute of Refrigeration, Heating and Air Conditioning Engineers (IRHACE). The results from that study were used as a starting point for the NZ Survey.

The NZ Survey could not be undertaken for a large number of each of the different types of "player" in the building "game". A representative sample was selected for interview from two regional centres, and three cities across the North and South Islands. As there was no intention to separate out regional variations in response, no effort was made to obtain a sufficient number of interviewees in each region to generate valid summary statistics (assumed to be a minimum of 20-30 people). Rather we interviewed as even a spread in number across the regions as the budget would allow.

Every effort was made to question people from large as well as small businesses. The sample was selected with approximately equal numbers of designers (architects, engineers, draughtspeople) and builders primarily working in those two groupings. There were sufficient numbers in these two groupings to permit separation of their responses. The first questions in the survey were designed to check that the persons selected for interview did indeed conform to the profile sought.

Prior to the interview, we contacted each company and asked to be put in touch with the person in that company who had most to do with specifying and designing for energy efficient performance of buildings. In this way we targeted a wide variety of companies but within each company tried to speak to the person with most knowledge about their company and the way it treated energy efficiency. Thus the goal was to survey the level of expertise available to a cross section of companies rather than a cross section of individuals. This survey gives a good indication of what is out there but it is not in sufficient numbers to allow statistically based generalisation of the results.

The data in **Table 1** shows the breakdown of respondents in the NZ Survey by type of activity undertaken by the respondents and the type of building they predominantly work on. The other information presented in the table notes the number of people surveyed by telephone and in person.

User Groups	Number Surveyed **Personal** *& Telephone*	
	<300m^2	>300m^2
Designers (e.g. architects, engineers, etc)	**10** & *10*	**9** & *10*
Small scale builders (e.g. one or two person)7	**7** & *5*	
Large scale builders (e.g. developers)	**4** & *2*	**5** & *5*
Inspectors	**5**&*5*	
Other (e.g. Research, Q.S.)	**1** & *2*	
TOTAL SURVEYED	**41** & *39*	

Table 2 NZ Survey: Number surveyed in each section of the building industry

Some general background of the interviewees was required in order to link answers to types of practice. This was necessary for the NZBC analysis. These background questions included the individual's Role in the company (Q2); the company's Activities (Q3) (e.g. Architectural, Engineering, Developer); and the Size of the company in terms of: number of employees (Q6); Number of buildings and Size of those buildings built in last 12 months (Q4 &5), and the total Value of those buildings (Q7). These questions were also asked in the USA Survey (Q 4 through 11 in that survey).

The respondents to the NZ Survey questionnaire fell into two distinct groups: the construction industry participants, that is the builders, developers, architects, engineers and the designers; and the building inspectors and 'others'. The 'Others' were 2 building industry support people and one quantity surveyor.

These two groups were often separated in the analysis of data. There were 67 construction industry participants and 13 inspectors and others (10 inspectors).

Construction Industry					Inspectors and Others	
Building Industry		Design Professionals				
Developer	Builder	Engineer	Architect	Designer	Inspector	Other

Table 3 NZ Survey: Categorisation of respondents' practice types

In total the NZ Survey approached 82 people to survey, and 80 participated. They were employed by organisations with the primary functions and sizes listed in **Table 1**. The USA Survey resulted in 44 valid responses. Of those who entered data about their firm, 17 described their firm's *primary role in the building industry* as *HVAC Engineer*; 16 described themselves as *Simulationists*; and 5 said they belonged to a *Utility support group*. There were fewer participants in the USA Survey, and data about size of firm was provided by only 12 of them, so no useful comparisons are possible between firms responding in each country. However, it is worth noting that, of the twelve USA firms who did respond, only two employed more than 4 people.

No of fulltime staff	Developer	Builder	Engineer	Architect	Designer	Inspector	Other
0-5	2	3	4	10	11	1	
6-10	4	1	2	3		2	1
11-20	3		2			2	1
21-30	1	2	3	1		1	
30-50	1	1		1		2	
51-100	1	2		1		2	1
100-200		4	1				
200-300	1	2					
Total Surveyed	13	15	12	16	11	10	3

Table 4 NZ Survey: Number of staff in each surveyed company by practice type

usa survey participants

For the USA Survey, two sets of mailing lists were obtained from the support teams for the BLAST[9] and DOE2[10] computer simulation programs. These were supplemented by a direct request to the developers of BLAST, DOE2 and SUNCODE[11] to identify expert users to whom specific telephone interview requests might be addressed. Here, the goal was to use telephone interviews to document the expertise of these experienced people. I was not interested to generalise from the analysis what some notional 'average' simulation program user's opinions might be.

The telephone survey list consisted initially of 6 names from the BLAST users' support group and 24 names from the DOE2 users' support group. Of these 30 people, 24 were actually available for

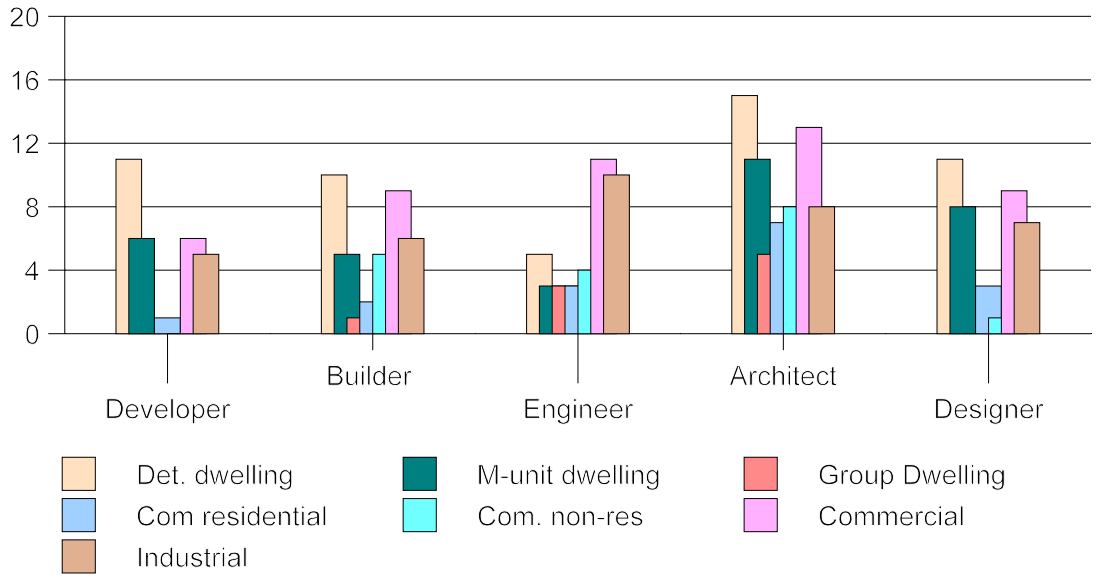

Figure 59 NZ Survey: Participants' type of practice vs type of building

interview when I made direct contact. The rest had changed offices, were no longer working in the area, or just could not be contacted. Of these 24, 20 were prepared to be interviewed.

Each individual in the telephone survey was written to with a copy of the brochure and a covering letter (Appendix D). The letter nominated a time when I would telephone to book a suitable time for the actual interview. With some, this process was very quick. They suggested getting it over with at the time I telephoned. With others, it was a process of negotiation. The 20 interviews, and all the setting up calls, took in excess of a full month to complete.

What took even longer than the development of the survey form itself, was consideration of the survey by the Human Subjects Protocol Committee. I am indebted to Chris Byrne of LBL for guiding me through this process in a relatively short time. The concerns raised by the committee were that the "subjects" be informed how their names had been obtained, and that their consent be obtained. This is the principal reason for the content and layout of the front page of the USA Survey. The Committee suggested that I needed the subject's written consent on a protocol before I telephoned them. To this end the approach letter contained a small section for those approached to sign and nominate times for interview. A small number did as I suggested and faxed their consent to me nominating a time for interview. The rest I telephoned at a time specified in the approach letter, to check whether they consented to the interview, and to book a time for the actual interview.

The subjects for the mail survey were selected from the 1000+ names on the DOE2 and BLAST user newsletter mailing lists. I selected users from the West Coast of the USA as the more likely to have had extensive experience in use of these simulation programs, because of the innovative approaches to Building Code compliance that the Western States have taken over the years. California in particular has more than 15 years history of mention of simulation in its building code compliance

schedules. The "West" was liberally interpreted - essentially it was states west of and including Colorado and Arizona. There were 587 names on the list of people with zip codes in the Western USA. 502 of these were at unique addresses. Many firms had multiple people on the mailing list. For these, I sent one letter and survey form to one of the individuals with a request that it be answered by one of the people in the firm who was currently using DOE2 or BLAST. I also removed from the list any people who were focused on education rather than consultancy use of the software or worked for libraries.

The total number of survey forms posted out was: 399. The responses to the postal survey totalled 24. This is a similar response rate to that LBL encountered in a 1995 survey of DOE2 users. Fred Winkelmann[12] of the DOE2 support team provided me with a copy of the responses from the 105 users who returned the survey sent out to 1200 people (See Appendix E). It is difficult to argue that 24/399 is a large sample. It was clear however that this was of about the same order of magnitude in response as had been encountered with this group previously (24/399 = 6% : 105/1200= 8.7%). It seemed that this was the practical limit to my sample. The survey covered similar ground to my survey but contained far more open-ended questions. The value of the personal approach of the telephone survey can be gauged from the response rate for this group: 30 people approached, and 20 participants. Including these in the equation, raised the overall response rate for my USA Survey to 44 out of 399 (11.0%).

At a total response of 44 there is a sufficient number of people in the US survey to be able to derive valid summary statistics describing the responses of these particular users of simulation programs. However, it is not possible to infer that these 44 are "representative" of the others on the original mail list. Primarily this is because it is not possible to distinguish these users from those who did not reply. Only a very small number wrote back to say that they could not participate. Most who did not participate just did not reply.

percentage energy savings achieved through use of simulation

Participants in the USA survey were asked to estimate the "percentage energy savings achieved through the use of simulation" . In the prior LBL survey of DOE2 users a very similar question was asked. By extrapolating from the average savings and amount of buildings analysed, LBL were able to estimate the total contribution to the economy resulting from the Government investment in the DOE2 computer program. This question about energy savings was the only question added after the questionnaire was distributed around 6 of the Building Science staff scientists at LBL.

39 people responded to this question. As **Figure 60** shows, they were in general agreement that savings typically fall in the range from 10% through 40%. The average savings level from these data (assuming that the centre value of each frequency bin is "typical" of the bin) is: 19%. The average calculated from the 105 responses to the LBL questionnaire was 21.8%. Given the wide spread of

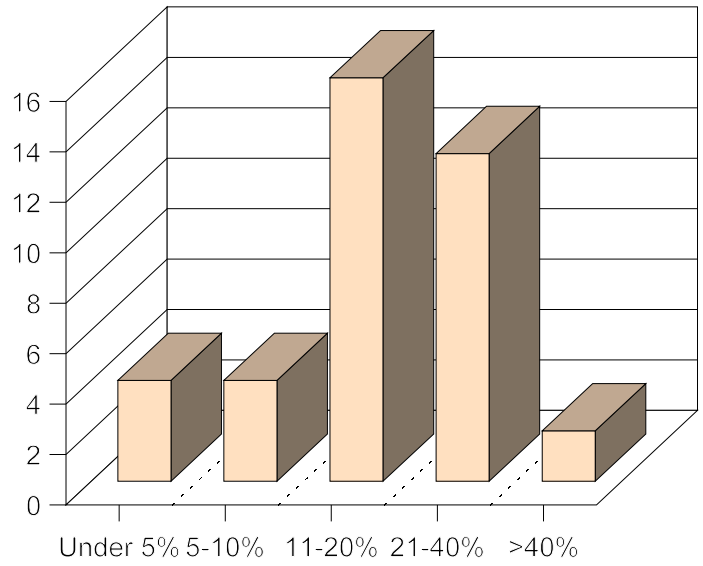

Figure 60 USA :Survey: Typical savings from use of simulation in design

the values reported, the closeness of these two figures provides further reassurance as to the general applicability of the results of this survey.

USA survey participants' use of thermal simulation programs

Figure 61 and **Figure 62** show the relative numbers of users of DOE2, BLAST and other simulation programs among the USA Survey participants. Two users reported using more than one program "for design of the building envelope as opposed to HVAC services design." The simulation programs used for building envelope design on the "other" category list were: MicroAxcess, SUNCODE, TRACE, Trakload. As the questions in the survey related to the programs identified in **Figure 62**, it can be seen that the responses can largely be interpreted as users' reactions to the one computer program that has dominance in the market: DOE2.

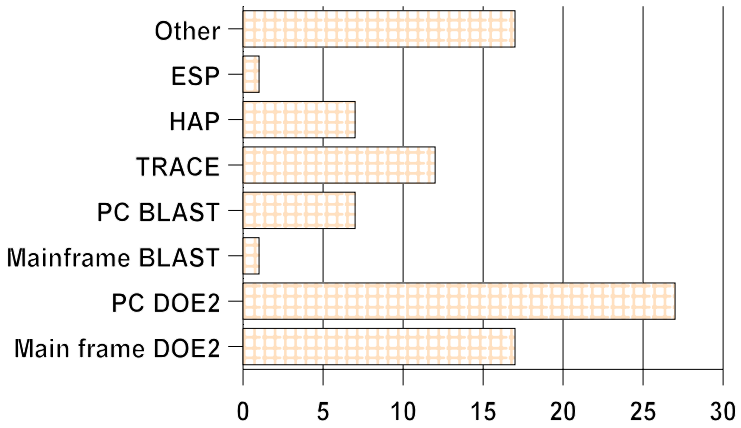

Figure 61 USA Survey: Computer programs used by the participants

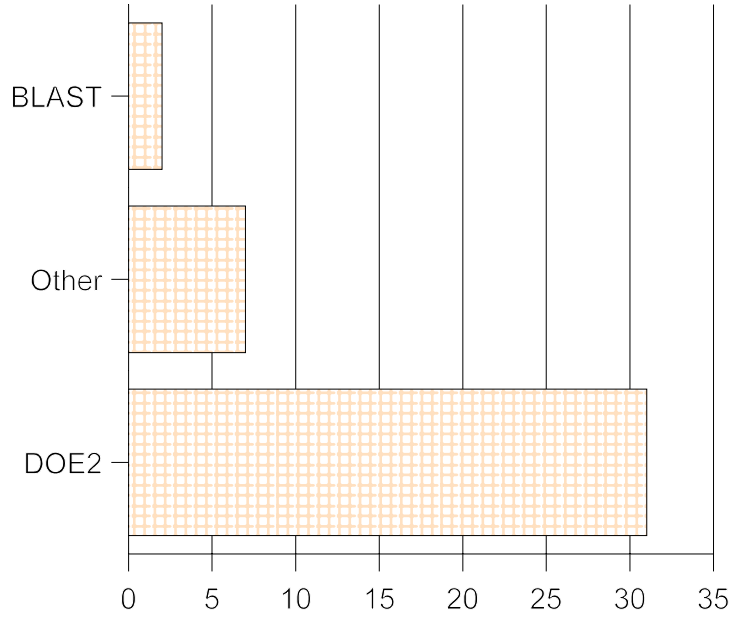

Figure 62 USA Survey: Simulation programs most used by respondents in *building* design

This response rate could be seen to limit the responses to users of DOE2, and it might therefore be argued that the users' evaluations are of this particular tool, rather than of eddst thermal simulation tools in general. However, the focus of the survey population on a market in the Western USA where the practitioners had through legislation many years of experience at the use of eddst thermal simulation tools in the service of improved building design, and the focus of the questions to these

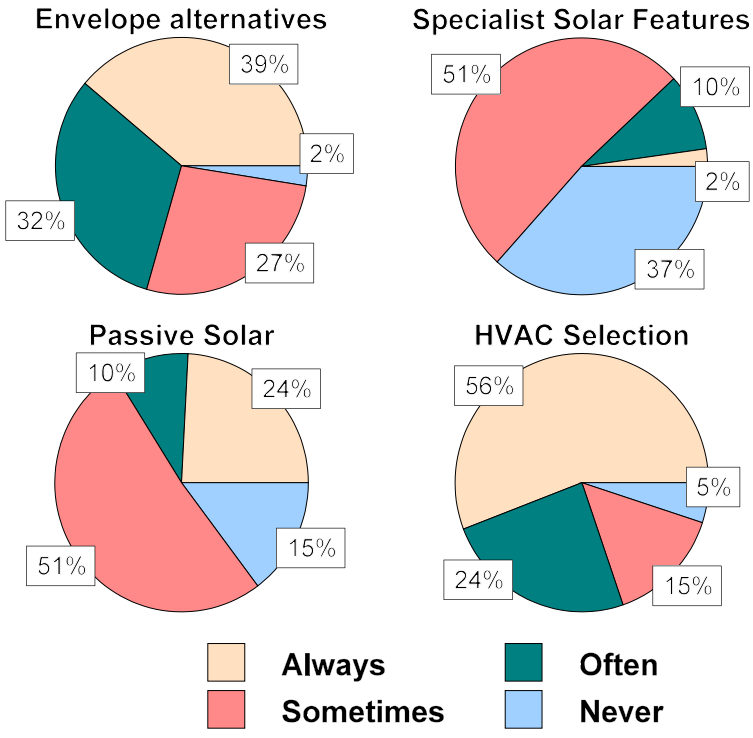

Figure 63 USA Survey: How often these energy efficiency options have affected buildings you worked on

highly experienced simulationists on the role of thermal simulation in the design process was designed to minimise this problem and provide responses of general application to the field of thermal simulation.

level and type of experience of the survey users

This portion of the two surveys was designed to reveal the nature of the work in which the surveyed people were involved. It was designed at the outset to establish the potential to disaggregate some responses to later questions - e,g, is post processing of simulation data more often done by people working on large buildngs. Because of the small number of surveyed persons the data merely characterises the NZ and USA participants.

In the USA Survey participants were asked how often they had worked on four different types of simple energy efficiency measures in building design over the past year. They were asked whether the design of buildings they had worked on had *"Always, Frequently, Sometimes* or *Never"* been influenced by study of *"Building envelope alternatives; Specialist solar features like Trombe walls; Passive solar features like orientation, mass and shading; or Selection of HVAC equipment. "* **Figure 64** shows the responses for all four of these design choices. Just over half the participants *always* were involved in selection of energy efficient HVAC equipment in the design of the building they worked on in the 12 months prior to the administration of the survey. Specialist solar measures like Trombe walls and sunspaces were *never* used by one third of participants and only sometimes used by most of the rest.

Arguably, study of building envelope alternatives is the most genuine form of involvement of the simulationist in building (as opposed to HVAC services) design. Only one person was *never* involved in envelope design. The rest reported in almost equal numbers being *"always, frequently* or *sometimes "* involved. There seems a definite split in the community of people being studied. There is one group that is much more likely to become involved in study of general building envelope and HVAC services design issues than either Passive Solar or Specific Solar solutions.

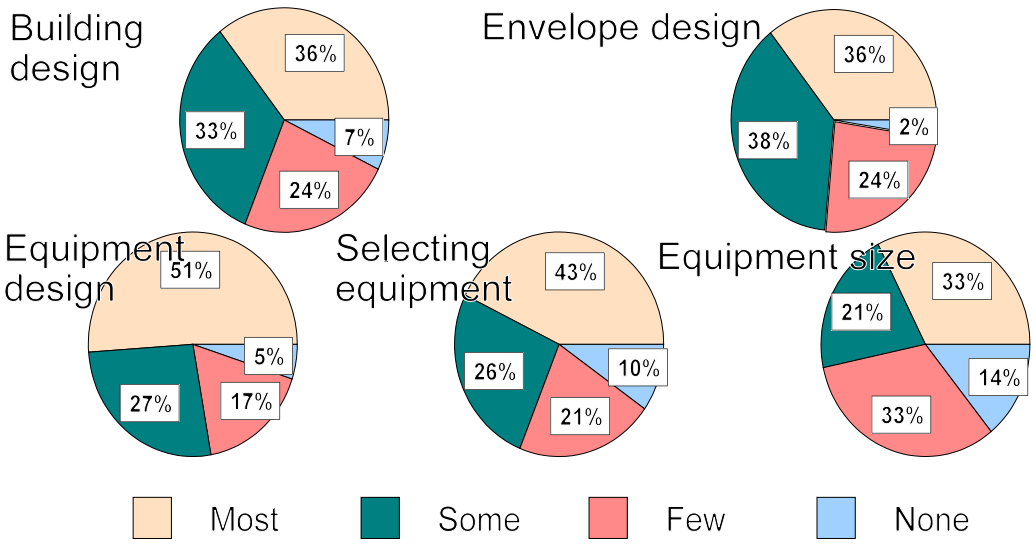

Figure 64 USA Survey: uses to which simulation is put in building design

A very similar question was asked in the main body of the NZ Survey. It did not function in that survey as an initial screening question as it did in the USA Survey. Answers to Question 16 in the NZ Survey are summarised in Table 1 and **Figure 65**. By dividing the responses into positive and negative bars and not counting the non-participants, the figure reveals the participant pattern as opposed to the raw resp[onse of the table. The biggest difference between the questions is in the last option: in the USA Survey participants were asked about *"HVAC equipment"* whereas in the NZ Survey they were asked about *"efficient appliances"*.

Frequency	building fabric	specialist passive solar features *(Trombe walls, sun spaces etc)*	other passive solar features *(window orientation, thermal mass, shading)*	choice of efficient appliances
every time	8	4	32	17
sometimes	39	31	23	31
never	12	26	5	11
no response	8	6	7	8
Total No	67	67	67	67

Table 5 NZ Survey: Frequency with which energy efficiency choices affect building design

The role that the participants' firms play in the building industry is explored in questions 4 through 11 in the USA Survey. The responses to question 4, allow categorisation of responses according to

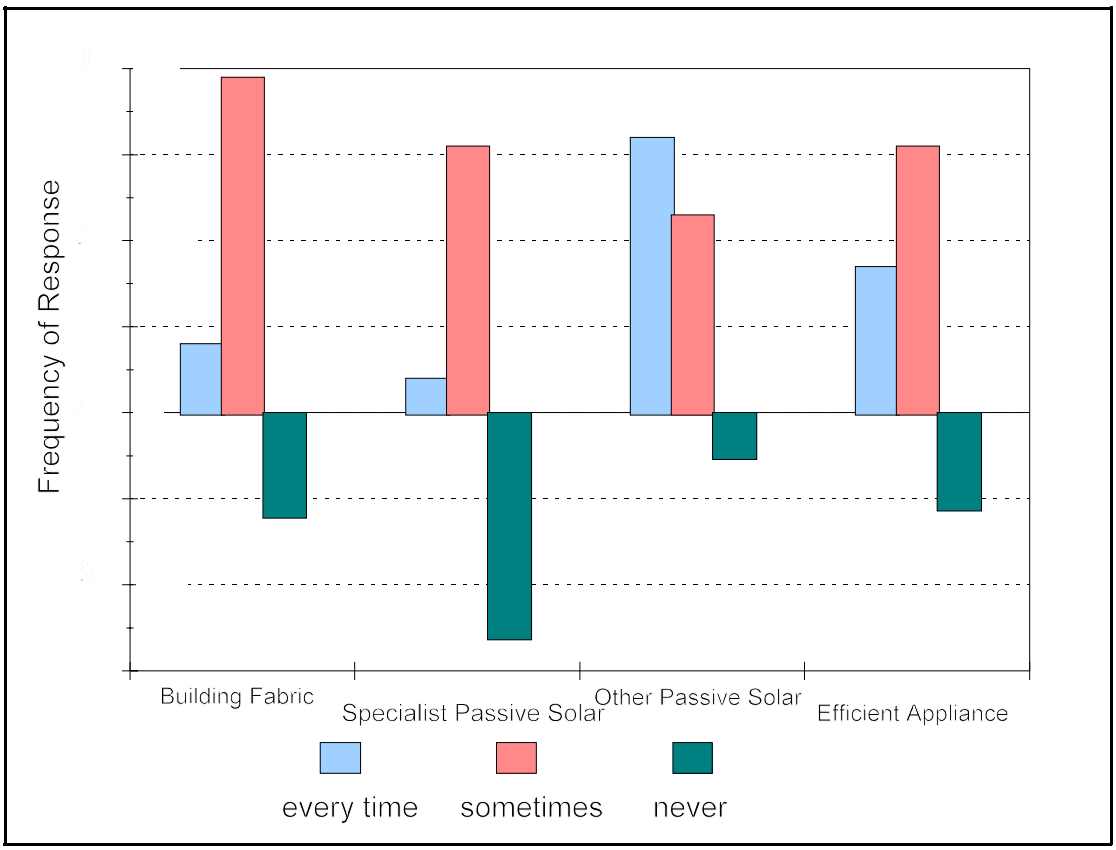

Figure 65 NZ Survey: Frequency with which the consideration of energy efficiency influenced the design of specific building elements

the two basic types of firm involved in the survey: those who *"describe their firm's role in the building industry as primarily HVAC Engineer"* and those who see themselves as *"Simulationists."* There is an even split in numbers between these two groups. This split seems to explain the separation of roles in the passive solar query as well: a small minority of 4 of the HVAC engineers *"Always"* or *"Frequently"* become involved in projects where passive solar design features influenced design choices. By contrast, over half of the Simulationists become involved this often. It seems that the split is related to simulationists' definition of their roles in more global building design terms than HVAC engineers.

In the NZ Survey, if inspectors and the people listed as 'other' are excluded, the people surveyed represented companies that had dealt with 2087 buildings under 300m^2, and 486 over 300m^2, in the previous 12 months. (2573 total). There is no directly corresponding data for the USA Survey. The divisions in the USA Survey were between buildings less than and more than 3000m^2 in area.

Amongst the NZ Survey participants, 15 (22%) of the 62 respondents built only buildings under 300m^2. Only one built buildings over 300m^2 exclusively. A large number of respondents - 30 (48%) - built mostly small buildings (80% of their buildings were under 300m^2). 21 (34%) of the respondents built fewer than 5 small (under 300m^2) buildings in the last year, while a large number - 43 (69%) - built fewer than 5 large (over 300m^2) buildings in the year. 31 (50%) worked with a mixture of both sizes (more than 20% and less than 80% of each size).

Figure 66 shows the diversity of types of firms which the 44 USA Survey participants' worked for over the 12 months prior to the survey.

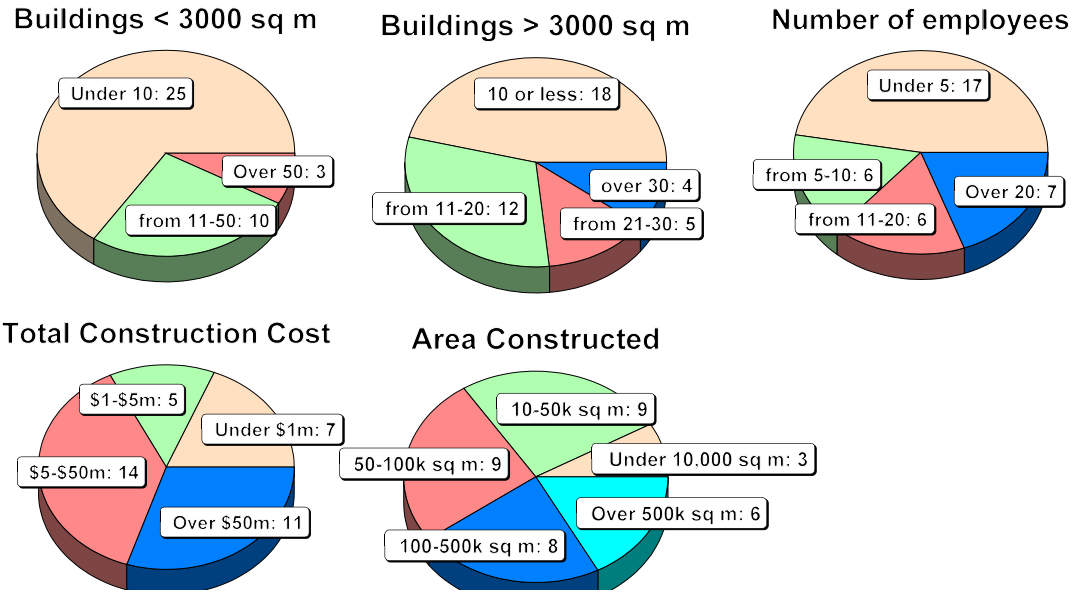

Figure 66 USA Survey: Characteristics of the Participants' Firms - including total cost and area of buildings constructed in past year

Apart from noting that the firms are relatively small, and that they each were involved in the construction of a relatively small number of buildings in the past year, there are no discernible

patterns in this data. Assuming that the centre value for the frequency "bins" within which the pie charts are arranged is actually the average, then we can estimate roughly how many buildings had been constructed by the USA Survey participants' firms in the previous year. (675 under and 520 over 3000 m^2). We can also use the same technique to estimate what total floor area these firms built in that time. This is approximately 6 million square metres. As approximately 100,000 million square metres were constructed per year in 1995, this represents a tiny fraction of even USA buildings.

Figure 67 demonstrates that the US Survey participants' firms are mostly involved in commercial office design, though there is obviously a wide diversity of other building types in which they occasionally become involved. For the NZ Survey, excluding inspectors and building support people, the statistics for the Construction Industry read as follows:

$0-$1 million	$1m-$5m	$5m-$50m	$50m +
7	24	32	4

Table 0 details the number of people in each group of practitioners in the NZ Survey who said that they had any involvement with buildings of the given types in the last 12 months. The numbers show the number of each group who had dealt with the given building types. Thus the answers in the table do not give an indication of the amounts of work each individual did in each different type but they give the range of work done. For example there is no distinction between some one who did 50 houses one office and one factory, and someone who may have done 20 of each.

The commercial buildings are also important in this group. However, residential buildings, particularly detached, and multi-unit dwellings are more significant in this NZ Survey group than for

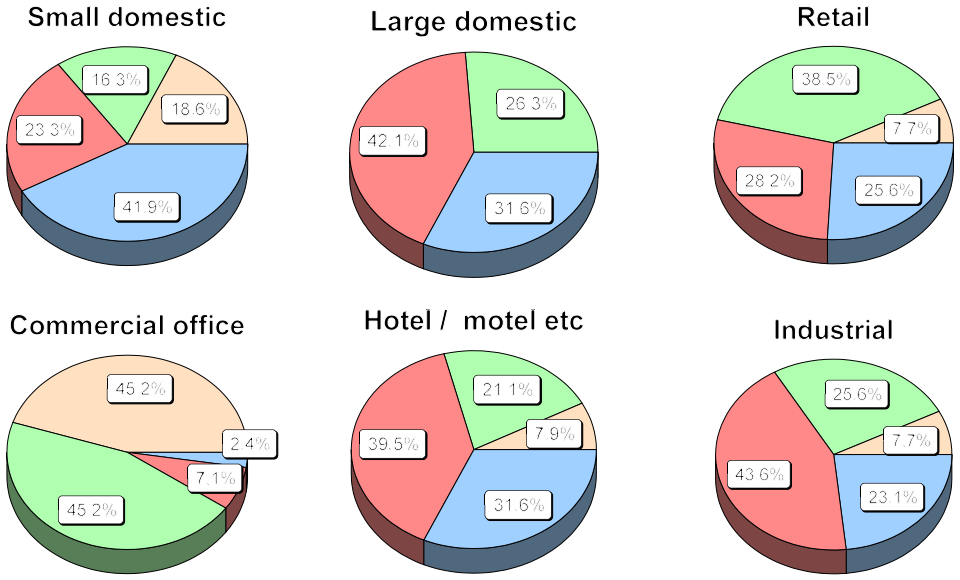

Figure 67 USA Survey: Building types in which participants' firms were involved in previous 12 months

the USA Survey participants. Looking at **Figure 59**, the graph of the data in **Table 6**, we can examine whether it is the presence of architects and builders in the NZ Survey group that makes its responses different from the USA survey group. It is quite clear that the pattern of building types for the engineers within the NZ Survey group is quite different from that for all the other construction industry "players" surveyed. The most striking difference is in the relative importance of detached dwellings for engineers by comparison with any of the other groups. Apart from this, what the graph demonstrates is that each group had a very distinctive pattern of building types that it worked on in the year leading up to the survey. The numbers in each cell in the table are too small to enable a statistical analysis of the significance of the differences.

Buildings types by practice type						Construction industry total
Frequency	Developer	Builder	Engineer	Architect	Designer	
Det. dwelling	11	10	5	15	11	52
M-unit dwelling	6	5	3	11	8	33
Group Dwelling	0	1	3	5	0	9
Com residential	1	2	3	7	3	16
Com. non-res	0	5	4	8	1	18
Commercial	6	9	11	13	9	48
Industrial	5	6	10	8	7	36
No. surveyed	13	15	12	16	11	67

Table 6 NZ Survey: Responses according to the type of buildings built in last 12 months

The overall pattern of the distribution is: 20% of survey participants are involved only with domestic buildings; 55% are involved with a mixture of both commercial and domestic type buildings; and the final 25% do no domestic building.

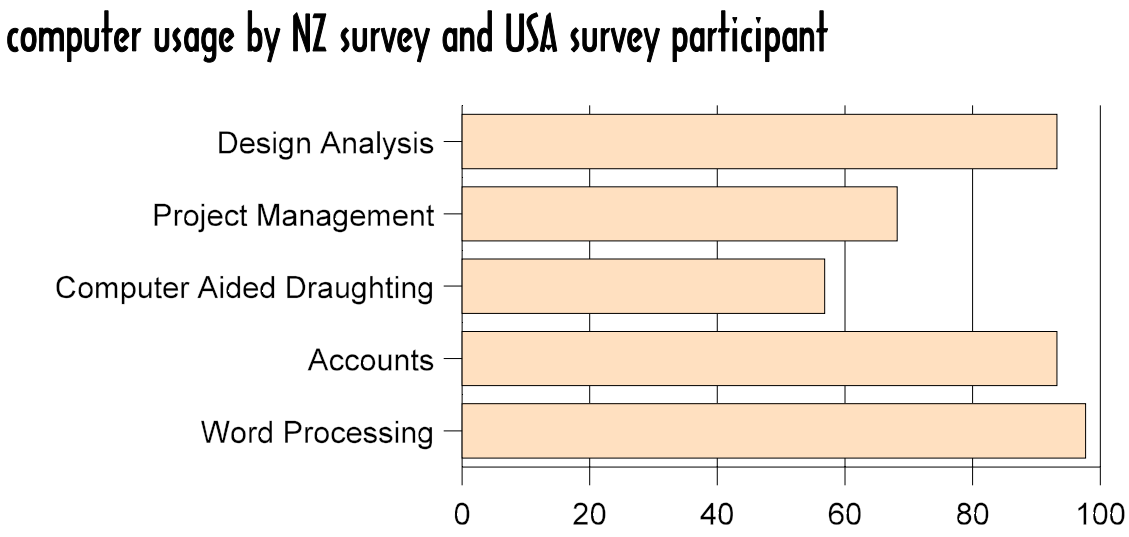

Figure 69 USA Survey: Use of computers within participants' offices

There is a marked difference between the usage of computers in the firms surveyed in the NZ Survey and those in the USA Survey. **Figure 69** shows that most of the 44 USA Survey responses indicate a high usage of computers in all facets of the firm. At 25, even the lowest response, for use of Computer Aided Draughting applications, represents over half the firms involved in the survey. Contrast this with the data for the NZ Survey in **Figure 68**. In the NZ Survey, the primary purpose of the question about computer use was to determine whether or not it is realistic to require the use of computer based energy efficiency compliance programmes in the New Zealand Building Code. Questions regarding software use give an indication of the level of expertise possessed within each company, and an indication of the difficulty that they would experience if asked to use software packages for energy efficiency compliance.

The USA Survey participants reported that they all use computers, whereas 9 (13%) of the NZ

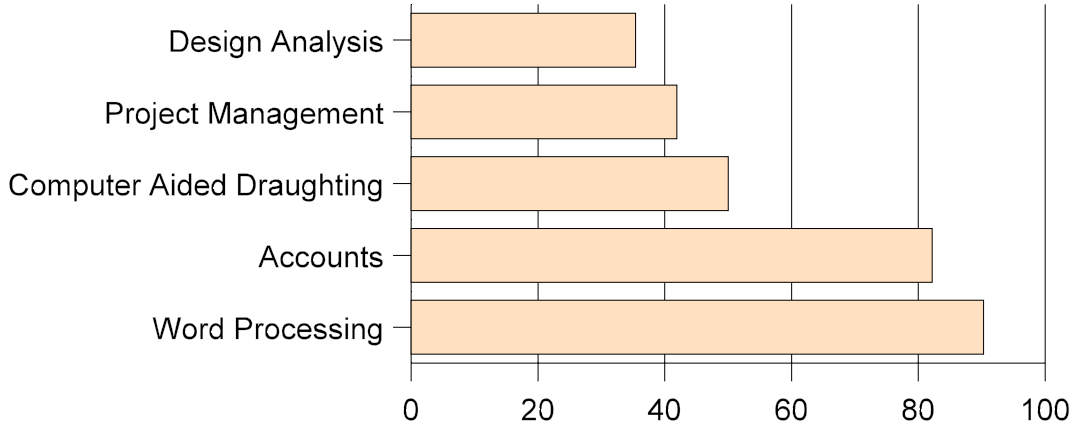

Figure 68 NZ Survey: Use of computers within participants' offices

Survey participants responded that they did not use computers.

7-1.7 use of design tools - training and preferences

The USA Survey asked three general questions about participants' use of building performance simulation. Question 14 asked about training; Question 15 asked how easy the simulation programs are to use; Question 16 asked which of four different *types* of design decision support tool (text book, calculation charts or simulation programs) were preferred by the participants. These had no specific correlates in the NZ Survey.

However, there were similarities to questions 18, 19 and 21 in the NZ Survey which were addressed to the use of "design aids/tools" to demonstrate compliance with NZBC Clause H1. Only the responses to Question 18 (*What training has the user had in the design aids/tools?)* Can be compared to the USA Survey responses. Because simulation programs do not appear in either of NZ Survey questions 19 or 21 the responses to them cannot be directly compared to USA Survey responses.

Given that the original goal of this research was to determine some common approaches to the construction of effective eddst's for use in architectural design, it seemed that this set of questions might reveal a correlation between successful tools and training. As will be noted later, such correlations proved to be irrelevant to the conclusions of the research.

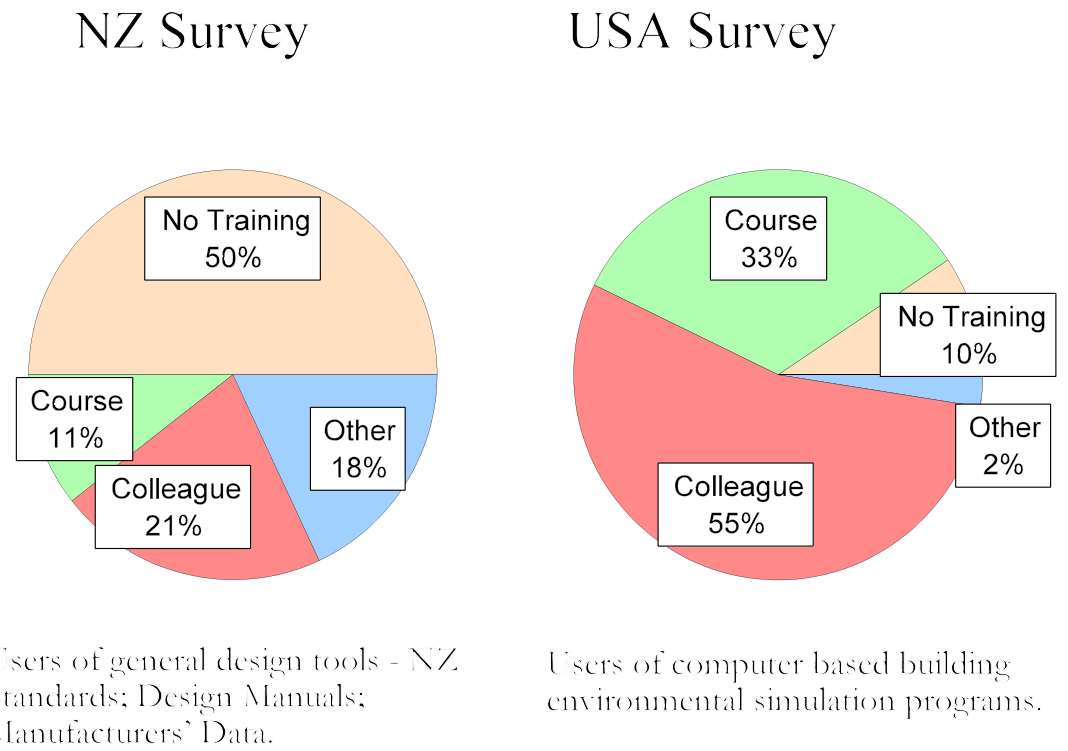

Figure 70 Both Surveys: Training of users of design tools

training

All but two of the USA Survey participants responded to the question about training in the use of the simulation program they nominated. Almost all of them (88%) had received some training. One third had formal training through taking a course. Over half had received *training* or at least assistance in learning from a *colleague*.

Although the topic of the New Zealand Survey question was more general, it is still instructive to compare the responses with those from the USA Survey. As can be seen in **Figure 70** only one third of the NZ participants had received any training. In fact, only one tenth of the participants had done any course on the design decision support tools that they used to demonstrate compliance with the building code.

ease of use of simulation programs

From **Figure 71** we can see that the USA Survey participants are equally divided over the ease of use of the environmental performance simulation programs they employ in building design.

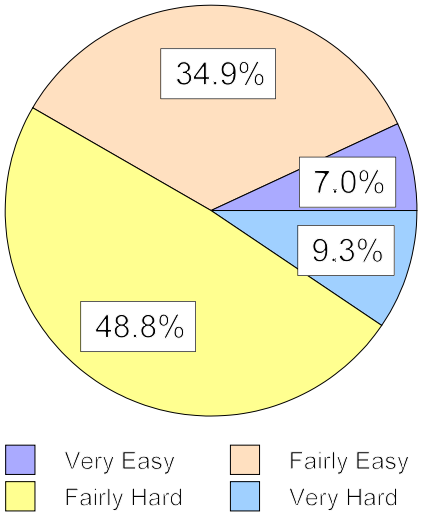

Figure 71 USA Survey: ease of use of environmental programs

preferred type of design decision support tool

The final question in this set of three examining the use of building performance simulation is the most revealing of general attitudes to design decision support tools. The goal was to establish the participants' attitudes to design decision support tools. By asking people to describe what type of tool they would find helpful in *the production of more energy efficient buildings* I tried to get them to express a view as to what type of information they considered useful. While their responses are of course coloured by their experience of each type of design decision support tool, they do give a good indication of what medium they prefer for delivery of environmental design advice when actually

working on the design of buildings. My aim here was to test the hypothesis that simulation of environmental performance has the greatest practical potential of any option at providing useful advice for a building design team. The USA Survey participants' responses are valuable because they are based on direct experience of simulation program use as well as all the other means of estimating building performance.

Figure 72 shows the USA Survey participants like all four of the options offered. The positive responses outnumber the negative. Very few respondents see any of the types of design decision support tool as *never* helpful. Savings estimators like charts and tables for use with calculators and their spreadsheets equivalents are least liked of the four options. However, a very high 79% of these participants responded that simulation programs would *help a lot* and *none* of them see such programs

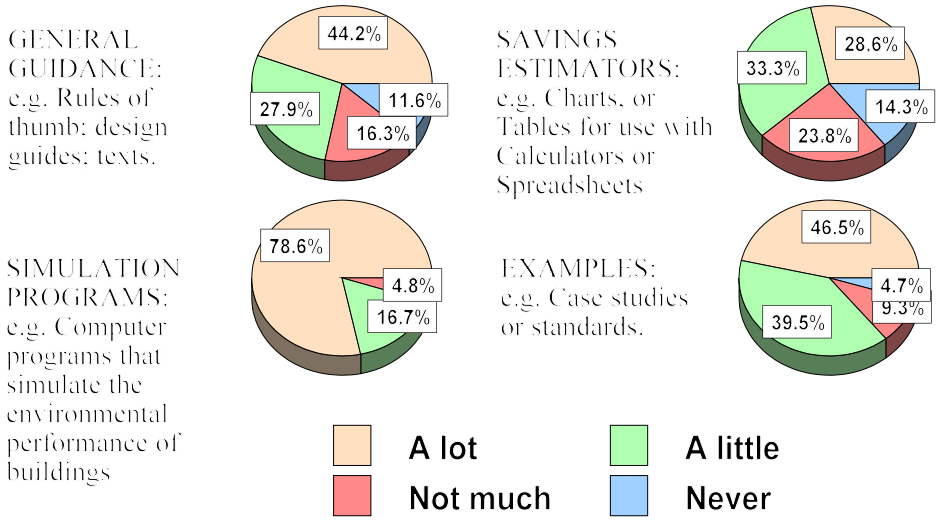

Figure 72 USA Survey: Preferences in type of design tool

as *never useful*. The pre-selection of simulation experts to survey seems to have found people who not only use simulation in their everyday practices, but also see a high value in continued and expanded use of simulation in building design. Whether their motivation is monetary (*more simulation is more design fees for them*) or altruistic (*they simply believe that simulation produces better designs*) is unknown.

other energy design decision support tools

Three questions were asked of the USA Survey participants about uses of design decision support tools other than the thermal performance simulation programs that were the central focus of the survey questions. They were asked *how often they tried to integrate daylighting or lighting with the thermal design*; *whether they used industry supplied HVAC or lighting programs for sizing equipment;* and *what equipment sizing design aids or tools* they use in addition to the thermal simulation program that was the subject of the survey.

Over 65% of the respondents *Always or often* tried to integrate daylighting and or lighting with the thermal design of the building. Only 4 (10%) *never* tried to do this. By contrast, a quarter of the respondents *never* use any other computer programs for sizing of HVAC or lighting equipment.

Among those who did use other equipment sizing design aids, there were 14 different programs or routines in regular use. Only two were widely used: 11 (25%) of the respondents reported using ASHRAE sizing routines; 6 reported using the Carrier company's program(s). The rest of the programs ranged from equipment component (duct, coil, burner) sizing programs to the lighting design programs SUPERLITE and GENESYS.

7-2 USA survey questions about simulation

For this thesis, questions 20 through to 43 of the USA Survey were the most important part of either the USA or the NZ survey. That importance arises because they address directly the properties of current simulation programs and the way in which the respondents use them in design. Therefore, they allow the analysis to examine the use of these programs in design from the point of view of simulation experts. They permit establishment of the state of the art in current application of simulation in building design. They enable us to look into the future and see what developments in simulation would encourage more widespread use of simulation as a tool for improving the environmental design of buildings.

Several of the questions were difficult to write in a simply quantifiable form so they were written open-ended. This has necessitated a textual analysis, with no statistics or percentages, just "summary quotes" "(highlighted in the text with this typeface)" .

The 24 questions can be divided into a number of categories:

- questions 20 through 23 establish the experience and expertise of the respondents;
- questions 25 through 27 examine the types of answers that clients want simulation to answer;
- questions 29 through 35, plus 42 and 43 explore the levels and types of customisation of the simulation programs that these experts use to obtain the answers in the format that they require and to communicate them to others;
- questions 36, 39 and 41 examine the means by which the users control the match between the simulation model of reality and the real world;
- question 37 asks when in the design process simulation is used by the respondent;
- question 38 looks to find out what three priority goals the respondent would suggest for an education programme which wished to teach new users of simulation programs;
- question 28 asks *what changes or improvements* the participants would like to see in the simulation software and question 40 asks *what single improvement in the computer simulation program* they would choose;
- question 24 was added at the request of my hosts at LBL to allow further extrapolation of the savings data they have accumulated already expressing the impact on the USA economy of the DOE2 program.

Each of these groups of questions is examined in a separate subsection of this chapter on the following pages.

7-2.1 experience and expertise of the users

These questions were intended to determine to what extent computer based thermal simulation was used as a design decision support tool by these simulationists. Thus it sought to ascertain the level of expertise, the types of applications and the motivations for use of thermal simulation.

38 (88%) of the 43 people who responded to Question 20 had more than three years experience with the application of simulation programs in design. 38 respondents also noted that they used simulation "on every project" (8 - 18%) or "regularly, but not on every project" (30 - 70%). The reasons for undertaking simulation analysis on buildings were mostly because the respondent was "commissioned to optimise the design" for the client or was "part of a utility company's Demand Side Management programme" . 65% of respondents said that "Most" or "Some" of their use of simulation in buildings had been for optimising the design; 72% of respondents said that "Most" or "Some" of their work was because they were part of a DSM programme.

Other rationales for the use of simulation were also explored. 71% of the respondents noted that for them, receiving a subsidy for doing a simulation was never a reason for their involvement. Doing Government (Federal Energy Management type) projects was never a reason for using simulation for 50% of the respondents.

Question 23 sought to ascertain what are the primary purposes for using performance simulation in building design. It asked participants when they "use ...[their selected simulation program]... how often did they use it for building design optimisation; building envelope option selection; equipment optimisation; equipment option selection; equipment sizing" . In my experience of the telephone survey, there was a little confusion in the participants' minds about what distinction there was between "option selection" and "optimisation" for the building design and equipment design operations. My purpose was to distinguish between simulation to optimise the building or equipment design where the simulationist had a free hand from merely providing a set of data to enable the designers to select which of the options they were interested in had the best performance.

No simple conclusion is suggested by the information in **Figure 73**. The participants are no more likely to use simulation for equipment sizing and selection than for equipment or building design optimisation or building option selection. 60-80% of the participants responded that they performed "Most" or "Some" of their simulations for all but one of the purposes listed in the question. Even for that other option, "equipment sizing," 54% of the participants reported that they used simulation for this purpose "Most" or "Some" of the time.

7-2.2 types of answer clients seek from simulation

The purpose of these questions was to tease out what processing simulation data might require to translate it for clients. It was prompted by CBPR experience with the mis-match between the data

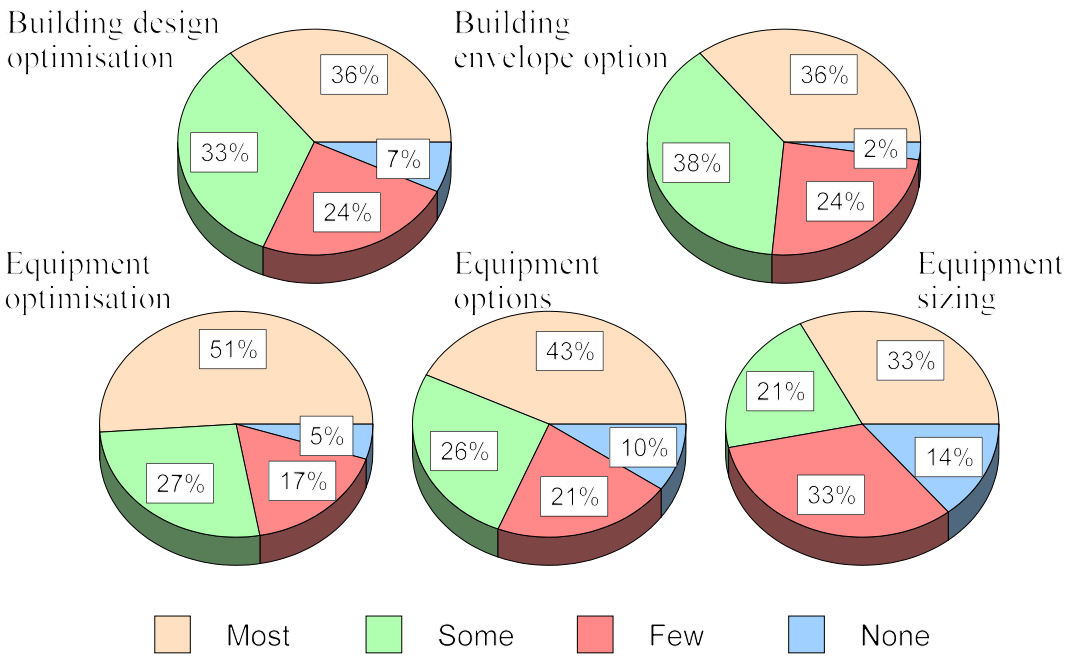

Figure 73 USA Survey: how often is simulation used for optimisation or option selection?

that simulation produces and the interests of clients. The questions asked how often clients were interested in the results of simulation and what aspects usually interest them.

Two of the questions addressing this issue were open-ended. This carried the risk with a small sample that there would be no discernible pattern in the answers. It also made the analysis much less straightforward than the ticks in boxes approach of most of the other questions. The reason for selecting this approach for these questions was that I had very few pre-conceptions as to what might interest the participants' clients .

There was apparently an even spread in the interest level of the participants' clients. Only 2 reported that their clients are *never* interested in simulation results. 17 (40%) of the participants reported that clients are *Sometimes* interested; 13 (30%) and 11(26%) reported that their clients are *Often* or *Always* interested. It may seem pedantic to ask about the client's interest, when they presumably are paying for the simulation analysis. However, the purpose was to ascertain whether clients were interested in the simulation data or just in the recommendations that result from interpretation of it. The answer is conclusive: clients take an interest in the simulation output.

The responses to the question about what interests clients were much more prosaic than expected. The CBPR experience that had generated the questions was that clients were less interested in annual

energy use predictions than they were in the risk to their comfort or their business efficiency. However 68% of the responses referred to *bottom line costs* as the aspect that interests clients. *Cost savings* and *Economic benefit* were referred to many times. Only one other aspect received 5 "votes", the rest of the aspects of interest to clients were referred to by 3 or fewer participants.

Some interesting comments were made, but by a minority of the participants:

- *sometimes a client is interested in functional energy use with respect to occupant comfort*
- *15% of clients are architects and* [they] *have an overly romantic notion of what is possible* ""
- *interested to the extent that if they get a law suit then a reasonable or good method has been used.*

When asked what options their firm would like to explore, the participants provided a much more varied response: *Costs* were still referred to most often (38%). However, 12 (29%) participants referred to building design options (e.g. *Effect of design changes* or *parametrics* or *verification of viability of exploratory design solutions*). A further 10 (24%) participants referred to specific Energy Conservation Opportunities like daylighting, night ventilation or control strategies as what they were most interested in.

Again, the opportunity to write more full responses elicited some interesting comments:

- *owners in Demand Side Management as indirect clients are really after improvements in building for free - [they] don't care intrinsically about better performance or equipment. Only do something because utility is putting up the dollars.*
- *the simulation part of the business is dying as energy code becomes harder to satisfy.*
- *many consulting engineers use the program as a come-on to demonstrate their expertise to the client.*
- *every engineer or scientist feels that they are providing the greatest good when dealing with a genuinely difficult problem. ... want to be convinced you've done a decent job of comparing alternatives*

7-2.3 customisation of input and output of simulation

The greatest level of understanding of the potential of simulation in design is demonstrated when one starts to customise it in order to move beyond basic mode. These responses also have the potential to reveal to what extent the basic operational mode of thermal simulation computer programs actually provides design decision support. Ultimately it was thought that these responses might also point towards needed developments in future versions of the Graphic User Interfaces to the programs.

The patterns of participants' responses to questions about customisation of the input and the output of simulation programs are very close. The largest response (36-38%) for both is that they *Sometimes* customise. Responses are evenly spread across the other categories of *Always, Frequently* and *Never*. As the *Never customise* option amounts to less than 25% of responses to either question, we can conclude that for 3 in every 4 users of simulation programs, the standard output or input is insufficient for their analysis purposes.

For the output customisation, a supplementary question was asked. It sought to find out ***whether there are particular circumstances when [the respondents] would customise the output of***

design simulation. None of the 14 responses to this question revealed anything about these circumstances. It is interesting that, instead, the replies mostly described the type of customisation undertaken, rather than why the customisation was needed. The type of input and output customisation used by participants was explored more fully in separate questions.

Question 30 asked how often participants would use one of seven different customised input procedures. The titles of these were left relatively wide so as to allow a wide interpretation by the people responding. They read:

4) ***The weather data;***
5) ***The building envelope (walls, roof, floor) description***;
6) ***The window description***;
7) ***The air infiltration levels***;
8) ***The users' schedules***;
9) ***Light & office equipment schedules***;
10) ***The HVAC services description***;
11) ***Other parameters....(SPECIFY) ...***

This question generated a number of clarifying queries during the telephone interviews. Essentially, people wanted to clarify whether entering one's own data for the U-values of a wall construction or the transmissivity of a glazing material counted as *customisation*. The answer was no. What I was seeking to find out was whether the building modelling capabilities provided by the simulation programs were adequate for the users. There was less potential for this confusion with the mail survey because the lengthy questions could be reviewed more easily than is possible over the telephone.

For approximately half of the participants, customisation was rarely or never undertaken across all categories. 35% of the 37 respondents *Never* customised the weather or the air infiltration input. It seems that the standard simulation tools are adequate for many simulations, but over half the participants would *Always* or *Sometimes* customise the input in order to improve the match between reality and their simulation model.

15 (41%) of respondents said they would *Always* customise Users' and Light and office equipment schedules. Two people noted under *Other* that they would customise simulation input in order to include *Daylighting* in their analysis.

Interpreting Question 34 about the type of output customisation was simpler because the abbreviated labels used in the question seemed easier for the participants to understand. Participants were asked how often they used any customisation in the following list:

1)	***Graphing the output data;***	***5)***	***Correlate input and output;***
2)	***Statistical analysis of output;***	***6)***	***Compare with "ideal" indices;***
3)	***Economic analysis of output;***	***7)***	***Other ... (SPECIFY)***
4)	***Generate comfort indices;***		

As **Figure 75** demonstrates, there was a wide range of responses to this question. For example, most people *graphed* the data output at some time or other. In fact 41% of them *Always graph the output*. By contrast 67% *never* calculate comfort indices. A surprising result for me was that statistical analysis was so little used. The picture that begins to arise from these responses, when combined with the responses described in earlier paragraphs is of a group of consultants who routinely study for clients what the capital and running cost options are for the HVAC equipment in their buildings. They can do more, but normally are not required or paid to do so.

Two final open ended questions round out the questions directly related to customisation. Again these reveal a wider range of opinions than the multi-choice, easier to analyse questions have. In each question, the participants were asked ***Why*** they customised particular ***inputs*** or ***outputs***.

31 people responded to the question of ***why customise input***. 27 people responded to the question about ***why customise output***. Of the 31 people, 17 of them indicated that they customised the input to better match the model with reality: *to more adequately simulate predicted building operations*. Interestingly two commented that they customised *primarily because this was how I was taught to do it.* One of these added that it was *habit evolving into philosophy.*

Amongst the 27 who responded with reasons for customising output, 13 did so because it allowed them to do custom chart (graph) making and to enter into spreadsheets for report writing or further analysis. 8 others customised output in order to debug the model or to assist with quality control in some unspecified manner.

Question 42 sought to understand whether simulationists felt the need to explain to their clients the nature of the relationship between reality and their one-time analysis for one particular "year" of weather data. Clients often want performance guarantees that simulation cannot provide without further analysis of the output and input data. 43 people responded to this question. Only 4 *Never* had to *interpret the results* [of simulation] *to assist* [clients] *to understand or use them appropriately*. 26 (60%) *Always* or *Frequently* had to do this.

My final question about customisation related to the rationale behind customisation of output (See **Figure 74**). The question pointed out that often simulation output is trivialised by being reduced to one single data point - a lone energy performance figure expressing the annual energy use of a

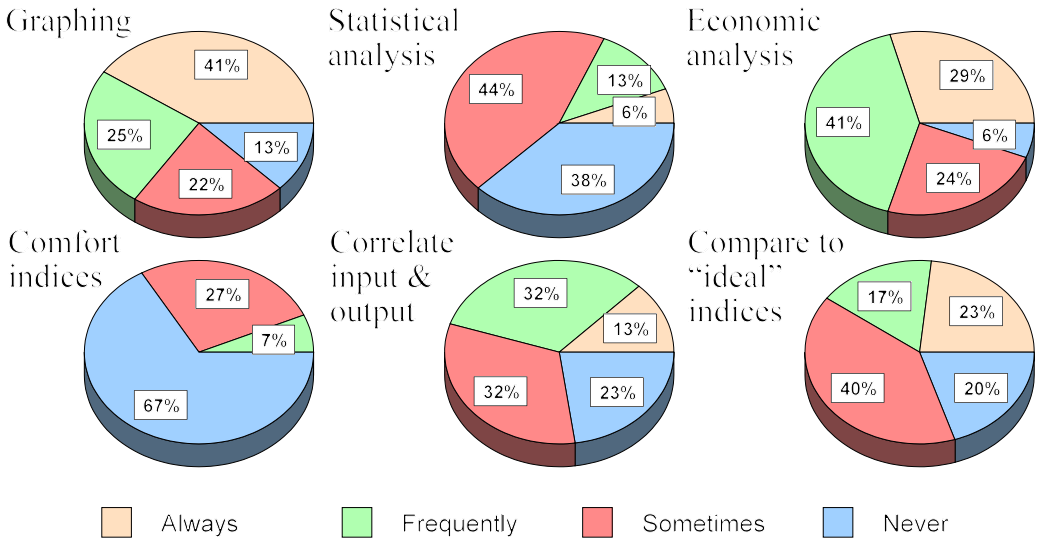

Figure 75 USA Survey: Frequency of use of customisation of output from simulations

building design. Participants were asked how often they used one of four techniques to incorporate into their design reports the ***rich availability of data typically produced by simulation***?

Graphing of the output is the most consistently used post-processing method used by participants. Both the first two options described types of graphical analysis: *Simple graphing* of the output is *Always* or *Frequently* used by 50% of the participants. ***Post-processing in order to demonstrate a principle by say plotting several simulations on one graph*** is used *Always* or *Frequently* by 50% of the participants.

Statistical analysis of the output or ***formatting the design report to highlight the seasonal or hourly variations of comfort or performance*** are rarely performed. For example, 81% of the

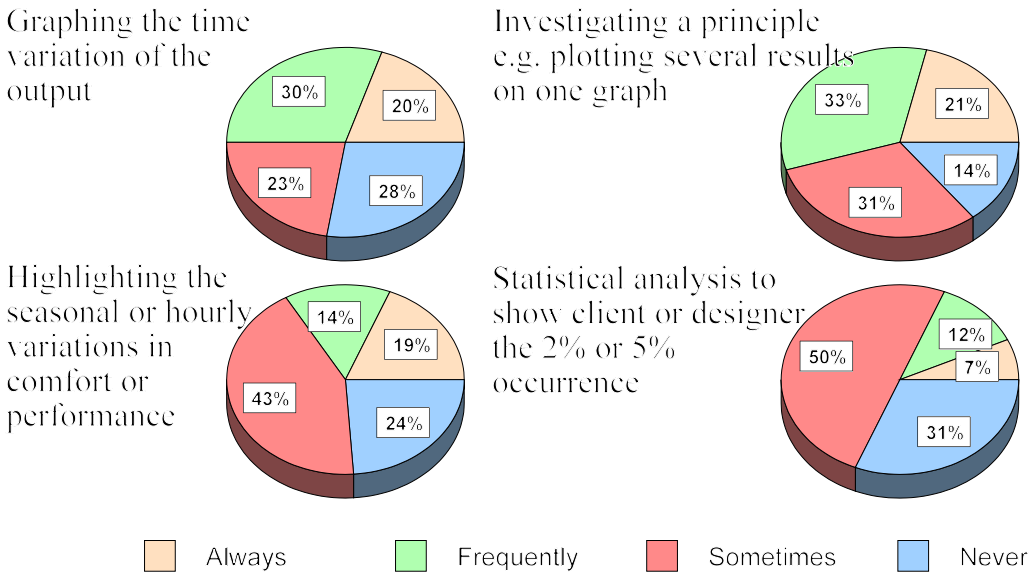

Figure 74 USA Survey: How often do you use post-processing of simulation output?

participants *Sometimes* or *Never* use statistical analysis.

7-2.4 techniques used to match reality and model

Question 36 asked directly what ***Quality Assurance*** processes the participants used to ensure that the simulation software produces reliable results. Question 39 offered a range of modes of working that are designed to ensure that the simulationist and the architect are working on the same design and asked how each matched the mode used by the participants. Question 41 addressed the techniques used by the participants to simplify the process of creation of a simulation model. Each question therefore sought feedback from participants on what techniques they used in simulation modelling to ensure that they created efficient but accurate models of reality.

Question 36 was open-ended because I was unsure that I knew enough of the possible Quality Assurance procedures to be able to create a useful set of categories for analysis of the answers. 40 of the participants responded to this question. Two of the responses were that the respondents had no formal QA procedures. All the telephone interview respondents commented that they had no formal QA procedures. They especially noted that there were no written procedures that they could provide as examples. The largest group of respondents used various other calculations to measure the simulation output. Rules of thumb, libraries of systematic simulation *studies of a range of buildings in different climates for policy development purposes*, spreadsheets *based on other methods* are all used as standards against which to measure the output of their simulations of building performance. The following comments demonstrate what these respondents do:

- *Rules of thumb*;
- *generated a bunch of tables using typical building for 15 building types and 8 climate zones - have from this a 2cm thick set of tables showing x building: y zone: z energy measure: versus yields*;
- *we have routines that collect under heated hours - synopsis of these for 100-300 zones shows errors*

The next largest group of participants (32%) reported that their form of Quality Assurance is to "eyeball" the data. Statements like "reality checks" and "we graphically review our data" abound. Typical of this group are comments like:

- *engineering judgement*;
- *scrutinise the output (e.g. hourly values) to check behaviour - does it look logical or reasonable?*
- *eyeball the demand on say the coil - if greater than or equal to the load then check*;
- *sanity checks - experience tells you whether x per square foot is OK.*
- *intuition, though unreliable when results not intuitive, is used.*

There was also a large group of people (22%) who compare their simulation model with monitored data for the building they are modelling. These people are involved in energy conservation studies of existing buildings and are using simulation to study equipment options for the refurbishment.

Question 39 asked how well 7 different modes of working matched those of the participants. The results seem to indicate that the most common modes of working are the standard modes of the

individual firm working as consultants to the building design team and communicating with them through regular meetings and exchange of drawings. The only two categories of response that more participants than not stated matched their mode of working were the options of ***Exchanging drawings regularly*** and ***Formal design team meetings***. Some people saw ***Electronic drawing exchange*** - matching *Exactly* (15%) or *Fairly well* (20%) their mode of working. Formation of ***project design teams*** by amalgamating personnel from several different practices in one office, or just membership of a ***multi-disciplinary firm*** are both rare. Also rare are ***weekly*** or ***daily*** team meetings. 26 (67%) of the participants saw weekly meetings as *not well* or *not* matching their mode of working; and 35 (88%) of the participants saw daily meetings as *not well* or *not* matching their mode of working.

There is nothing in any of these answers to point to any major degree of innovation in the mode of working.

Question 41 offered a set of four very different options which were described at length. The participants were asked to select from the list, techniques which they used to ***expedite the simulation process and thus provide the design team with timely answers***. The options offered were:

- ***Use an abstraction of the building design as a first approximation (say a one zone building in thermal design - or roughly equivalent opening areas, with no window details in daylight design)***;
- ***Run the simulation for typical days or times that enable you as expert user to interpret the full year or inter seasonal performance***;
- ***Used approximate materials properties or library values that are close to but not the same as those specified to speed up data entry***;
- ***Modify previously used model***.

Three of these techniques are used *Frequently* or *Always* by most of those who responded to the

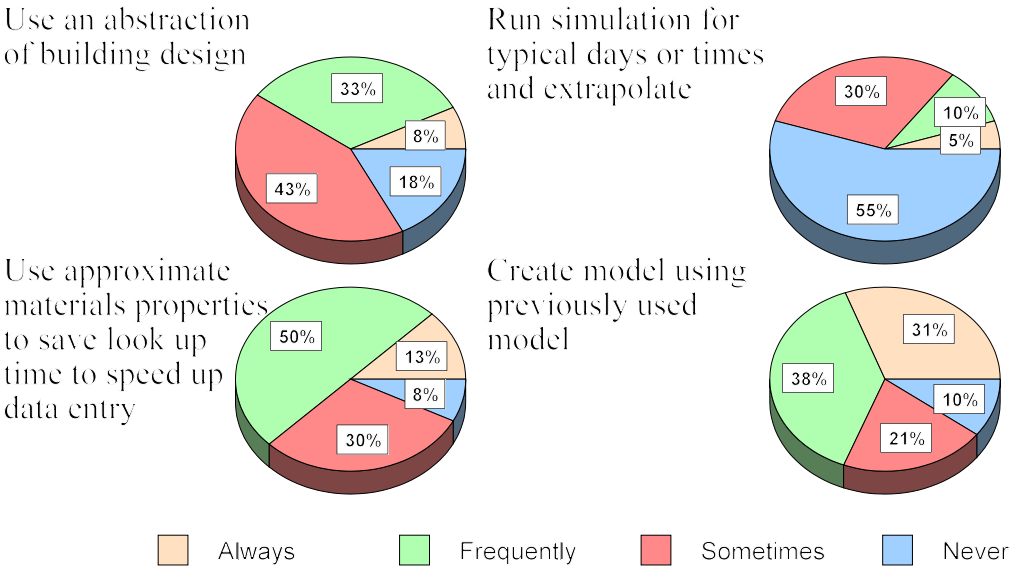

Figure 76 USA Survey: How often did you use one of these techniques to expedite the process of creating a simulation model

question (See **Figure 76**). 55% of them report that the fourth technique - ***running the simulation for typical days or times*** is something they *Never* do. In the past this was a common technique because the calculation time for the actual simulation was several hours. It is apparently less necessary now because the computational time for the computer simulation has shortened with recent increases in computer speeds. What takes the time now is the creation of the simulation model itself.

7-2.5 stages of design process that simulation advances

Question 37 asks ***at what stage in design the participant seeks results that can be used in design***? Four options were offered. Three referred to the conventional stages in design: ***Preliminary, Design development*** and ***Working drawings***. The fourth option offered the participants the opportunity to point out that their design process was different to this convention. Many of the 44 participants in the survey ticked more than one of these options following the ***Code all that apply*** instruction. 32 selected *Early or preliminary design*. 30 selected *Design development*. And 21 selected *Working drawings*. 17 of the participants selected all three of these options. 8 of them selected just the first two options. A further 4 participants ticked only option 4: *none* [of these design processes] *design process different*.

This question refers directly back to the issues raised in the introduction to this thesis. Specifically, it tackled the idea of the current suitability of computer based thermal simulation to design decision support particularly in the early phases of the building design process. What is most intriguing is that the conventional notion of thermal simulation being unsuited to these early phases of design is clearly turned on its head by this research result. The reality of practitioner use is that although it is used by many in all phases of the design process, the preponderance of usage is already in the early design phases.

7-2.6 improvements to the software

The question of what the participants would like to see by way of improvements to the simulation software they use was asked in two different ways. Both were open-ended questions. Again, the goal was to extract information on users' needs and desires for software improvement without feeding them what limited improvements I might be interested in. The purpose of a second question on the topic was to elicit the priorities the participants had for the changes they were suggesting as well as generating a "laundry list" of changes. The questions therefore asked first in Question 28 ***what changes or improvements*** [participants] ***would like to see*** in the building performance simulation software; then Question 40 asked what ***single improvement*** participants would like to see in the software.

17 of 42 (40%) respondents' answers suggested improvements were required to the User Interface. A Graphic User Interface (GUI) with windows and mouse control was most often suggested. When

asked for a single change, 27 of 38 (71%) respondents placed a GUI top of their list. There was no general agreement on how the user interface might be better improved as this selection of comments from this group in both Question 28 and Question 40 indicate:

- *more friendly to the user* (#28); - *user friendly interface* (#28);
- *make the reference material more accurate and simpler to understand* (#40); and *most documentation stinks - vast improvement possible* (#28); *better visual link to the building shape / configurator* (#28); *ability to extract data from CAD drawings* (#40); and *easier to model buildings in schematic design phase*;(#28)
- *customised defaults and schedules* (#40); and *different levels of simulation for different stages of design*; (#28)
- *self checking routines to flag HVAC system errors*; (#28) *and more descriptions with libraries so when call out a system or plant pull out whole text description of file*; (#28)
- *I would like it to be easier to determine the interrelation of an input in one area of the program on the calculations in other areas*;(#28) and *error checking of interaction of components - e.g. warnings of things that don't make sense together*; (#28)
- *I would like [all programs I use] to ... know me and the way I work - from data entry to format of help file: if I start repeating a process, I want the program to assist (to anticipate)*; (#28) and *BDL writers currently will produce a new bdl file well, but when you make changes they have problems*; (#40)

The other significant group of respondents sought changes in the modelling capabilities of the software. The suggested changes ranged from improved physics to additional models of components. An attempt was made to group the suggested changes in modelling capability to ascertain what was collectively viewed as important:

- building physics changes such as *a better ground coupling algorithm* (#40); and *better "passive solar" or heat storage of various building materials* (#28);
- additional building model features such as: *air transfer between zones* (#40); and *relation between air infiltration and system air movement*; (#28)
- additional plant modelling capabilities such as: *keeping up with new technologies especially on the air system side*(#28); and *direct modelling of ground source heat pumps* (#40);
- better modelling of control systems: *accurate modelling of control strategies and sequences* (#28); and *a simple way to model part load performance*; (#40)

(None of the other suggested changes could be organised into groups bigger than 7 (18%).

The individual responses still reveal some intriguing insights:

- *Get DOE2 group privatised - working for us the users. Lot of DOE sponsored work on DOE2 is making new models rather than making what is there work better (without holes). ..Half our costs are in working on the 10% or the program that does not work well... Users don't have a say in what the DOE2 group does* (#40)
- *Integrated Quality Control and Help reference*.(#40)
- *DOE requires a cumbersome non-intuitive way of working [due to].its data structure: e.g. specify fan/chiller in four different places; DOE2 engine suffers through being written by scientists and engineers*;

7-2.7 education of users of simulation programs

Participants were asked what (three maximum) ***priority goals*** they would set if they were designing an education programme for ***new users of simulation programs***. The subtext of this question was

to gather more information about what aspects of simulation of building thermal performance were, in the opinions of these expert users, the most difficult to understand or to do. Again, this question was made more difficult to analyse because it was an open-ended question. I had no idea what these people might decide would be the areas of simulation that were most difficult, nor did I wish to pre-determine their responses with my own labels or classifications.

39 people responded to this question. Very few offered only one goal. Amongst the responses there were three groups of response that were numerous: one group with 18 responses addressed issues of Quality Control, Calibration of the model and techniques for efficiently modelling reality; a second group with 15 responses talked of similar issues to the first but essentially sought to teach Scepticism - a distrust of the Black Box simulation program; and the third large group of responses (14) wanted to make sure that the users understood the basics: they were split evenly between those who saw understanding of the algorithms used by the program (7) as important and those who saw the basics of Building Science - how a building and its HVAC systems work - as important (7).

The following priority goals for illustrate the wide ranging views expressed by participants on the subject of education of simulationists:

- *understanding of context and limitations of simulation*;
- *ability manipulate simulation features to produce valid and useful design information*;
- *concepts and relative accuracy of modelling (what is and isn't important)*;
- *for graduate class: how simulation works so they understand why something goes wrong; for extension class: make sure they can run the program when they leave*;
- *teaching fundamentals of building energy use as opposed to how to use the tool itself*;
- *teach scepticism*;
- *what combinations of input typically give problems*;
- *correct interpretation of drawings for quantity take offs and equipment sizing*;
- *students know envelope issues well, but not how systems interact*;
- *stochastic versus deterministic - there are all those questions about confidence levels*;
- *rules of thumb - with caveats on applicability are useful*;
- *leave students with usable templates for data input*;
- *the program itself has a teaching or instructive role*;

7-2.8 future design decision support tools

Both the NZ Survey and the USA Survey contained four questions which sought the participants' preferences as to the nature of design decision support tool they would like to be able to use to improve the energy efficiency of buildings. In the NZ Survey the questions were numbered 45-48; in the USA Survey, they were 44-47. The questions were expanded in terms of the amount of information they provided the reader in the USA Survey. **Figure 77** and **Figure 78** show the text of Question 46 in the NZ Survey and the corresponding Question 47 in the USA Survey. These two figures illustrate the changes that occurred between the two surveys. The change that will have influenced the replies received is the definition in the USA Survey of the design decision support tool as a ***simulation program***.

46 If you had a choice, would you prefer to use an energy efficiency design aid/ tool which:
1 □ - is only able to be used once all the dimensions of the building are known;
2 □ - contains sufficient best guess data that it can be used very early in the design process (when only building size and type may be known)

Figure 77 NZ Survey: Text of Question 46 - future design tool?

The analysis was intended to explore the following issues:

- The level of complexity (checklist / manual / computer) (NZ Survey Q45; USA Survey Q44)
- The place of tool in the design process (initial design / final design) (NZ: Q46; USA:Q45)
- The purpose of the design decision support tools (code compliance / general energy efficiency) (NZ: Q47; USA: Q46)
- The relationship to other packages (integrated / stand alone) (NZ: Q48; USA: Q47)

45 **If you had to choose would you rather use a simulation program as an energy efficiency design aid / tool which can only be used after all the dimensions of the building are known OR one which contains sufficient best-guess data that it can be used as an estimator early in the design process when only building size and type may be known?**
Only usable once all the dimensions of the building are known ..... □-1
Contains sufficient best-guess data for use early in the design process ..... □-2

Figure 78 USA Survey: Question 45 text - future design tools?

Results for the NZ Survey are listed in **Table 1** by design profession. Some respondents gave more than one answer, hence columns do not sum to the total number of respondents.

Preferred tool type	Developer	Builder	Engineer	Architect	Designer	Total
Checklist	10	8	5	11	6	40
Manual Calculation		3	2	2		7
Computer Calculation	2	3	6	4	6	21
Don't Know	2	1	0	1		4
No, Surveyed	13	15	12	16	11	67

Table 7 NZ Survey: Preference for type of design decision support tool

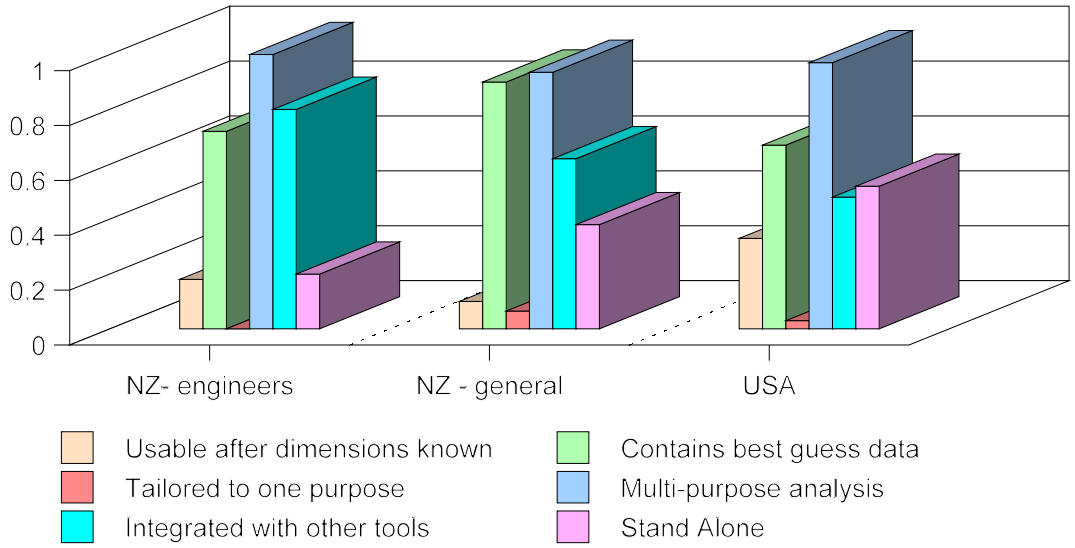

Figure 79 NZ and USA Surveys: Participants' selections of preferred qualities in design tools of the future

Most (95%) NZ Survey participants answered this question. With the exception of the engineers, most professional groups show preference for checklist type tools. Manual calculations were least favoured, with computer calculations coming second. The engineers favoured computer calculation over checklist tools. The designers were equally divided in preference for checklists and computer tools.

For the USA Survey, the results are slightly more complex because the participants could tick all options. The USA Survey participants are also much more like the NZ Survey engineers than any of the other user groups. Their preferences are charted in **Figure 80**. Clearly favoured by these regular users of simulation is simulation (64% said they would be very likely to use computer simulation as an energy efficiency design tool). After this result conclusions about preferences among the rest of the options are much more difficult to reach. ***Checklists*** and ***manual calculations*** are *very likely* to be used by 32% and 27% of the people who responded. Equal proportions of the respondents are *not likely* to use checklists and manual calculations.

The other three questions on the future of design tools were all simple selections between two options. The results for all three questions are presented in **Figure 79**.

The questions asked the participants to select between the options listed on each line of the legend. Thus the bars referred to by the first line of the legend report the responses to the questions in **Figure 77** and **Figure 78**. An overwhelming majority of the respondents (9 of 11 NZ engineers, 55 of 61 NZ building design participants or 27 of 40 USA participants) seek a design decision support tool which ***contains sufficient best guess data [that it can be] used early in the design process.***

The participants are even more convinced of the value of a general building energy efficiency design tool as opposed to a tool which has one purpose such as code compliance. All 11 of the NZ engineers favour the general purpose design decision support tool. Including the engineers in the

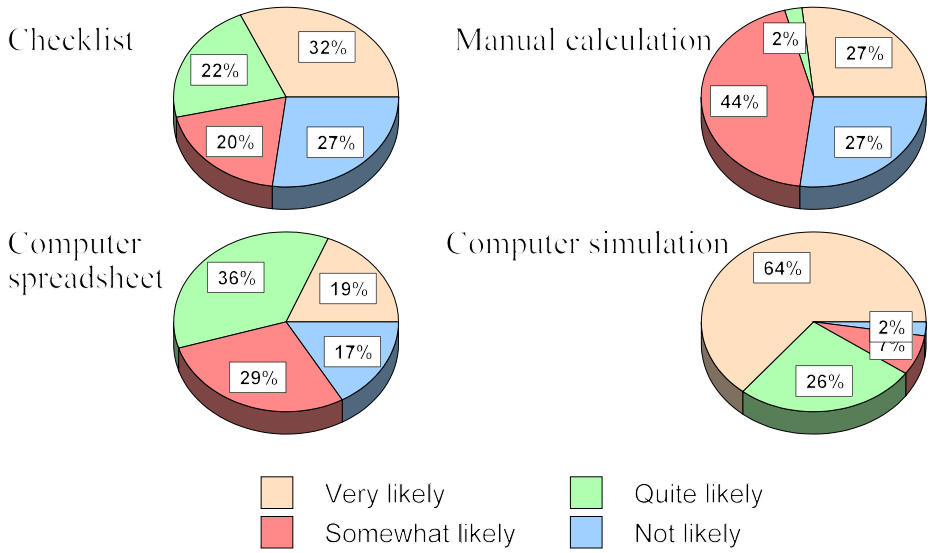

Figure 80 USA Survey: Likelihood of use of different types of simulation based design tool

total, 58 of the 62 NZ participants favour a general purpose energy efficiency design decision support tool. 39 of the 40 USA participants favoured this option.

The last of these questions about options for future design decision support tools is much less decisively answered by the participants. 10 NZ engineers vote 8 to 2 for an environmental design decision support tool that is integrated with other design decision support tools like Computer Aided Drafting (CAD) programs.

Including the builders and designers in this total sees the vote at 37 for integration with CAD and 23 for a stand alone product. The USA participants who are largely from an engineering background and are experienced users of computer simulation as design decision support tools voted 19 for integration and 21 for a stand alone simulation program.

7-2.9 users of energy efficiency design tools

The last four questions of the NZ Survey and the last three in the USA Survey ask what roles people from different professions using environmental design decision support tools are expected to take. The professions listed are:

- architect, architectural designer
- HVAC engineer
- Energy consultant
- Builder / contractor
- Design / build contractor (USA only)

The questions were divided into two parts. I sought to distinguish between small and large buildings. The idea was to see whether it was true that design teams for smaller buildings have less resources within the overall project cost to devote to design analysis. For the NZ Survey, as houses and commercial and institutional buildings were all of interest, the split between small and large was at 300 m^2. For the USA Survey, the split was at 3000 m^2. In the following paragraphs, the distinction is made between very small buildings (under 300 m^2), small buildings (under 3000 m^2) and large (over 3000 m^2).

Participants gave more than one answer to most of these questions even in the much more simply phrased NZ Survey.

building construction design decision support tool use

In the NZ Survey for small buildings 93% (73) of the people who answered thought that this tool would be used by the architect or designer. 11 (14%) thought that the engineer might use the tool 12 (15%) thought that builders would also use it. 6 (8%) thought that an energy consultant may use it.

When the same question was asked in the NZ Survey with respect to buildings of over 300 m^2 area, only 63 of the respondents answered. 42 (66%) said the architect or designer would use these tools and 33 (52%) said that an engineer would use them; 18 (29%) thought a specialist energy consultant would use them, while 3 (5%) thought that a builder would use tools like these.

In the USA Survey, opinion for small buildings was split. 16 (40%) of those surveyed saw the HVAC engineer as a *primary* or *major* user of *simulation based design tools affecting building construction*. 63% saw the *Energy consultant* as the *primary* or *major* user. 38 (95%) of the participants saw architects as *not* users or as *occasional* users. A similar number saw architects and builders as *not* or *occasional* users for *large* buildings.

The only significant difference in these responses was that the *energy consultant* is seen as playing a more significant role in buildings over 3000 m^2 than in smaller buildings (See **Figure 81**). 26 (62%) participants saw the energy consultant as the *Primary* user in the larger buildings compared to 16 (38%) in the smaller buildings.

Although a tool for designing the construction of a building would be expected to be used mostly by architects as the NZ Survey results suggest, the USA Survey contradicts this finding. It would seem that the USA Survey simulationists do not trust the architects' judgement - presumably as a result of experience? There are only slight differences between reported behaviour for small and large buildings.

Almost every participant in the NZ Survey answered this question about design of the thermal envelope. Most answers contain more than one reason. Listed below is an indicative selection of some of the answers given (referring, as the respondents most often did to the architect as "he").

- *this is the way we do it; traditionally his role; that is their role*
- *not large enough to bring in consultants; small jobs architect does all; only have a consultant for large jobs;*
- *because they design it;*
- *because it is an integral part of the design*
- *because it has to be decided early on in the design stage*
- *that's where those things are addressed*
- *they are the people with the expertise*
- *greatest influence*
- *most client contact*

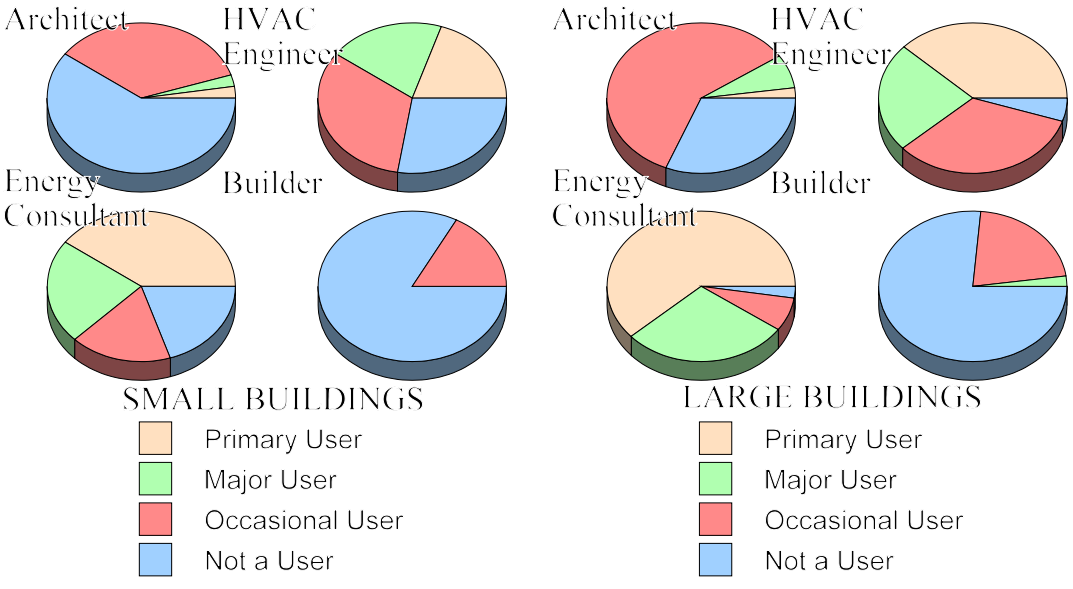

Figure 81 USA Survey: Participants' views of what degree of use design tools which affect building construction will receive from the various building professions

eddst use for lighting design

70 (90%) of the people who answered this question for the NZ Survey with reference to small buildings believed that lighting design was the architect's responsibility. 16 (20%) also thought that it may be the engineer's job, 9 (12%) looked to an energy consultant. 5 (6%) thought that builders may also need to use this tool.

When the same question for the NZ Survey was asked with respect to large buildings, 41 (65%) thought that the architect would use an eddst; 35 (56%) thought it would be the engineer, 19 (30%) thought of an energy consultant and 2 (3%) thought a builder would use it.

Once again these answers show similar trends. The architect or designer takes a more central role in the small building, while there was more possibility of specialists using these tools in larger buildings. Few people believed builders were likely to use these tools.

Many respondents gave exactly the same answer to this question as to the previous question even to the point of suggesting the same reasons why they had given these answers. Such answers stated that it was the architect's role or job, that it was part of the basic design of the building, or that buildings are too small to justify the use of an engineer. Listed below are some of the answers that are more specific to lighting:

- *Architect works on aesthetics, engineer works on lighting*
- *The lighting firm designs the lighting.*
- *Architects not up to speed with lighting calculations*
- *I don't trust lighting consultants I believe that they over design.*
- *Window arrangement has to make the house look good*

Here again the USA Survey participants' views are at variance with those of the NZ Survey participants. They have little expectation that the architects will be heavy users of lighting design decision support tools. However, the difference is not as startling as appears at first glance. The USA Survey is asking about ***simulation based energy efficiency design aids/tools*** as opposed to the NZ Survey which just asks about ***energy efficiency design aids/tools***. Also, the USA Survey is asking a more subtly graded question. In the NZ Survey all we have is an indication that participants see lighting design as an activity for which an architect would use design decision support tools.

One way to check the USA Survey on the same basis as the NZ Survey is to add together the total count of participants' selections of *Primary, Major* or *Occasional* usage. In this case, we are comparing the USA participants' expectation of "some" use by the various professions with the NZ participants' expectation. The count is 16 (40%) in small buildings and 28 (67%) in large buildings for architects; 29 (73%) small, 40 (95%) large for engineers; and 32 (80%) small, 41 (98%) large for energy consultants out of a total of 40 small, 42 large responses.

There is little consensus between the two surveys as**Figure 81** below shows. In fact, I believe that what the results really show is the difference between the groups of people surveyed, rather than the differences in their beliefs about the roles of people in design analysis.

	Architect	Engineer	Energy Consultant
	SMALL BUILDINGS		
NZ Survey	70%	20%	12%
USA Survey	40%	73%	80%
	LARGE BUILDINGS		
NZ Survey	65%	56%	30%
USA Survey	67%	95%	98%

Table 8 Difference between USA and NZ Survey responses on role of architect and engineer in lighting design

design of heating and cooling

For the NZ Survey, in buildings under 300m^2 (small, essentially residential buildings), 57% of participants thought that it was the architect's responsibility to use design aids for the heating and cooling services; 32% believed that engineers would be the primary users; 6% saw builders and 17% energy consultants as being the users of these tools in small buildings.

In larger buildings, 24 (38%) people believed that it was the architects responsibility; 44 (71%) thought that the engineer would use heating and cooling design decision support tools; 20 (32%) people thought that an energy consultant would use them, and 3 (5%) saw a builder using them.

Again, many of the answers to the question about why participants in the NZ Survey expressed these opinions were repeats of the reasons given for previous questions. A selection of answers that seem significant to heating and cooling are as follows:

Those who said that architects did the job claimed that it was because the *heating and cooling was an integral part of the design,* and that these things had to be considered at the beginning of the design process.

Those who said the engineer did the job said that the engineers were the specialists or *that the engineers are more involved in the calculations*. Some who saw the job as the engineer's or consultant's responsibility believed that it was *the energy consultants' job because it doesn't impact the design of the building so much.*

There also appeared to be an opinion that, in smaller buildings, heating and cooling was a more integral part of the building and therefore designed by the architect, whereas with a larger building a specialist was required.

One architect expressed *reluctance to let HVAC engineers make all the decisions as they had a tendency to over design. It is advantageous having the designer there to moderate their design.*

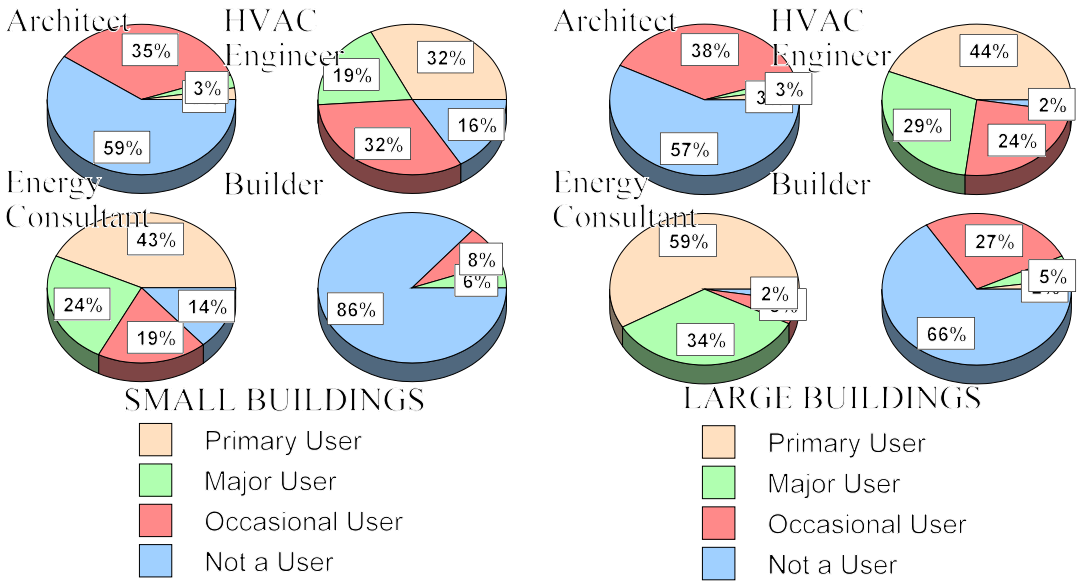

Figure 82 USA Survey: Participants' views of what degree of use heating and cooling services design tools will receive from the various building professions

For the USA Survey, the results for this question are very little different from those for the previous two questions. The HVAC engineer and the energy consultant are expected to be the people who are the primary user of design decision support tools for energy efficient heating and cooling services. The architect is expected to have a small involvement. And the builder is not expected to have an involvement (see **Figure 82**).

design of building plan (NZ Survey only)

Question 52 of the NZ Survey asked: ***Who would the primary users of energy efficiency design aids/tools which affect building planning? (eg grouping living areas on the warm side of the house)***

As expected, this was seen by most (92%) as the domain of the architect whether in small buildings or larger ones. However, most of the other professions were selected by a small number of the respondents. The reason offered for the selection of the architect was that spatial planning is "their job" and is fundamental to very early design choices.

confusion?

An unresolved side issue arising out of this whole final set of questions is the dichotomy between the views expressed here by the simulationists in the USA Survey and their views expressed in answer to question 37. For that question, 32 of the 44 said they sought simulation results that could be used in design at *early or preliminary stages in the design process*. If simulation analysis at this stage in design is to be effective, then it surely must involve the architect more than they are suggesting here. Perhaps the answer is expressed better by the broader range of professions surveyed for the NZ Survey?

7-2.10 analysis

This case study is central to the research in this thesis because of the number of people interviewed and because it not only documents the current state of the art in computer simulation but also identifies the desires and wishes of practitioners. Given that the focus of this research is the application of environmental design decision support tools in architecture, the lack of architects in the USA Survey could be seen as a significant methodological flaw. However, the focus in the USA Survey on digital simulation as design decision support was found to preclude involvement of architects, even in the Western United States building market where simulation was relatively commonplace. The most that could be done was to ascertain these specialists' views of the current and future role of the architect as reported in the preceding pages.

The practitioners in the USA survey applied themselves mostly to commercial office buildings, while the NZ Survey participants' work was spread relatively evenly across commercial, industrial and residential buildings. Of the participants in the NZ Survey, 20% were architects and a further 12% were "building designers". None however were users of building performance simulation software. Taken together, the NZ and the USA Surveys complement each other neatly when the analysis is addressed to the central question of this thesis: what might be the nature of any common problems in the application of design decision support tools for architects and clients.

The *à priori* analysis of design decision support tools in chapter 3 suggested the following advantages and disadvantages of computer simulation based design decision support tools:

Advantages

- Simple and direct relationship between the environmental factors and the performance of the building looks real.
- Clients find the model and the environmental effects very easy to understand.
- The freedom to examine almost any design is much wider than with many other design tools.
- Although computer building models take a long time to construct the process of construction of the model is increasingly part of the routine of design using CAD[13].
- Once the computer model is constructed, modelling variations can be a simple process. Designers can be encouraged to try many variations.
- Post-processing data from performance calculations makes

Disadvantages

- The biggest problem for designers using computer models to study environmental quality in buildings is that they have to have a completed design before they can conduct the test.
- The calibration of a model to reality is often very difficult.

computer-based simulation
potentially a far richer medium than
any of the other design decision
support tool.

The following paragraphs draw this case study chapter together by reviewing the USA and NZ survey results in the light of this analytical framework.

Advantages

Immediate feedback: When offered an informed choice, the experienced users of simulation in the USA Survey saw computer simulation as a useful design decision support in the early stages of design. This is when the literature in the first section of this thesis suggests the most important decisions are made. In fact, these users express a distinct preference for simulation over text-based tools, charts and tables or case studies.

Clients understand environmental effects: In both surveys, clients and designers were interested in analysis of the annual energy use with a view to achieving bottom line cost reductions. There were a number of people who were extending the capabilities of the software beyond this into occupant comfort studies. Many were involved in pre- and post- processing data to test ideas or demonstrate principles.

Electronic models already exist: the participants saw this as a highly desirable improvement on the GUI's of existing simulation tools used for design decision support, but made no comment on re-using other people's electronic models at present.

Design variations easy with electronic models: the manner of usage of simulation, and the comments that it could be used for pre-design studies support this model of simulation program usage.

Performance data post-processing provides more data analysis potential: almost all the participants in the USA Survey commented that they used graphical post-processing of the data from simulation routinely.

Disadvantages

Models time consuming to construct: this is confirmed by the desire of the participants for greatly improved GUI's in the USA Survey.

Designers require finished design before test can be constructed: this was not supported by the simulationists' comments in the USA Survey: they all saw simulation as useful early in the design process when much was still unconfirmed in the design.

Calibration with reality can be difficult: Surprisingly, despite this amount of processing, very few people have formal systems in place for Quality Assurance in simulation. Improved Graphic User Interfaces, better error checking, and improved components that model building behaviour like air

movement and ground conduction were the principal suggestions for improvement of the computer based design decision support tools. These are all different aspects of improving the model of reality - Assurance of the Quality of the performance prediction.

This analysis is continued in the first chapter of the three chapter final section of this thesis where the analyses of all five cases are brought together. In the next chapter, the third of the detailed surveys of practitioners is described. The eddst uses **Physical Models** in wind tunnels.

7

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8

physical (wind tunnel) model simulation

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

thwincas_2006.wpd

HE PREFERS TO ENDURE ALL THE DRAUGHTS FROM THE DOORS, IN ORDER THAT THEY MAY APPEAR OPPOSITE ONE ANOTHER - YOU MUST PERISH IN SYMMETRY

JOHN RUSKIN IN THE SEVEN LAMPS OF ARCHITECTURE QUOTING MADAME DE MAINTENON FROM QUARTERLY REVIEW, MARCH, 1855, PP423-428.

This is the fourth in a series of five detailed studies of the application in architectural design of environmental design decision support tools (eddst's). The five studies are:

- a **text based design guide** containing **graphical design aids** . . . . . Solar House Design Guide - **survey**.
- **computer simulation** of **lighting** and **thermal** performance. . . . . CBPR client reaction - **individual case study**.
- **computer (thermal) simulation** packages. USA and NZ interviews - **survey**.
- **physical model studies** of pedestrian wind environments interviews with architects in Wellington City - **survey**.
- **physical model studies** of daylighting interviews SFMoMA- **individual case study**.

This study is one of the three in this thesis that reports reactions to the use of an eddst gleaned from a survey of a range of experienced practitioners. It analyses the use of an eddst that applies ***physical models*** to the ***simulation*** of the building environmental performance. Specifically, models are placed in a wind tunnel in order to determine the likely impact of a proposed building design on the street level wind environment.

8-1 *background*

In late 1991 I employed an MBSc student for the summer to interview architects in Wellington about the Wellington City Council (WCC) Wind Ordinance. The goal was to survey architects experienced at working with the Ordinance on building aerodynamics which I had helped draft some years before (See Appendix H for a full copy of the Ordinance text). It was the intention of that 'legislation' to assist architects to design more aerodynamically suitable buildings by:

- providing them with the design decision support tools to assess their buildings' aerodynamic performance;
- (in the process) educating them as to the types of interaction that occur between wind and buildings.

This set of interviews was to be an important practical test of one approach to the development of design tools for architectural designers for this thesis. A re-write of the Ordinance in 1985, which I was instrumental in setting up, had concentrated on two flaws with the previous format of the wind environment requirements in Wellington: a) it required developers to state in the wind report how they would alter the building in response to the wind tunnel test results; and b) it provided the architects with a two stage testing process, the first stage of which was a simple and exploratory flow visualisation exercise in the wind tunnel and was aimed at providing them with the tools to consider

aerodynamics themselves early in the design process. Rather than the practice of employing outside consultants to test the building after a considerable expense of time and money in creating a design, the aim was to encourage architects to design using simple models in the wind tunnel. The incentive to use this simple do-it-yourself test was that successful completion avoided the necessity for the detailed second stage which was more complex, more expensive, and because it required external consultants had to be done on a completed design.

This simple pre-design wind tunnel test procedure was intended to make it easy for wind environmental design to be an integral part of the early design phase of all CBD buildings in Wellington. As mentioned in this thesis many times, decisions made early in the building design process are crucial to the success or otherwise of a building. "Remedial" measures tacked onto a fundamentally flawed basic design are far less successful than getting the basic design right to start with. Building aerodynamics text book authors also recommend that early intervention[1] in the building design process is by far the most effective. The 1985 WCC Wind Ordinance specified three Wind Tunnel Tests: a *Pre-Design Test*, a *Standard Test* and a *Full Wind Test*. Where the results of the simple *Pre-Design Wind Report* met the Council's performance criteria, "the Council's requirements in respect of wind design will be deemed satisfied" .[2]

The survey sought to ascertain attitudes towards the Ordinance. It also sought to ascertain whether the process of use of the Ordinance had improved the architects' general understanding of the interaction between building design and the wind.

8-1.1 city council wind regulation

A number of cities around the world have introduced wind ordinances requiring reports on the pedestrian level wind environment. Davies[3] describes the approaches taken by a range of cities (based in part on data in a report to the Wellington City Council (WCC) of my WCC sponsored visit to Canada and USA in 1986[4]):

- "**Wellington, New Zealand**: requires tests to be carried out on all building proposals in the central business district, and imposes strict performance criteria based on maximum gust speed (Wellington City Council, 1985). Developers must demonstrate that their building meets the criteria, or provide evidence that the criteria cannot be met because of local wind effects that cannot be controlled by changes to the building design."
- "**Edmonton, Canada**: established wind regulations in 1981 with its Land Use Bylaw 6626 (City of Edmonton, 1981). Requirements for pedestrian comfort are included in the City's General Municipal Plan (City of Edmonton, 1985). A wind report is required at the discretion of the Development Officer. In practice, a wind study requirement is applicable to all major developments in the central area of the city, and is discretionary in other parts of the city. Criteria are not specified in the legislation, which results in negotiation between developer and city authorities on a case-by-case basis."
- "**Calgary, Canada**: introduced a wind ordinance as part of its City By-Laws in 1980 (City of Calgary, 1980). The Land Use By-Law 2P80, which regulates development in central Calgary, covers density, sunlight, noise and wind conditions resulting from a development. All high rise developments in central Calgary are required to submit a detailed wind tunnel test which presents the effects of the proposed development in

relation to the existing area. Criteria are given in terms of mean wind speed, and depend on the use of the area and the season of occurrence, with more severe winter criteria to counter the wind chill effect."

- "**San Francisco, USA**: introduced a new pedestrian level wind ordinance in 1985, which sets out criteria for pedestrian comfort and safety (Arens et al., 1989; White, 1991). The criteria use an equivalent wind speed and are based on the amount of time the criteria are exceeded. Different wind speeds are set for areas of different uses. Buildings proposed for a site are required to conform to the criteria, or be redesigned in order to conform. As with the Wellington ordinance, if a developer can provide evidence that the criteria cannot be met with any design option, exceptions will be granted after consultation with the city authority. The ordinance provides for specified procedures and methodologies to be followed in complying with the wind tunnel test procedure."

8-1.2 wellington city wind and regulations

High ambient wind speeds are experienced on a regular basis in Wellington. At least one CBD building has been causing wind problems at ground level for pedestrians since the 1920's. Traffic police were stationed on these windy corners in the 1920's and 30's to assist people across the street. Well into the 1960's ropes were placed at particularly windy corners to prevent people from being thrown inadvertently in front of passing traffic.

The Wind Ordinance was first introduced in Wellington[5] as an apparent response to the public debate about the impact on the wind of the then proposed BNZ headquarters building on the corner of Willeston and Willis Streets[6]. That early wind ordinance required developers to submit a "Wind Report" if they were constructing a building of over four storeys in the CBD. The revision brought into force in 1985 required the developer not just to submit the report but also to deal with the issues

Figure 83 Photograph from Evening Post newspaper, 1967- at the corner that has been windy since the 1920's.

raised by the required wind tunnel test. It specified performance criteria. Buildings which failed to meet these criteria would not gain a permit for construction - at that time known as a "building permit".

For the Standard and Full Wind Tunnel Tests the Performance requirements were:

Existing Wind Speeds	Wind speeds resulting from development proposal	Requirements on developer
	If exceeding 10m/second within a proposed open space or landscaping area for which a development bonus is sought.	Reduce to 10m/second where public have access within open space/landscaping area or relinquish the development bonus.
Up to 15m/second	If exceeding 15m/second	1) Reduce to 15m/second 2) Although other directional wind speeds may be increased towards 15m/second, the overall impact is to be no worse than existing.
15-18m/second	If exceeding 15m/second	Reduce to 15m/second
Above 18m/second	If more than 18m/second	Reduce to max 18m/second.

Figure 84 Table of pedestrian level wind speeds above which design action is required in the Wellington City District Plan

8-2 *the wind tunnel test*

The wind tunnel test consists of making a physical model of the existing and proposed buildings, and visualising the wind flow around each. Decisions for and against development are made according to the Wellington City District Plan criteria as determined by measurements of wind speeds with miniature anemometers placed at strategic positions around the model.

8-2.1 the model

The following pictures illustrate the nature of the model for a wind tunnel test performed by external consultants for Resource Consent approval as required by the Wellington City District Plan. The proposed building is highlighted in blue.

Figure 85 Opus Central Laboratories wind tunnel test model

8-2.2 the test results

The wind tunnel tests typically consist of a flow visualisation phase - consisting of blowing lightweight material (in this case polystyrene beads) from around a model. Observation of where the beads clear first and the most indicate where the greatest wind acceleration occurs near the existing or proposed buildings.

Figure 86 Opus flow visualisation: cleared areas are the windiest; wind from right of picture

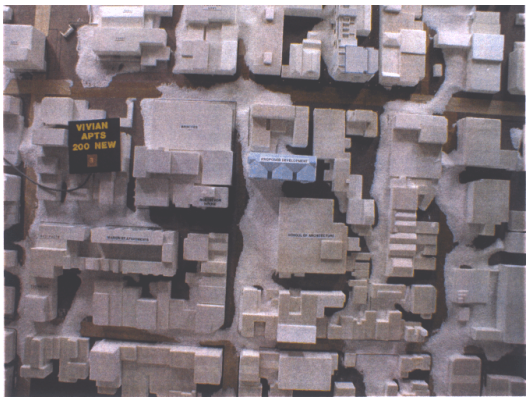

Figure 87 Opus flow visualisation: proposed building highlighted in blue; wind from right of picture

In a pre-design wind tunnel test, the bead clearance for the proposed and existing building is all that needs to be done. If the proposed situation reveals similar or less bead clearance than the existing situation, no more needs to be done. The full wind tunnel test consists of the flow visualisation phase followed by miniature anemometers measuring actual wind speeds at strategic positions around the building / model:

Table 1: Net Effective Gust Speeds, V_{net} (m/s)
Notes: exg = with existing buildings, new = with proposed development.
▲ = increase of 2m/s or more over existing wind conditions
▽ = decrease of 2m/s or more over existing wind conditions

Location	Southerly winds			Northerly winds		
	exg		new	exg		new
A	14	▲	22	16		16
B	13	▲	18	8	▲	20
C	10	▲	14	16	▲	18
D	10	▲	21	19	▲	21
E	10	▲	18	12	▲	15
F	9	▲	20	19	▽	17
G	16		16	23		22
H	13	▲	18	21		20
I	11	▲	16	15		14
J	15	▽	9	20		19
K	15		15	19	▽	17
L	13	▲	15	13		12
M	17		16	14		13
N	18		18	12		12
O	20	▽	15	14		13

Figure 88 Opus wind tunnel test anemometer readings

8-3 *the architect interviews and analysis*

8-3.1 interviews

In the six years of operation of the WCC Wind Ordinance from 1985 to the application of this survey, wind reports on 51 buildings designed by 23 architectural firms were presented to Council for approval and hence to me as the WCC "Wind Consultant" for audit. Sixteen architects from fourteen firms involved in the design of these buildings agreed to be interviewed for the survey. During the development and testing of the standard questionnaire for the face-to-face interviews, the WCC Town Planning staff were also consulted as to their view of the Ordinance. The survey was piloted with four of these respondents. It was not significantly revised as a result of the review of the results of the pilot study. The results of the pilot study of 4 and the full study of 12 participants are combined in the analysis.

The research design was matched to the limited population being interviewed and to the limited time resources available. A summer research assistantship is at most 6-8 weeks in length. The structured interviews were conducted in person, with a target maximum time of 30 minutes. The interviews were intended to be key-word analysed rather than statistically summarised. It was thought that dividing the small number of Wellington architecture firms involved in large building construction even into binary categories of yes/no answers was unlikely to produce groups large enough to facilitate statistical analysis. The key-word analysis was abandoned in favour of the concept summary approach of the following paragraphs.

The research plan involved the following steps: Design the questionnaire; Contact architects and set up interviews; Pilot the interviews; Finalise the questionnaire; Conduct the main interviews; Analyse the data.

The first step in this process was to extract names of firms and the buildings they had been involved with from the wind reports for Wellington City. The summary data in **Figure 90** classifies the respondents' level of experience with building aerodynamics and the WCC Wind Ordinance.

Figure 89 Child clinging to lamppost Jervois Quay, 1971

The full interview form which was used as an aide-memoire in the interviews is enclosed in Appendix K. The interviews were recorded and the responses organised into the summary response format shown in Appendix K by the research assistant. The eleven questions were all centred on the architects' response to what they knew - the Ordinance itself. The Pre-Design Wind Report with its designer-performed Wind Tunnel Test was evaluated as an integral part of this response. To evaluate only the Pre-Design Wind Tunnel Test would not provide the context for the responses that was desired.

The eleven questions actually posed during the interviews sought to assess the following broad research questions:

- To what degree has the Ordinance affected architects' thinking about environmental design?
- What understanding do the architects have of the designs that should work in windy environments? - and how has that understanding developed - instruction or experience?

- What value these designers saw in designer-performed wind tunnel tests - assisting with or hindering the "early design" decision process?

8-3.2 raw research results

The first question asked whether ***the Ordinance has made the wind environment in Wellington better or worse***? In general, the architects replied that they had no basis on which to know this: *Has made it better in terms of it would have been worse if it* [the ordinance] *hadn't been there. I don't know that the Ordinance has made it any better on what has been there in the past. Without the Ordinance it would have been even worse still* {architect: L}. *Must have improved the city. I don't think any clients or developers or architects dispute that the Ordinance has improved the environment for Wellington* {K}.

When asked to specifically list ***particular problems or issues with the wind environment in Wellington not addressed by the Ordinance***, the architects essentially said they knew of none. Several mentioned problems with the Ordinance later in the interview. The problems mentioned can be categorised under two broad headings: concerns with the accuracy of the Wind Tunnel Test process; and "problems or issues with the wind environment in Wellington" not addressed by the Ordinance. The problems in this latter category were:

- the dynamic or changing nature of the City - *Main problem is changing shape of the city. If buildings are coming down/going up, how to measure wind speed, how many development proposals to consider in test, what happens when problems are the result of another building?* {D} *Building environment changes, buildings pulled down, new buildings built, alter wind effect on a building. Proposed new buildings used in test may be changed or may not be built.* {B} *Ordinance doesn't allow for initial development in an area where further development is going to change the environment significantly* {M,N}
- the Ordinance only applies to significant new buildings - *Some problem areas exist on sites where redevelopment is not likely to happen for a long time, if ever.* {E} *Council requires property owner to rectify problem that is not of his* [sic] *making[xvi], passes responsibility on to most recent development.* {J} *Council expects each building to solve problems created over years, often impossible to do. Many years to cause the problem, have to recognise that may take years to rectify the problems.* {M,N}
- the Ordinance is *Not strong enough in writing or enforcement... Having chosen to live in a windy environment we should be prepared to spend quite a lot of money protecting ourselves from the wind* {L}
- the Ordinance only applies to a limited Central Business District area of the City - *Only covers the central business district, doesn't cover other shopping areas...Housing should be looked at, particularly for worst residential areas* {K} *Fringe area is not covered, intermediate stage between CBD and outside city.* {M,N}

[xvi] This comment is technically not true, and exposes a poor understanding of the wording and intent of the Ordinance. As can be seen from the text of the Ordinance, there is very specific recognition in the ordinance of the differences between wind problems caused by the proposed building and pre-existing wind problems.

8-3.3 what effect did the ordinance have on building design?

When asked whether they used ***particular design techniques to improve wind effects...***the architects said *No. driven by economics* {B} *Don't have any rules of thumb* {C} However, during the interview most indicated an awareness of several techniques: *aware of tower-podium as positive effect on wind* {B}. *Tower-podium, curved/aerodynamic shape, verandahs* {D}. *landscaping, wind baffles, rounded corners* {E}

Firm Code	Individual Code	Number of buildings	Positive about Ordinance?	Attended a Wind Tunnel Test in Person?
1	A	3	N	
2	B		Y	Y
3	C		Y	N
4	D	4	Y	Y
5	E	1	Y	Y
6	F	2	Y	Y
7	G	3	Y	Y
8	H	1	-	Y
6	I		Y	Y
9	J	1	N	Y
10	K	4	Y	Y
11	L	3	N	Y
12	M			
12	N	2		
13	O	1		
14	P	2		
		27	8 Yes / 3 No	9 Yes / 2 No

Figure 90 Summary of the participants' level of experience with Wind issues

wind breaks, canopies, screening, elements protruding from the building to deflect wind {F}. *Rounded corners, curved facade, verandahs, canopies. Keep wind effects in mind while designing. If wind looks like being a serious problem, call on experts to advise.* {G} *Just what was taught at school. Use consultant when necessary.* {H} *Modulate form of building to break up wind flow.* {I} *verandahs to stop downdrafts.* {J} *aerodynamic shapes, aerofoils to deflect wind.* {K} *basically try to solve the problems before they start, and go from there and think in terms of verandahs and what's*

happening at pedestrian level. {L} *use Council guide for designing with wind, try to avoid troublesome building forms*[q] {M,N}

When asked whether they had had to ***alter or redesign a building proposal because of the Ordinance,*** most replied yes. However, the changes were mostly minor: extending verandahs and adding porous screens. In general, only *opportunities* rather than *problems* had arisen as a result of these alterations: *opportunity to consider other aspects of design "subtle argument for the accountants".* {E} *Can work to advantage, justification to client for additional ornamentation.* {F} *Provides opportunity to vary building form, gives architects some leverage over clients.* {I}

In general, most architects replied that they found *taking part in a wind tunnel test helped* [them] *in the design process*. Several added comments like: *Provides increased awareness of problems and a feel for why they happen. Indicates a way of dealing with problems.* {D} *Reinforced some preconceptions on what works well and what doesn't work well.* {E} *realise where potential problems are...* {I} *In pre-design stage, not so much at later stages* {H} However, there were dissenting opinions about the value of direct involvement in the wind tunnel test: *Report is comprehensive so no need to observe each test. Once you've seen how one operates the report is probably sufficient* {K} *Not unless you're pretty dumb and can't see the results from the photographs* [of polystyrene bead erosion due to wind flow around the models in the wind tunnel] *and take the word of a few people: if you have a problem with trust of other people, you'd shouldn't have to get involved in it.* {L}

In the comments about the ***practical difficulties ... in carrying out wind tunnel tests*** [such as pre-design wind tunnel tests] ***yourself***, there was no consensus. A few themes were developed:

- Time: *Not enough people in the office to spare someone for that time. Not confident to have done it efficiently and to have come out with good report.* {E} *Is it necessary? Why can't others do it?* {L} *Design time is usually quite short, and anything adding to that is an obstacle.* {K}
- Cost *Expensive, once time, models and analysis taken into account.* {C} *Client resists spending money before building is ready for Council approval. If wind test is all that stands between them and approval, will do it to get it out of the way. Not prepared to meet such a cost at an early stage when the design may undergo a lot of change in later design stages anyway. Architect will build model and observe testing as part of fee but not pay for testing or analysis. If costs were lower situation could change.* {B} *...Time, expertise, cost all have an effect - testing takes much longer than it should as a result of the lack of experience, wasting time, costing money while gaining experience, not economical or time efficient for developer. "Dreaming about buildings"* {K}
- Lack of Expertise *Lack of expertise in office. If there are experts, might as well use them.* {D} *Not impartial, acting for developers; believe if case went to Council or court wind report would be thrown out as a biassed document..* {K}

Only three people expressed varying levels of favour for the concept of pre-design wind tunnel tests. *No problems, great idea. Should be more emphasis on pre-design approach.* {F} *Best approach. Don't carry out test personally, hire someone to do it, but very favourable to pre-design approach.* {G} *process is intuitive anyway so appears an unnecessary hold-up to carry out pre-design test. If Council is serious about Ordinance they should enforce pre-design step.* {I}

[xvii] Only reference to the WCC Design Guide for Wind produced specifically to educate architects and to assist with compliance process.

what works and does not work in the Ordinance?

In general, the architects found ***the Ordinance easy to understand*** and also ***easy to work with***. The biggest problem seemed to be with *the interpretation of the results....* {M,N}. *Often we are at variance over the interpretation of the reports with Council...Town Planners... are not prepared to accept trade-offs...*{K} *As long as other factors are taken into account. If wind is treated as paramount with no regard to sun/aesthetics/height/plot ratio etc the Ordinance would become unworkable...There must be room for flexibility and common sense.* {D} *Some of the problems arise when you start getting pedantic about certain speeds that have been tested.* {I} *Problem lies in adherence to wind speeds set out in Ordinance, without regard to individual situations.* {J}

what architects understand of the Ordinance and building aerodynamics?

The architects' understanding of the Ordinance, its goals and operation was tested by two questions. One asked: ***Do you have any suggestions for how the ordinance might be improved?*** The other asked: ***How would you describe your attitude towards the wind Ordinance?*** The general response was to look for a great deal of procedural improvements. Only one person seemed to think that the approach was a total waste of time: *The whole thing is a joke in Wellington. Buildings will create wind, nothing can be done about it[xviii]. People will adapt to a changing environment. Can't stop progress. Waste of time and money to keep someone in a job.*{A}

The improvements suggested by the other architects fall into the following groups:

- Lack of flexibility in process. *Needs administrators with greater knowledge of wind design requirements and design needs. Would be helpful to have someone in Council who can look over early plans and indicate areas where problems could occur, who could take responsibility for accepting plans or referring them on for wind tunnel testing.* {J} *Ultimately the Ordinance is a good thing as long as kept in its place along with the other factors that affect the city. Wind can't become the dominant concern...* {I} *Objectivity must be maintained; while negotiation is necessary there should be limits to what is conceded. Levels of tolerance for areas and occupations should be made clear from the outset. Designers should be aware of the degree of flexibility in the Ordinance and be shown that it is not going to bend further..* {C}
- Simplification of the method. *Needs to be simplified; has been over-complicated in the administration. ... Like to see whole thing reviewed to find some simpler method, preferably to be usable at an early stage in the design process.* {J} *As long as it's not over-elaborated, as long as it's kept fairly basic and it's realised that the results are only a guide...* {F} *Prepare a wind contour map of Wellington City so designers know in advance which areas will require particular attention.* {K}
- Lack of follow-through leads to inconsistency. *Don't believe that the wind tunnel simulation is accurate enough for some sites to give a sensible solution to the problem. Dixon Towers development required a "fence" along the top of the adjacent building to improve wind conditions. Developer went bust before completion of the project and fence was never built[xix], but the area is none the worse for it..For*

[xviii] It is most disappointing to note that this architect is from a firm that had been involved in testing and constructing three buildings under the Ordinance. That he did not yet understand that a building's design fundamentally affects the wind conditions at street level, and that something can be done about this at the design stage is a clear indication of the lack of success of the Wind Tunnel Test procedure as an educative tool.

[xix] No measurements have ever been made to confirm this. It is another indication of the lack of understanding of the wind tunnel process that someone so intimately involved in the design and testing of a building should so incompletely understand the effect of his building. The street was relatively windy and was to be made more so by the proposed

(continued...)

anything in the CBD it's [The wind tunnel test process] *really not relevant.* {H} *Relate test results to what you actually get down in the street.* {K} *Need a follow-through to show that the testing has been justified, that the finished result is successful.* {F}

- Precise recommendations hard to justify as, at the detailed level, the modelling is unconvincing. *By very strong local body inducement the wind situation in Wellington is being made very much worse as they are granting a bonus for tower podium development ... that's going to mean a building of nearly twice the height of what could normally have been built. On one hand the Council says they want wind tunnel tests and they want wind speeds reduced, and on the other hand they grant tower-podium bonuses..*[t] {C} *Need more expert consultants, no confidence in recommendations at present - a very inexact science, has no confidence in accuracy of wind tunnel testing or conclusions drawn from results.* {G} *Timing of wind tunnel testing is difficult. Can't happen earlier in the project as building has not been approved by the client prior to that, but at the late stage it is generally carried out the building design is almost completely determined.* {K}

8-4 *summary and conclusion*

It is very hard to see a strong pattern in this set of individually valid and fascinating responses. It is even harder not to impose a pattern based on one's own prejudices by selecting responses sympathetic to a specific interest. However, the overall pattern of the responses summarised above is expressive of the following general trend: *The big opportunity is that a large number of people have to look at the wind and think about it constructively.* {L}

The following conclusions are based on this premise: *The Ordinance is important in Wellington.* [It is] *essential that safety is required from developers.* [It is] *not unreasonable that comfort be required in some locations as well. If designers leave it until the last minute to get approval for wind environment, they should be prepared to pay the price of redesign etc if required, no matter how long or expensive the process.* [They] *should be encouraged to get early approval and made aware of the consequences if they don't.* {C}

Davies[7] produced a summary of the interviews as well as the data that has been analysed above. That summary is contained in **Figure 91**.

[xix](...continued)
building. The average person was not likely to notice the deterioration because as I noted in my audit of the test for the City (WCC-WR139 report to WCC, 10-Oct-1986): *it is possible that the effect of the proposed building is to shift a wind problem rather than exacerbate it.* This street would become more like many people experience in other parts of the city on a windy day. The enforcement of the Ordinance was merely an attempt to address the *general deterioration in the wind environment in Dixon Street.*

[xx] Yet another architect who does not understand the fundamentals of the aerodynamics of buildings! A "tower-podium" design is clearly better than a shorter but more prismatic shape of building where there is no large horizontal surface to impede the progress of the wind down the face of the building into the street. It is in fact documented as an appropriate "solution" in the WCC Wind Design Guide.

8-4.1 trends in the data

There are three very strong trends in the interviews:

- General recognition of the need for consideration of the wind environment when designing buildings in Wellington. *I don't think that any clients or developers or architects dispute that the Ordinance has improved the environment for Wellington.* {K} *Has made it better in terms of it would have been worse if it* [the Ordinance] *hadn't been there.*
- The general level of understanding of aerodynamics of buildings is disappointing. A number of the architects showed an understanding of the importance of *tower podium* {B and D} *curved facade, verandahs, canopies..* {G} and *increasing wind speeds with height* {L}. However, on many other occasions they spoke of *wind baffles* {E} or *aerofoils* {K}; and said things like: *Buildings create wind, nothing can be done about it* {A}; *Tower-podium concept for wind is really bad.* {L}.
- The architects thought that taking part in wind tunnel tests helped them to design better - *Provides increased awareness of problems and a feel for why they happen.* {D}. However they do not favour being the people who do pre-design wind tunnel tests because with it, the Ordinance is too complex and because they feel they *lack .. expertise in the office* {D} and because it was likely to be *not economical or time efficient...* {K}.

The analysis has demonstrated that architects acknowledge the importance of getting the design right early, but want to do less work to get the design right. *Can't stop progress* {A}; *Architect will build model and observe testing as part of fee but not pay for testing or analysis. If costs were lower, situation could change.*

8-4.2 developments since the 1991 survey

A further simplification in the new District Plan[8] in the late 1980's saw the re-introduction of the four storey minimum building height before wind tunnel testing was required. This latter action was based largely on economic grounds. It was argued that it was unreasonable to impose the high cost of a wind tunnel test on the developer of a small building. The positive value to the city of the wind tunnel testing of a new one storey supermarket building was not enough to outweigh the negative

QUESTION	TYPE OF RESPONSE
Do you feel the Ordinance has made the wind environment in Wellington city better or worse? Are there specific locations you are thinking of in your answer?	"Hard to assess if it has improved things. I guess on balance it probably has." "I don't know that the Ordinance has made it any better than what has been there in the past. Without the Ordinance it would have been even worse still."
Are there particular problems or issues with the wind environment in Wellington that you feel the Ordinance does not address? List.	Testing available is not sufficiently detailed, it is not very accurate, "pretty much a hit and miss affair." "The main problem is the changing shape of the city. If buildings are coming down/going up, how should wind speed be measured, how many development proposals should the test consider, what happens when problems are the result of another building?"
Do you find the Ordinance easy to understand? Summarise the main requirements of the Ordinance.	Easy to understand. Follow Town Planning requirements. In brief: "Test performance of a building proposal, effectively add or alter verandahs or add wind screens".
Do you feel the Ordinance is easy to work with? Examples?	Council interpretations of the Ordinance is the problem, "Often we are at variance over the interpretation of the reports with the Council...The planners tend to work like engineers with numbers, and unless the numbers work they are not interested".
Do you use particular design techniques to improve the wind effects on your buildings? List.	Mostly "no", but indicated awareness of several techniques during interview.
Have you ever had to alter or redesign a building proposal because of the Ordinance? Have particular problems or opportunities arisen as a result of this?	Mostly "yes", but only minor changes, such as extending verandahs or adding porous screens. "Ordinance provides opportunity to vary building form, gives architects some leverage over clients".
Have you ever observed or taken part in wind tunnel testing of a building proposal? Do you think taking part in a wind tunnel test helps/would help you in the design process?	Two "no", 14 "yes" "Realise where potential problems are..usually only reinforces what was expected anyway, particularly at that level of accuracy."
What practical difficulties are there in carrying out wind tunnel tests yourself?.	Time, expertise, cost all have an effect - testing takes longer than it should as a result of the lack of experience, wasting time, costing money while gaining experience. Legal considerations. "Dreaming about buildings." Impractical to spend so much time and money on a building that is little more than a proposal.
How easy to understand do you find the report on the wind tunnel testing?	Question the recommendations; don't feel that "experts" have enough knowledge to say what should be done, so recommendations should not be taken as absolutes.
Do you have any suggestions for how the Ordinance might be improved?	Needs to be simplified, has been over-complicated in the administration. Needs administrators with greater knowledge of wind design requirements and design needs. Increase the accuracy and level of detail that can be achieved if you require it. Map of the wind speeds in different areas of the city. Relate test results to what you get down in the street.
How would you describe your attitude towards the wind Ordinance?	10 "positive, 1 "neutral", 3 "negative"

Figure 91 Overall summary of questions and responses to survey questionnaire

feedback from several developers about the wind tunnel testing of their one-storey low cost building.

Overall, the survey analysis shows Architectural Technology as a very positive contributor to the quality of life in Wellington City. Wind tunnel simulation of reality contributes greatly to the nature and development of this improved quality of life. In the time that the Ordinance has been in place a complete shift has occurred in the thinking of Wellingtonians. Every Wellingtonian who walks through the City on a regular basis has encountered the 'Lido effect'. The Lido was the first café to put its tables out on the street. Now many others do the same. The Lido café benefits from the shelter provided by the wind tunnel tested, and hence aerodynamically sound, new Civic Centre buildings. During the debates in 1984 about the Wind Ordinance the suggestion that good design could make sheltered outdoor cafés a possibility was considered laughable. Now this quality of life is expected by all.

On the basis of this success, I have suggested[9] that the City could set up performance criteria for all desirable environmental qualities and not set height or other physical limits at all. It would make the conflicts that sometimes arise in wind analysis less complex. In studies of the aerodynamics of buildings it is sometimes found that making a building taller while retaining the same volume will improve the wind at ground level. This taller building is in direct conflict with the height limits and other physical restrictions set out in the Ordinance.

For both the wind environment and solar access assessment in Wellington the expected intractable problem with performance specification is the training required by Council officers who are to check the performance calculation. Checking a reported wind speed in a wind tunnel test against the published criteria is relatively easy. But total performance specification and compliance checking require that the Council staff be knowledgeable in all the relevant environmental performance simulation techniques. Without this knowledge they have little hope of negotiating trade-offs between different performance requirements.

8-4.3 analysis

The pros and cons of physical model simulation are listed in Chapter 3 of this thesis as:

Advantages

- Immediate understandable feedback on the environmental behaviour of the building.
- Clients find the model and the environmental effects very easy to understand.
- The test is often very simple to set up.
- The calibration of a model to reality is often very simple.
- The freedom to examine almost any design is much wider than with many other design tools.

Disadvantages

- Models for wind tunnel and lighting studies can take a very long time to construct.
- Model making mitigates against designers making more than one or two changes to explore options.
- Designers using physical models have to have a completed design before they can conduct the test.

In the following paragraphs, the above framework is used to analyse the overall significance of this survey of users of a physical model as an eddst for simulating the effects of a building on wind flow.

Advantages

Immediate feedback: Overall, the research suggests that Architectural Technology, in the form of Wind Tunnel Simulation has contributed much to the nature and development of an improved quality of street life in Wellington.

Clients understand environmental effects: *I don't think that any clients or developers or architects dispute that the Ordinance has improved the environment for Wellington.* {K}

Test is easy to set up: In recent years the Wind Ordinance in Wellington has been simplified. It was argued during a major review of the whole set of Ordinances that in their replacement - the City Plan - a fix should be found for the following problems with the Ordinance: a) very few architects had used the pre-design wind tunnel test options; and b) the quality assurance specifications in the Ordinance for the self-certification of wind tunnel tests to be done by architects were so complex that these pre-design wind test provisions were seen to be counter-productive. Appendix H contains the revised text of the new District Plan.

Figure 92 Courtenay Place cafés. People sitting at the tables even on a rainy day! Verandah here is on North side of street. These outdoor areas mostly occur on the south (shady) sides of the buildings in this street because here people are protected from the prevailing North winds.

Calibration is simple :the comparison of the building performance tests with reality was difficult for the architects. They tended to see in the models many reasons for not trusting the wind simulations(e.g. lack of model trees - *a very inexact science* {G}). They needed some form of assurance of the quality that these tests were reliable.
Designs not limited by simulation: It is clear the pre-design wind tunnel experiment has not been successful. The City has removed it from the Ordinance because so few people were using it - a fact borne out in the interviews. Comparing the architects' comments on the wind environmental analysis processes with the advantages and disadvantages listed above, it can be concluded that the advantages of easily understood results which arise from the virtual world created by the simulation are outweighed by the inconvenience of the simulation process (the wind tunnel test) itself.

Disadvantages

Models time consuming to construct: one of the major barriers to the performance of the wind tunnel simulations reported by participants was the cost in time and resources.

Options are time consuming to construct: these costs tended also to affect the number of design options done. However, in the case of a legislated performance test like this, there is a strong tendency for the designers to stop testing as soon as their building complies. There is very little design optimisation effort unless there is a question that the building might not gain approval for construction.

Designers require finished design before test can be constructed: most of the comments about wind tunnel design simulation were focussed on the legislative process rather than the test itself.

This penultimate case study has examined a simulation based on physical models and considered its suitability for a role in environmental design decision support. The complexity of the simulation process seems to be a major barrier to people becoming more involved Even though the modelling can be simple, people do not seem aware of this. The general analysis begun here is continued in the first chapter of the three chapter final section of this thesis where the analyses of all five cases are brought together. In the next chapter, the last of the case surveys of practitioners is described. It is a single building case study. The application considered is another use of **Physical Models:** this time for daylight analysis.

8

Notes & References

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9

physical (lighting) model simulation

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

thessfmoma_2006a.wpd

WHEN YOU HAVE ALL THE ANSWERS ABOUT A BUILDING BEFORE YOU START BUILDING IT, YOUR ANSWERS ARE NOT TRUE. THE BUILDING GIVES YOU THE ANSWERS AS IT GROWS AND BECOMES ITSELF.

LOUIS KAHN IN LIGHT IS THE THEME[1]

This is the fifth in a series of five detailed studies of the application in architectural design of environmental design decision support tools (eddst's). The five studies are:

1. a **text based design guide** containing **graphical design aids** . . . . . Solar House Design Guide - **survey**.
2. **computer simulation** of **lighting** and **thermal** performance - **individual case study**.
3. **computer (thermal) simulation** packages. USA and NZ interviews - **survey**.
4. **physical model studies** of pedestrian wind environments - **survey**.
5. **physical model studies** of daylighting - **individual case study**.

This case study is one of the two in this thesis that reports reactions to the use of an eddst gleaned from interviews with individual practitioners about their involvement in specific projects. It analyses the use of an eddst that applies ***physical models*** to the ***simulation*** of the building environmental performance. Specifically, 1:100, 1:4 and 1:1 mock ups of the building are subjected to various lighting conditions, including the weather at the site, in order to determine the likely impact of a proposed building design on the internal lighting environment.

9-1 *background*

According to the press release prepared for its 1995 opening, the new building for the San Francisco Museum of Modern Art (SF MoMA) "replaced the Beaux-Arts-style War memorial Veterans Building" . My interest in it arose after a casual visit to the Building Manager to ascertain whether I could do a case study for teaching purposes of what I saw as an elegant Mario Botta museum building. As I investigated the design process further, I recognised the value for this thesis of studying how the daylighting requirements of the client were translated into architecture.

What made the investigation more exciting was the generally enthusiastic public reaction to the building. An initial approach for access through Greg Johnston of the Museum staff in late 1995, generated a telephone reply after I returned to New Zealand in 1996. I followed up the inquiry when I returned to San Francisco in September 1996. The research techniques applied were:

- Interviews with the "major" players in the daylighting design:
  - Greg Johnston Director of Facilities and Kent Roberts Operations/Installations Manager.
  - Mark Otsea and Andres Grecchi Project Architects in Helmuth, Obata and Kassabaum, (HOK) Inc., San Francisco, the "architect of record"
  - Paul Marantz of Fisher Marantz, the lighting designers
  - Ugo Früh, project architect with Mario Botta Architetto, Lugano, Switzerland.

- Measurements of the daylight levels (luminance as well as illuminance) in the daylit galleries on three consecutive Mondays when SF MOMA was closed so the electric lighting could be off.
- Administration of a survey of staff in the Museum on their perceptions of what works and does not work with the daylighting n the galleries.
- Collation of all the drawings stored by the architects and the Museum from the design genesis to the construction documentation phases of the building, in order to track the design development - and development of a design chronology.
- Collation also of the extensive literature on the building to determine the reaction of popular and informed opinion on the building.
- Comparison of the design programme lighting goals with the achieved lighting levels and appearance.

9-1.1 chapter structure

In addition to the research background and design brief in this introductory section, this chapter includes a section describing interviews with the design team and measurements of building performance. The bulk of the pages contain a chronological examination of design sketches documenting the building's design development in response to eddst performance analysis using a physical model. The chapter concludes with analysis of this design process in terms of the design tool classification described in Volume A.

9-1.2 SFMoMA brief

One of the most useful aspects of my visit to the Lugano office of Mario Botta was to discover the three ring binders full of cuttings just about the SFMoMA. The material in them was most helpful. The following paragraphs demonstrating the huge significance daylight had for the client are largely extracted from the information in one of those journal extracts: an article by Janet Abrams in the *Lotus International* journal *Electa*.

A quote first from John Lane the Director of the SFMoMA: "...in a way, having built an art museum was not a criterion [in selection of an architect] for us because there are too many instances where new museums had not come out too well: where the architect has entered into the galleries in a way that is intrusive and unfriendly to the works of art. We wanted an architect who would back off when it came to the design of the galleries, and would create spaces that were beautifully proportioned, very clean, to a large extent naturally lighted, and deferential to the art..." [2] It is clear that natural light is a key in this. The interviews below support this interpretation.

An even more significant pointer to me is the comment also attributed to Lane[3] that "the most memorable day" during a tour of museums he and key people from the building committee undertook with Botta after his appointment "was spent in Texas, visiting Kahn's Kimbell Art Museum in the morning, and Renzo Piano's De Menil Collection in the afternoon." If one were to ask 100 architects to list 5 icons of modern use of daylight in museums these two buildings would

figure on most of those lists. Both use top lighting in the galleries in a manner that has an extreme influence on the form and appearance of the building as well as the appearance of the galleries.

In a summary to her article on the building Abrams lists three main objectives for the project. One of the three is: "Using natural light (from overhead) for the majority of the exhibition areas. Operating with natural light gives the exhibition spaces a special character, linked to the climate and light of a particular place. It is a unique environmental quality that will exercise a strong influence over the exhibition spaces and give them a precise identity." [4]

In a 1992 article in the Christian Science Monitor[5] Olivia Snaije notes: "What struck Botta about San Francisco was its natural light, which he describes as "extraordinary - Mediterranean, almost Greek, and very pure." Structurally, the raison d'être of a museum says Botta is its location. "There's no point in us designing synthetic laboratories that could just as well be in Düsseldorf or Helsinki. San Francisco has its light, which must be used.""

"This light became one of the most important elements of the project. Botta is critical of museums built in the 1980's in which artificial light rather than natural light was preferred."

"Artificial light is used because you can control it better, technically it is more homogeneous, more delicate and less damaging to artwork. But I think it's interesting when the visitor can see variations in the light, when it is not only technical or suitable. I made an effort so that the museum, whenever possible, will have diffused light and the visitor can assimilate works of art with this special San Francisco light."

Botta is quoted later as desiring that on the upper floor galleries the visitor will feel "... the architecture will recede, and the works of art will be the protagonists. The space will be defined only by its light, and the visitor consequently will feel more discreet and humble, will sense that the art has become the nucleus" .

In the San Francisco Focus tourist magazine "Pulitzer Prize-winning Critic" Allan Temko states " At the fifth and topmost floor of the building, the high-ceilinged main gallery is one of the most majestic rooms in recent American architecture. ... a temple for fine art, transfigured by light..."

"Light drifts down from coffered vaults, twenty three feet above, that span the width of the room (which measures 55 feet by 102 feet). Botta conceived these high tech ceiling fixtures as "lanterns" and they are true winners. They are among the most refined devices of their kind, balancing natural and artificial light, so that there is not the slightest discordance, even on dark days..."

In an article in the San Francisco Chronicle on September 12 1990 writing about the unveiling of a model of the proposed building the previous day the staff writer Michael McCabe states: "...the building's exterior consists of a single natural material, yet to be determined, that will capture and pull into the museum what Botta described as 'the unique quality of San Francisco's ever-changing light.'

Botta said his design seeks to present a maximum amount of natural San Francisco light to the gallery roofs... [6]"

9-2 *analysis of the design process*

In contrast to the other detailed studies in this thesis, this chapter examines not only eddst use during the design process, but also the performance of the building itself. It contrasts interviews with the design team with measurements of the light levels inside the building, and with a visual analysis of the evolution of the design documentation as the building's daylight performance was further and further analysed using physical models. The design documentation comprises mostly drawings supplemented by a few construction photographs.

9-2.1 SFMoMA interviews

Greg Johnson and Kent Roberts of SF MOMA

This interview was originally conducted as an exploration for teaching purposes of the process by which the daylighting for the new building for the San Francisco Museum of Modern Art was designed. Greg and Kent are engineers. Greg is Director of Facilities and Kent is Operations/Installations Manager.

The issues I planned to cover in the interview were:

- Obtaining permission to take photographs of the building for a daylighting study.
- Establishing the process by which the daylighting was designed, including the use to which the external shades were put, the electric and the natural lighting was controlled by the users and the curator involvement in illuminance control.
- Interaction between the daylighting design imperatives and the architectural concept
- The degree of analysis involved in the daylighting design
- The changes in the design that may have resulted from the daylight analysis
- The actual performance from the point of view of the curatorial staff, the maintenance staff, the managerial staff and the public.

These issues were communicated by telephone to Greg before the interview so as to smooth the process. The aim was to avoid the necessity of him continually searching for information during the interview. As a result of knowing my interests, Greg invited Kent to join us for the interview.

They described the building as daylit extensively on the second, fourth and fifth floors, but not on the third. MOMA apparently wanted daylit galleries from the outset for three principal reasons: a strong link to tradition; a shared view of the importance of daylight in displaying art; and a particular view from the painting and sculpture sections that daylight is important in the viewing of their media. Lighting in general *was one of the major issues for the people involved in the design of the museum.*

Greg reported that the Museum employed Marcy Goodwin in March 1989 to obtain user input to develop the programme for the new building. SF MOMA then hired Bechtel Corp. as Project Managers. Subsequent to this, later in 1989, the architect, Mario Botta, was appointed. Hellmuth, Obata and Kassabaum (HOK) of San Francisco were appointed next, as the *architects of record* soon after.

The pair reported that the rumour was that Botta did not do too much at the end of the project. If asked to draw up a share of the work undertaken by Botta's firm and HOK, then they suggested: for the Schematics, Botta 90%, HOK 10%; for the Design Development, Botta 60%, HOK 40%; for the Contract Documents, Botta 25%, HOK 75%. Two people were seconded from Botta's office for 18 months during the contract documentation phase. Mario Botta himself visited the site once every three months over a two year period.

Fisher Marantz the lighting consultants were involved early, from January 1991. They were employed by the Museum to do the electric lighting and the daylighting. They noted again in this context that lighting was one of the major issues in the design of the museum.

Kent reported that *programming* felt that they had been consulted as much as they could expect. The driving forces in the project were design, needs of the programme, the cost, and delivery time limits. The Conservation department also provided strict guidelines on what light levels were acceptable

When we concentrated specifically on the daylighting, I made my first exciting discovery about this building: the skylights, contrary to then popular local belief amongst the architecture science community, had little canvas covers designed for them because of the Museum's desire to achieve blackout without moving parts. It was not a last minute fixing of a design fault. Movable louvres and other electronically controlled devices were not to be used. Greg and Kent pointed out that the turret also resulted from a key part of the original programme: a requirement for the building to be designed in such a way that people did not get lost inside it.

Because of the light conditions measured in some of the galleries, and because the conservation department wishes to lower them, they *have discussed* achieving medium black out with translucent covers. Hit and miss usage would not give good light distribution.

My second discovery at this point was about the design process. Greg and Kent reported that the lighting designers had constructed a 2/3 scale (actually it turned out to be quarter scale) model of a gallery and left it on the clear site for a lengthy period of time. *Fisher-Marantz did footcandle readings* for some time in various San Francisco climatic conditions. This last discovery led to my inclusion of SFMoMA in the thesis. It is the influence (or otherwise) of just such simulations that I am examining. Finally, I was informed that Fisher-Marantz also measured illuminance (*light*) levels in a full-scale mock-up of a gallery on the north-west corner of the second floor. This was done during the construction of the building.

When asked to suggest whether there were any problems or drawbacks with the lighting design about which they were generally positive Greg and Kent noted the following:

- The Turret. The turret areas, and especially the bridge on the fifth level are too bright. This is particularly so when one experiences the contrast on coming out of or going into the galleries. The possibility of changing the glass in the turret was also raised. Apparently the architect was very keen to ensure that the light through this turret was not tainted by a glazing tint. Talk was of a fritted glass with white dots to reduce the total amount of light entering.
- Vertical Glass. Despite the dark tint and the *mecho shades* the glare through these is at times unreasonable. It is also damaging to the artefacts.

When asked whether they would do anything different the second time around, both found it hard to say anything useful. They did note that they would probably make the vertical glass darker. There seemed very little desire to get rid of even these troublesome features of the design. They recognised that orientation for the visitor to the outside through these windows was a key element in ensuring that people did not get lost as they walked around inside.

On the artificial lighting of the galleries there was very little to report. Each gallery has two light tracks which can accept any number of lamps. All lights are scheduled by computer. The schedules are typically changed month by month to recognise the length of day. For some shows the fluorescent lights in the skylights are off all the time. The value engineering phase of the construction process removed the fluorescent uplighters and the electronic sensors and associated controls for all the lighting.

Mark Otsea and Andres Grechi of HOK - San Francisco

This interview was with Mark Otsea. Andres provided access to the drawing documentation and to his own personal file of cuttings, photographs and memorabilia on the project. It was through him that I obtained the set of working drawings for the building. It was also through him that I obtained permission to copy the slides of the hand-coloured presentation drawings used in the fund-raising for the building.

According to Mark Otsea, Mario Botta does not normally use technical consultants in the area of lighting. He does not trust computers - in fact the drawings of SF MOMA were at Botta's insistence, mostly done by hand even though HOK would normally use a computer for this purpose.

Fisher-Marantz were employed by the Museum. However, because *Mario had clear ideas about what he wanted to do with light* the design team meetings *went well*.

The initial sketch design ideas were apparently inspired by Kahn's Kimbell Museum. *Bits* of the building were then modelled at 1/8th inch to one foot scale (approximately 1:100) to demonstrate the ideas to the client. The lighting was studied principally through these models. The models were evaluated by Fisher-Marantz in New York and the design team met in New York to discuss the results.

Eventually Fisher-Marantz had a quarter scale model constructed on the site of the proposed building. This model even represented the transmittance of the glass accurately. Over a period of three months daily *light level* measurements were conducted inside the model. The output from these measurements fed into the glass and diffuser design for the skylights and into the design of the electric lighting.

The drawing specification required a mock up of one bay including skylight during construction. Two of the walls were constructed with black *tarps* and more measurements were made. Apparently the design team also visited this mock-up. As a result of these particular measurements, it was determined that a little more light than was planned was entering the gallery. A grille was interposed into the skylight between the outer gazing and the inner lay-light. The grille has blades. The angle of the blades was set to intercept direct sun that might penetrate into the *tube* of the skylight assembly.

Ugo Früh of Botta Architects - Lugano

Ugo was most helpful in providing me with access to the clippings file and the files of drawing transfer records that showed each drawing that had been donated to SF MoMA by the Botta firm. Ugo had been the Botta project architect in San Francisco during the latter stages of design and the construction of the building. However his comments about the design were singularly unhelpful. He knew nothing of the measurements. He appeared uninterested in them.

When asked if the design had changed as a result of the lighting analysis he said it had not changed at all. When pressed on the topic of the skylights he was adamant that these changes had been internal, not a part of the architecture. His perception was of an architecture that exploited the qualities of the light in San Francisco - the new world - but not of an architecture that had been influenced by the technical analysis.

Unfortunately there was no other documentation of the design process on file that I could access which might indicate the debate or the advice that was received as a result of the three stages of analysis - the different scales of model - undertaken by the lighting consultants.

Paul Marantz and Scott Herdsman of Fisher Marantz of New York

Scott was the initial contact person. Paul was obviously in charge of the project. Scott was concerned about charging for time spent in talking to me. Paul was just very hard to contact. The only comments that Paul made in addition to those already made by the client and architect were that the most profound design changes occurred one year before the quarter scale model. These came about partly through discussion and evaluation of the $1/8^{th}$ inch to one foot scale models, and partly through debate between the members of the design team. The $1/8^{th}$ inch to one foot scale models were studied in the Fisher-Marantz light-box in New York. This is where the client and design team meetings on lighting often took place.

It was a *back and forth* process. No photographs were apparently made of the models. In fact the models no longer exist. They were destroyed at the end of the job. In Scott Herdsman's estimation, digging out the before and after drawings and the design reports and meeting minutes relevant to these drawings would be very time-consuming and hence expensive for the firm. They were therefore unprepared to do this.

9-2.2 one-off measurements

The normal difficulty posed by a one-off measurement approach that is to be representative of the seasonal performance of a whole building arose in the planning of this project. Having made arrangements to be escorted by the security staff around the building during a Monday when it was closed, I was faced with the prospect of only being able to make spot measurements in the galleries. The goal was to measure illuminance in the galleries when the electric lighting was turned off. To make any sense, these measurements would have to be scaled by the outside light conditions at the time.

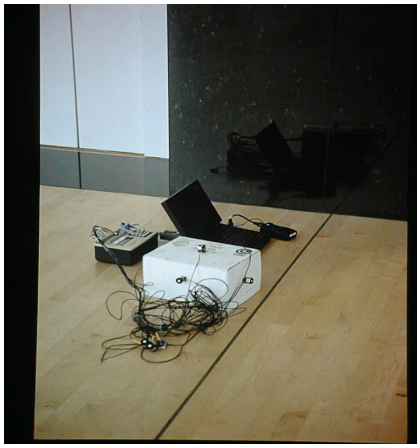


Figure 93 Datalogger, sensors and portable computer in data transfer mode in the laboratory.

Figure 94 External Sensor on the roof

Figure 95 Trolley and sensors in position near gallery entry to atrium bridge top floor.

The normal approach in a daylit room is to create a grid across the room at desk height - the working plane - and to measure the spot levels at these grid points across the room. These values are then integrated into a series of contours of illuminance in much the same way as spot heights are converted to land contours in surveying. The desk height is the working plane which the lighting designer focuses their efforts on illuminating in an office. The problem with an art museum is what is the equivalent working plane. In the SF MoMA, when daylight is the source of illumination, the art on display can be both three dimensional freestanding sculpture and two dimensional wall-hanging.

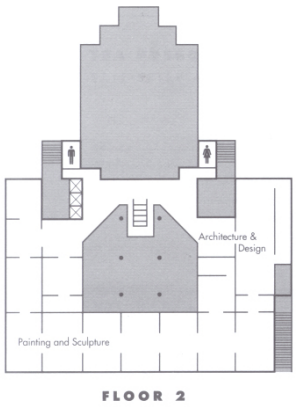


Figure 96 SFMoMA Level 2 Plan

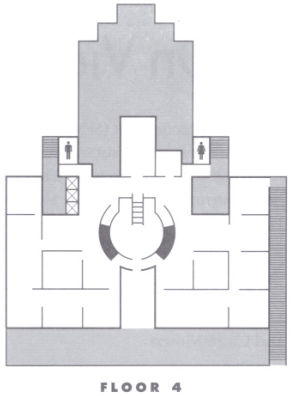


Figure 97 SFMoMA Level 4 Plan

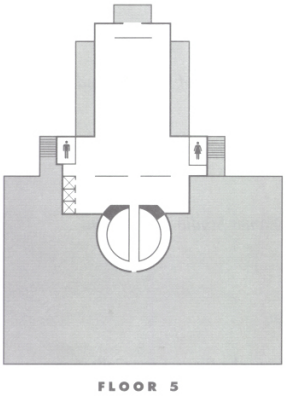


Figure 98 SFMoMA Level 5 Plan

Figure 99 Level 5

The solution to the working plane issue was to measure the building interior using an array of 8 LiCor lighting sensors mounted on a trolley and connected to a Cambridge Scientific datalogger. A single sensor was connected to a further CS datalogger on the roof to measure external illuminance. The goal was, over a period of a day, to record the daylight factors inside the building on a standard horizontal "desktop" plus on vertical surfaces at various heights. The sensors were mounted: one horizontal at approximately a metre from the floor; four vertical at the cardinal points of a circle around the horizontal sensor; two on a pole at a height of 2m and 4m from the floor, on one side of the trolley able to be oriented to whichever direction was appropriate for the measuring position

(such as away from the wall against which the trolley was leaning); and finally one underneath the tray of the trolley - horizontal, but facing the floor not the skylights.

A grid plan layout was drawn up for each room. The trolley was wheeled through each gallery and, with the aid of a tape measure, was stopped at metre intervals and a reading taken for each sensor. The datalogger recorded the time and the illuminance level of each. Meanwhile, the outdoor sensor recorded a single illuminance reading every 10 seconds. Using a small routine provided by the PG&E company staff who had donated the use of the sensors this data was later downloaded into a portable computer and also backed up to floppy disk.

In addition, at each reading, a manual reading was made of the luminance of the skylights and of the luminance distribution across the roof cove and walls from the skylight to the floor. This data was all transferred to a spreadsheet. The graphs on pages 13 through 14 show some of the results for the top (fifth) floor gallery. The purpose here is to use this data for analysis of the process of daylight design, not to complete a comprehensive daylight performance analysis of the SFMoMA building. Thus only level five results are presented. It can be seen that the illuminances on the vertical surfaces are well within the target range for an art museum as recommended by the Lighting Engineers at 10-30 footcandles (108 - 324 lux), *"...controllable by the user though lamp selection"*.[7] This on a sunny day when the average illuminance in the shade was over 30,000 lux.

Figure 103 has no distance measure on it as it traces readings in a zig zag manner across a grid pattern for a portion of the floor of this fifth floor gallery. It shows a more even level of illuminance on each surface than **Figure 101** because at this point the sensors are out of line of sight to the atrium.

The illustrations in **Figure 102** show a definite flow of light across the gallery, adding to the modelling quality and potential to reveal texture in art works. This ingress of daylight helps maintain the client's goal of viewer connection to the outside. However, as soon as one can look along the main axis of this top floor gallery to the outside (**Figure 104**) one is subject to considerable potential glare. The west facing sensor also shows a much higher reading than the East sensor in **Figure 101**.

Figure 100 shows a series of photographs overlaid on a plan of the top floor illustrating the luminances experienced on the path from the atrium bridge on the right to the depths of the gallery itself where only the top lights impact on the surfaces. **Figure 101** shows the measurements of illuminance made on this path down the East/West axis centre line of the gallery. The graph shows the average of two or three readings at 2m intervals along the path from the East wall of the gallery almost to the bridge over the atrium space at the west end of the building. On the bridge the illuminances climb rapidly to 3-4000 lux (while the outside illuminances are 30,000+). It should be noted that the sensor facing downwards produced no useful readings.

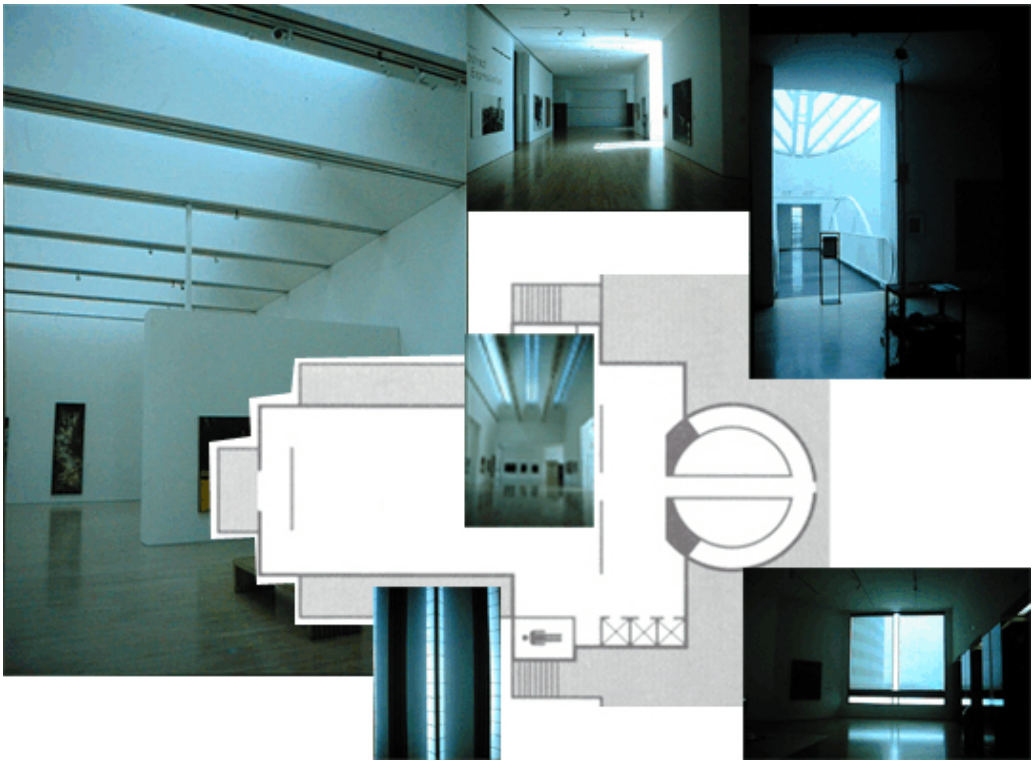


Figure 100 Level 5: sunny day interior views of bridge and gallery

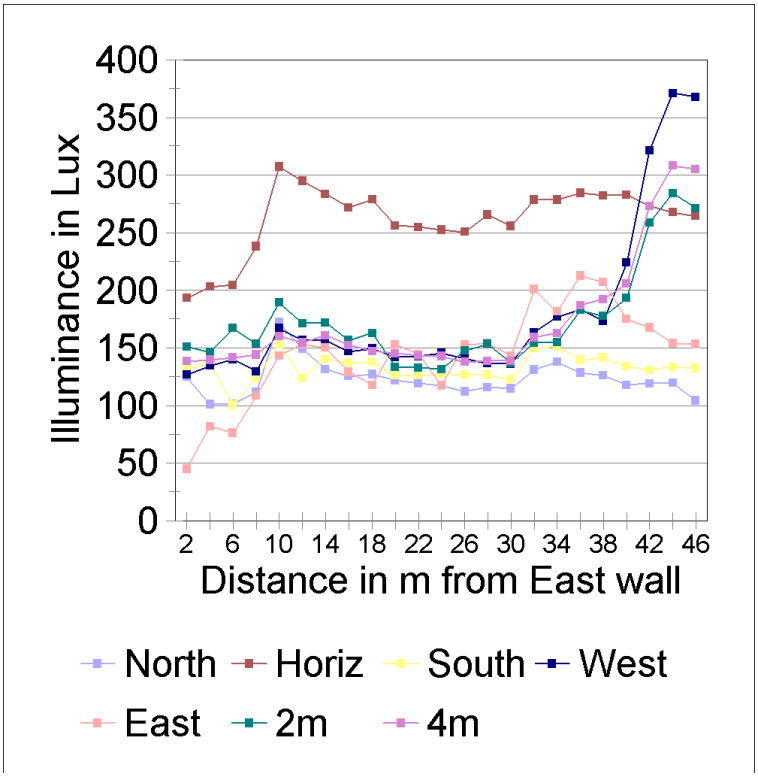


Figure 101 Level 5: sunny day illuminance measurements on East West centre line of gallery

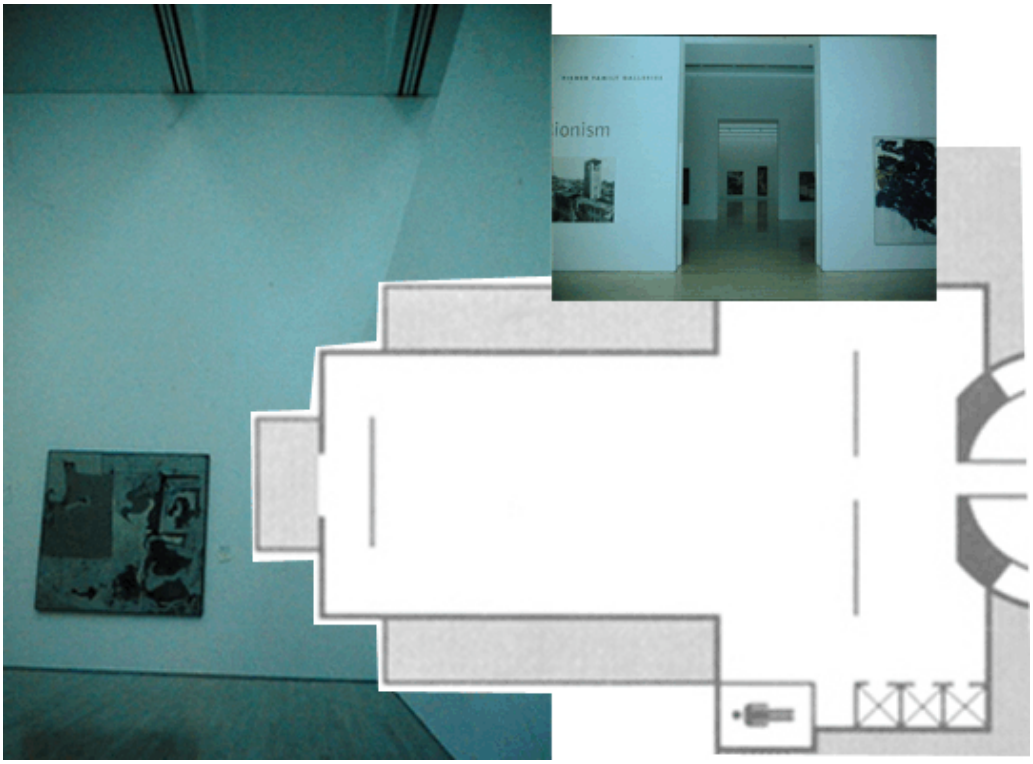


Figure 102 Level 5: sunny day interior views of daylit gallery areas

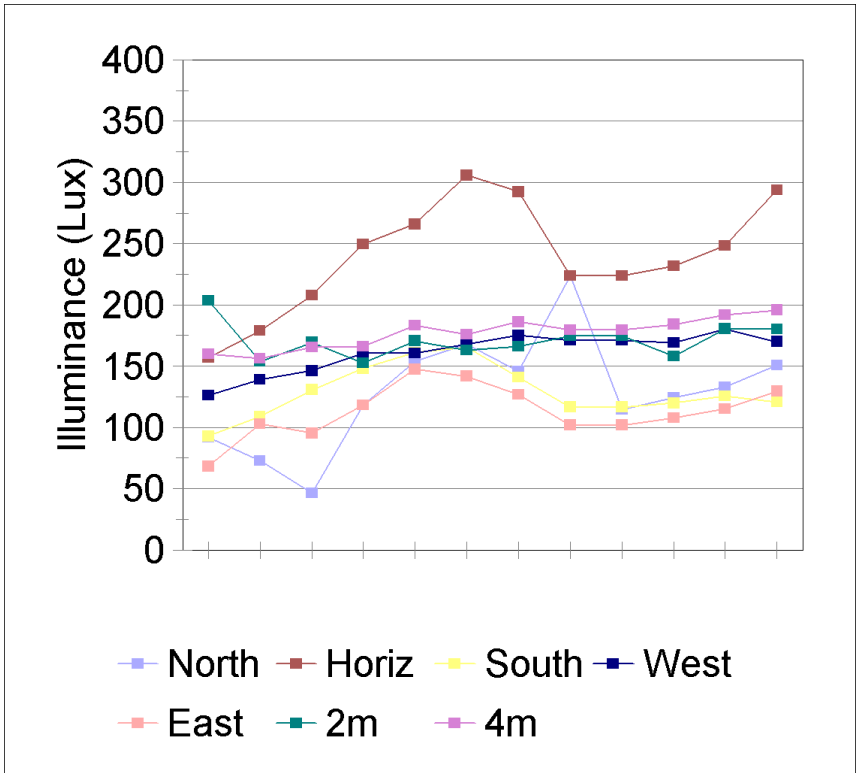


Figure 103 Level 5: sunny day illuminance measurements in gallery away from centre line view to atrium

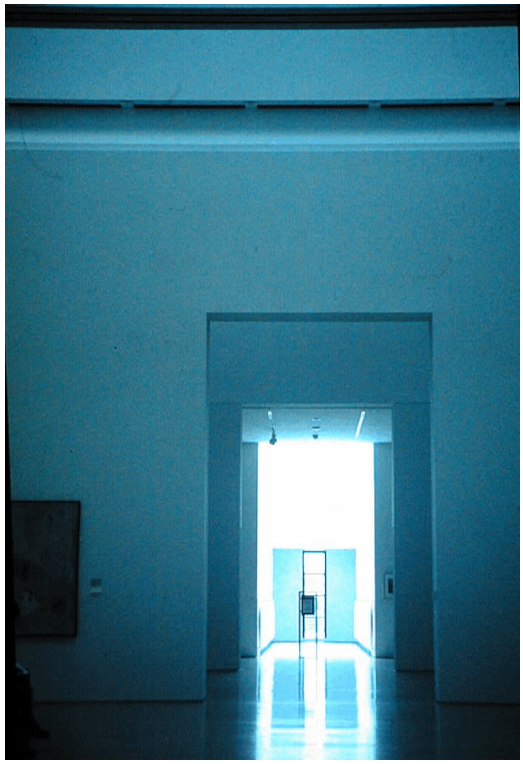


Figure 104 Level 5: sunny day interior view from gallery to atrium glare

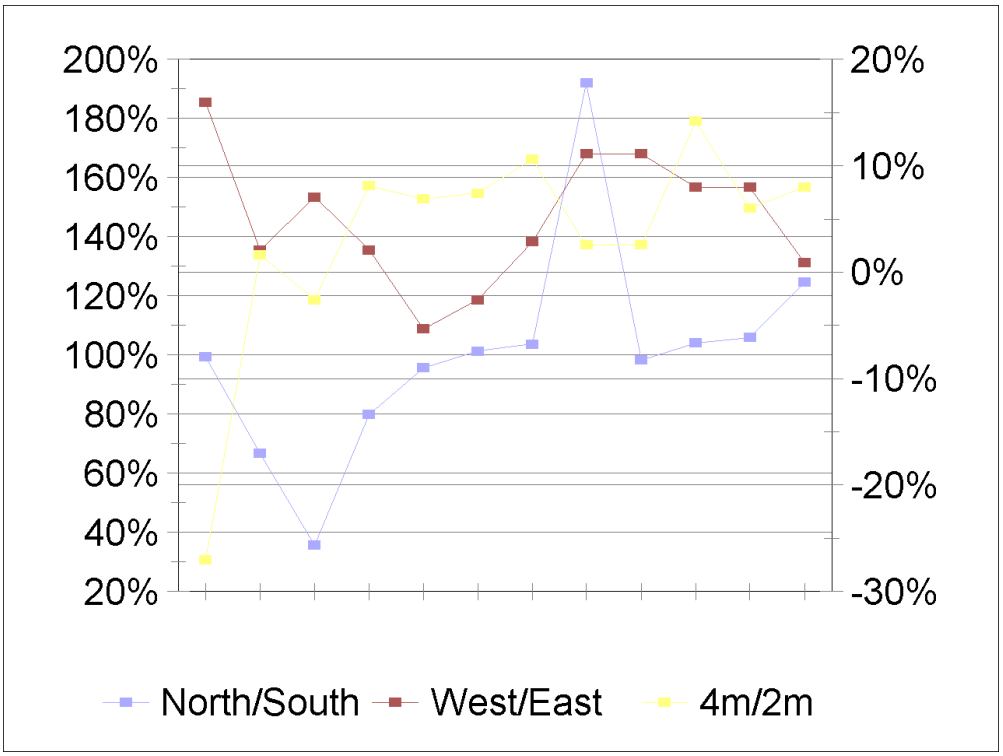


Figure 105 Level 5: sunny day vertical illuminance ratios North/South; West/East and heights of 4m/2m

A physical measure of this flow of light can be gained from the ratios between the illuminances measured on sensors facing opposing compass points. These ratios are explored in **Figure 105**. The

graph shows the ratio (expressed as a percentage) between North/South and West/East illuminances; these are plotted against the left vertical axis of the graph. The difference between the illuminance at 2m and at 4m from the ground is also plotted as a percentage measured on the right vertical axis of the graph. There is no spatial pattern across the gallery in this graph as it is plotted for the points shown in **Figure 103**. What is of note is that for a broad central area of the gallery away from the walls and direct line of sight to the atrium: the vertical illuminances on surfaces facing North are around 50% bigger than those on South facing surfaces; similarly, West facing surfaces receive more light than East facing surfaces. A definite, perceptible flow of light.

The differences shown in the third line in **Figure 105** between the illuminance on the wall surface at 2m and 4m give a good impression of the quality of the daylighting of this gallery for display purposes. Apart from the very first point, which was measured very near a wall, this line shows that the light levels on this principal display zone on the walls vary very little - a commendable result and one that is hard to achieve even with electric light that has more freedom of positioning relative to the art work.

9-2.3 long-term daylight measurements

While visiting the museum for the case study I discovered that a set of light readings had been taken once a week for a year by Museum staff from June 1995 until June 1996 in rooms 206, 207, 208, 209, 210, 211, 213 on the second floor. It was hoped that these could be compared to outside light conditions over this time. A year long trace of illuminances expressed as daylight factors would be very much more interesting than the one-off measure that I had been able to perform. Unfortunately, exhaustive searches of the available data sources have failed to identify any suitable data on light or sun in San Francisco over this time period. The analysis here is therefore more limited than would be ideal in a full daylight case study..

The graphs on page 18 show the year's readings for rooms 209 and 213, placed at the centre and the Southwest (sunny) corner of the front (West) facade respectively. Room 209 has a narrow vertical slot window facing the street over the main entry as well as the skylights. The 11am readings for October 2 1995 were not taken for any room. The 11am readings in room 209 on 31 July were not obtained for the WS wall for some of the July - August 1995 period. The SE wall was often not measured at all in room 213. For all these readings the respective trace in the graph dips to zero on the vertical axis. The vertical axes of the graphs are set to 1000 lux for the 11am light levels; 3000 lux for the midday ("lunchtime" according to the notes) light levels; and 2000 lux for the afternoon light levels. To have graphed them all on the same basis would have hidden too much of the structure of the smaller readings, particularly the early morning readings.

The top, yellow, trace for these graphs shows the horizontal illuminance in the centre of the room. The rest of the readings were taken approximately two per wall on the North East, West and South

walls. The labels for each trace in the graph are intended to indicate on which wall and where on the wall a measurement has been made. The labels consist of one or two letters: if a measurement is a single central wall measurement it is labelled with a single letter such as **W**est or **E**ast; or if it is one of a pair then it is labelled with two letters according to which half of the wall it is on so that. on a South wall there is an East and a West half labelled **SE** and **SW** respectively.

The target illuminances for the gallery electric lighting[8] of up to 320 lux are much lower than is experienced on the walls in these galleries for the afternoon hours of most of the year. These Fisher Marantz derived numbers are consistent with the range of 200-400 lux recommended for daylight by Fisher Marantz in their initial 1991 briefing report[9]: "Our feeling is that Thompson's values (200 lux) are somewhat low to permit color vision, and so in other projects we have been seeking full illumination in the range of up to 200-400 lux. This higher range is based on the luminance required to produce threshold response in the cone receptors in the eye... A frustrating aspect of such a scientific approach is the "standard observer" therein assumed. Few of us are "standard" observers. One predictable variation among museum visitors is age. It can be estimated that the aging eye requires 50% to 70% higher illuminances for equivalent vision..."

From October through February, the design achieves levels lower than this target even at midday. Electric lighting will be necessary. For the rest of the year the daylight light levels alone are in the range of 500-1000 lux. It is the sunniness of the San Francisco climate that we are observing here. The consistently higher light levels in the afternoon on the West facade, when the bulk of the rest of the building would shade the skylights from any morning sun are a direct result of illumination from the sun diffused as it is, penetrating through the skylights as we can see happening in **Figure 102**.

The important figure here is the illuminance on the walls. The measurements made by me on 30 September indicated that, because the design works so well at distributing light, a single spot measurement taken around mid-painting level on these walls would be characteristic (within 10%) of the illuminance on the whole display area on the wall. The horizontal illuminance taken in the centre of the room will necessarily be significantly larger because it is facing directly at the light source - the skylights. This is akin to pointing a meter at the spotlight and measuring output. It shows that placing a painting horizontally in this full illumination at this point makes little sense. But, as my measurements also indicate, a painting placed vertically at this point will experience significantly less direct illumination.

The question that arises from these measurements is: to what degree simulation assisted in the design. From the interviews it is apparent that the architects saw all this modelling as affecting only the light fittings - the skylights. The original simulation in the artificial sky in New York looked only at cloudy sky conditions. It is a first approximation designed to get 'window' sizes roughly right. The lighting designers' on-site measurements at quarter scale are unfortunately unavailable. However, they were clearly needed to supplement the cloudy sky predictions of the artificial sky with real data on sunny

conditions. They also will have provided data on the likely intensity of the daylight even under cloudy skies - a scaling that the physical model simulation method is incapable of without reliable on-site data.

As can be seen from the chronological record of drawings and models in the drawings reproduced between **Figure 112** and **Figure 167**, the skylight design has evolved considerably in engineering terms. The simulations have apparently had a significant influence. The initial sizing of the skylight elements was influenced by the model in the artificial sky, and, from the chronology, by the results of the quarter scale model (**Figure 154**). Then the full-scale simulation of the mock up gallery led to the addition of the louvres to keep out the sun(**Figure 165**).

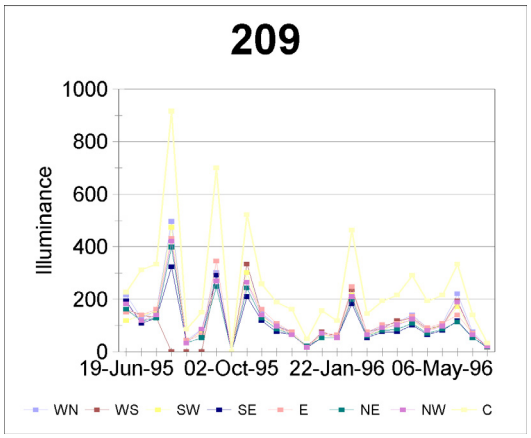


Figure 106 June-Sep 1995 11am light levels

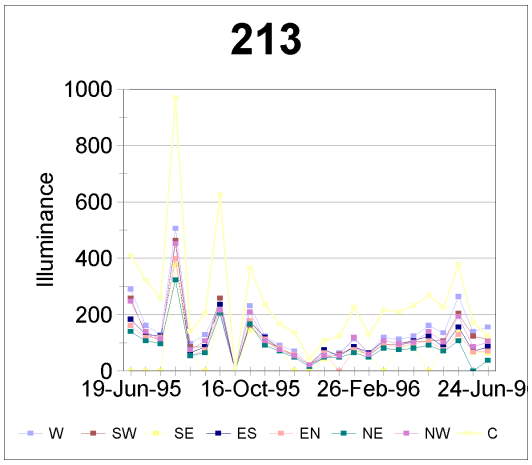


Figure 107 June-Sep 1995 11am light levels

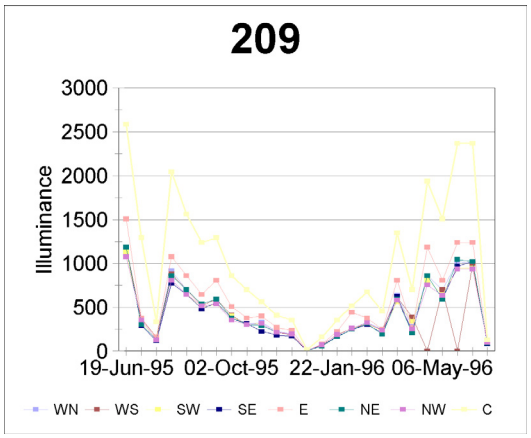


Figure 108 June-Sep 1995 midday light levels

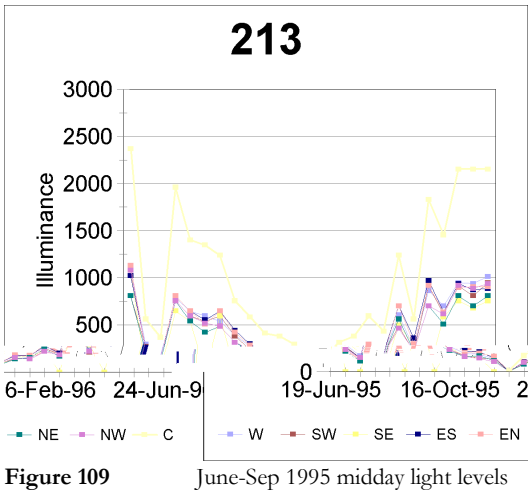


Figure 109 June-Sep 1995 midday light levels

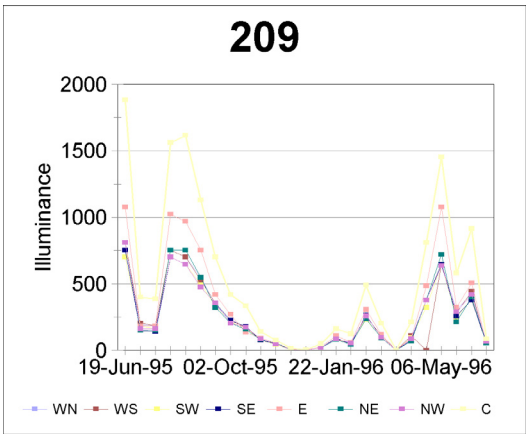


Figure 110 June-Sep 1995 4pm light levels

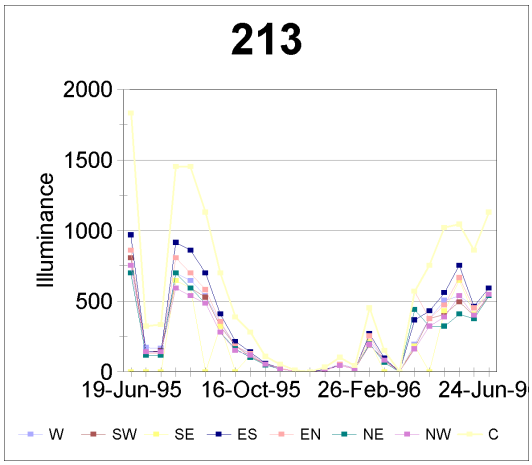


Figure 111 June-Sep 1995 4pm light levels

9-2.4 the chronology of the design process

For this case study approximately 100 copies were made of sketches by the architect and of the lighting designers' notes. These were obtained from the architect's offices in Lugano and from the SFMoMA drawing archive in San Francisco. A partial set of working drawings for the building was also obtained from the offices of HOK, the architects of record in San Francisco. They provide a direct illustration of the design process described by Mario Botta in a CD ROM on his work: "I like to start from the first sketches, from the first intuitions, from the first interpretations of the setting of the territory. And I like to retain memories of these first intuitions during the whole evolution of the project." [10]

Rebecca Schnier, a San Francisco architect, noted[11] Botta had worked briefly for Louis Kahn and le Corbusier and claimed Carlo Scarpa as a significant influence. She pointed out that the Board of trustees wanted a monument or icon. Botta's view of the gallery as a "cathedral to art" matched these desires. She also commented that the beautifully lit galleries with a combination of natural and artificial light were direct descendants of classic 19th Century museums. Drawing on examples from Schinkel: "...an enfilade of galleries around central dome topped circular gallery or rotunda..." to Stirling; "...central rotunda in Design Museum in Stuttgart" , she said Botta's contribution was to "play with traditional circulation" .

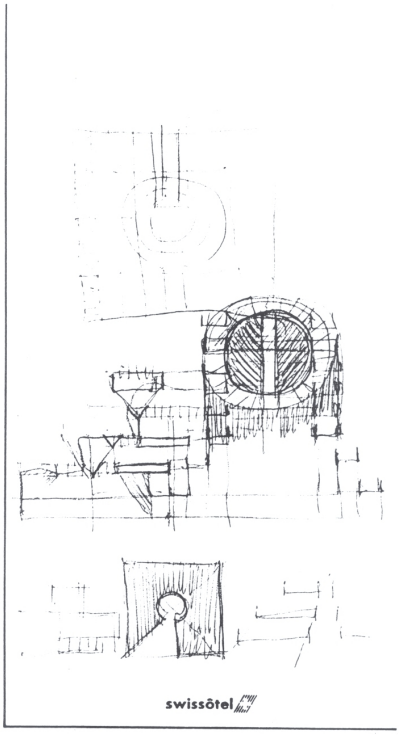
Introduction to the illustrations on the following pages

The illustrations on the following pages[12] are presented in chronological order. The larger pictures show the lighting ideas development. The codes in the captions refer to the file codes from the Botta office for each series (e.g. E for lighting; A and B general plans and elevations; C and D for sections and details). The smaller right hand pictures are from the B and C series, informing the broader

design development. Presentation in this format is intended to illustrate how the building design continued to develop while the daylighting vaults "which he (Botta) intends to treat as "lamps" [13] were treated as engineered light fittings, not architecturally designed objects.

Some of the illustrations were obtained from the offices of the lighting designers Fisher Marantz Remfrey Stone (FMRS) during my September 1997 visit to New York. Fisher Marantz appears to have been the name of the firm during the SF MoMA design process. For this reason the illustrations from their offices are labelled with an FM code.

The process illustrated here includes the construction period. A set of photographs were obtained from Botta's office that were taken of the construction during 1993. They, along with the drawings and diagrams form a coherent time-line for the project which supplements graphically the information obtained in interview.

Design Detail: Chronology of sections and details	Associated Design Concept
 **Figure 112** C4: Early design concept - 1989	Where the overall sketches are available showing the design development as a more holistic level, they are included here to provide a context for the ideas development that is illustrated in the column on the left. The exception to this 'rule' is the picture to the left. It is the legendary first sketch produced by Botta after visiting San Francisco. It was reputedly done on an airline notepad in flight!

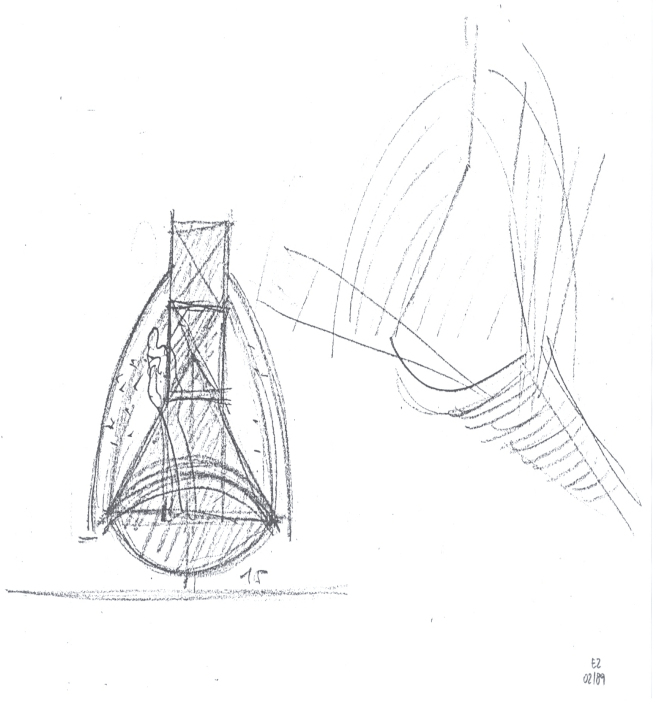


Figure 113 E2: Skylight idea 02/89

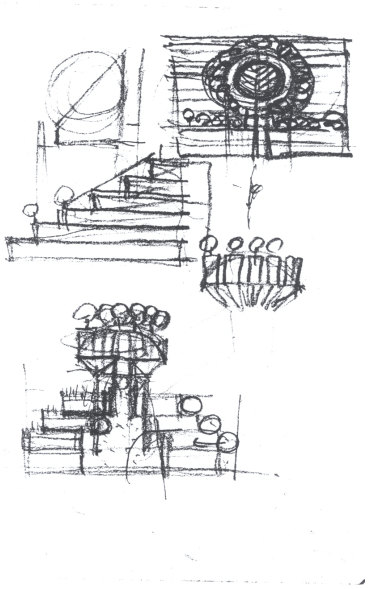


Figure 114 C5: Early design ideas - 1989

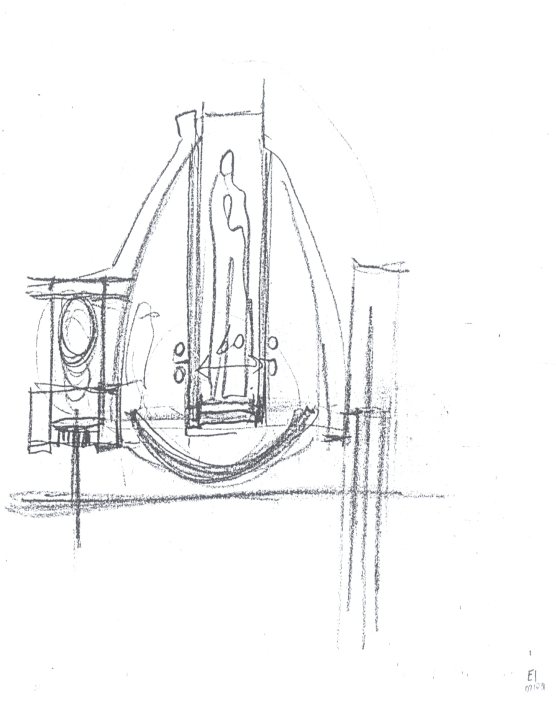


Figure 115 E1: Skylight section- 02/89

The skylight design evolves. One can assume that there was consideration around this time of the possibility of a skylight system which was large enough for maintenance and lighting rigger personnel to walk through?

Figure 116 E2: Skylight section 02/89

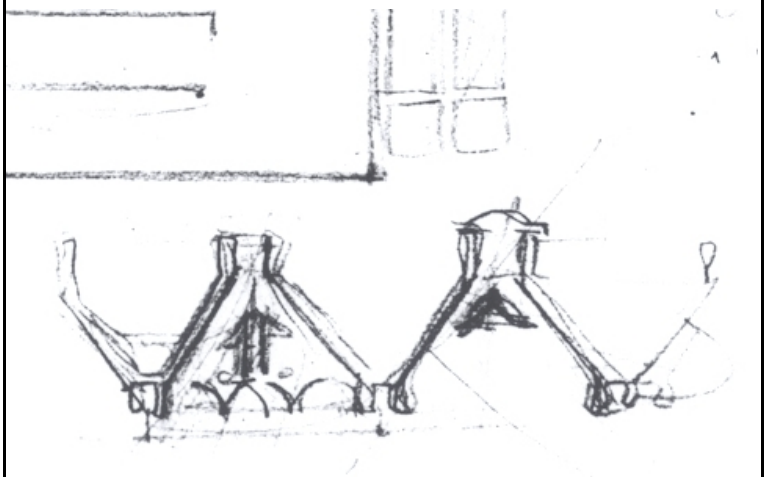


Figure 117 A3: Detail of skylights - 1989

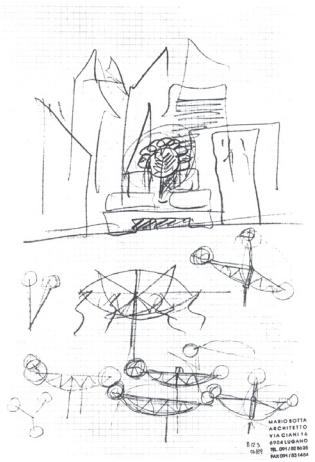


Figure 118 B12.3: West elevation - turret detail 06 89

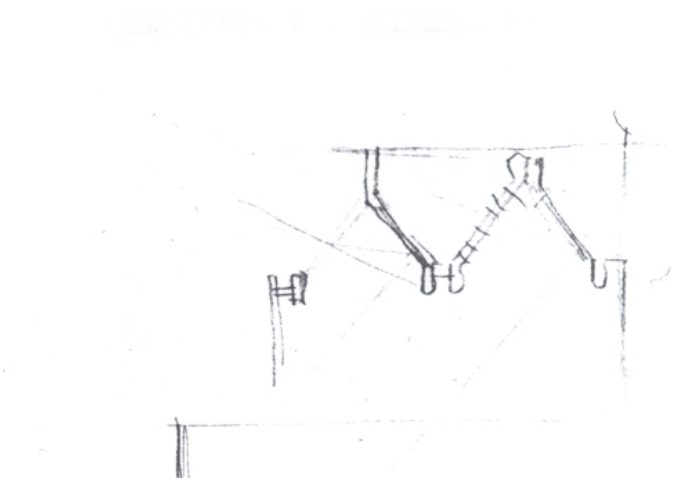


Figure 119 B8.1: skylight variants 10/89

Much of the detail of the skylights appears to still be very strongly expressed in the interior. The Fisher Marantz influence is not apparent.

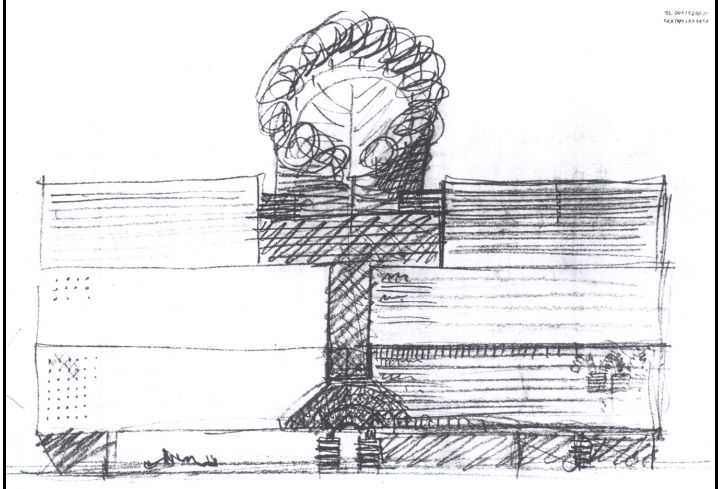


Figure 120 B3: Early elevation - 11/89

In the chronology of drawings in SFMOMA itself, and at Botta's office in Lugano, there seemed very few early overall concept drawings that informed about the connection between interior and the daylight outside. The section below left is therefore critical to any interpretation of the role of analysis in the design of the musesum.

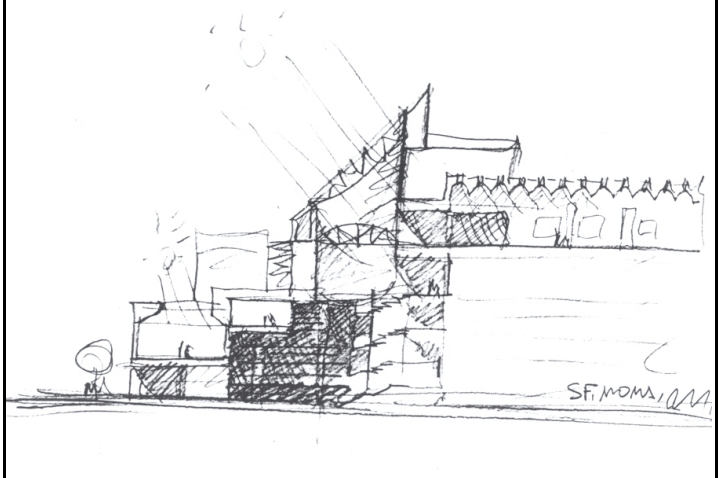


Figure 121 Mario Botta Lighting concept sketch 10-89?

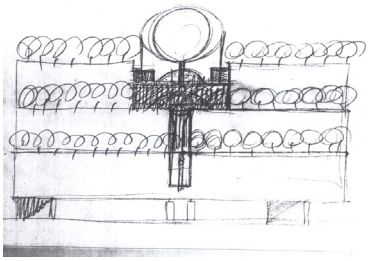


Figure 122 B2:Early elevation - 11/89

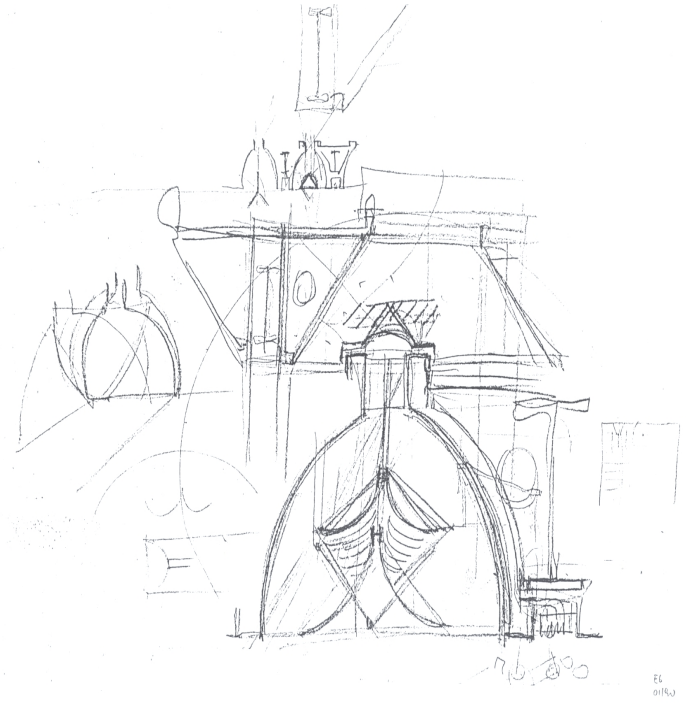


Figure 123 E6: Skylight ideas 01/90

The skylight system is still a broad concept at the time of the public announcement of the design. The picture below left does show in the right section a hint of the reflecting surface and diffusing element and upper simple skylight system of the final design.

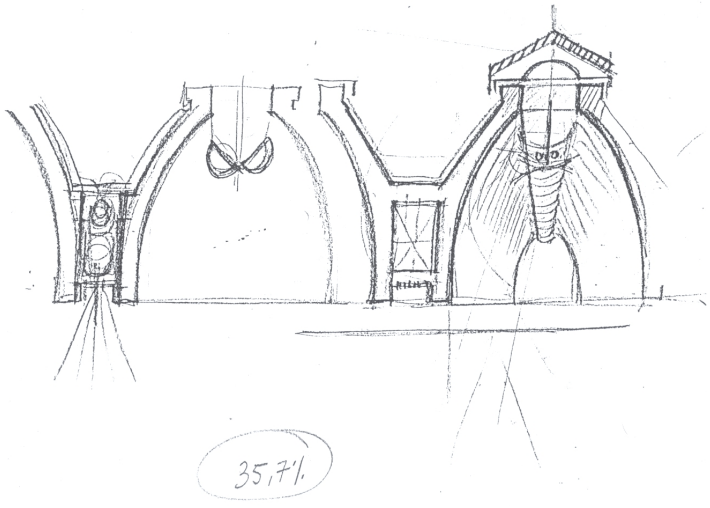


Figure 124 E8: Skylight sections - 01/90

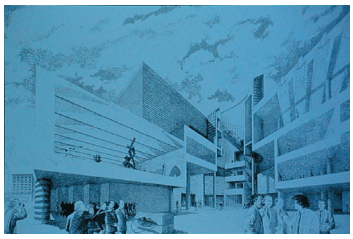


Figure 125 Cutaway section

Design Concept goes public ...These illustrations are from the marketing brochure for the fund-raising.

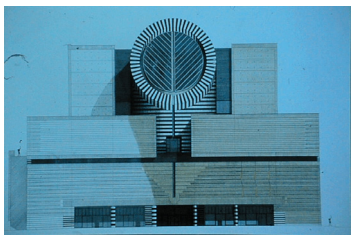


Figure 126 West elevation

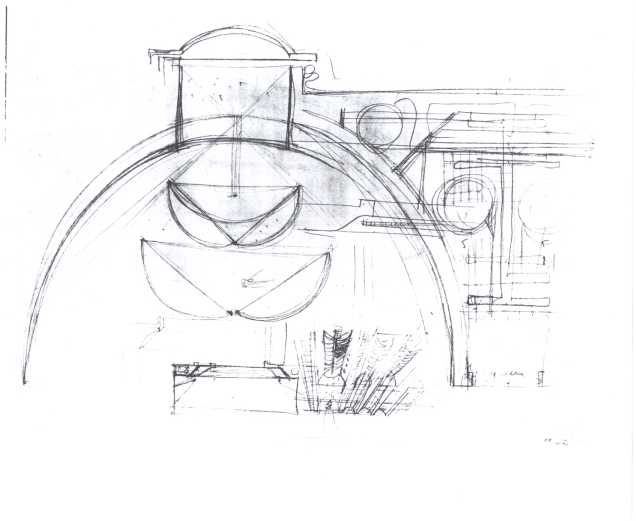


Figure 127 E5: Skylights/reflectors 01/90

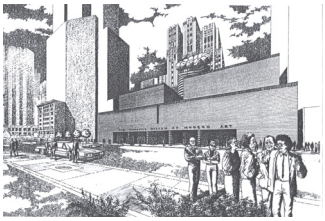


Figure 128 sketch: early 1990

"... "Botta's formidable almost forbidding facade - in its one serious flaw - has no windows facing west" ...[14]

The distance from the top of the curved reflecting surfaces to the skylights begins to grow.

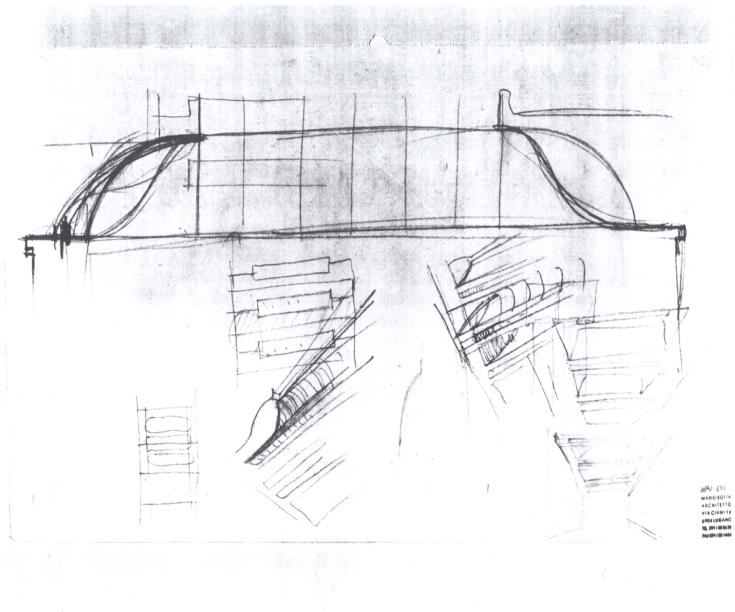


Figure 129 E5.1: Skylight long section 01/90

"...Some of the galleries will be small and intimate, others lordly, high-ceilinged, skylit areas ...culminating in a magnificent topmost exhibition area illuminated by natural light through curved plaster vaults 25 feet overhead... All this needs further study. Botta still has to define the vaults, which he intends to treat as "lamps"" ...[15]

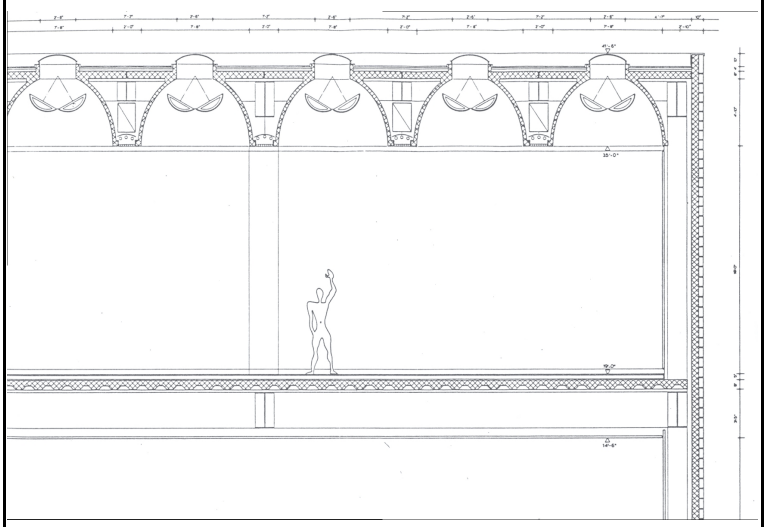


Figure 130 Section through fifth floor skylights from 1990 initial design

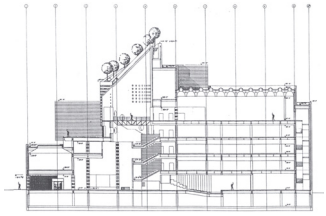


Figure 131 Section from 1990 initial design

Initial design complete. No apparent contribution of analysis to the 'design' at all. The lighting analysts start their initial feasibility study in their artificial sky in New York a year later (below).

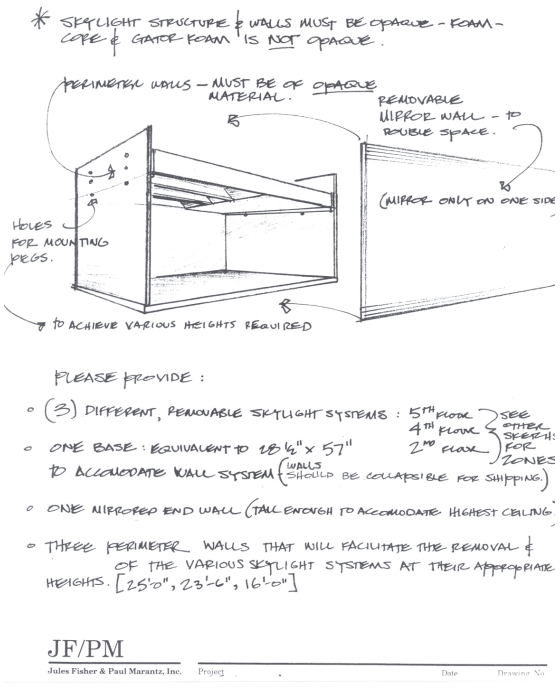


Figure 132 FM Daylight model 26 2 91

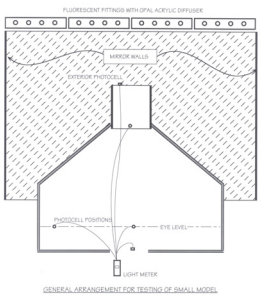


Figure 133 FM Artificial sky

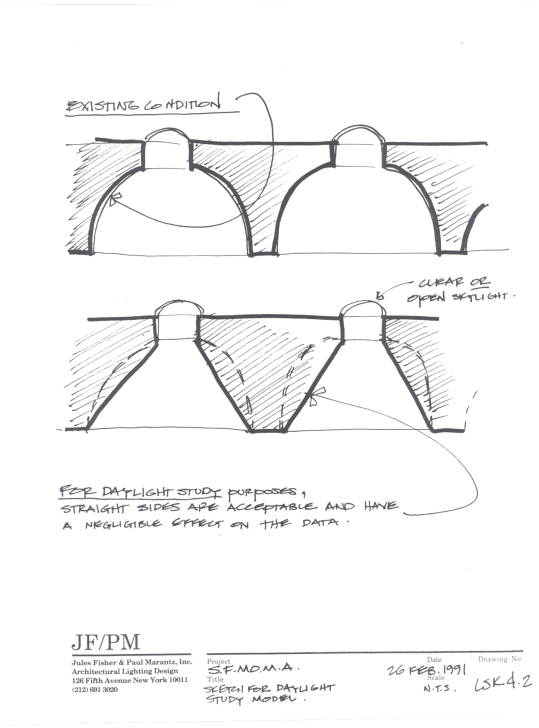


Figure 134 FM Skylight model drawings: 26 2 91

The Fisher Marantz Remfrey Stone sketches on these pages show the nature of the simulation model studies.

Optional skylight configurations in the sketch on the left. Not apparently closely related to the concepts shown on the previous pages that were being explored by the architects.

Note, at this stage these were tested in a mirror box artificial sky in FMRS offices, so were only testing cloudy sky daylight access, not sunlight access.

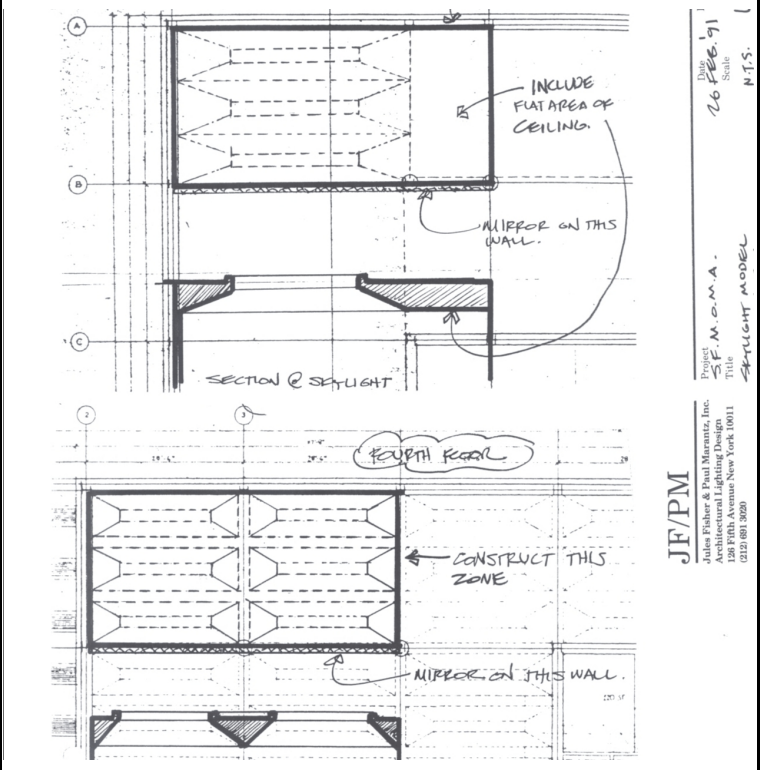


Figure 135 FM Skylight zones: 26 2 91

Mirror wall is placed to simulate a room that is much longer than this typical portion of the plan of a gallery - a standard simplifying assumption made when constructing physical models. This relies on the gallery being the same either side of the mirror so that the light that is reflected back by the mirror is merely replicating the light that would have come from the skylights in the adjacent gallery space.

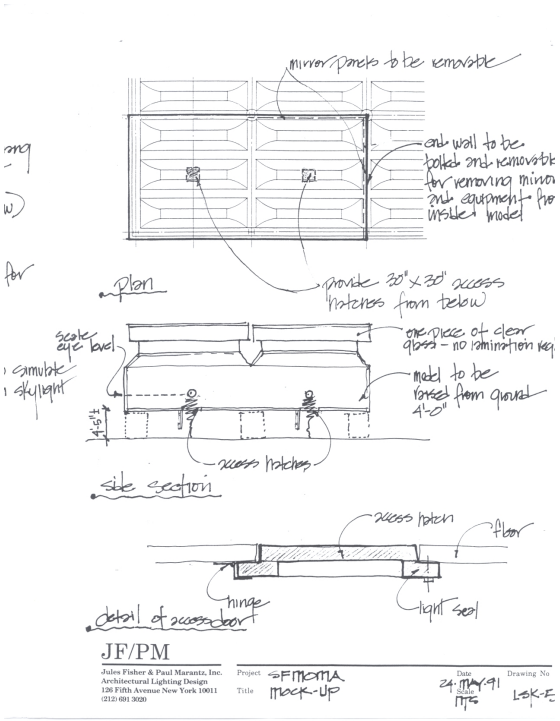


Figure 136 FM 1/4 scale Mock-up 24 5 91

This second stage 'model' was placed on site in San Francisco and the light levels measured inside for some months.

No records were made available to me, though I understand that they may be in an archive in New York somewhere. There was no suggestion in any of my discussions with FMRS or with the architects in San Francisco who oversaw the site during this time of major changes to the skylight design at this time. This was testing and perhaps refining a few dimensions of a basic design confirmed through the artificial sky evaluations.

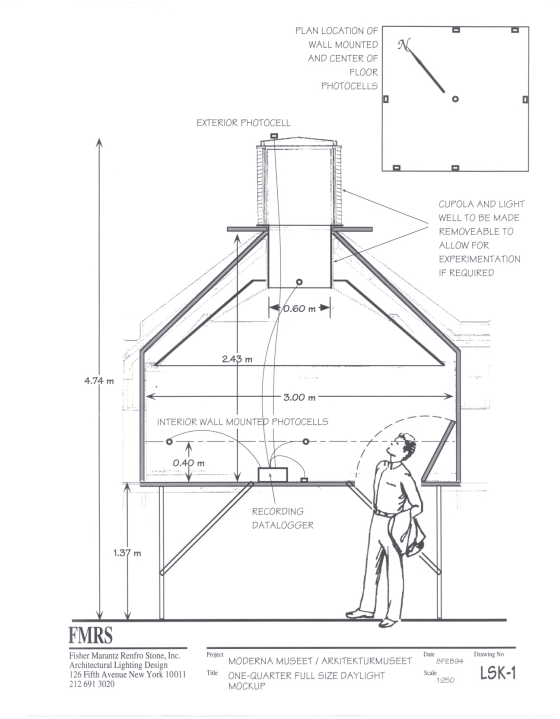


Figure 137 FM Mock up section

Unfortunately the data collected from the months of monitoring were not available.

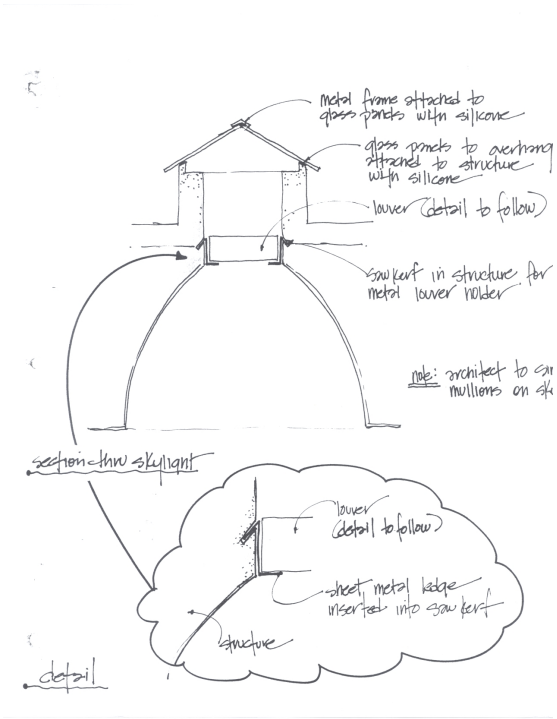


Figure 138 FM Mock up detail 24 5 91

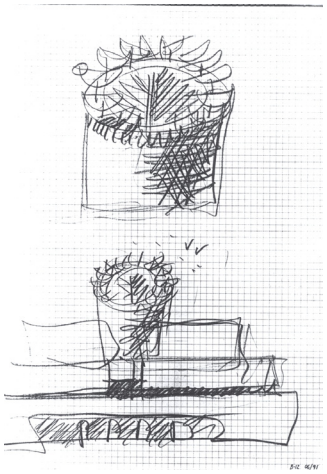


Figure 139 B12: 06 91

Parallel with this design tweaking at the macro level, the skylight deign was being refined (see left and left below)

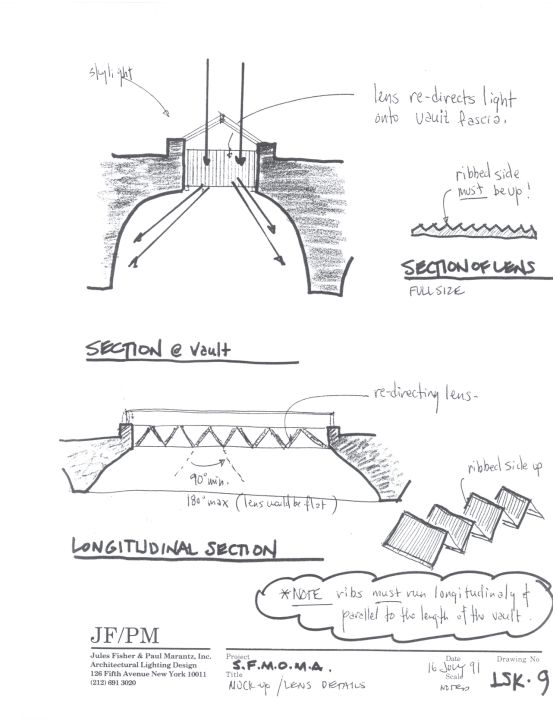


Figure 140 FM Lens trial 16 8 91

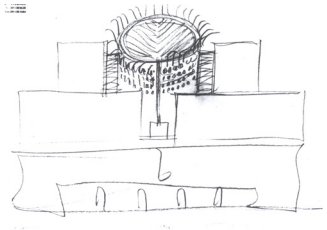


Figure 141 B13: elevation - 1991

There are more West elevation sketches available in the archive from this period of time. The architects seemed to have been more interested in these questions and left the skylight design to the lighting designers.

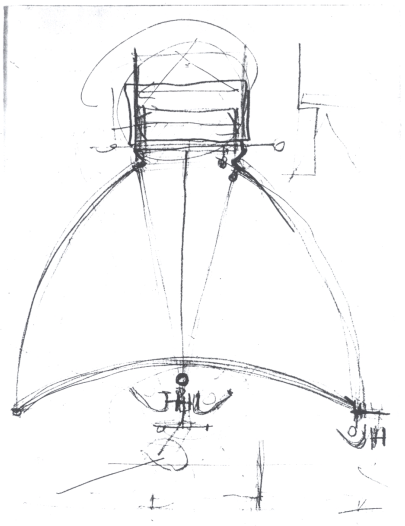


Figure 142 E12: revised skylight section 9-91

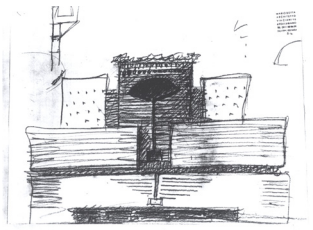


Figure 143 B14: elevation - 1991

These skylight studies on the left are architects' sketches contemporaneous with the elevational studies in this column. Refinement of the curve and placement of electric light is being explored?

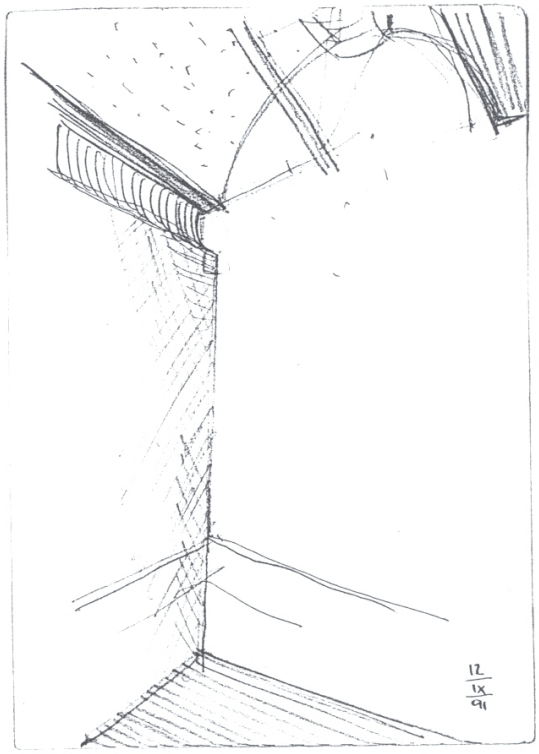


Figure 144 E11: Gallery perspective 12-9-91

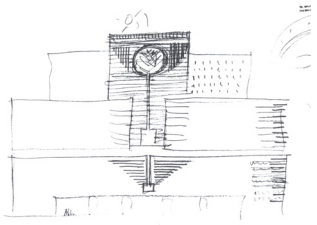


Figure 145 B15: elevation - 1991

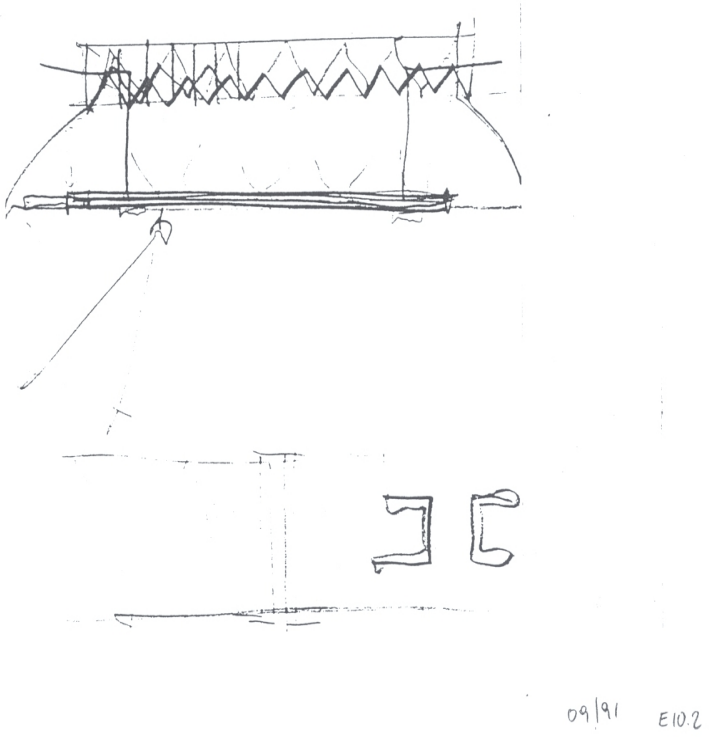


Figure 146 E 10.2: Skylight long section 09-91

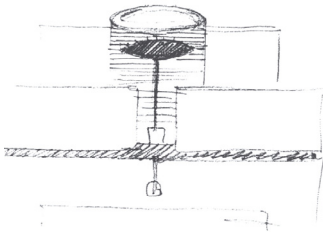


Figure 147 B15.2: elevation - 05 91

Is the skylight being subjected to a rigorous deign exploration in the same manner as the front elevation? No.

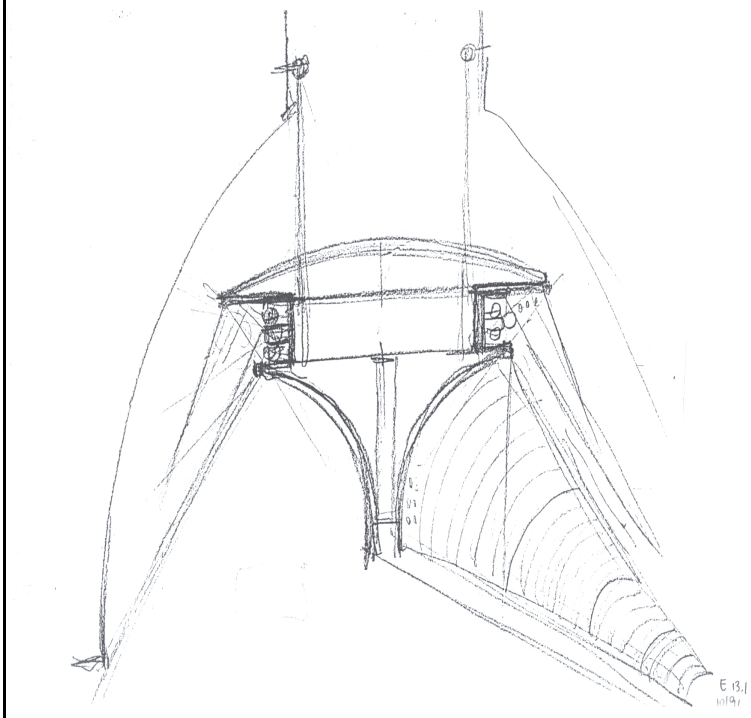


Figure 148 E13.1: Centre detail of skylight 10/91

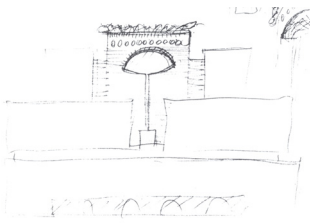


Figure 149 B15: elevation - 11 91

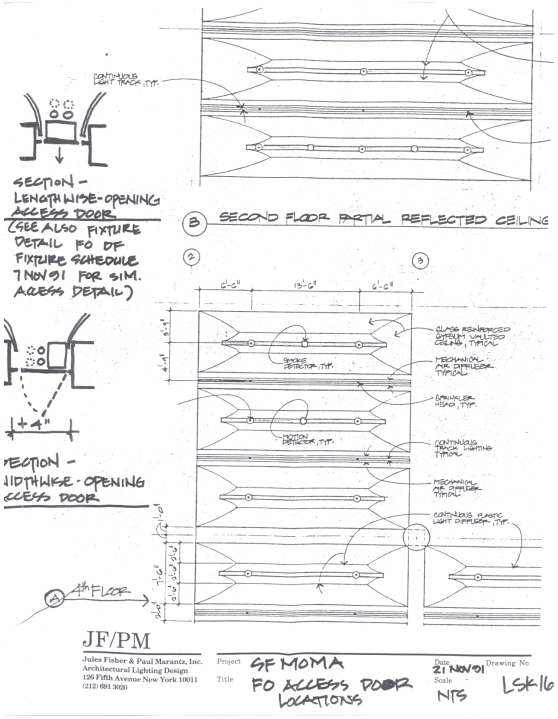


Figure 150 FM Reflected ceiling plan: 11/91

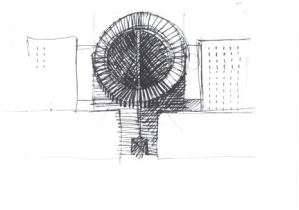


Figure 151 B17: turret elevation - 1991

Design development apparently ending by 1992.

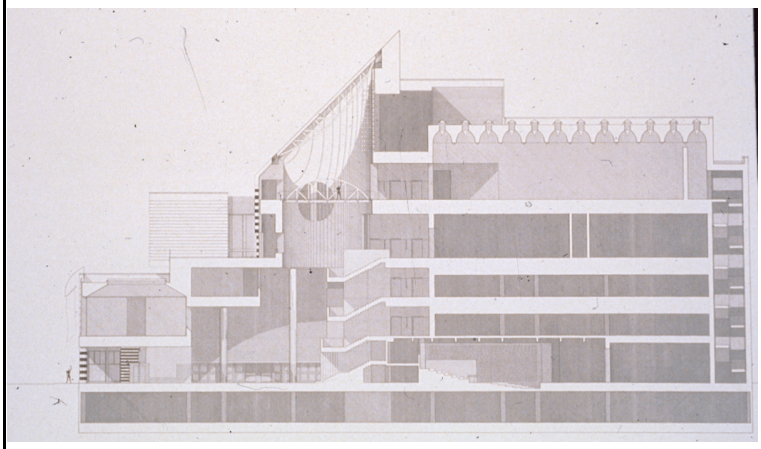


Figure 152 Section - 1992

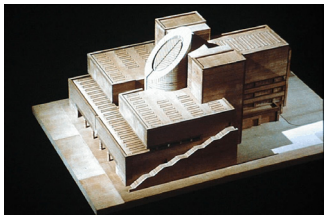


Figure 153 Model - 1992

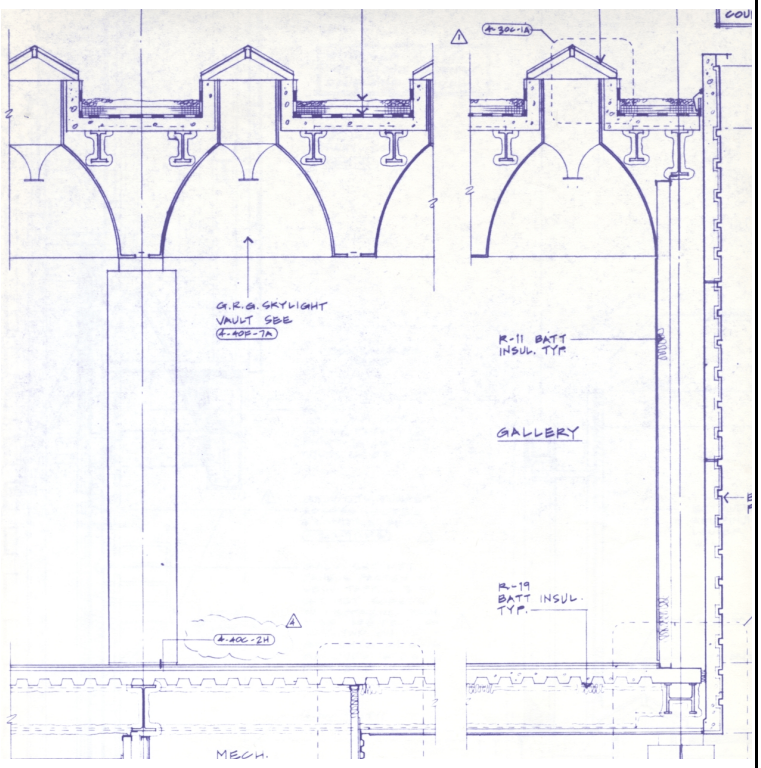


Figure 154 Working Drawing Exterior wall section showing skylight- issued 22 - 6 - 1992

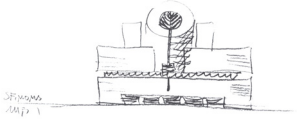


Figure 155 B18: elevation - 01 92

Mid 1992: thedesign documentation for the skylights is complete. The 'neck' of the skylight tube is now much longer from the top of the curved diffusing/reflecting surfaces to the skylight glazing surface than in any previous sketch.

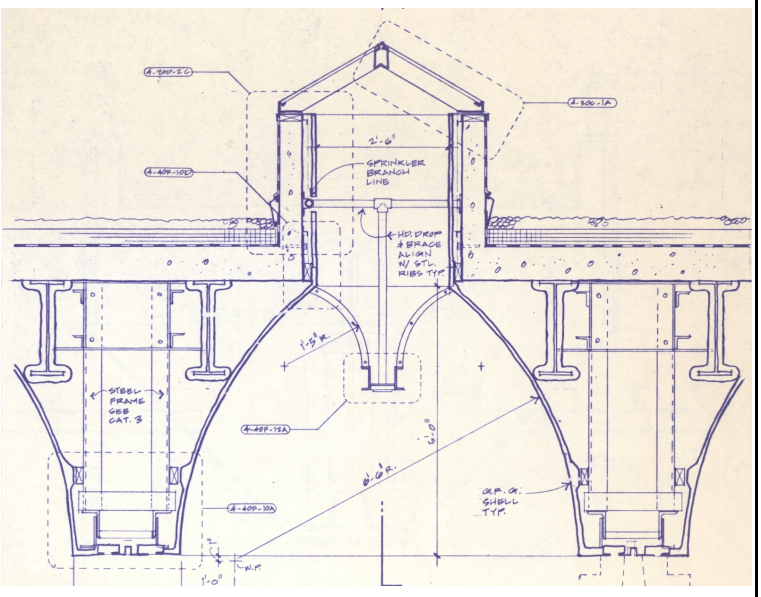


Figure 156 Working drawing - skylight detail: 22-6-92

Note: no sign of the louvres in the skylight at this point. These apparently resulted from the on-site testing.

The inner curved surfaces have ended up being diffusing surfaces rather than reflectors. Track lighting is between rather than in the skylight channels.

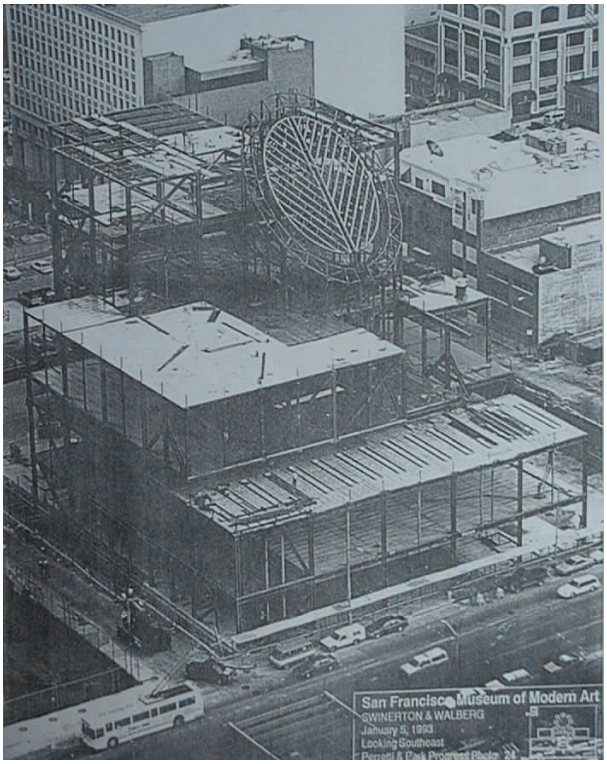


Figure 157 Construction photo: 01 93

These are a selection from a set of photographs commissioned to follow the construction process. It is possible to see in this sequence the construction of the third and final lighting simulation model: the full scale gallery on level 2 in the Northwest corner of the building closest to the camera position.

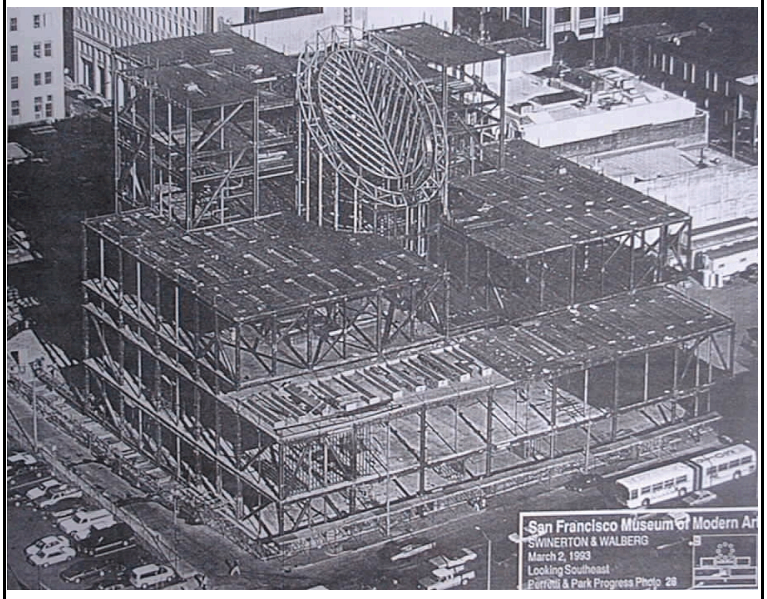


Figure 158 Construction photo: 03 93

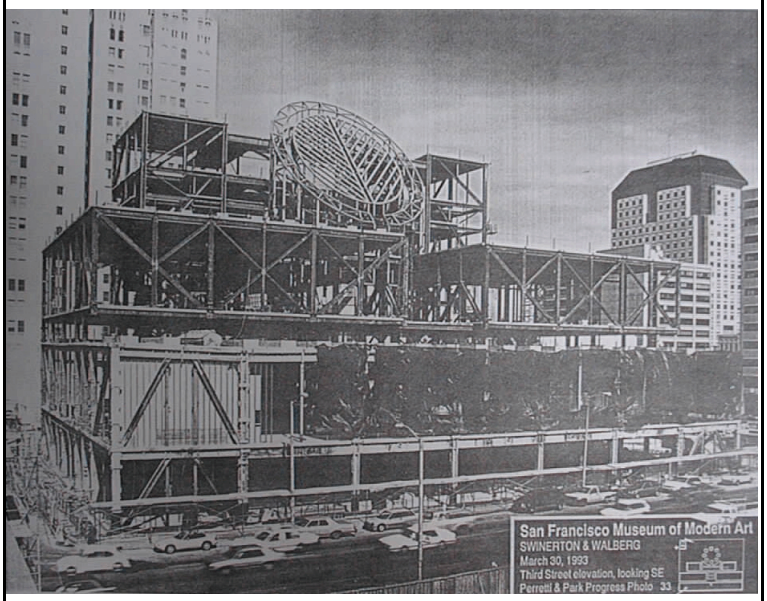


Figure 159 Construction photo: gallery mock up 30 03 93

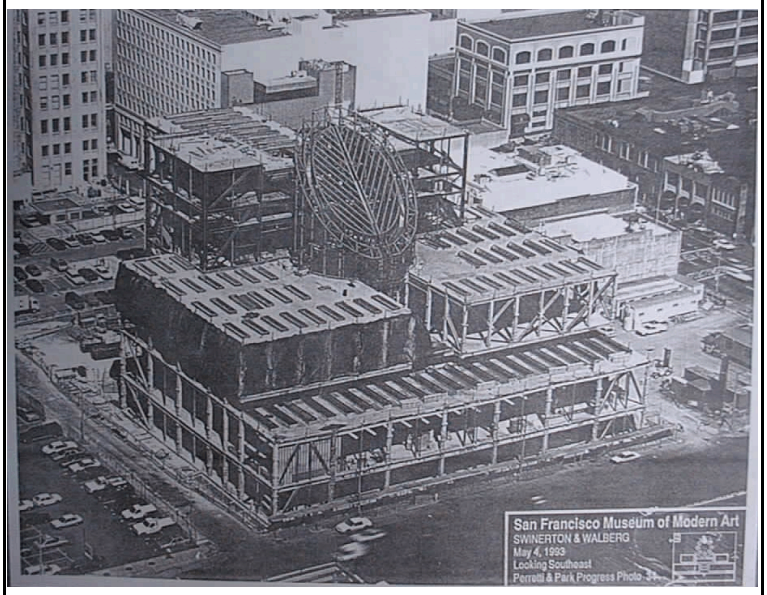


Figure 160 Construction photo: gallery mock up Northwest (near) corner, 2nd floor - 05 93

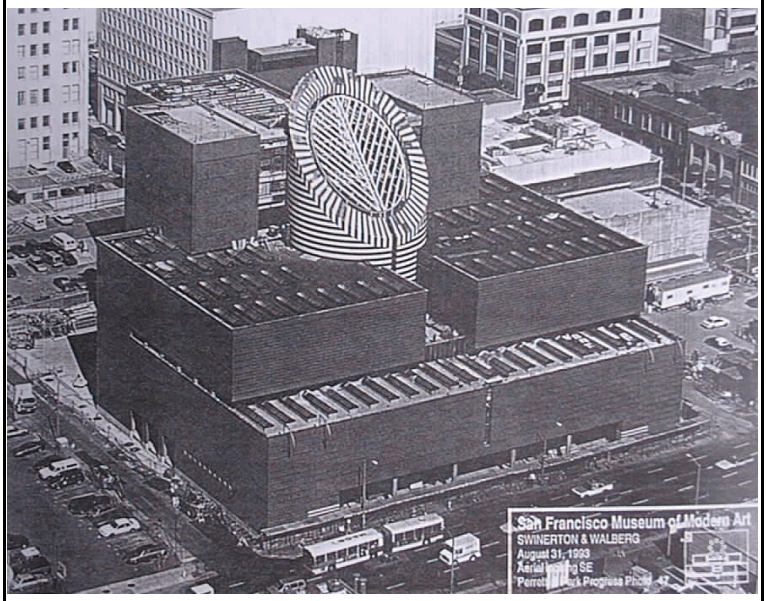


Figure 161 Construction photo: more skylights 08 93

The extensive skylights on the roof of the 'podium' step at the front reveal something of the manner in which light has been brought into more than just the top level of galleries.

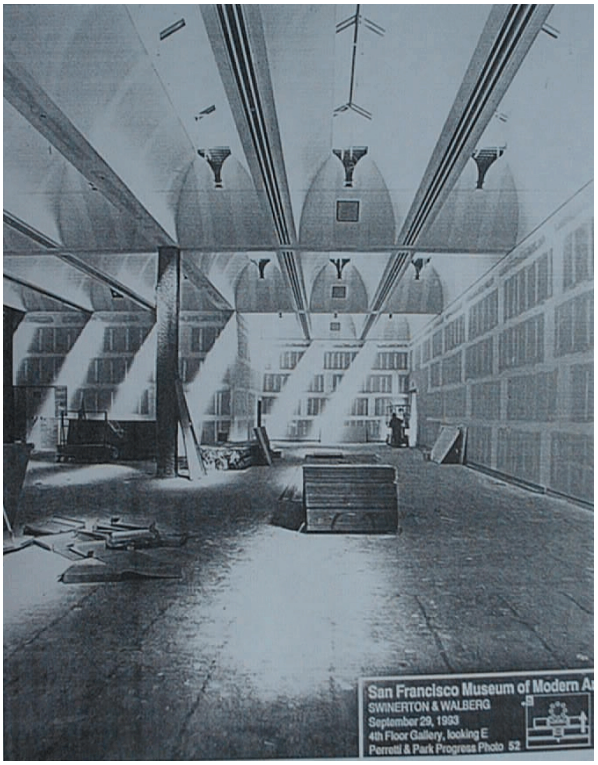


Figure 162 Construction photo: interior of skylights: 09 93

Note the very strong directionality of the SUNlight streaming through the apparently unfinished skylights. Even when the diffusers were put in this might be expected to cause a problem. The question were are left pondering is whether this might have been determined by a more sophisticated analysis - involving the architect - of the direct beam of the SUNlight as well as diffuse DAYlight of the artificial sky.

But then, looking at the final result now, the analogue models at small (artifical sky), medium (quarter scale on-site) and large (full scale) scales seem to have done an excellent job.

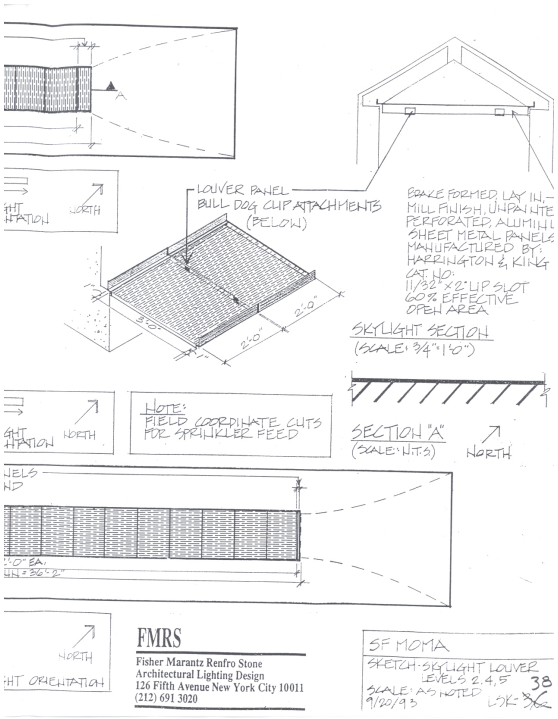


Figure 163 FM Skylight louvres 20 09 93

Note: the louvres in the skylight appear at this point. These apparently resulted from the on-site testing - I presume at the full-scale mock-up stage from the dates on these drawings.

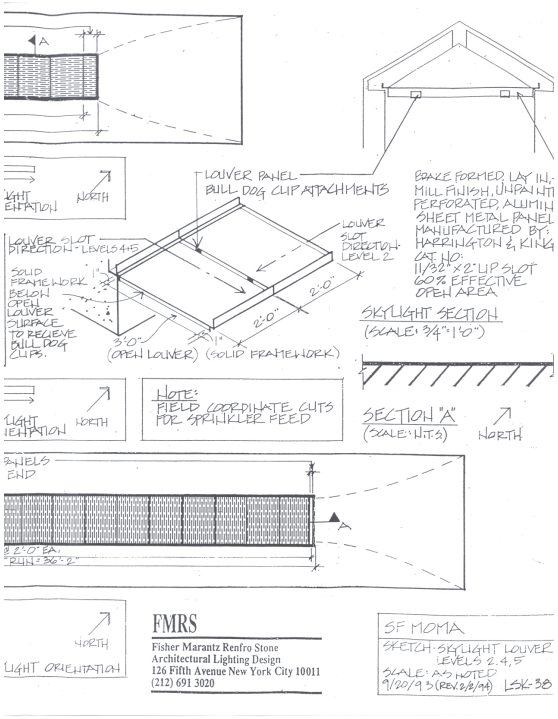


Figure 164 FM Louvre revisions 2 2 94

The skylights - complete with 'perforated metal panel'.

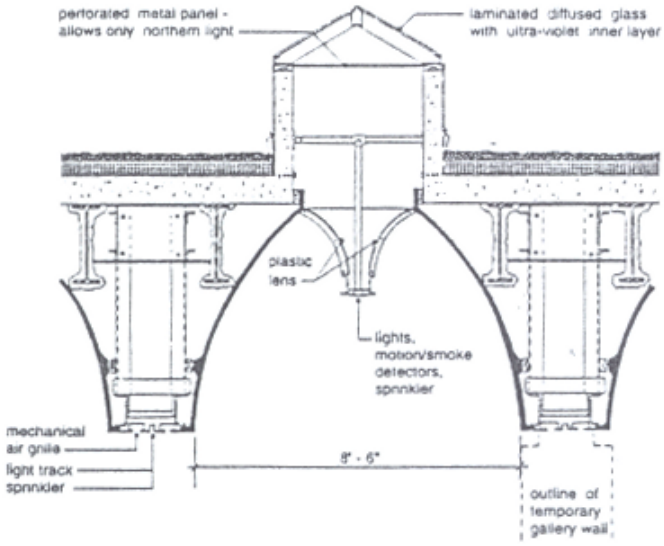


Figure 165 As-built diagram of skylights - from article by Abrams in Lotus International 86 (1995)

Figure 166 Exterior - 1994

Figure 167 Top floor - 1996

9-2.5 digital simulation?

Figure 168 Lightscape rendering of SFMoMA atrium: (from 2003 http://www.viewbyview.com)

Picture on left is on the distribution disk for Lightscape[16] as an example file. It was originally on the box in which the software was distributed.

Figure 169 SFMoMA Atrium photograph

Figure 170 Personal photo - atrium - 1994

As the pictures in **Figure 168** through **Figure 170** show, digital simulation could have provided design decision support. The Lightscape picture was produced by Mieczyslaw Boryslawski of View by View in San Francisco prior to building construction. The choice of physical model simulation

was made by the Lighting Designers who[17] distrust the 'black box' nature of computer simulation. This does raise the obvious question: would a computer simulation have produced any more or different information? Would the design process have been any different? After all, as the producer of the image in **Figure 168** was fond of bragging in 1995 when I spoke to him and he now documents on his web site: the SF MOMA proprietors and their lawyers were sufficiently fooled by the image to threaten legal proceedings as the Museum owns copyright in all photographic images of the building[18].

Three different physical models were constructed in the real design process: a small one in the artificial sky in New York, a one quarter scale model of a gallery bay on-site, and a full scale mock up of a gallery in the building during construction. With digital simulation, there would only be one model, though it might be modified a number of times. However, the significant limitation of the digital model would be its representation of the illumination available from the sky and the sun. Obtaining quality weather data the equivalent of that which would have been found with the on-site models is extremely difficult from conventional sources. It is likely that an on-site illuminance measuring station would have been needed had the digital model been used in order to provide the same quality of illuminance prediction as the physical model.

With a good digital model and accurate sky data the necessity for the louvres in the skylights could have been discovered well before the full scale mock up stage of the design and construction process. However, it is unlikely that this would mean that the building could be completed without the final physical simulation model - the full scale mock up - being constructed. This model would probably have to be built to assist the client and design team to do the final development work on the display systems.

9-2.6 analysis

The pros and cons of physical model simulation are listed in chapter 3 as:

Advantages

- Immediate understandable feedback on the environmental behaviour of the building.
- Clients find the model and the environmental effects very easy to understand.
- The test is often very simple to set up.
- The calibration of a model to reality is often very simple.
- The freedom to examine almost any design is much wider than with many other design tools.

Disadvantages

- Models for wind tunnel and lighting studies can take a very long time to construct.
- Model making mitigates against designers making more than one or two changes to explore options.
- Designers using physical models have to have a completed design before they can conduct the test.

Advantages

Immediate feedback: it is difficult to assess this from the information available from the records. Unfortunately none of the participants had records in a format or place that were accessible to me that documented the way that the model studies had influenced the design decisions. Immediacy of feedback is therefore hard to assess in a project whose design development took a number of years. Clearly, walking into the full scale mock up gave immediate sensory feedback. The measurements made in May 1993 (**Figure 160**) led to the new design details in the September construction drawings (**Figure 163**).

Clients understand environmental effects: the client showed strong awareness of the intended result and drove the daylit building process. However, their understanding of the value of the models is clearly very low. They have not retained these models or any record of them in the archive. What they have stored in their archive is six different architectural (read form and appearance) study and presentation models[19].

Test is easy to set up: the mirror box artificial (cloudy) sky model construction in the Fisher Marantz Remfrey Stone New York office is simple and cheap as the illustrations from their office guides show (**Figure 133**). However, the quarter scale and full scale mock up models are much more complex and costly. Andres Grechi who worked on the project in HOK's San Francisco office, remembered the model for the amount of time taken to collect the measurements even though he had no record of them or of their interpretation.

Calibration is simple : With the full scale model, and even to a large extent the quarter scale one, what you see is what you will get on completion. One need only take care with the dimensions and colours. However, the calibration of these one-off results with a prediction of long term performance is revealed to be much more difficult: as already noted, there is very little data available on the outdoor illumination in San Francisco with which to calibrate these on-site interior measurements. In order to make performance predictions one would need not only to measure the light levels outside the 'models' on site but also to be able to relate those outside measurements for a few weeks or months to multi-year records of the probability of occurrence of particular daylight levels in the region.

Designs not limited by simulation: this is clearly the simplest way to test a building of any arbitrary design. The construction drawings for the mock ups can be exactly the same, just for a building at a different scale to the real building. The most difficult problem can be to decide what details can be left out at the smaller scale. However, if the building can be constructed, generally, a model of it can be constructed.

Disadvantages

Models time consuming to construct: there was no evidence available in this study for the truth or otherwise of this statement. The large models required full construction drawings, but whether they took long to build is impossible to discover. Clearly the final full-scale mockup was simple and quick to construct: it was just one of the first parts of the building to be completed. It is good practice to work in this manner: testing all the processes of construction on a part of the building to iron out any potential problems.

Options are time consuming to construct: again, this is hard to evaluate from the data available. It is certain that the options available to the design team at the mockup test stage were very limited. A change in the design of the skylight and vault systems was not possible. The intervention of a screen or louvre was all that could be tested and constructed within the constraints imposed by the already existing design.

Designers require finished design before test can be constructed: this was clearly not an issue. The systematic small, medium and large physical model approach ensured that initial answers were available early and quickly. However, if one looks at the design in **Figure 112** it is clear that a fully completed model was available. Where this project differs from many, including all the other projects examined in this thesis, is in the amount of time available to the design team well after presentation of sketch plans and confirmation of finance for development of the design.

This is the last of the detailed studies examined in this thesis. In the next three chapter volume of the thesis, all the observations and analyses of these five studies are drawn together. First is a summary analysis chapter. This is followed by a conclusions chapter which specifies a possible approach to the establishment of eddst's whose predictions are trusted. A final chapter looks to future practical developments of the specified approach.

9

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19. Reference numbers **95.191** through **95.196** in the SFMoMA archive.

PART C

ANALYSIS and FUTURE WORK

table of contents

This final volume aims to put some pattern into the potentially chaotic analysis of the wide range of design tools used for analyses of different aspects of building environmental performance. The design tool classification hypothesis outlined in the Volume A was used in each detailed study. This provided a consistent methodology for dissecting the studies in order to reveal the common threads in the application of each of the different eddst's. The goal in this volume is still as outlined Volume A: 'to analyse these forms of "design guidance" to establish how a systematic approach might be taken to examination of the role of environmental design tools in architecture.' This final volume comprises:

10 . . . . . analysis

summary analysis of the detailed studies that steps back one level above the detailed advantages and disadvantages and looks for the common factors in all the users' uses of and reactions t o these environmental design decision support tools . . . . . **research goals and the detailed studies.**

11 . . . . . conclusions

examination of these analytical conclusions with a view to creating a specification for the principal features of an environmental design decision support tool (eddst) to be used by building designers early in the design process which guarantee that its predictions will be convincing. . . . . **the nature of design simulation.**

12 . . . . . postscript: the future?

a hypothesis as to what might be a reality test in digital simulation that would be sufficient to convince users that the results of their own simulation represented an accurate picture of future building performance. . . . . **simulation tool agents**.

10
analysis

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

analysis_2006.wpd

CALIBRATING A CUP OF CHAR WITH ROSSY AS ONE EXTREME, AND TEA AT GLADSTONE MANSIONS AS THE OTHER, TEA WITH THE MEARES..CAME ABOUT HALFWAY.
M. SHARP *SOMETHING LIGHT* VIII. 74, 1960. IN OXFORD ENGLISH DICTIONARY ON CD

10-3 *research goals and case studies*

This final volume comprises:

1. summary **analysis** of the detailed studies of Volume B that looks for the common factors in all the users' uses of and reactions to these environmental design decision support tools.

. . . . . research goals and the detailed studies.

2. examination of these analytical **conclusions** with a view to identifying the principal features of an environmental design decision support tool (eddst) which guarantee that its predictions will be convincing.

. . . . . the nature of design simulation.

3. a hypothesis as to what might be a reality test in digital simulation that would be sufficient to convince users that the results of their own simulation represented an accurate picture of future building performance.

. . . . . simulation tool agents.

10-3.1 introduction

The first volume of this thesis notes that its: " ...basic hypothesis ... is that ...the tools available to .." .[architects to produce good quality design] "... do not address their specific interests." The Detailed Studies have investigated the building environmental design processes from the point of view of the architect-designer and the consultant to the designer. The analysis of the studies has sought to identify whether there is a commonality in the modes of interaction between designers environmental design decision support tools across the different environmental disciplines of thermal, visual and external aerodynamic design.

The common thread that draws this thesis together is the topic of simulation. I have concluded that all environmental design tools used by the designers interviewed for this thesis are simulations, in more or less detail, of the environment in the buildings being designed. However, it is noted that what is conventionally called simulation is the use of a computer to assess the effect on a building environment of many of these small formulae (mini-simulations) in combination. In this thesis, these are labelled digital simulations. Digital simulations of the thermal or the visual environment in buildings such as those produced by Radiance[1] or DOE2[2] are merely attempts at producing a more detailed, and potentially more realistic performance prediction than can normally be achieved with the simpler simulation tools. They are in principle no different than their chart and formula based predecessors - they are merely more complex in data output (and sometimes also data input).

What this thesis has done is identify a number of common problems with the application of simulation in design. These problems all contribute to the principal limitation on the use of

simulation in design: a lack of trust in the design team of its predictions. The problems are discussed in this chapter under the general heading *The Simulation Problem*. The chapter following specifies the principal features of an environmental design decision support tool (eddst) which will ensure that its predictions will be convincing. This specification is the conclusions and principal product of the thesis. It is a definition of the development path for the next generation of simulation. It presumes this next generation will be digital simulation. This presumption is based on the evidence of the Detailed Studies and the greater ease with which digital simulation GUI's can be improved compared to simulation based on physical models or other forms of calculation. It also presumes that digital simulation programs like DOE2 and Radiance which are currently used by a few expert 'simulationists' will increasingly be a part of the building designer's repertoire of design decision support tools. The basis for this presumption is again the Detailed Studies. These building performance evaluation tools will supplant the less complex tools in common use today as they become easier to use and as clients demand the sort of quality feedback on building performance illustrated in **Figure 1**.

The specification describes the key characteristics of digital simulation tools for use in building

Figure 1 AutoCAD model of Richard Meier's Kunsthandwerk Museum constructed by Hamish Muir and Regan Johnston and rendered in Lightscape by Hamish: BBSC 303 (http://www.arch.vuw.ac.nz/papers/bbsc303/ class of 2000,(Last accessed December 2003)

design. It does not specify how these might be coded. It assumes Building Product Modelling[xxi] and

[xxi] A mechanism for coding the exchange of data between design simulation programs in a way that ensures the description of a building is entered only once, even though several different computer programs may be used to evaluate its performance. See, for example the COMBINE Project papers: *The Combine Project: A Global Assessment*, Godfried Augenbroe, in Proc. of CIB W78 Working Commission on Information technology in Construction Task Group T10 1995 Workshop at Stanford University on Computers and Information in Construction "Modeling of Buildings through their Life-Cycle"

XML[v] representations of data will be developed to their full potential. It does specify the necessary conditions for successful operation of simulation in architectural design, including a list stating the level of knowledge of simulation principles and of the underlying environmental science principles in which the user should be trained prior to using tools of this type.

The specification does not presume to guess whether these digital simulation eddst's will be used directly by the designer or by a specialist consultant to the designer. It focuses on developing a means by which the trust of all members of the design team in eddst performance prediction can be increased. The proposal is basically to develop an internet based Quality Assurance (QA) process that would provide a series of Quality Control (QC) tests that would form the basis for this increased trust.

The final chapter in this volume describes how this internet based QA process could be developed. It outlines the functions of the QA web site. It evaluates the web proposal against a set of internet design principles. And, it outlines the work needed to finally address the concerns that were the inspiration for this research: how can the design team be encouraged to place sufficient trust in the predictions of eddst's that they will routinely use them to improve the quality of the design of the built environment.

10-4 *the simulation problem*

This summary analysis of the detailed studies discusses the problem of simulation under a number of headings. These headings are features identified as problems common to all simulations whether based on a physical or a virtual (digital) model. These headings are:

1. lack of preparation time for model construction;
2. lack of clear guidance as to which are the important features of a building that should be modelled well, and which are the features that make such a small change to the predicted performance that they need hardly be modelled at all;
3. lack of Quality Control[w] (QC) systems such that the user can self-calibrate their predictions

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[xxii] ***E**xtensible **M**arkup **L**anguage (XML) is the universal format for structured documents and data on the Web.* For further information see: **Extensible Markup Language (XML)** at http://www.w3.org/XML/ , Dan Connolly, Created April 1997; Revision: 1.121 $ $Date: 2000/02/01 06:12:40 (Last accessed February 2000)

[xxiii] In my mind, there was some looseness in the definition of the terms **Quality Control** and **Quality Assurance**: The field of Quality Management is a major field of study in Management. I consulted merriam-webster's collegiate dictionary for clarification as it was the only dictionary which I found dealt with phrases: http://www.m-w.com/cgi-bin/netdict (Last accessed March 2000). The result was:
Main Entry: **quality control**; Function: noun; Date: 1935:
: an aggregate of activities (as design analysis and inspection for defects) designed to ensure adequate quality especially in manufactured products LABEL USED IN THIS THESIS
Main Entry: **quality assurance**; Function: noun; Date: 1982

(continued...)

ensuring the recommendations they are making are relevant and accurate;

4. lack of performance guidelines for buildings which provide a means for the person who does not use the eddst every day to understand the implications of the design recommendations;
5. lack of tools for summarising and detecting patterns within the simulation "output" such that the designer can deal with the information overload resulting from dealing with the seasonality of much of a building's response to climate and the richness of the various scenarios that well-applied simulation can explore.[x] (E.g. the seasonality and diurnal variation of building climate response)

Within each of these headings, the lessons from each of the Detailed Studies are summarised. I have selected the order in which the studies are described in the preceding pages for ease of cross-referencing. Alternative approaches were considered. The following table presents alternative approaches to the ordering of the presentation of the studies. None of the columns made a more logical ordering device for this analysis than the order in which they are presented in the preceding chapters.

	Detailed study	Type of eddst	Building Scale/type	Topic
1	Passive Solar House Design Survey	text based design aid	House	Thermal Design
2	CBPR Design Experiencedigital simulationLarge InstitutionalThermal & Daylight Design3Thermal Simulation Program Survey	digital simulation	Large and small Commercial	Thermal Design
4	Wind Tunnel Test User Survey	physical modelling	Large Commercial	Design for Wind
5	SF MOMA Daylight	physical modelling	Large Institutional	Daylight Design

[xxiii](...continued)
: a program for the systematic monitoring and evaluation of the various aspects of a project, service, or facility to ensure that standards of quality are being met QC TOOLS FIT INTO QA

[xxiv] A corollary of this is the lack of time spent becoming totally familiar with the simulation model so that the lessons of the model that might easily be derived from the 'behaviour' of the model are lost principally due to the pressure of consulting work; user-friendly data entry theoretically allowed more time for this type of activity, because it speeds data entry, the pressure remains to do the calculation and move on.

10-4.1 lack of time for model construction:

Even the simplest R-value 'simulation' requires careful and often time-consuming input data collection. The more complex the model the more time required merely to collect the data and the dimensions to be entered. A common thread in the studies was the pressure to spend as little time as possible on the model making. In most consultancies the old adage of 'time is money' places severe constraints on how long a person can be spared for the mere act of model building, rather than using the model for performance analysis.

study 1 - passive solar house design

With expert assistance in the form of tutors employed by the Ministry of Energy, it took the participants two days of these workshops to design and evaluate a building with the Design to the Sun[3] passive solar design manual. Half of the two day period was in lectures, half in workshops. Given the time it took, it was intriguing to discover the strong interest shown by the participants in learning the calculation techniques as well as the Rules of Thumb. *(..perhaps after doing calc's on further buildings...)* When required to prove that their designs would work, the seminar participants reverted to use of the calculations.

The designers were very interested in being able to assess the worth of a particular passive solar feature. They needed a number or an index to do this and they saw a calculation simulating the performance of the building as providing this index. A rule of thumb would not describe the amount of energy to be saved in the solar houses they were designing. Rules of thumb merely suggest how large a window, or thermal storage mass should be, given the authors of the rules own definitions of what is "sensible" building performance.

However, as noted in the Thermal Simulation Survey, New Zealand practitioners when approached about their use of calculations in day-to-day practice express a very different viewpoint. Essentially they never use them, or they rely on others to perform them. There are at least two reasons for this: 1) fee structures mean that architects and engineers are not likely to be paid for extra time spent doing a simulation in addition to their normal range of services; 2) lack of confidence in the eddst resulting from lack of use because the eddst is perhaps used on 2-3 projects a year.

study 2 - CBPR design consultancy experience

One architect said that the number of jobs for which he is having to tender is increasing, and this is pushing fees down. *[We] had limited funds, therefore we had to produce a design quickly to come within the fees we were being paid. [Because of the] minimum fee we weren't interested in pursuing alternatives unless we were paid for it.* There is a clear time limitation applying to this architect's work.

In evaluation of the CBPR delivery of simulation results to their architect clients, time is the most significant aspect of any negative comments. The information was not available quickly enough

during the design process, to keep pace with the required design speed. The architects indicated that the extra time required to consider fully the options put forward by the CBPR would have put them behind schedule and they couldn't afford to do that because the short design time was necessary to ensure the architects didn't lose money on the job. Even the analysts working in the CBPR noted the constraints on their effectiveness imposed by the project time limitations: *Perhaps it was an impossible task....*

Both architects interviewed apparently thought the computer based testing of design options could be useful to architects. But the speed with which results could be produced was too slow for the tight building schedules they had to operate under. If simulation is to provide useful design guidance, then it must be quicker and easier to use. The best way of ensuring this speed is to put simulation into the hands of the designers - to make sophisticated simulation design tools available to the people making the design decisions. It is clear that there is a need to ensure that the simulation is trying to operate on the building designers' questions directly rather than by some remote consultancy process. The remoteness of the CBPR analysts from the design process was to the analysts a major impediment to the effectiveness of their analyses of the building's performance: *Simply, the design process was not two way. Nor was it interactive.* At the very least the simulation results need to be much more accessible to the design team so that they become an integral part of the design process rather than an irritating, time consuming distraction.

study 3 - thermal simulation program survey

The USA survey examined the question of which ***stage in design the participant seeks results that can be used in design?*** Of the 44 participants, 32 selected *Early or preliminary design*; 30 selected *Design development*, and 21 selected *Working drawings*. 17 of the participants selected all three of these options. 8 of them selected just the first two options. It is clear from these answers that, as with researchers[4] in the area, the respondents see the most influential phases of the design process for ultimate environmental quality are at the beginning, rather than at the end of the building design process.

The participants in the New Zealand and USA surveys did not comment directly on the time taken to use a simulation program. A large number of the USA participants when asked what improvements they wanted to the capabilities of simulation software commented that they wanted changes that made the programs easier to use. The principal benefit of this would be to reduce the time it takes to use the simulation program.

A very high proportion (79%) of the USA participants responded that simulation programs would *help a lot* and none of them see such programs as *never useful*. They see a high value in continued and expanded use of simulation in building design. Whether their motivation is monetary *(more simulation is more design fees for them)* or altruistic *(they simply believe that simulation produces better designs)* is unknown. However, none commented that the nature of simulation was that it would be better applied later in

design. It seems that to these experts the time problems described by the architects involved in the CBPR studies are not insurmountable. However, it must be borne in mind that the respondents quoted here are simulationists providing architects with information, not architects themselves as in Study 2.

study 4 - wind tunnel test user survey

In the comments about the *practical difficulties ... in carrying out wind tunnel tests* [such as pre-design wind tunnel tests] *yourself*, the typical comments were about the time that this type of simulation takes away from the design process: *Not enough people in the office to spare someone for that time. Not confident to have done it efficiently and to have come out with good report.* {E} *Is it necessary? Why can't others do it?* **{L}** *Design time is usually quite short, and anything adding to that is an obstacle.* **{K}** Another aspect of time is the cost of doing a wind tunnel simulation. Comments on this aspect included: *Expensive, one-time, models and analysis taken into account.* {C} *...Time, expertise, cost all have an effect - testing takes much longer than it should as a result of the lack of experience, wasting time, costing money while gaining experience, not economical or time efficient for developer. "Dreaming about buildings"* {K} Finally the participants argued for a simplification of the method. The implication was that simplification would produce quicker turn-around of applications in the Council approval process - a saving in time: *Needs to be simplified; has been over-complicated in the administration. ... Like to see whole thing reviewed to find some simpler method, preferably to be usable at an early stage in the design process.* {J} *As long as it's not over-elaborated, as long as it's kept fairly basic and it's realised that the results are only a guide...* {F} *Prepare a wind contour map of Wellington City so designers know in advance which areas will require particular attention.* {K}

Only three people expressed varying levels of favour for the concept of pre-design wind tunnel tests. *No problems, great idea. Should be more emphasis on pre-design approach.* {F} *Best approach. Don't carry out test personally, hire someone to do it, but very favourable to pre-design approach.* {G} No comment was made specifically about time.

study 5 - SF MOMA daylighting

The most interesting aspect of the SFMOMA design analysis was that it was drawn out and apparently without time pressure. The three stages of physical modelling seem in retrospect to have taken as long as was necessary. The small desktop model in an artificial sky in New York influenced the skylight design immensely. A quarter scale gallery mock up on site in San Francisco seems almost to have been forgotten, or at best to have functioned as a confirmation or reassurance about the truth of what was already known from the smaller model; and, the full scale mock up in one of the galleries of the new building during construction merely changed the type of louvres in the skylights - an *engineering* rather than *architectural* detail in the view of the architects.

No-one involved in these processes found them time consuming. Apparently, this is just the way Fisher Marantz work. This identical approach was also used on the Getty Museum in Los Angeles[5] where they also did the lighting design.

The most telling comment of the case study was the complete blank drawn when interviewing the architects on the role of these models - these simulations of daylight - in the architecture. Despite the amount of effort in collecting this data, the design architects seem to have seen the information as engineering data of no import in terms of the design of the building itself. Even the architects of record, who were aware of the amount of measurement that had been undertaken could not express how this might have influenced the design of the building. In this situation, where extensive simulation is seen as peripheral to the design process, it is no surprise that the time taken to construct the models and to make the measurements was seen as unimportant.

summary

People interviewed seemed reluctant to spend too long doing this type of modelling. This was most obvious with the wind tunnel model in Study 4 where the model clearly had no other use. Having someone else make it and then use it because they were familiar with the process was preferred. In other situations this was less an issue. The definition of too long was situation and model specific. With the construction of interoperability schema enabling a single data entry process for ebuilding models of very different types[6], and the increasingly routine sharing of this model data amongst members of the design team, it seems likely this issue will be less significant in the future.

10-4.2 lack of guidance on building features to model well

The first time anyone makes a model they normally have great difficulty sorting out which are the important bits to model and which the bits they can leave out. It takes years of practice in an architectural design studio to figure out what detail needs to be incorporated in a model for a client meeting, or for a crit by one's colleagues or for a code officials meeting. Similarly, it can take many years to gain sufficient experience to enable one to know how to divide the say 200 rooms in a tower office into the 15-20 thermal zones whose properties need to be individually modelled in a thermal simulation model.

study 1 - passive solar house design

The general behaviour of the participants in the passive solar seminars was to try the 'simulation' formulae provided in the Design for the Sun manual[7] almost at random to try to sort out what worked. They did not behave as if they had any idea, even after the lectures, as to which building feature would have the greatest effect. What was the most disappointing aspect of this as a tutor was that there was little connection made between the 'Rules of thumb' and the calculations. This is the weakness of any rule of thumb approach referred to earlier under 'lack of time for modelling'. Rules of thumb specify what the size of a building feature (window, wall thickness, amount of thermal storage) 'should' be. They do not normally say why this size is recommended. The type of

performance that should be expected if these features match the recommended sizes is implicit, not explicit.

In the concluding sessions of each seminar, participants were required to present their building in a standard format specifying the performance and to list certain critical parameters defined by the tutors. These concluding sessions became quite crucial because there the participants and the tutors compared the performance of all the groups' houses. Through these comparisons it quickly became clear which were the important and which the unimportant features of the buildings from the point of view of energy performance. However, this was a lesson drawn out by the session tutors rather than a lesson easily learned from the rule of thumb process.

The New Zealand Design Guidelines[8] resulting from the IEA Solar Heating and Cooling programme Task VIII research Programme[9] produced an alternate example of how to present design rules of thumb. Rather than present Rules of Thumb which had as output recommended sizes for thermal elements in the building design (window area, wall insulation R-value etc) the diagrams presented the energy performance of a standard house with different sizes of thermal element.

My goal in writing these guidelines in this way was to improve understanding in the user of the relationship between rule of thumb and performance. The assumption was made that trend lines are easier to understand than simple tables of numbers. However, there is still a major problem with this type of presentation. The problem is that each such diagram stands alone and it is therefore very hard to combine one with another. Design guidance of this simplistic rule of thumb variety cannot cope with the complexity of representation of all the potential interactions in a building between say, orientation, window size, wall insulation and system thermostat set points.

The solution is to produce genuine simulations which do provide this flexibility. If designers could explore the interaction of all these different parameters in a design, they would produce buildings that performed better environmentally. However I am aware of only one digital simulation tool that as yet provides guidance on which element of the digital building (the 'ebuilding') that it has 'constructed' have a significant effect on the performance it has recorded.[y] The work of Ian MacDonald at ESRU has explored stochastically varying ESP-r input parameters to assist with just this activity.[10] It still requires a well-trained user to interpret the output of these variations. Often simulationists resort to using rules of thumb to check the performance of these ebuildings predicted by digital simulation. We are left with the simulation equivalent of a circular argument:

- Step 1: researchers run many hundreds of simulations on simple variants of a basic ebuilding and look to graph general trends as rules of thumb reporting interdependencies of building design and performance;
- Step 2: the ebuildings studied in the research are so simplistic that many practitioners doubt the validity of the rules in general practice;

[xxv] ESP-r has in its results recovery module in the RES sub-program the data and some of the tools to enable this type of information to be mined from the results database.

- Step 3: practitioners use the original digital simulation tool as an environmental performance design decision support tool, digitally modelling the actual building as closely as possible;
- Step 4: the rules of thumb are used to check that the performance predictions for these ebuildings are legitimate - and so we come back to step 1.

study 2 - CBPR design consultancy experience

Radiance[11] has a very large number of input variables describing a scene. This provides the user with an apparently infinite number of ways of `getting it wrong' or `getting it right'. The uncertainty is typically compounded by the complexity of the definitions of the environment variables in the input, and that these variables have no readily apparent absolute `real world' correlates. Many of the values used to describe the elements of the ebuilding are required because of the type of lighting calculation method used by Radiance, not because they are an intrinsic well-known property of a material or its interaction with light.

Much of the work currently being put into development of improved interfaces for building performance simulation engines is focussed on improving their accessibility[12]. Provision of libraries of materials, collections of real climate data, and tools for graphic analysis of the results are seen as making computer simulation programs more user-friendly. With Radiance, this last aspect of the simulation is exacerbated by the fact that its principal output is graphic: pictures or renderings of the appearance of a space under the given illumination. The results from the projects described in the CBPR Case Study demonstrate some of the difficulties that remain to be addressed if building performance simulation engines are to be truly user-friendly.

The Radiance program permits the user to produce pictures which contain more than just the normal visual messages implied by contrasting luminances of adjacent pixels in computer graphics. Daylight factor analyses, glare calculations for large sources of light (typically windows) and small sources of light (typically electric lamps); and actual luminances (in nits) or illuminances (in lux) of adjacent surfaces can be extracted from the pictures produced by the program.

The increased sophistication of modern building performance digital simulation tools has not rid the design profession of its traditional problem with simulation tools: that they evaluate completed designs. With such tools, guidance as to how to move forward in improving a design comes only from the informed user looking backwards at how the current version of the design performs. Often the designer has a need for information from the simulation before they have enough firm data to be able to provide the necessary description of the elements of the ebuilding to make the simulation possible.

It is common in building simulation to produce an initial run of simulations to test the integrity of the ebuilding and to plan the full simulations properly. For example, CBPR practice is to use Radiance as soon as possible after the building design is developed in order at least to test which viewpoints define the scenes to be rendered. These are the scenes which show best the aspects of the building that the client wants studied. These renderings also provide ideas for the scope of the tests, times of the year and durations, plus highlighted `holes' or inaccuracies in the model and places

where the material definitions require changes.These simulations are often in shades of grey to avoid pre-determining material choices and are simplifications of the likely form. Such approaches would be best facilitated by a library of tested appropriate base-line simulation models - ebuildings. These would provide a basis for quickly constructing new ebuildings and a comparison for measuring performance.

study 3 - thermal simulation program survey

When asked to describe education priorities in thermal simulation one of the largest groups of responses (almost equal to that which dealt with QC Issues) talked of teaching *Scepticism* - a distrust of the Black Box simulation program. They were trying to convey the importance of knowing what to model and how important this could be. They were also referring to the essential requirement of users of simulation that they have sufficient curiosity to go beyond reporting of the basic simulation output to ensure they understand why they have that output and what elements of their 'ebuilding' have a significant effect on the realism of the calculated performance.

If we group these "Sceptics" with those who wanted to make sure that the users understood the basics of Building Science then by far the largest (by 2:1 majority) proportion of the participants saw a basic knowledge of what was important to simulate as an essential skill to teach new simulationists. At present there are no mainstream building performance digital simulation tools known to me which provide guidance on which parameters are significant for the simulation at hand.

For example, new users of a computer thermal simulation do not have much guidance available on modelling the rooms in their ebuilding. Should they treat each as a different 'thermal zone' or should they group them according to the 'zones' that have different thermostat control settings to be met by the boiler? Similarly the importance of the climate variability between summer and winter when calculating daylight performance using a rendering engine is left to the designer.

The simulationists saw *understanding of context and limitations of simulation* so as to *manipulate simulation features to produce valid and useful design information* as essential. The *concepts and relative accuracy of modelling (what is and isn't important)* had to be communicated to each new user. This is best handled by the computer program itself. What is required is a systematic QC procedure which enables the user to be fed data on which of the variables are important amongst those they have used to describe a building to the simulation.

study 4 - wind tunnel test user survey

The architects interviewed did not get sufficiently involved with the Pre-Design Wind Tunnel Test to be able to comment on issues of what was important to model. However, most demonstrated a singular lack of understanding of the concept of "accuracy" in the results. Comments about the inaccuracy of the modelling process calling into question the conclusions and recommendations were common from these architects who, because of their experience with mandatory wind tunnel tests in Wellington, are arguably amongst the most experienced in this field in the world. They appeared

to have no understanding of the insignificance, in terms of the predictions of building performance, of many of the so-called "inaccuracies" they noted in the modelling process. For example, including or not including trees even as little as 50m upwind or balconies on the 3rd to the 10th floors was in most situations unlikely to affect the accuracy of any of their wind tunnel studies.

Any simulation tool which allowed these or other architects to model wind flows by computer would have to include some very sophisticated "help" files and "verification" options. These would check that the designer had not so complicated the model by inclusion of extraneous details that the calculation was impossible to complete. Again, a verify option might well feed back a message to the user that a 1000-fold increase in speed of calculation might be achieved through removal from the calculation of all the window mullions with an undetectable reduction in the accuracy of the predicted flow conditions.

study 5 - SF MOMA daylighting

The members of the design team were not asked directly which features they deemed important to model. However, it is possible to pose some interesting questions about how this type of process might be used by other design teams. First, even in the full-scale model/mock-up there are questions as to what ought to be modelled: one gallery? two inter-linked galleries? a whole floor? a gallery with a side window as well as the skylights? length of time for the measurements to be made? These questions clearly can be applied also to the quarter scale gallery model constructed and measured on-site. In addition, in both the models the modellers had to predetermine: what colours might be used on the interior surfaces of the skylights and on the walls and floor; how carefully dimensioned the skylights needed to be; and what were the critical dimensions of design parameters such as curvature of the ceilings, vertical depth of the skylight shafts, framing of the glazing systems. The first, small models under the artificial sky in New York had the same physical limits as the two larger models plus limits imposed by the type of sky model used. A sky model of this type could only really be relied upon to predict performance under cloudy sky conditions. San Francisco is sunny for quite a large proportion of the time.

The major benefit of the three stage process adopted by the SF MoMA design team is that many of the questions that might be raised about the modelling process for each stage are answered by one of the other stages. The quick and dirty model in New York was supported by and developed into the on-site quarter-scale model which in turn was critiqued by the full-scale appraisals. What is unique and reassuring in terms of QC with this type of process is that the client can be quite significantly involved at every step in the design appraisal process. There is no evidence of this occurring in San Francisco, but in my initial discussion of the SF MoMA Case Study with the lighting designers the Getty Museum was instanced as an even more interesting project because of the involvement of the client at the full-scale mock-up stage in appraisal of the lighting with alternate selections of appropriate furnishings and wall colours[13]. A brief scene from the movie about the construction of

the Getty[14] shows the clients clambering out of a less than full-scale model on the site of one of the galleries.

Unfortunately, most clients and most designers have no possibility of making the investment in time and money required to make this range of models. The Radiance predictions of the light levels in the interior of Te Papa - the Museum of New Zealand - are more likely to be the norm[15]. They provided an insight, not a guarantee. There was no budget to conduct the on-site measurements of sky luminance that CBPR would have preferred. Nor was there time or budget to confirm the quick and dirty digital predictions with more comprehensive on-site measurements at full or quarter scale. Given budget pressures, and increased availability of affordable computer tools, it seems increasingly likely that digital simulation of daylight will be conducted in a similar manner to the Fisher-Marantz studies of small physical models in their New York offices, but without the backup of on-site measurements. The trick will be to use appropriately detailed ebuildings that can be created quickly but which can still provide useful feedback about performance in the way the F-M models did.

summary

The desire expressed by the thermal simulation program users to make sure that users understood the basics of Building Science points to the heart of the problem of ensuring that simulation is accessible. As experienced users they saw the need to understand the (digital) model well if you were to interpret its behaviour. The solar house designers had no comprehension of the enrichment of their design intuition that might arise from an understanding of the relationships encapsulated in the rules of thumb they played with. In the wind tunnel tests, the people interviewed did not know enough about the process to be able to distinguish the influence of a small detail from that of a large design feature, and had difficulty using the results because of this. The CBPR design analysts had to spend a considerable amount of time convincing themselves of the accuracy of the Radiance output in order to be able to interpret its meaning beyond mere picture production. This was a pragmatic reaction to the fact that the data entry to the model itself was difficult to understand and thus to trust. What shines through the SFMOMA lighting analysts' approach is a thorough understanding built up from long experience of what really needs to be modelled. The simplicity of their early models shows an elegant sparseness in the modelling of reality. The difficulty is to develop in others this level of understanding of just what needs to be modelled without a lengthy apprenticeship with FMRS.

The specification in the next chapter of a simulation tool for architects describes how guidance for simulationists on what to model might be provided in the digital simulation itself. For the same reasons that design manuals and guidelines are never comprehensive, it is impossible to pre-define which variable will be important for each new building. To do so would require an infinite number of combinations and permutations to be pre-defined. The specification proposes an international database of tested model examples as simulation modelling starting points. It also proposes that the

simulation tool should have a "verify" option which could be run for every new ebuilding. This would invoke a standard parametric routine altering each of the building elements and quantifying their effect on performance against measures that the user selects based on their goals for the particular type of analysis they are doing. Each ebuilding verified in this manner would be able to be added to the database.

The trick for the building simulation program builder is to provide tools like the database that can assist with creating the model rather than analytical tools that check the completed building performance simulation model.

10-4.3 lack of quality control systems

The question of Quality Assurance (QA), and the associated Quality Control (QC) measures that might be required to provide it were only directly canvassed in the survey of USA digital thermal simulation tools. It has however achieved a larger significance in this analysis as it has become clear that it is a unifying theme for the observations in all the Studies. The lessons on time limitations described above are ultimately other complementary aspects of the QA process.

The following paragraphs detail the QC lessons to be drawn from each of the Studies.

study 1 - passive solar house design

The influence of QC on the accuracy or otherwise of the solar designers' use of the "Design to the Sun" [16] manual was not evaluated. It was clear however from the manner of the interaction between the tutors and the participants in the seminars that like many other users of simulation tools the participants required some independent verification of the veracity of their calculations. It was common to be asked whether a result of a calculation was "correct" or "right". With each participant working in a group that had designed their own approach to the brief provided by the tutors, there was of course no 'right' answer.

Away from the seminar context, designers have to rely on their own knowledge and abilities to "verify" this output from the performance calculation (a simulation by personal calculator rather than computer). In many situations they abandon this calculation, not because they believe it is unusable in discussions of performance with the client, but because they have no way of independently verifying the "correctness" of the performance prediction.

Any computer program version of such a calculation must include a programmed expert advisor whose job is to assist with interpretation of the output from the calculation (simulation). This advisor is essential, even for the expert simulationist let alone for the average designer looking for environmental design decision support. Many simulationists develop their own version of such an expert advisor. They keep a library or database of old simulations. They look these up to discover which simulation they have done in the past is most like the current one, and they compare

performance. Architects, and others who might be infrequent users of this type of tool, required a pre-developed library of such simulations. In the next chapter the specification of a simulation tool for architects recommends such a database.

study 2 - CBPR design consultancy experience

Figure 2 Museum of New Zealand, Orientation lobby, North facing glazing.

One of the two CBPR architect-clients interviewed for this research noted: *Architects already have one of the highest risk factors of all professionals in New Zealand and they would need to be paid a good fees before they were willing to experiment with ideas and technologies which were new to them.* For him, no matter how good the software or the firm, the calculation results were not enough. There was a great need to have an independent certification of the "truth" of the digital performance predictions.

For Radiance the realistic appearance and graphic nature of the output is extraordinarily attractive to the design community. It is likely that it and programs like it[z] will be used more and more to provide "pictures" of interiors. However, because the process of production of the pictures is not

[xxvi] At the time of writing there are at least three Physically based light rendering programs in wide distribution for use with commercial Computer Aided Design (CAD) programs: Lightscape; Accurender and Microstation's own in-built radiosity renderer. These programs claim not only to produce better quality pictures but to incorporate a reality based model which permits the user to include real specifications of light sources and fittings in their CAD models. In addition programs like Design Workshop Pro had Radiance Export modules and the vendors even provided an internet based Radiance rendering service (Artifice Inc. http://www.artifice.com Last accessed December 2003). Georg Mischler's Rayfront (www.schorsch.com Last accessed December 2003) and Desktop Radiance (http://radsite.lbl.gov/deskrad/ Last accessed December 2003) offer direct front ends to the rendering ability of Radiance. Others such as Genelux in France (http://www.genelux.entpe.fr Last accessed December 2003) and Inspirer in Japan (http://www.integra.co.jp Last accessed February 2004) are less widely used, but gaining increasing attention as practitioners search for the elusive realistic yet seductive image.

well understood, interpretation of quantitative information from these pictures remains problematical.

In addition, in the early stages of design, architects can be nervous about being committed to defining colours or textures in their buildings. They wish to know the effects of the window sizing on the quality of light in their proposed building and have only a vague understanding of the interactions of light and room colour. Digital simulation showing these interactions in the context of their own building design would be of great assistance, but is distrusted as unrealistic if done in neutral greys, and not accurate if done in colours that have changed in the day or so that it has taken to construct the ebuilding.

Also at issue is the mode of presentation of the data. Clients require more than an attractive rendered picture. They want to know things like: Will the sun penetrate this space and cause damage to the objects stored in my Museum? Or: will the space be lit to the performance limits defined in the specification? A minute by minute animation might satisfy these needs. Tools to make routine the answering of this type of question are still being developed.

The luminance information obtained from Radiance and other rendering programs' pictures is difficult to verify. In daylight applications, this difficulty is not only tied up with the accuracy of specification of the reflectivities of the materials and the geometry of the light reflecting surfaces but is also dependent on the accuracy of the sky hemisphere luminance model. No tools are currently provided by rendering programs to permit a user to calibrate their simulation and ensure its validity - to maintain Quality Control.

A further QC complication arises in the presentation of the results of climate dependent simulation. It is very difficult to define a standard situation. For example, even the most naive client can understand the rendered pictures in a daylight simulation and immediately has reservations based mostly on the definition of a "standard sky". They think of it in terms of sunny versus overcast conditions and mixed light conditions. They raise the question of defining conditions representative of different times of day and times of year. Even if it were possible to render quickly enough for it to be practical, a `movie' of each hour of each day for a real year would be impossible to analyse without the aid of some very sophisticated statistical analysis tools. More fundamentally, the simulation program user needs a guide to the use of the various "standard skies" that are available to best represent the building locality.

Any specification of a simulation tool for architects must include an allowance for QC . This has two aspects: ensuring that simple mistakes are not made in coding data; and more significantly, ensuring that the computer model represents the ideas and reality that is being designed and that will be constructed.

study 3 - thermal simulation program survey

When asked about ***QC in computer simulation*** the expert simulationist participants produced a disappointing set of responses. Most had no formal or written QA procedures for simulation. For those with some informal system, rules of thumb and libraries of other systematic simulation studies are used as standards against which to measure the output of their simulations of building performance.

One third of participants reported that their form of QC is to *eyeball* the data. A considerable number of people (22%) compared their simulation model with monitored data for the building they are modelling. These people were involved in energy conservation studies of existing buildings and were using simulation to study equipment options for the refurbishment. QC by calibration of their simulation against some independent standard - the existing building performance - was to them the "obvious" thing to do.

It would seem that these experienced simulationists undertake a lot of ad-hoc modelling of building performance. It is essential that systems are provided which assist the documenting of the process by which the simulationist has ensured that the building that is modelled is genuinely the real or proposed building they are analysing. Without these systems the process of computer simulation will remain no more than a rare activity undertaken by a small group of aficionados or gurus - almost a priesthood who require their predictions to be accepted on faith.

study 4 - wind tunnel test user survey

The comments of the architects interviewed about the wind tunnel tests were from a group that largely did not participate in wind tunnel tests themselves and thus could not be expected to understand issues of QC in detail. However, there was a number of comments about the whole process which indicated an awareness of issues that would have to be dealt with by any QC system.

The architects expressed concern over the accuracy of the Wind Tunnel Test process. They wanted to see an effort made to "Relate test results to what you actually get down in the street. {K} and described the current process as *Need[ing] a follow-through to show that the testing has been justified, that the finished result is successful.* {F}" These concerns lead them to call into question the whole wind tunnel simulation process. Any systematic incorporation of such features into the wind tunnel testing would form the basis of a QC process. In wind flow studies around buildings (wind tunnel simulations now; digital Computational Fluid Dynamics simulations in future) QC has two aspects: a clear definition of how detailed the model must be and how much of the building context must be modelled for "accuracy", plus an evaluation process that "follows through" in the manner described by these architects ensuring that the wind speeds reported are representative of the scale of the typical effects of new buildings.

study 5 - SF MOMA daylighting

The more one examines the sophisticated three stage simulation process adopted by Fisher-Marantz with the SF MoMA, the more one recognises it as a QC procedure in itself. The simple models in the artificial sky are calibrated against the quarter scale and finally the full-scale measurements. The process happens sufficiently slowly and with sufficient lee-way in the design and working drawing parameters that changes can be made to the design once the calibration data is available. The challenge is to find a way of using this process in other designs with smaller budgets, more time constraints and also to apply it in areas other than daylighting design.

If we are to heed the admonitions of the building scientists in the US Department of Energy's Passive Solar Commercial buildings programme to ensure that early design decisions are correct[17], then we must find a way of using the QC features of this three stage design analysis process within a much tighter resource and time framework.

summary

A desire for good Quality Control procedures was expressed differently in each Study. The solar house designers just wanted to know enough to be able to tell whether their hand calculated building performance was 'right'. For those users of digital thermal simulation with some informal QC system, rules of thumb and libraries of other systematic simulation studies were used as standards against which to measure the output of their simulations of building performance. The wind tunnel test people wanted a clear definition of how to make an accurate model, plus an evaluation process that ensured that the wind speeds reported were representative of the scale of the typical effects of new buildings. The CBPR clients wanted assurance that they could trust the calculations. An independent QC process could provide that reassurance. Finally, the lighting designers of the SF MOMA had a system of lighting design analysis that was in itself a QC process.

10-4.4 lack of performance guidelines for buildings

One of the interesting lessons to be learned about building performance simulation can be learned from teaching others a building performance simulation technique. It is clear when people have completed the exercise and are connecting with the content. They normally start to ask "have I got the right answer?". The least satisfactory and most accurate answer is of course that all answers are potentially correct. If they have accurately modelled their building then the answer represents that building's performance. Since it is a basic principle of building performance simulation that design has such a significance that the time spent on simulation is worthwhile, it is therefore impossible to create a simple ruler against which one could compare a particular performance simulation and say categorically either that it is "correct" or that it is "good". As with real building's[18] performance, the only realistic way in which to measure an ebuilding's performance is to compare that building with

other similar buildings. However, readily accessible databases of building performance are hard to find.

study 1 - passive solar house design

One of the most difficult parts of the passive solar seminar presentations, and indeed one of the most difficult parts of any presentation to new users of any calculation for building performance evaluation is the definition of performance benchmarks. The conventional approach is to use the ebuilding itself as the benchmark. Essentially, the argument is that performance simulation, whether with computer programs or with simpler tools, can never model all parameters, especially the occupants' behaviour once the building is actually constructed. And, the argument continues, since what is important is to know the effect of a design decision, the recommendation is to compare two variants of the same ebuilding: one with a standard value for the sizes of the significant building elements (window size, R value etc) and the other with the value you plan to use. The difference in performance is attributed to the difference in these values. This approach has been adopted and developed by the whole thermal simulation industry. Definition of the standard building against which to contrast the performance of one's own building requires very careful planning and documentation[19].

In the solar seminars, the participants wanted to know whether the results of their calculations were "good". The only way in which this could be defined was through comparison with other groups' calculations for their buildings. Any simulation tool for use by architects must contain the tools for such a performance comparison. Indeed, if the design decision support tool is well-designed, it will also contain: i) a means for storing and comparing past simulations in a manner that allows ready comparison with current simulations; and ii) a means of representing graphically the relationship between building performance and the sizes of various building elements like window area and wall thickness.

study 2 - CBPR design consultancy experience

Figure 3 WCCouncil Art Gallery, "reference" 150 lux spot defines "good" performance goal

The most challenging problem encountered with the use of rendered light arises in presenting the pictures of the output of the light simulations to the client. Often, without a visual reference point in the picture, no amount of annotation or graphical overlay can convince them of the results. They are as aware as anyone that by adjusting the "exposure" of our "digital camera" we can make very bright conditions look quite innocuous, or very dark conditions very pleasant.

This problem is an example of the difficulty of communicating the results of the performance analysis in a form and format that can be understood. Graphical representations, where the light intensities are represented as a series of coloured contour lines across the rendered picture are commonly used for this. They do not convey the full picture as they represent only quantity and not quality. They cannot yet easily highlight the areas of a picture where a specified performance criterion is exceeded.

A specification of a design simulation tool for architects must include associated data analysis and manipulation "tools" like the spotlight we "placed" in rendered art gallery scenes to provide a well-understood reference against which to judge the natural light. Rather than requiring the ingenious user to devise "tools" like this to calibrate the output for the user, an architects' design tool should include the means to automatically compare and contrast design options using in-built indices of performance. In lighting, these indices might include glare indices and simple means of simultaneous presentation of pictures or output from the different design options such as provided by LBNL's Building Design Advisor[20] or ESRU's integrated performance views[21].

study 3 - thermal simulation program survey

A Graphic User Interface (GUI) with windows and mouse control was most often suggested as the improvement desired by the USA users of simulation programs. There was no general agreement on how the user interface might be better improved but many of the comments described features that are beyond the conventional image of a GUI. Rather than suggesting changes that would just make a program more like other Microsoft Windows programs they described features that would assist users to interpret the output data or to determine whether the calculated building performance was a logical result of that particular combination of input data. Benchmarks are needed that enable the user to determine this logic, advising if particular components make sense together, and whether the building performance is reasonably determined by these individual component values.

study 4 - wind tunnel test user survey

When asked whether they used ***particular design techniques to improve wind effects...***the architects said *no. driven by economics {B} Don't have any rules of thumb {C}* However, during the interview most indicated an awareness of several techniques. When asked whether they had ever had to *alter or redesign a building proposal because of the Ordinance* most replied yes. However, the changes were mostly minor: extending verandahs and adding porous screens. In general, only *opportunities* rather than

problems had arisen as a result of these alterations: *Provides opportunity to vary building form, gives architects some leverage over clients.*

In general, most architects replied that they found *taking part in a wind tunnel test helped* [them] *in the design process*. However, there were dissenting opinions about the value of direct involvement in the wind tunnel test: *Report is comprehensive so no need to observe each test.* For these architects the definition of "good" was absolute: the Wellington City Council Ordinance defined acceptable wind speeds. A building either passes or not.

However, the responses to the survey suggest that there is some concern about the meaning of the wind tunnel measurements: *Don't believe that the wind tunnel simulation is accurate enough for some sites to give a sensible solution to the problem*. A further complicating factor is that the Ordinance in its current form emphasises danger because it specifies what are essentially one-off annual events. To place emphasis on comfort, these Council criteria would have to be changed from extremes representing annual gusts to averages more expressive of the typical wind found in a space.

A design tool for this type of application also requires an analytical "tool" which permits the user to specify what performance targets are to be met and to specify the automated tests of compliance with them. Both the current wind tunnel application and its associated physical model, as well as any likely future CFD computer program will require add-on "tools" that help people set relevant performance criteria if they are to be used as design tools rather than compliance checkers by architects.

study 5 - SF MOMA daylighting

The architects and the client apparently had no clue what was being done in lighting design on their behalf until they could enter the quarter scale and full-scale models. At this point they could measure (the client) and visually assess (architect and client) the light levels they observed under the many different external lighting conditions. This improved the level of assured Quality because the non-simulationists understood the performance analysis. They could in fact engage in a little uncontrolled or unmediated assessment of their own, without the intervention or assistance of the simulationist..

The challenge to the simulationist of the future conducting such a process under more constrained circumstances, and thus perhaps using only digital models, is to communicate the same concepts in the same easy to understand language. For the simulationist conducting a heating energy analysis or an acoustical analysis there are different and no less obvious issues. For example, a graph comparing internal and external temperatures will always look ok, if the heating is on - how to communicate how hard it is for a person to keep feeling warm in one building relative to another? It is possible to let people listen through headphones to the effect of the internal environment in a building on the sound produced by a concert pianist and help them to understand the impact of their decisions, but it is much less obvious how to let

them assess the impact of sound penetration on the performance, or to move around simply and compare one position with another.

What are required in all these situations are performance guidelines for each discipline which are easy to understand. The performance values in a code or standard are insufficient. For example, the normalised thermal performance measures in standards such as energy use per square metre of floor area are meaningless without a performance 'yardstick'. Most people could not tell how important a difference of 100MJ per square metre in energy performance was. Similar limitations exist for all other performance analysis techniques. The advantage of the physical quarter and full-scale model was that it was its own calibrator: people could move into and out of the models comparing their experiences with everyday experiences. Digital thermal, visual or acoustic simulation requires the same touchstone in reality.

summary

The solar designers wanted to know what benchmark they could compare their performance calculations against to know what was a "good" performance. Computer thermal simulationists sought benchmarks that enabled them to be sure that the building performance is reasonably determined by the individual component values. The wind tunnel test users sought add-on "tools" that help people set relevant performance criteria. CBPR experience of presenting rendered pictures containing built-in accurate representations of the light levels was that the client needed assistance translating the pictures into something they could relate to reality. Despite the many hundreds of papers that exist in the field of human perception[22] correlating our perceptions of landscapes with photographs of those landscapes, little work exists in the field of human perception of light via photograph or computer screen. What was significant about the SF MOMA modelling process was that the process was so open and accessible that people other than the lighting experts could use it for their own forms of qualitative lighting analyses. Provision of widely understood benchmarks must remain a goal of all new eddst development as it ensures this wide accessibility for all performance data produced.

10-4.5 lack of tools for summarising and detecting patterns within the simulation "output"

One of the most complicated aspects of digital thermal performance simulation is relating the many possible data output report formats and even graphing options to the questions asked by the designer or the client. To the new user of a program which is capable of producing a report containing say the surface temperature of every element in the ebuilding for every one of the 8760 hours in a year, selecting the appropriate graph or statistic to represent this rich data set is daunting. This is a particular problem of digital simulation. In ebuilding performance reports, there is such a wide range of possible output parameters that can be calculated that the mark of real experience is how few are

selected to answer the simulation analysis questions. Because this type of problem arises from ebuilding performance simulation, only Studies 2 and 4 are summarised in the next few paragraphs under this heading.

study 2 - CBPR design consultancy experience

The weak link in all CBPR consultancy activities has been the basic data on which our simulations are based. Whether we are performing thermal or visual and digital or physical model simulations, at the core of our concerns in reporting the results of our analyses has been a concern to link the calculations to reality. We wish to ensure that the client can understand the information we produce. In order for this to happen, we must be able to relate the energy use, lighting performance or comfort predictions to their experience.

This requires basic data like weather data in digital thermal simulation that relates to the situations they experience. Standard weather data used in thermal simulation is based on some form of 'average' year. Sometimes the average year of data is calculated by assembling all 12 of the most average months from a set of 30 or more years of hourly measurements and sometimes it is the most average year among the 30 years. In either situation, the client is easily able to understand the concept of average or typical year. What they immediately want to know is 'what is my risk if I encounter a year that is hotter or colder than average'? In 1990 the CBPR recognised this and established a set of weather data including cold, cloudy and hot, windy years[23]. There remains a task for a future interface to a digital thermal simulation tool to make full use of these different standard years and to report patterns of comfort and energy use in terms that incorporate these aspects of risk.

Good weather data is also important in lighting simulation. Without an accurate description of the luminance distribution of a clear, a cloudy and an intermediate sky for each location, a lighting simulation is likely to be in error. What is also required is an accurate description of the hourly mix across the year of clear, cloudy and intermediate skies. Often the data is not available so the simulationist uses a standard CIE sky[24].

Given its size and the ready availability of many different work situations and lighting conditions, the Victoria University School of Architecture building is a natural test-bed for measurements of daylight potential in Wellington. In addition, the national research laboratory Industrial Research Limited has measured the luminance and spectral distribution of New Zealand skies[25]. This data is being used to calibrate Radiance for CBPR use in local conditions.

At present, each new location for the application of a design simulation like Radiance requires this calibration effort. As user experience extends, and as the science of daylight study develops, we will find that this type of calibration becomes a less and less significant issue. Future versions of daylight simulation programs will include tools that assist the designer to specify the weather conditions for a location in such a way that the patterns of daylight availability will be as accurately modelled as the

light distribution within a space. In this way, the patterns of daylight in the interior will be reported in a manner that is as close to an accurate picture of reality as possible.

study 3 - thermal simulation program survey

For approximately half of the participants in the simulation program survey, *customisation* was rarely or never undertaken across all categories. However, most people *graphed* the data output at some time or other. In fact 41% of them *Always graph the output*. By contrast 67% *never* calculate comfort indices. A surprising result was that statistical analysis was so little used.

Those who customised the input were normally trying to better match the model with reality. Half those who customised output did so because it allowed them to do custom chart (graph) making and to enter into spreadsheets for report writing or further analysis. Eight (30%) customised output in order to debug the model or to assist with QC in some unspecified manner.

Graphing of the output is the most consistently used post-processing method. Statistical *analysis* of the trends in the graphs is however rarely performed. In most digital simulations of building performance intended for use as design decision support tools for architects, whether thermal simulation, light rendering or acoustics modelling, there will be a need for interpretation of the input and of the output. To be useful, this interpretation process will be assisted by the presence in the simulation package of simple tools for analysing and comparing design options graphically and statistically.

The most crucial aspect of the output analysis is to ensure that there are tools of sufficient sophistication that they can make use of and summarise the comprehensive output of which the design tool is capable. As one of the USA simulationists suggested: "I would like it easier to determine the interrelation of an input in one area of the program on the calculations in other areas..." Far too often at present design decisions are based on very simple, single figure performance indices like the annual energy use or the daylight factor at a single position inside for a single cloudy day condition. With computer programs that are capable of calculating the dynamic behaviour of the building to the second for an hour or to the hour for a year, merely to amalgamate the thousands of data points into an annual index of performance is to miss totally the rich picture of building performance that the program is capable of producing.

summary

Many computer simulation program users graph the plethora of basic data that the programs produce. This common place means of creating pictures for summarising the building's performance is not matched by what might be expected to be the natural next step: deriving secondary data such as routinely combining the various output numbers into indices of performance such as comfort scores. While one of the most interesting ways in which digital simulation can be used is to provide risk analysis, there is little guidance available from simulation program developers in the form of

output data post processors. It is not currently easy to deliver reliable answers to the questions clients want to know: how precise is a performance calculation? what happens in cold years? what if I don't open the windows for ventilation? what happens to the daylight on a partially cloudy day?

10-4.6 overview

Digital simulation tools like Radiance are very powerful means of examining many lighting design options for a building and easily comparing and contrasting them. This can be done both visually, in terms of a simulated snapshot of the space, and numerically through standard glare calculations and lighting level measures. These simulations can give good feedback to the designers on the performance impact of their design modification and the rendered images that are created are certainly pleasing to the eye.

Similarly, digital thermal simulation tools like DOE2[26] and SuNREL[27] and digital acoustic simulation tools like CATT[28] are becoming easier to use and their output is very seductive. CATT in particular has virtual reality auralisation options that permit the client to sit and listen to music as if they were inside the CATT ebuilding.

However, there are problems associated with ensuring the simulation is accurate for local conditions. Problems are also encountered in the use of such a highly sophisticated simulation system or even of its resultant output by architects and other building designers who are not experts in the field of lighting or acoustics even though it is these architects and designers who must make best use of the information produced if they are to create buildings that perform better. The field of digital simulation of building performance has reached a development plateau where the conjunction of improvements in computer speed and in computational algorithms has removed most of the practical barriers to use of the tools. Computer code developers have the luxury of being able to work on interface design rather than developing more calculation tricks to provide practical response times.

This research suggests use of this digital interface technology to remove the barriers to designers' understanding and trust of environmental design decision support tool is needed to advance the field beyond its current plateau. It is not enough to focus on easing the input and output of data and the interoperability of different tools. There is a need for tools that don't just ease data entry but ones that aid understanding of the relationships between design factors and building performance. Digital simulation by its very nature is most useful when it enables the designer to extend their ideas well beyond the 'comfort zone' of previous experience. Where a digital simulation merely repeats analyses already performed on a nearly identical building in nearly identical circumstances it merely produces the familiar old answers and can be seen as a sophisticated form of procrastination. Therefore, the normal situation where digital eddst's are most useful in the design process is also the situation where the performance predictions are least familiar. In this situation, intuition based on experience which might reveal out of the ordinary performance patterns has no place.

With a simple, non-digital simulation, one learns quickly what is a reasonable result. For example, one quickly learns reasonable ranges for R-values. As one does more and more of these simple R-value simulations of the thermal performance of a building element so one acquires the experience of the expert who 'knows' when a number does not 'look' right, and determines to repeat the calculation to check it. In digital thermal simulation becoming such an expert is no longer a simple process of repetition. One embarks on each new simulation only 1) when the building design is sufficiently complicated or different from previous work to warrant the effort entailed in a simulation because one does not know how this design functions; or 2) when the questions about the building design are sufficiently different from any previously considered that the simulation effort is warranted. No amount of experience can create the intuition needed to spot the incorrect simulation.

To remove the barriers to designers' understanding and trust of digital simulation, without also contributing to information overload for the designer, requires providing better understanding of the input data and adding interpretive sophistication to the tools provided for processing the output data. This requires establishment of the basic data in plain language descriptions to support the use of each computer program. It also requires the development of the tools which are needed to put the data into the simulation and to extract useful design information from its output.

The type of basic data that is needed to support each digital simulation program is:

- weather and other environmental data that is more than just 'typical' data for a location - it provides data on aspects of the external environment including: likely extremes (of say outdoor temperatures, external noise levels, sky luminance distributions) and probability of occurrence of influential events (say, combinations of temperature and wind); it contains data sets for each risk scenario: under/ over sizing; 'good' and 'bad' years; a 'bad' winter / summer week.
- standard building element descriptions such as IAI[29]-style building product models that permit one ebuilding to be constructed and then several different digital simulations to be run to evaluate its performance from different points of view such as lighting, airflow, acoustics, heating, cooling.
- standard building descriptions that combine likely patterns of room occupancy, room size and required performance for the labelled activity (e.g. 'school', 'hospital', 'office' or 'house').

The key feature of data like this is that it provides a common link with well-defined international and national standards between all digital simulation eedst's. With these common standards agreed, then the trade-offs that mark the design process - balancing one priority against another - can be made in a common language and potentially through a common interface.

The second area of research and development looks to develop an 'expert advisor'[30] assisting the designer to input the correct data and to interpret the output data. This advisor 'knows' how many days out of 365 are sufficient to simulate in order to infer a picture of the daylight performance of a particular type of building. It 'knows' how many hours out of each prototypical day should be simulated, to infer the daily variability in performance. It 'knows' how many cloudy and sunny sky types to simulate in order reliably to infer the average annual performance of a building.

The designer requires an interface that is an expert system, an advisor, on the input and the output of each digital simulation if it is to provide genuinely useful design decision support. The final two chapters of this thesis examine what might be the nature of digital simulation in the role of design decision support for environmental quality in buildings. The penultimate chapter draws conclusions about the needs for design information that have been identified by this research. The final chapter defines the characteristics of the systems that must be put in place to convert digital simulation into design decision support.

10

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11

conclusions

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

final_conclusions_2006.wpd

THE BEST WAY TO GET A GOOD IDEA IS TO GET A LOT OF GOOD IDEAS.
LINUS PAULING, WWW.WISDOMQUOTES.COM (LAST ACCESSED, 2003)

11-1 *the nature of design simulation*

This final volume comprises:

- summary **analysis** of the detailed studies of Volume B that looks for the common factors in all the users' uses of and reactions to these environmental design decision support tools.
  . . . . . research goals and the detailed studies.
- examination of these analytical **conclusions** with a view to identifying the principal features of an environmental design decision support tool (eddst) which guarantee that its predictions will be convincing.
  . . . . . the nature of design simulation.
- a hypothesis as to what might be a reality test in digital simulation that would be sufficient to convince users that the results of their own simulation represented an accurate picture of future building performance.
  . . . . . simulation tool agents.

11-1.1 introduction

A specification is presented in this chapter of the principal features of an environmental design decision support tool (eddst) to be used by building designers from the early stages right through the design process which guarantee that its predictions will be convincing. These features form the principal conclusions to the Detailed Study research. The chapter begins with a brief overview of the conclusions; it then describes a test that might be used for Quality Control (QC) in digital simulation of building performance; a detailed study is subsequently presented of the Quality Assurance (QA) processes by which such a QC test would be applied to the various design scenarios examined in the Detailed Studies; finally, the last two sections of the Chapter contain a detailed step by step specification of the QC test process. As noted in the footnote dictionary quote in Chapter 9, this separation of QC and QA is a semantic device adopted in this thesis. Others use these phrases differently. None appears to have more weight than any other. A QC test enables one to measure the quality of a simulation. The QA process places the QC test into the context necessary to make it useful.

The crucial question posed by this thesis is what is the nature of the information sought by building designers when they want support for their environmental design decisions? The manner in which this question is posed implies a fundamental assumption that improved building performance for the individual building owner or occupier is the goal of all designers. A necessary corollary of this assumption is that numerical information, and by association the numerate designer who can use and interpret this information, is central to the improvement of performance.

The thesis argues from the premise that merely asserting that architecture has "profound significance" [1] or "embodies timeless laws" [2] requiring architects to understand and acknowledge

significant architectural "precedents" [3] does not equip these architects to adapt those precedents for the specific locations and uses of new buildings. Whether the architect is the simulationist or is merely the user of eddst simulation output, is not important. What is required is a profound and inevitably numeric understanding of the relationship of those precedents to the environment.

The designer cannot ensure that a building will provide the correct lighting conditions for the tasks to be housed unless some calculation is made of the daylight from the windows. Similarly, if a building is to provide the levels of thermal comfort and stimulation that are expected by today's building users, the designer must be able to do more than merely 'understand' the ways various construction precedents respond to variations in climate. Building users expect that, within particular aesthetic norms, the designer will make a building that functions well in addition to fitting their architectural taste. This means the designer must have a sufficiently detailed knowledge of the nature of the interaction between indoor temperature, climate and building construction that the implications for the interior climate, of changes in the building design, can be predicted accurately. Accurate prediction of this interaction can only be accomplished through numerical modelling.

The 'obvious' question that is implied by the questions raised here is what is the role of the building designer and especially to what degree should a 'consultant' provide the analytical input necessary for numerically based performance prediction? The thesis research returns always to this critical point. To what degree should the role of the designer/architect in the team of people working on the building design include analytical or numeracy skills? The conventional architectural notion[4] is of the architect as team leader. Building science researchers frequently conclude that a design approach compatible with these conventions[5] which is also to deliver quality environments should place central importance on "early design decision making" if their environmental design advice is to be effective. Indeed, many spend long hours developing design tools that are designed to improve on the effectiveness of architectural decision making in the early stages of design[6] .

This thesis has demonstrated that in most situations environmental design decision support tools are not used by architects. Even when the predictions of those tools are sought by architects they are applied at a stage in design when practical improvement in building performance is impossible. The problem that has been identified is one of a mis-match between building performance design tool input/output (i/o in computer jargon) and architects' expectations of what their role is in that i/o. An associated problem is that building environmental design professionals are unable to provide design advice of the type sought by architects at these early stages in design. Partly this is because of the nature of the environmental design decision support tools used by these building environmental science professionals. This problem, however, is being addressed by developers of a new generation of computer programs for environmental design analysis[7,8].

Building scientists and other analysts in my surveys reported high expectations of the new generation of programs. Their wish lists are being tapped into by program developers. However, it still seems questionable whether these programs will ever produce the answers to questions of architects and

others involved at the earliest phases of the design process? Most digital simulation programs for predicting the environmental performance of buildings are designed for use in the later phases of design - the so-called 'developed design' phase(s). They are intended to be used by the designer to refine their basic ideas, not to formulate those basic ideas - so they still do not address the fundamental need for early design advice.

The detailed studies have demonstrated that in order to build a digital simulation into an eddst that helps designers to formulate a high performance building design, each eddst must be constructed so that it can function early in the design process when the building description is incomplete. It is clear from the surveys that architects are strongly interested in the qualities of the environment that design tools describe. Where this interest has been noted in the past, simplified eddst's have been developed to provide beneficial 'output' from architects' 'inputs'. Examples of such developments include: Waldram diagrams[9], R-value calculations[10] and daylight nomograms[11]. Even these typically simplistic summary tools have often required education intended to assist the architects to understand their application.

At times the numeracy of architects is addressed through education programs with the avowed aim of helping them reach a level capable of using these design tools 'correctly'. More often, a training[aa] programme like that studied in Detailed Study 1 is introduced which aims to show architects how to use the tool(s) 'properly'. From observation of architects in Detailed Study 1, and the reaction of interviewees in other Studies, numeracy - or rather its lack - seems still to be one of the major barriers to architects' use of predictive design tools. The reluctance of many architecture firms to get involved in the design performance prediction business which has been emphasised by this thesis apparently has its origin in the belief of the senior members of architecture firm that numeracy skills are not part of the core business of an architecture firm (Study 3 firms). They also have no confidence in the skills of junior staff who may have received training in numerical building performance evaluation techniques because they have no way that they personally can determine the quality of the work done by this junior. Our experience of the pre-design wind tunnel tests described in Study 3 was that architecture firms preferred to see others do the tests, not the designer. This was despite the learn-in-half-an-hour nature of the pre-design tests.

However, what seems to be attractive to these same senior members of architecture firms about the recent availability of rendering software which simulates lighting is that, at least superficially, they can use their traditional 'architectural' skills to assess the quality of the 'output' because this output is often published in the form of pictures. For these senior architects, and in fact as the Surveys and Case Studies in this thesis have shown, for all users of building performance prediction software, the greatest single need in design decision support is for reassurance in terms they can comprehend of the reliability of the 'advice' produced by the eddst's. They need quality control systems they can

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[xxvii] Training is meant here to imply *passing on skills of use*; as opposed to education - *passing on understanding of principles*.

trust. The interviews and questionnaires reported in this thesis demonstrate that not just architects but all users of simulation in design decision support require some means of ensuring that what they have modelled with a simulation tool is a real building. Whether they are analysts specialising in the use of a design tool, or architects who are less regular and hence probably less skilled users of the tool, they all require more feedback about the relationship between their simulated e-building and real buildings than simulation programs currently provide. Even the architect or other member of the design team requires some means of defining their level of confidence in the predictions of the analyst.

On the evidence of the comments made in these survey interviews, if building performance prediction tools like thermal or lighting simulation software contained the right quality control mechanisms, then architects' interest in the environmental quality of their buildings would naturally drive the use of this software. The difficulty at present with performance prediction tools and software that leads to this i/o mis-match problem for these architects is that there is no independent measure of the reliability of the performance predictions for the e-building. The results seem seductively believable. However, there is no means by which a user of the simulation program can determine whether the ebuilding they have created is a) genuinely a model of the building they have designed; and b) is a model that will perform in the way that a real building will perform.

Obviously, something as simple as an R-value calculation - which is a 'simulation' of the thermal performance of a building component - can be compared with a specification in a code or standard. But even for this R-value calculation it is difficult to guarantee quality. The major difficulty is the numbers are not easy to check. No systems exist for independently verifying the calculation, apart from repeating it and checking whether the second 'run' gets the same answer as the first. The issue is not the precision of the numbers - the number of decimal places in the 'answer' - but the accuracy of the relationship between the numbers and the reality they are intended to represent. As simulations become more and more comprehensive, so it becomes less easy to scan the output and see in it that something is inconsistent or illogical. Improvement of the Quality Control (QC) and Quality Assurance (QA) procedures for environmental performance prediction using digital simulation will make these potential eddst's more accessible not only to the professions who currently use them, but also to those architects who currently avoid them.

11-1.2 quality control - simulation and the real world

Design simulation requires building designers to develop a mental model of the relationship between the real world and the information they are feeding into and getting back from the simulation. The quality of this mental model determines the quality of the information that they can obtain from the simulation. If a person does not understand the simulation process, they cannot easily use the simulation results to inform their design. Rather, the conscientious but uninformed user will have a series of numbers and a set of concerns about their meaning and reliability. There is an associated

danger that the casual but uninformed user will have a series of potentially erroneous numbers they trust unreservedly.

Ultimately, the difficulty with trust of simulation software, whether thermal, lighting or acoustic performance prediction, is the same as it is with more simplistic algorithms: in order to obtain a calculated result in a finite time period, many mathematical tricks have been used to generate a simulation program that works. These tricks can be justified mathematically. They follow well-accepted mathematical methods for (say) the solution of differential equations. However, they add artefacts to the calculation process which can confuse or undermine confidence in the output. In some situations they can place limitations on the degree to which reality can actually be modelled. For example, in thermal simulation programs, the modelling of changing heat paths, like the change in R-value of a window when the curtains are pulled is often not possible when the solution technique for the heat flow equations involves response functions. In Computational Fluid Dynamics simulation of air flow in buildings many simplifications are made - not the least being a quasi steady state solution of the air flow. Fixed values for *boundary conditions,* such as the amount of solar radiation falling on a floor, are assumed in order to permit the solution of the flow equations. In commercial lighting software, radiosity[12] and ray tracing[13] approaches each have their own parameter settings which users must tease their way through in order to solve the light distribution balance in a room. In radiosity programs, the setting of the scale of the mesh parameters affects the accuracy of the lighting; and in ray-tracing programs, the setting of the number of rays the program tracks to model the bounces of light around the room affects that same accuracy.

The thermal simulation program survey (Detailed Study 3) in particular identified lack of Quality Control (QC) procedures as its principal finding. The USA survey participants specialised in thermal simulation. None were architects. They analysed buildings designed by others rather than designing them. Yet, even these specialists did not have documented and standardised Quality Assurance (QA) procedures incorporating QC tests of their simulations.

Part of the i/o mis-match problem when environmental performance prediction simulation software is used as a design decision support tool is that the users do not normally understand the limitations of that software. To date, designers who have not applied their schooling in environmental analysis in their architectural practice can be argued to have demonstrated a certain degree of common sense. It may be disappointing that their buildings are not designed as well as they would be if they were designed from the initial stages using the design tools in which they have been schooled. However, it is common sense that if they do not feel confident in the use of these tools, then they should leave them to those who know them sufficiently well that they understand their limitations.

The architect who leaves to others the knowledge of what an R-value truly represents or consults a lighting designer about the requirements in the standard for certain illuminance levels is insuring against mistakes. They are declaring that training in R-values and illuminances received during their professional education is insufficient preparation for making design decisions based on these

concepts unless they continue to receive sufficient day-to-day practice that they can play with the concepts in the same way they play with their design ideas.

Being sufficiently confident with an eddst that one can play with the design opportunities it offers should be the ultimate goal of all users of design tools. Architects are trained to do this with their 6B pencils and graphic thinking techniques[14]. *Back-of-envelope* calculations attempted by many engineers result from the same ability to play - but with formulae rather than pictures. Familiarity with the technique breeds an understanding of the ways in which it might be manipulated in new situations. It also breeds an understanding of what cannot be done with the technique - whether graphic or calculational. This familiarity only comes about through continued trained experience: coaching, whether in the studio through *reflection-in-action*[15] or in the laboratory through repetitive calculation provides the necessary basis for a lifetime of practice.

As Malcolm McCullough [16] has suggested, knowledge of the *affordances* of a computer tool is a skill that must be expected of the craftsperson of the 21st Century. Pictures produced by radiosity and by phong shading have very different affordances. In a radiosity solution, the picture produced contains accurate information about the light distribution in a space; a phong shaded picture represents the geometry in a view that looks as realistic as possible. However, Phong shading will only light surfaces so the light distribution is convincing to the eye. Its 'predictions' will probably bear little relationship to the light levels that will be experienced in the space. Thermal performance predictions also have different affordances: finite difference techniques for the solution of the thermal flow equations describe the response of a building, particularly the building fabric and its varying properties (e.g. thermal insulation of curtains), to highly varying internal and external temperatures and radiation; response function solution techniques are better suited to study of the energy performance of the services needed to maintain the spaces inside the building at certain condition levels.

In the near future, when design tools are more readily available because they are being incorporated into user-friendly computer analysis programs, and where clients are routinely asking for more responsive building environments, it is likely that there will be increasing pressure on designers to use eddst's that analyse building performance. Many will still be untrained in their use. The risk is that the external pressures will overcome the current lack of trust, and increasingly the *black-box*[17] computer analysis program will be trusted implicitly to analyse the thermal, visual or acoustic properties of their building. The purpose of Quality Assurance instruments in this situation is to provide people with the intuition for the application of their design decision support tool that marks genuine expertise - to help them to understand the affordances of each tool. While nothing can replace practice as a means of training a user, the goal of QA instruments has to be to ensure that the training is reinforced and strengthened every time the design tool is used.

The difficulty reported in this thesis by inexperienced users of design tools when using even the simplest of design prediction formulae and computer programs would be much reduced if these formulae and programs included reliable self-checking routines. Much the same as architects

inexperienced in environmental design analysis, the full-time thermal simulationist has a need for routines that check the quality of the simulations of new people working in the office. These routines should communicate to the user in the language of the building professional, rather than the abstract language of the mathematical representation formulae used in digital simulation.

It is not easy to imagine a QA process for even the simplest formulae-based simulations such as an R-value or a Reverberation Time (RT) calculation. Quality Control of these calculations inevitably degenerates into a process of checking and re-checking the numbers entered into the formulae against their 'book' values, but not as easily checking what those numbers represent. For example, it is my common experience to encounter a strong belief at least in the New Zealand construction industry that if one buys R2.2 insulating batts, and squeezes their 100+mm bulk into a 50mm gap, they will retain the R-value rating on their packaging of 2.2 m^2 K/W! Any QA of the calculation has to relate to the physical properties that the user is working with - thickness - rather than just to the R-value that they do not fully comprehend.

QA for computer-based calculations requires that the foundation work establishing the accuracy of the relationship between e-building and real building performance is done only once by the writers of the program, when the digital simulation is first compiled. This is the validation that the digital simulation will produce predictions that relate to reality. The BESTEST[18] system is the most comprehensive independent system available for validation of thermal simulation software. Similar systematic validation approaches are still to be developed and are equally necessary for digital simulation of air flow in and around buildings and of acoustics of buildings. A recent initiative within IEA Task 31 Daylight for the 21st Century[19] seeks to establish a web site for the reporting of a similar analytical and empirical process for lighting simulation software[20]. The BESTEST approach uses real measurements and individual algorithm tests in combination to establish 'validity' and also to diagnose problems with the simulation. This is a most necessary tool when writing a program, and a subset of it would be useful when the software is first set up in an office.

Beyond this validation process comes the user issue: **how to ensure that the e-building constructed digitally with the simulation program is in fact the building we want it to be.** The digital simulation of the e-building's performance may well be valid. The e-building may even be constructable but it may not be the building we have designed. How do we confirm first that it is constructable and second that it is the building we imagine. QA processes in digital simulation should allow the user to understand the relationship between performance predictions and building design. With clear feedback on the relationship between building and performance, rather than as at present between numbers representing the building and numbers representing performance, architects would be much more likely to use simulation software. The reluctance of architects to take responsibility for the predictions of simulation software that has been identified during the Detailed Studies is likely to be reduced by simulation software that produces reports in the language of buildings rather than the mathematical abstractions of the writers of digital simulation programs. This

reluctance affects their use of simulation done by specialists and by in-house staff. What is needed is a means of establishing the trust of the user in the performance predictions of the digital simulation. A means of calibration of the user and the software in combination is needed, so that the predictions are sufficiently well understood that they can become trusted environmental design decision support.

The principal problem is how to establish a system by which one might calibrate the output of a simulation program in such a way as to ensure that its predictions represent the reality the user understands. What is proposed below is a test for the output from a simulation program that functions for the "reality" of a simulation in the same way that the *Turing Test*[21] functions for the 'existence' of computer-based (so-called artificial) intelligence. This test of the output of simulations programs would be applied as a theoretical analysis of the input and output of any environmental simulation program. Its theoretical application would derive a number of practical assessment procedures which could be used by the program vendor to demonstrate the validity of their simulation process to their users. It could also be used to develop calibration procedures for these programs. These would enable the users to ensure that their use of the program produces reliable predictions of building environmental performance. In a manner parallel to the function of the Turing test in the field of artificial intelligence, this reality test has to function as a critique of the "reality" of the output from any environmental performance simulation program.

11-2 *quality assurance - reality test*

The following statement is intended to be the type of truism in digital building performance simulation that the Turing test is in artificial intelligence. Its careful application to digital simulation processes should generate Quality Control tests that convince the sceptics interviewed in the Detailed Studies in this thesis that the simulation processes they are using to support their design decisions are dependable.

Changes in the predictions of a simulation program with changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

This is perhaps an obvious 'truth' that most simulations, whether calculator or computer based, would claim to match. After all, what use is a formula for, say, calculating the Reverberation Time (RT) of an auditorium if it only applies to the size of auditorium for which it was derived? Indeed the claim for the value of many digital simulation tools for energy performance analysis has been that although the absolute numbers may not be completely reliable, the relative size of the changes in performance is accurate. Basically, the claim made by the producers of these design tools is that because of the vagaries of people's operation of buildings, prediction of actual energy use is not

possible but equipment purchase or building design decisions can be made on the basis of the predicted differences in energy performance.

So how might this reality statement be converted into a Quality Control test? In the following paragraphs I try to answer this question by applying it to example situations based on the Detailed Studies. These are intended to be illustrative of the potential of the application of this test. In the process, the goal is to generalise the lessons of the Detailed Studies - to draw conclusions. The text refers back to the hypothesis outlined in the thesis introduction that there are general lessons to be learned from these Studies about improving designers' use of environmental design decision support tools (eddst's). Each example shows the theoretical application of the test, and the practical result - the user calibration tests and the reliability assessment procedures - that ensue from its application.

A strong parallel is drawn with the structure of the Turing Test of artificial (machine) intelligence. ""In that test the interrogator is connected to one person and one machine via a terminal therefore cannot see her counterparts. Her task is to find out which of the two candidates is the machine, and which is human only by asking them questions. If the interrogator cannot make a decision within a certain time the machine is intelligent." " In the simulation reality test proposed here there is also an interrogator. She is able to observe the performance of two different buildings. Her task is to determine which of the two is an ebuilding. If the interrogator cannot make a decision within a certain time, the ebuilding can be considered "real". The reality of the ebuilding should be sufficient to convince the user that they can depend on design decisions supported by these simulation processes.

The nature of the test of reality is at the heart of the test. It is not enough that the simulation reproduce a sample ebuilding performance. What is important is that the 'behaviour' of the real buildng is reproduced. The behaviour referred to is the response of the building to known changes in the design. The approach takes its lead from the standard approach to simulation described in chapter two which is to make comparisons of the effects of building design changes not to rely on absolute predictions of performance. The "real" reference is then a set of data that establishes what are "normal" changes in behaviour resulting from particular changes in a well-documented building design.

In each of the quality assurance processes examined in the following paragraphs the reality test is systematically considered from the viewpoints of three major classes of interest group. These three are the producers, users and clients of users of eddst's.

- the producer of the eddst must be able to demonstrate that for their simulation: "changes in building design should always be of the same scale and nature as those changes in performance observed in reality."
- the user of the eddst must be convinced that their uses of the simulation tool are always "of the same scale and nature as those changes in performance observed in reality."
- the client being advised by the user of the eddst must be able to rely on the fact that its predictions are always "of the same scale and nature as those changes in performance

observed in reality."

The question is how to create operational features like this within environmental design decision support tools?

study 1 - passive solar house design and study 3 - thermal simulation program survey

Changes in the predictions of a simulation program with changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

The discussion that follows uses lessons from the solar house survey and from the thermal simulation program survey. The application of the lessons from the two is essentially the same. The reason is that in solar house design, as soon as we wish to break away from the norm that has been examined systematically by the developers of simplified design tools, we move into the realm of the comprehensive thermal simulation program examined in the thermal simulation program survey.

In passive solar house design the number of alternative design tools that might be applied is large. Approaches vary from consulting a list of good ideas in case studies of existing solar houses to full digital simulation of house thermal performance. The conventional approach has been for developers of environmental design decision support tools to apply a comprehensive thermal simulation program to the situation. Multiple digital simulations are made of a systematically varied series of e-buildings. The results of these simulations are summarised in graphs, tables and simplified correlation formulae. The goal is to test the range of buildings 'normally' built by performing a set of computer simulations that covers the important parameters describing this range of buildings.

Assessment of the reality test is divided into three separate, independent sections representing the three classes of interest group: the producers and users of eddst's, and then the eddst users' clients.

for the producer of the design tool

changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

Conventionally, a design tool producer conducts a series of validation tests for the tool. The literature on validation is considerable[22] and has progressed beyond mere comparison of one prediction against one measurement point (say the annual energy use of a building) to identification of several different scales and types of validation. The type of activity often referred to by consultants involved in simulation as 'validation' is more properly known as 'calibration'. For example, a simulationist engaged in a project on an existing building who simulates the existing building and compares the result against measurements in that existing building is merely 'calibrating' their simulation to the current situation. True 'validation' requires far more control over the input and output variables in both the measurement and the simulation. It normally requires laboratory controlled 'validation' of the individual algorithms in the simulation as well as the controlled 'validation' of the predictions of the collection of algorithms in the tool against measurements of a real situation.

Often the developers of digital simulation programs as design decision support tools provide sample files or e-buildings with their software. The idea is that the sample e-building provides the new user with confirmation that the system is installed on their computer properly because the program can be run with this standard e-building as soon as it is installed, before the user is familiar with its use. Successful comparison of the predicted performance with the supplied sample performance prediction is intended to confirm that the software is running correctly in this new installation. These sample e-buildings often serve an additional function: templates for 'constructing' new e-buildings. In a process where a single mis-placed comma in the e-building description might cause the digital simulation program to crash inexplicably, making changes to an existing e-building file that the program can already analyse, rather than starting with a new ebuilding model is often just plain common sense.

To achieve the goals highlighted by the reality test, a QA system built into a solar house digital simulation program for use as a design decision support tool must provide the following:

- a means of confirming that the mathematical operation of the software installed in a new situation is still accurate - the role played by sample files now.
- a description of the sample e-building and its input file in simple construction terminology.
- a simple set of automated tests that demonstrate the performance response of that e-building to systematic changes in its design.

To achieve each of these goals the design tool must contain an automated set of routines for applying a standard set of changes to the parameters describing 'sample' buildings and for comparing the simulated responses of the buildings' performance to a library of corresponding building performance responses. It is essential that this set of routines be automated so that the user is not required to invent test routines but rather is reassured by learning how to compare the e-building description with its predicted performance using standards which the software independently verifies. Once this process is successfully implemented, it should influence consultancy use of the software so that before making recommendations based on its predictions users would ensure that their e-building 'behaves' in a standard manner given the pre-defined standard stimuli.

The three keys to making this process work are: first, the automation of the process; second, establishing the reporting process in language that is understood by all users; and third, most crucially determining an appropriate set of standard stimuli which reveal the reality of the e-building. These keys are easier to write about than to create. The third requires the most work. There is no known internationally respected library of standard responses of buildings to standard stimuli (such as changes in design) which could be used to test the reality of the response of an e-building. The second key, description of the building in the language and terminology of the building site rather than the mathematics of the algorithms simulating their behaviour, is the subject of much of the interface design work being put in by software vendors internationally. The first key is largely unexplored by vendors and even by users and requires the other two to be complete before it can be attempted.

The closest that any research team has come to the required standard stimuli of the third key component of such a QA system is in the BESTEST[23] system for design tool 'validation'. This system was devised by Task 12 of the International Energy Agency Solar Heating and Cooling research Programme. Task 12 examined software tools and their application and one of its products was a complex set of validated data based on measurements of real buildings against which the predictions of simulation programs can be compared using the BESTEST system. An illustration of the complexity of this type of reliability test can be found in the 'simplicity' of the test devised by the BESTEST team: the only measured data they could document well-enough for their purposes is from *test cells* - one room buildings which have been systematically monitored. Work is progressing on expanding the database to include measurements from buildings with more than one heated interior zone. However, the process of ensuring that this data is of sufficient quality is complex and time consuming[24].

A QA instrument produced to be incorporated into a simulation package for designers of **solar houses**, and of more general application in thermal simulation must contain the following automated package:

- **sample e-buildings that represent the full range of complexity and size of buildings that might be designed by the user of the package** - e.g. a three room dwelling; a five room dwelling with loft and basement; this same five room building with slab-on-ground heat loss; the same building with a sunspace; the same building with a Trombe wall; full disk copies of the output files for these buildings; an on-line tutorial guide instructing the user a) in how to write these input files; and b) in how to make standard changes to them; and finally, an on-line checker that automates the comparison of the output of the user's simulations of these buildings and of standardised changes in them with the expected values.
- **sample e-buildings which are one-room validation files** describing the real data developed for the BESTEST validation programme.
- **a 'validate' button which institutes a standard set of simulations** of the user's building under certain specified standard conditions and compares (graphically) the relative size of the changes in the output with the relative size of changes in the output of the sample buildings. The changes to be tested would be: doubling and halving of all glass areas; making the infiltration rate rise to 5 times and fall to half its established value ; doubling and halving the R-value of every external surface element in the building; doubling and halving the heat capacity of the floor and wall elements of the building.
- **a standard set of output graphs which contain *base cases*[25]** which allow the output to be measured consistently against well-characterised buildings: these base cases would be described in detailed case notes and would represent relevant situations: they may even be generated by the software based on the user's choices when setting up the model of their building (e.g. it may be a standard building operated as the proposed building is modelled). The most important aspect of these standard graphs would be the accompanying descriptions of their performance. (e.g. a temperature graph for each month of a year would show pictorially as well as in words a high thermal mass building as having a very stable, but perhaps quite cool internal air temperature throughout a winter season).
- **on-line test or evaluation aids** which graphically compare the fractional changes in the user's own e-building with the changes in the sample and base case e-buildings.

for the user of the design tool

changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

Users of simulation-based design tools should expect that QA tools built into the simulation programs they use will guarantee that the changes in predicted building performance are always *"of the same scale and nature as those changes in performance observed in reality"*. The lessons of the detailed studies in this thesis are that there are two distinctly different users of these design tools:

- the expert who has a strong knowledge of the theory of heat transfer and some knowledge of the heat transfer calculation techniques used by the software; they also have strong views as to how the software should be used and operated, but very little systematic checking for Quality Assurance purposes built into the office procedures.
- the novice who is unsure what the terminologies of building science and particularly the mathematical representation of heat transfer might be, let alone symbolise, but who know what thermal comfort goals they are aiming for and how they wish to achieve them. These people are at present looking for systems or programs that answer design questions: how hot? how cold? how much heating? is an insulated glazing unit useful? but have no clear idea of how to judge the value of the answers that might be provided by a computer simulation program. They do not trust the language of the mathematician solving the heat transfer equations, but they do understand buildings. They would institute any QA systems that would assure them as to the accuracy and reliability of the design recommendations that they might derive from the output of simulations. They would demand that the expert user use these tools when providing feedback on their design analysis services.

QA instruments like those suggested as necessary for the thermal simulation program vendor to produce would be extremely useful to these two types of user of design tools.

As noted in the thermal simulation program survey, experts in digital thermal simulation need cheaper but more reliable ways of conducting simulations:

- they need a means of educating junior staff if they have them in the intricacies of thermal simulation - particularly in making relevant assumptions about the aspects of the design that are and are not important to model.
- they particularly need to develop in new staff that healthy suspicion of the predictions of the computer that they have acquired through long years of experience.
- they also need a means of simply guaranteeing the reliability of the conclusions reached by the junior staff - everyone has a horror of the misplaced decimal place deep within the intricate melee of data that is a normal simulation input file.

A new breed of architects and designers are also in great need of a QA system that assists them to trust the environmental design decision advice resulting from digital simulation. They are the people who are being encouraged by their education, by the burgeoning market for solar and environmentally responsive design, and by the availability of 'user-friendly' software for thermal analysis of building performance to look more carefully at the likely performance of their designs. Either as analysts themselves, or as clients of the expert simulationist, they need:

- to learn how to use the digital simulation in a manner that does not place them open to litigation;
- to learn to trust the output of the digital simulation to the extent that they feel comfortable making design decisions weighing up the thermal performance of the building against other client criteria for view, aesthetic appearance and access;

- to produce evidence of building performance to support design decisions that is convincing for the client as well as themselves because it is described in language that can be readily understood.

The QA instruments described above as required from vendors of thermal simulation software should function very well in answering these user needs.

- **sample e-buildings that represent the full range of complexity and size of buildings that might be designed by the user of the package**: as noted by the surveyed expert users of simulation programs, there is no better way to guarantee the reliability of one's simulation than to alter an existing validated and thoroughly checked input file. There is also no better way to learn.
- **sample e-buildings which are one-room validation files**
- **a 'validate' button which institutes a standard set of simulations**
- **a standard set of output graphs which contain *base cases***
- **on-line test or evaluation aids**

for the client advised by the user of the design tool

changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

To me the most interesting result of passive solar design decision support produced by digital simulation is the likelihood that the client can become much more intimately involved in decisions about their future comfort *if the QA procedures are available to assist them to understand the performance predictions.* The following checklist is based on the features of the software described as required of the software developer. It has been annotated from the clients' viewpoint. A QA instrument to be incorporated into a simulation package for designers of solar houses would have the following client-specific benefits:

- **sample e-buildings that represent the full range of complexity and size of buildings that might be designed by the user of the package** - there is no easier way to understand the performance of one e-building than to compare it to others. These buildings can be used as performance benchmarks for any new development simply by constructing them in the local climate and reporting their performance.
- **sample e-buildings which are one-room validation files** describing the real data developed for the BESTEST validation programme - is convincing evidence, if packaged as simple time-traces of temperature and energy use, of the validity of the analysts' claim that the package is reliable.
- **a 'validate' button which institutes a standard set of simulations** of the client's building under specified standard conditions and compares the relative size of the changes in the output with the relative size of changes in the output of the sample buildings. Again, the benefit of this output is that the performance of the e-building is shown to be reliable because it behaves like other solar houses.
- **a standard set of output graphs which contain *base cases*[26]** which allow the output to be measured consistently against well-characterised buildings. The detailed case notes would assist the client to make qualitative judgements based on the simulation data. Without these touchstones in 'reality' it is very difficult to translate or to understand the relevance of the performance of the e-building to the reality of construction and occupation of a house.
- **on-line test or evaluation aids** which graphically compare the fractional changes in the user's own e-building with the changes in the sample and base case e-buildings. These are the tools with which the above comparisons can be made. The client reading the performance reports from the software and making decisions based on their understanding of these reports needs these evaluation aids as much as the user of the

software.

study 4 - wind tunnel test user survey

Changes in the predictions of a simulation program with changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

There were three strong trends in the interviews with architects who were experienced with wind tunnel assessment of their designs:

- General recognition of the need for consideration of the wind environment when designing buildings in Wellington.
- The level of general understanding of aerodynamics was low even amongst those experienced with the wind tunnel assessment process.
- The architects thought that taking part in the wind tunnel tests helped them design better, however they do not favour being the people who do the pre-design wind tunnel tests.

Recent developments in the field of Computational Fluid Dynamics (CFD) have produced a number of computer programs which can be used to model airflow in and around buildings[bb]. The stage has not quite been reached where an e-city can be constructed and its performance under various wind conditions studied via digital simulation. However, the time when this is possible does not seem far away.

Clearly any QA process which describes the interaction of the building and the wind in the terminology of construction rather than CFD has great potential to assist the designer to understand the issues better. It is likely that the general preparedness of architects to work for continued improvement of the wind environment in the city that was identified in the interviews will be assisted hugely by the improved understanding they can gain of the impact of their designs on the wind from informative feedback from a QA process.

The architects commented on a range of improvements to the wind tunnel test process. These would all be addressed by eddst's based on digital simulation with an associated Quality Assurance process. All the improvements relate to perceived 'inaccuracy' in the wind tunnel simulation which would be dealt with by the QA reality test. In particular, many of the architects were unconvinced by the level of detail in the wind tunnel model. They felt that the lack of detail would affect the reliability of the simulated performance as an indicator of performance in reality. This is just what the reality test is supposed to address:

- the producer of the building aerodynamics design decision support tool must demonstrate that for their simulation: "changes in building design should always be of the same scale and nature as those changes in performance observed in reality."
- the user of the building aerodynamics design decision support tool must be convinced that their uses of the simulation tool are always "of the same scale and nature as those

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[xxviii] Computational Fluid Dynamics: The School of Architecture has two such programs: CFD-ACE (CFDRC, **CFD-ACE Command Langauage Manual**, v4.0, Huntsville, CFD Research Corporation, 1998) and Flo-VENT (Flomerics Corporation, http://www.flovent.com , last accessed December 2003). See also over 80 products listed at: **CFD Codes List- commercial products** http://www.icemcfd.com/cfd/CFD_codes_c.html (Last accessed December 2003).

changes in performance observed in reality."

- the client being advised by the user of the building aerodynamics design decision support tool must be able to rely on the fact that its predictions are always "of the same scale and nature as those changes in performance observed in reality."

As with the solar house design decision support tool, the question is in practice how to create features like this?

for the producer of the design tool

changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

Wind tunnels are one-off constructions designed as much around the available space as any physical theory of air flow[27]. In contrast to the inter-comparisons of digital simulation in thermal modelling, the literature on their validation is essentially a collection of reports of one-off tests of individual construction projects. There is only one example building available against which these one-off tests of wind tunnel function can be evaluated. It is the Texas-Tech[28,29] building. Wind tunnel users make a scale model of this real building for each validation exercise.

With CFD, as with all other digital simulation programs, the software is typically distributed with sample or tutorial files to assist the novice user to understand how to use the program well. What is needed in an eddst for CFD based air flow prediction is sample e-buildings like this whose performance is well-documented to assist the user to understand how performance might reasonably be expected to change as the building design changes. With such information available it becomes feasible for users to develop an understanding of how their own e-buildings should perform and hence to trust the performance predictions of the software.

Recently at the School of Architecture we have established a procedure by which the data from the Texas Tech. measurements of wind pressures on a real building might be used to calibrate digital (CFD) simulation[30]. This would form the basis of a further Quality Control test. At the very least, it would establish a means of checking that a CFD user was able to reproduce real observations with the digital simulation software.

What is needed in addition to this QC test is extremely good statistical data. The Reference Year weather data of the digital thermal simulation has no straight corollary in building aerodynamics. The wind speeds measured in the wind tunnel are normally converted to full scale predictions of the frequency of occurrence of particular phenomena using annual statistics describing the probability of exceeding particular measured mean wind speeds at the local meteorological office. These figures are converted from mean wind speeds to gust wind speeds using some form of conversion factor[31].

With CFD simulation, as with simulation in the wind tunnel, the analyst has to translate the single test - the one time measurement of air flow with its assumed particular strength and turbulence - into generalisations. These generalisations cover storm force winds and gentle breezes which have different degrees of turbulence. They have to cope with daily, hourly and seasonal variations in wind

strength and direction. In all situations they require risk analysis as part of the suite of QC tests. Risk analysis would help the user to understand the likelihood of things being much better or worse if the weather was not 'typical'. It would also establish how many separate calculations of air flow for particular wind strengths and directions would be needed to gain a full picture of the interaction of the e-building and the simulated wind.

for the user of the design tool

changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

The building aerodynamics Survey demonstrates that at present, while acknowledging the benefit for the environment of a general awareness of the effects of buildings on the wind, the architects interviewed believe that the wind tunnel test procedure is unreliable. They talk about it as "an inexact science" or describe it as "not accurate enough for some sites to give a sensible solution..." A QA process that was based on a reliability test would provide the feedback needed to convince these sceptics of the reliability of the design decision support arising from use of digital simulations of building aerodynamics. At present, one of the biggest problems illustrated by these comments is that these sceptics do not understand the building aerodynamics modelling process. The QA process must also improve this situation.

The biggest single benefit of the use of a trusted building aerodynamics digital design decision support tool would be that the design team might be able to use it early in the design process. This would address the other issue raised in the Survey: "Timing of wind tunnel testing is difficult. Can't happen earlier in the project as building has not been approved by the client prior to that, but at the late stage it is generally carried out the building design is almost completely determined. {K}" Difficulties arise when a design to which a lot of time and resources have been committed is rejected by Council because it does not perform well enough. With a design tool that analyses the performance of building designs and reports the results in a format that can be generally understood there is the likelihood that architects will look to use the tool right through the design process.

for the client advised by the user of the design tool

changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

At present, the biggest single problem with the operation of the District Plan in Wellington that I personally face as a consultant advising the Wellington City Council is with designs that have been completed before any analysis is conducted of their aerodynamics. In such circumstances, if the building is found not to comply with the District Plan, the client is quite likely faced with enormous additional expense. Repeating the design documentation process for an altered design is the smallest part of these. The largest cost will arise from the discovery that the only construction that will work

aerodynamically is a much smaller building than has been accepted by the finance company and on which perhaps the cost of the original proposal was established.

The ability of design teams to conduct pre-design feasibility studies with digital simulation that produces output that is trusted and well-documented could help avoid such problems. A Quality Control test that establishes the reality of the output of the digital simulation is a key requirement for such a digital simulation. The user needs to be able to convince themselves and hence the client that the e-building they have constructed would not produce different results if they spent another ten days adding details like balconies on the upper floors or verandahs on the buildings two city blocks upwind.

The user also needs feedback that enables them to compare the performance in terms that are understandable to the majority of people. It has been customary for many years to report wind speeds and their frequency of occurrence for different wind directions. What is really needed is a means for the client and the city councillor and the designer to understand the real impact of the design on the wind environment. It is not enough to look at changes in wind speed. What is needed is a measure of the significance of the changes. Three features are required of a digital simulation of building aerodynamics for such a measure of significance to be comprehensible:

- the wind speeds should be converted into wind speed effects on people (danger, discomfort in restaurants, etc) and reported as changes in hours per year that each effect is experienced (e.g. currently 200 hours per year moving to 600 hours per year after the e-building is constructed).
- a risk analysis needs to be provided exploring the boundaries of applicability of the performance predictions resulting from the digital simulation.
- these changes in hours per year need to be scaled against generally understood good and bad situations - this would be achieved if the QA process simply reported that an e-building has the same effect as one of the sample e-buildings placed in a well-known public space.

studies 2 and 5 - CBPR design consultancy and SF MoMA daylighting

changes in the predictions of a simulation program with changes in building design should always be of the same scale and nature as those changes in performance observed in reality.

There are no separate lessons for developer, user and client here. Rather, the digital version of the (Study 5) Fisher, Marantz, Stone process, backed by on-site spot measurements calibrating the output would address the needs of all three.

At the core of both of these Detailed Studies was a thorough design analysis of daylighting. It seems advantageous to compare these two design processes because the CBPR process offers an insight into the pro's and con's of digital lighting simulation as lessons for the future of such applications in building design; while the SF MoMA process shows us how all buildings' lighting ought to be designed, if we all had access to large budgets and near infinite amounts of time. In the buildings in the CBPR Case study, RADIANCE digital light simulation was used with digital thermal simulation to support design decisions. In the SF MoMA Case study, the simulation tool supporting the design decision making was a series of ever larger physical models. If only all buildings could have so much

time and care spent on examining their environmental performance ensuring that the conclusions of each test were continually scrutinised and re-evaluated during all phases of design and construction! It should not be forgotten that the SFMoMA study also benefitted from the ready accessibility of the physical model simulations not only to the analyst but also to the architect and the client.

What is attractive about the SF MoMA process is that it has its quick-and-dirty early design phase, but this is followed up by two phases of careful and systematically more accurate measurement. It is also as readily understood by the lay person - the client - as by the building professional. The first phase was merely measuring the performance of simple models under a small mirror box cloudy sky simulation in the FMS offices in New York. The two more detailed modelling phases use closer and closer approximations to the actual site lighting conditions: the quarter scale model on site before and during construction; and the full-scale mock-up in one of the galleries during construction.

The two latter phases are essentially Quality Control test processes in operation. In the FMS design process they provide assurances for themselves and their clients of the 'reality' of their modelling, and hence the reliability of their design advice. This FMS process is ideal in a digital simulation as well. What is needed is the same QC in digital simulation as the FMS measurements under real skies provide. In digital daylight simulation this grounding in reality can be readily translated into simple measurements inside and outside the new building as it is constructed. The quick-and-dirty digital simulation would produce early pictures of the interior during a wider range of lighting scenarios than the mirror box allows. The digital simulation predictions would be calibrated against the measurements on-site as the building is constructed

However, the person from FMS wishing to analyse their measured data still has problems: what is a typical day or hour? Assuming good measured data is available describing the sky digitally, the user of digital simulation for making design decisions faces the same problems as the person from FMS: how to determine a representative number of hours of the day, sun angles and levels of cloudiness to test. What is representative of the range of daylight that is to be experienced?

11-3 *veracity test for simulation*

The paragraphs above mention a Quality Control test - a veracity test, which would improve designers' confidence in the performance predictions of digital simulation. The following paragraphs describe what such a simple veracity test might look like.

The QC test presented here is an example of how a veracity test might be inserted into a building design process. To establish the test in the office, the form in **Figure 4** would be completed for each simulation in the office. It is an expert system intended to establish the reliability of the simulation results. At each step the goal is to cause the user to ask *what is the truth here?* The idea is that the users

should be continuously asking themselves whether the data in front of them representing a building's performance is from a real building. Like its inspiration, the original Turing Test[32], this is a 'game'. It also requires a minimum of three 'players'. One person asks the questions, the other two answer on the basis of the data they have. The aim of the two responders is to convince the questioner that 'their' building is real. One of the buildings is the ebuilding simulation being evaluated. If the questioner cannot distinguish the real from the simulation then they can be assured of the quality of the simulation.

The problem with this QA idea is the same problem as affects the Turing 'Test': how to make it operational. Very few offices can afford to have three people working on a QA process for a simulation. In a large office, it might be the means by which a design review is conducted systematically. Partners involved in the design review would have access to a database of their own and others' trusted building performance information.

The purpose of the form in **Figure 4** is to pose questions that can be answered by the individual user with the simulation process independently providing information from the other two 'players' in the game. The user in this instance should not be the person who undertook the simulation. As a general principle, a QA auditor should probably not have been part of the simulation team. The goal of the other two players is to convince the simulation auditor that both the real and the simulated building are behaving in the same manner - if their behaviours are indistinguishable, then they are both 'real'.

In computer-based simulation the computer program that does the post processing of the simulation data should play the part of the player who has a 'real' building to describe in their answers. The person who has done the simulation provides the answers from their simulation data. Again, ideally two people are required for this process - self-assessment runs the risk of missing crucial details and is to be avoided. The real building data is likely in this instance to be a combination of case studies constructed from monitoring programmes in real buildings and from structured parametric runs of the simulation program itself. This database, if constructed carefully will develop over time as more and more buildings pass the test and are thus eligible to be added to the database.

The key concept is that the development of a database of this type be internet powered. It would be shared and added to electronically. In suggesting this approach I have been inspired by the approach established by music enthusiasts around the world with the CDDB[33] internet database of CD recording data. In that database, data is recorded about the data on the music CD. It is in this situation an illustration of what computer science theorists call Meta-data: data about the music (data) on each disk. Crucially, it relies on the automatic assignment of ID numbers to each CD in a process that is replicable: it works to produce the same ID number for each CD on every computer on which it runs.

If a unique number like the identifier of each CD was assigned to each building by a replicable process on the basis of the building description, people would be able to upload and download cases

to supplement their own set of real buildings. At present, the goal is to ensure that the owner and the architect believe the analyst. In the future it is likely that the architect will be working with simulation data from their CAD program's expert agents and will be required to convince themselves and the client of the veracity of the output predictions.

In hand calculations and model-based simulations, the QA process is at least as important in the simulation of a building's performance as it is in computer simulation. It is very easy for the viewer of the physical model in particular to be seduced by the pseudo reality of the model. However it is harder to construct a set of building case studies that is self-checking and develops as simply as the computer-organised database described above. The onus is on each analyst to create their own QA database whether they are conducting wind tunnel tests, measuring daylight in models, or doing calculations of R-value based heat loss or Sabine-Eyring Reverberation Time. The goal of a QA process for simulations other than digital simulations would still be to produce evidence of the reality of their simulation to the independent auditor - the architect or the owner or someone employed just to conduct the audit.

The instruction to the simulation auditor is simple:

> Ask the provider of the performance data and the database of real buildings at a minimum the questions in the QA form. Ask as many other questions as you wish about the performance of these buildings. If the responses about the simulation cannot be distinguished from the real building, then the simulation performance predictions can be relied upon.

ESTABLISH A STANDARD	The ruler which conventionally establishes the units of the simulation. The performance of the simulated building is measured against this 'ruler'. The ruler may be supplemented by a set of well-understood and documented previous simulations 1 In a **thermal simulation** of an energy efficient design or a **cfd simulation** of a natural ventilation design the standard is a 'normal' building without the energy efficiency design features . 2 In a **wind tunnel test** of a new design or in a **thermal simulation** of an energy management retrofit the standard is the existing building on the building site. 3 In a picture generated by a **light rendering** simulation the standard is a well-understood illuminance patch in the picture. 4 In an **acoustic simulation** of auditoria the standard is anechoically recorded sound in combination with recordings of its playback in known auditoria.
RANGE CHECKING	Demonstrate how cross-checking has been achieved to guarantee that every piece of input data is a realistic value. E.g. to ensure that a misplaced decimal point has not converted a 100mm thick wall into a metre thick wall. With a computer-based simulation much of this process can be automated. 1 In a **thermal simulation** and a **cfd simulation** there is no substitute for having a library of real building materials drawn from standard texts and cross-checked independent of the current simulation; every piece of data describing the e-building is to be referenced to its independent data source. The digital simulation QC process will automatically cross-check every data point entered against the library and seek independent cross-references for each unrecognised input value. 2 In a **wind tunnel test** a visual check of photographs of the model against photographs of the real buildings - from the same angles - should suffice for gross dimension checking. This process could be automated - there are already programs available (http://www.realviz.com Last accessed December 2003) which will construct e-buildings in 3D from digital images of real buildings. However, all small details, such as gaps between buildings, verandahs and balconies, should be measured by a person independent of the model-maker. 3 For reliability in a **light rendering** a library of real building materials drawn from standard texts and cross-checked independent of the current simulation is needed; every data input value is to be referenced to an external source. The digital simulation QC process will automatically cross-check every data point entered against the library and seek independent cross-references for each unrecognised input value. 4 For reliability in **acoustic simulation**, a library of real building materials drawn from standard texts and cross-checked independent of the current simulation is needed; every data input value is to be referenced to an external source. The digital simulation QC process will automatically cross-check every data point entered against the library and seek independent cross-references for each unrecognised input value.

Figure 4 Quality Assurance Test Form

INPUT PARAMETER CHANGES	These are the key to assuring the analyst/simulationist and the independent auditor of the quality of the simulations. They must be set separately for each building and for each type of simulation. Typical changes would be: 1 For **thermal simulation** (each item is altered separately and within practical constraints - e.g. walls may have to thicken to achieve some of the doubling of R-values): 1.1 doubling and halving the R-values of the major opaque components; 1.2 doubling and halving the infiltration rates in small buildings where skin losses dominate the energy losses; 1.3 doubling and halving the principal heat capacity elements of the building; 1.4 doubling and halving the areas of the solar radiation collectors (typically windows) in the building. 2 For **digital wind tunnel tests** 2.1 for the wind direction with the greatest wind problems, run the test again with the wind a mere 5^{o} at variance from the original direction; 2.2 ensure that if the wind tunnel test is based on predictions taken from single point measurements in the wind tunnel, then each 'point' is measured twice - the second time a small distance from the first. It would probably be advantageous to move to this second point by some standard fraction of the distance away from the first point towards the next measuring point on the grid laid out; 2.3 double and halve the height of the building; 2.4 double and halve the size (each item separately) of the principal aerodynamically ameliorating features of the building: verandah; opening for carparks through the building; set backs or podia; 2.5 increase and decrease the level of model detail to check to see whether the effect is one of detail or design: spacings between model buildings are important in physical wind tunnel tests, but degree of detail in the facade of a building such as mullions, small balconies and columns is not important. 3 For **light rendering** 3.1 add and subtract 50% to the reflectivity of each of the principal surfaces in the room at the same time, so that the roof, walls and floor may increase and decrease their reflecting power; 3.2 add and subtract 50% to the transmissivity of each of the principal glazing surfaces in the room at the same time. 4 For **cfd** 4.1 double and halve the driving forces for the indoor air flow; 4.2 double and halve the size of the major flow elements. 5 For **acoustic simulation** 5.1 add and subtract 50% to the absorptivity of each of the principal surfaces in the room at the same time., so that the roof, walls and floor may increase and decrease their absorption; 5.2 make the sound source twice as loud and half as loud.

Figure 5 Quality Assurance Test Form IIa

STOCHASTIC VALIDITY CHANGES	Demonstrate that the conclusions are Robust in the face of changes in the External environment. Typical changes would be deviations in the average or typical values used in the standard digital simulation of building performance: 1 For **thermal simulation** 1.1 5 percentile hot and cold days in summer and winter; 1.2 hot cloudy weeks and cold windy weeks; 1.3 hot cloudy years and cold windy years. 2 For **wind tunnel tests** 2.1 check if the conclusions reached are any different if the calculation of gustiness is switched from the gustiness in storms - a safety criterion - to the gustiness in breezes - a windiness or comfort criterion. 3 For **light rendering** 3.1 bright sunny days; 3.2 bright hazy days; 3.3 light cloudy days, sun high in sky; 3.4 dark cloudy days, sun low in sky; 3.5 sunrise and sunset. 4 For **cfd** 4.1 wind direction; 4.2 wind strength; 4.3 gustiness. 5 For **acoustic simulation** 5.1 there are no appropriate external environment acoustic parameters relevant to the calculation of the acoustic performance of an auditorium.
EYEBALLING I	Convert output data into real world units. kWh or GJ do not count unless the auditor is very familiar with these units. Far better units are: maximum or minimum temperatures, duct diameters, monetary values of the energy purchased, Air Changes per Hour; listening to the 'sound' of an interior as a result of digital simulation of the acoustics of an auditorium, checking the flow of light in an interior.
EYEBALLING II	Visual checks of the building description used for the simulation where such visualisations are not a normal part of the simulation process. The visualisation program DrawBDL© from Joe Huang used to visualise the buildings defined by the DOE program Building Description Language is the most obvious. CATT Acoustic has a similar visualiser of the geometry confirming the relative placement of the building elements.
EYEBALLING III	Random checks of the output values against simple 'common sense' back-of-the-envelope calculations or previous simulations on similar buildings. The key is to find back-of-the-envelope calculations that are useful. If they were really useful, they would be the simulation. Nothing more would be needed.

Figure 6 Quality Assurance Test Form IIb

11-4 *other necessary qa tools*

11-4.1 analysis of i/o data

As noted above in the conclusions about the Detailed Studies, the aspect of simulation that is most commonly seen as problematical by the non-analyst - the person who is being suggested is ideally

qualified as the auditor - is the description of the 'external environment'. This is often the climate data in thermal, cfd and even lighting simulation. In acoustic simulation it is more likely to be the road or other external noise environment. In all situations where questions are raised about simulation validity, what is often very strongly debated is how the 'typical' external environment has been characterised. Is it an average day/week/year? What might the risk to the building owner or operator be if the normally expected variations around the average occur from year to year? Stochastically valid risk analysis is essential in all Quality Assurance procedures related to building performance simulation.

An often-overlooked aspect of the external environment is the operational environment. The designer needs to know just how vulnerable the simulated performance will be to variations in the way the building is occupied or operated. If the building is no longer operated as it was assumed it would be, what might the performance consequences be?

11-5 *bringing it all together*

The analysis of the Detailed Studies has set out to seek answers to the question of whether it is possible to formulate general guidelines for the improvement of building environment design decision support tools. It was hypothesised that there might be particular types of environment question to which architects and building designers wished to find answers. The goal was to develop a formula for the generation of new design decision support tools in the fields of building acoustics, lighting, thermal design and aerodynamics. This has not happened. What has been found is a more fundamental common denominator underlying building design environmental decision support tools: the need for built-in Quality Assurance measures that assure the user of the reality of the buildings and the environments they are simulating (modelling) with these tools.

To return to the description of the purposes of the Detailed Study research stated in the introduction:

i. the conclusion we can draw about **the types of questions environmental design decision support tools should answer** is that although the designers want detailed environmental information there is no general format or pattern to the **type** of information they want. They want to be able to use it to persuade themselves and others of the **value** of their design decisions. This means normally that the information must first be quantitative, so that values such as costs and benefits can be attributed to it. However, they also want to be able to understand and trust it. It must therefore also be qualitative in the sense that it communicates the quality of life that will result from the design decision.

ii. **the nature of the input and output to these tools that is acceptable:** (drawing lines on graphs; entering numbers in spreadsheets; automatically transferring data from the CAD drawing to the environmental calculation program?...) No general information was forthcoming on this topic. That graphical presentation of data is important is unquestioned - the human brain understands patterns much more easily than lists of numbers. What types of graphic or data presentation format are wanted is not clear.

What we can state unequivocally is that all involved in the building design team wish that the process of building performance assessment were simpler. Architects were highly interested in

the results but reluctant to get involved in wind tunnel testing because it was time consuming to produce the design decision support data. Equally, they wanted precise data on building performance in the solar house design and daylighting Studies, but found the information took too long to be made available. Simulationists too look to improved GUI's in the thermal simulation Survey. They saw this as freeing their time from time wasting issues to do with wringing the data out of the simulation package in order to concentrate more on the reported performance and its connection to the building design. The most likely answer to this problem was seen as the IAI[34] proposals for the exchange of building descriptions between digital simulation programs.

The IAI goal is that only one model, one e-building, is ever created and all performance assessments can be conducted on it, no matter what digital simulation program or tool is used to perform the assessment.

iii. **the types of quality control procedures adopted by the current small numbers of regular users of design tools that provide some guarantee of the reliability of their analyses.** These procedures need to be codified and incorporated into the design tools themselves to ensure that the 'black box' design tool yields information that designers feel they can trust.

The research has finally concentrated on the results of studying the questions and issues surrounding this third purpose. It was examination of this that identified Quality Assurance measures as the most urgently required new development in building environment design decision support tools based on digital simulation. Further, it demonstrated that to address the issues identified in this research a reality test is the single most important feature needed in any Quality Assurance process for building eddst's. The benefits of such a test have been described for each of the Detailed Study areas in these conclusions. The test is suggested as an electronic aide. It is intended that it be an automated add-on to a digital simulation of building performance used as a design decision support tool. It examines the reality or not of the e-buildings constructed with the tool.

Like its inspiration, the Turing test of artificial intelligence, this reality test requires three participants, none of whom are the person who created the original e-building. This, and several other questions about its implementation suggest that also like the Turing test, the most severe problem with this reality test is the difficulty of putting it into operation. The final chapter of this thesis describes a proposal for a Quality Assurance process for building environment simulation incorporating a Quality Control reality test and suggests how it might be implemented using internet technologies. In this final volume of the thesis, I am attempting to look beyond the conclusions in this chapter to the nature of the Research & Development required to make these conclusions a reality. The final chapter is therefore more in the nature of a hypothesis to be tested by myself and others in future work. Work that will I believe be best conducted as a live experiment - on the web - collaborating with a network of designers using simulation software and software developers developing and refining the interfaces of their software to incorporate reality tests.

11

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21. A *gedanken experiment* or test in computer science which proposes that the test for computer intelligence is that the responses to a given set of inputs via a typed or otherwise neutral interface cannot be distinguished from those which would be anticipated from a person. *This test was invented by Alan M. Turing (1912-1954) and first described in his 1950 article Computing machinery and intelligence (Mind, Vol. 59, No. 236, pp. 433-460).The interrogator is connected to one person and one machine via a terminal, therefore can't see her counterparts. Her task is to find out which of the two candidates is the machine, and which is human only by asking them questions. If the interrogator cannot make a decision within a certain time (Turing proposed five minutes, but the exact amount of time is generally considered irrelevant), the machine is intelligent.*
This test has been subject to many different kinds of criticism, but it is the only one known. And while there is no definition for (human) intelligence, it will most probably remain so. The most important argument against the Turing Test, in my opinion, is that it only provides a test for human intelligence (see French, Robert M.: Subcognition and the Limits of the Turing Test). But even if the second candidate was a real person from a different culture, she might be considered a 'machine' (i.e. not intelligent) because of certain questions she wouldn't be able to answer, or would answer in an unexpected way. For example, the question 'If you open a book, which direction does its back point to?' would be answered with 'left' by a European or American, but 'right' by most Asians. Thus, the Turing Test shares its fate with early IQ tests the US Army used, and that immigrants usually failed because of their little knowledge of the American culture. - © Robert Kosara, e9425704@student.tuwien.ac.at/ Last changed: April 5th, 1996 : http://stud2.tuwien.ac.at/~e9425704/turing.html (Last accessed February 1999)
The Turing Test was introduced by Alan M. Turing (1912-1954) as "the imitation game" in his 1950 article (now available online at http://www.sscf.ucsb.edu/~sung/comm115/writing-define-computing/Computing-machinery.html [NOTE: this reference still occurs on the web, but no longer works: try http://www.wps.com/projects/Computing-machinery.html last accessed December 2003] *Computing Machinery and Intelligence (Mind, Vol. 59, No. 236, pp. 433-460) which he so boldly began by the following sentence: I propose to consider the question 'Can machines think?' This should begin with definitions of the meaning of the terms 'machine' and 'think.' Turing Test is meant to determine if a computer program has intelligence. Quoting Turing, the original imitation game can be described as follows: The new form of the problem can be described in terms of a game which we call the 'imitation game.' It is played with three people, a man (A), a woman (B), and an interrogator (C) who may be of either sex. The interrogator stays in a room apart from the other two. The object of the game for the interrogator is to determine which of the other two is the man and which is the woman. He knows them by labels X and Y, and at the end of the game he says either 'X is A and Y is B' or 'X is B and Y is A.' The interrogator is allowed to put questions to A and B.*

The Turing Test that we now understand is something like the following: The interrogator is connected to one person and one machine via a terminal, therefore can't see her counterparts. Her task is to find out which of the two candidates is the machine, and which is human only by asking them questions. If the interrogator cannot make a decision within a certain time (Turing proposed five minutes, but the exact amount of time is generally considered irrelevant), the machine is intelligent. This test has been subject to many different kinds of criticism. - © Pinar Saygin http://www.cs.bilkent.edu.tr/~psaygin (Last accessed December 1999) and Varol Akman http://www.cs.bilkent.edu.tr/~akman (Last accessed December 1999). This page was created on April 6, 1998 and Last updated: July 7, 1998: http://www.cs.bilkent.edu.tr/~psaygin/ttest.html (Last accessed December 1999)

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33. *CDDB is a net of computers around the world which manage a database with information like artist, title and track title about all available CDs.* From CDCOPY Program Helpfile © Markus Barth (mbarth2193@aol.com). Further information can be found about CDDB at http://www.cddb.com (Last accessed December 2003) :*The CDDB Story:* Before CDDB, when you played a CD on your personal computer, there was no way for your CD player to tell you the name of the artist, the album or the song being played without typing in that information yourself. ...there was clearly a need for a system that would automatically recognize and display that information. Thus, CDDB was created in 1993 as the world's first CD database on the Internet. Like many successful Internet companies, CDDB started as a hobby with founders, Ti Kan, Graham Toal and Steve Scherf filling this basic consumer need. Little did they know that what they had architected would become an Internet standard, where the CDDB's titles grow at a rate of over 500 new CDs a day. With a burgeoning developer base, third party CD players began integrating CDDB's unique functionality, and a unique network emerged. To accomplish the considerable technical feat of being able to recognize the CD playing in the drive, even differentiating between various releases ..., CDDB conceived its own proprietary Disc Recognition Service (DRS) in 1995. ... In August 1998, ...the founders sold their young company to Indiana based Escient, Inc., ...

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12

postscript: the future?

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

future_2006.wpd

UP TO NOW IT (THE MODEL) HAS SERVED MAINLY TO DELIVER A MINIATURE OF THE FUTURE BUILDING. BUT IN VIRTUAL REALITY YOU CAN CREATE MODELS AT A SCALE OF 1:1. AND AS SOON A YOU CAN BUILD VIRTUAL SPACES IN WHICH YOU CAN EXPERIENCE EVENTS THAT ACTUALLY TAKE PLACE SOMEWHERE ELSE, IT WILL BE POSSIBLE TO IMAGINE THE VIRTUAL MODEL AS A DESIGN TOOL OF FUTURE ARCHITECTURAL PRACTICE... YOU WOULD MORE THAN LIKELY END UP USING IT TO ALSO "LIVE" IN THAT SPACE.

ARCHITECTURE IN THE AGE OF ITS VIRTUAL DISAPPEARANCE - AN INTERVIEW WITH PAUL VIRILIO BY ANDREAS RUBY REPORTED IN *THE VIRTUAL DIMENSION*, JOHN BECKMAN ED. PRINCETON ARCHITECTURAL PRESS, NEW YORK 1998.

This final volume comprises:

- summary **analysis** of the detailed studies of Volume B that looks for the common factors in all the users' uses of and reactions to these environmental design decision support tools.
  . . . . . research goals and the detailed studies.
- examination of these analytical **conclusions** with a view to identifying the principal features of an environmental design decision support tool (eddst) which guarantee that its predictions will be convincing.
  . . . . . the nature of design simulation.
- a hypothesis as to what might be a reality test in digital simulation that would be sufficient to convince users that the results of their own simulation represented an accurate picture of future building performance.
  . . . . . simulation tool agents.

12-1 *simulation tool agents*

The Detailed Study research of Volume B has suggested that a Quality Assurance process for building environment simulation is essential to develop sufficient trust in the simulation that it will be used for design decision support. Central to this Quality Assurance process is a Quality Control test. The test assesses the reality of the e-building constructed with the simulation. The measure of reality used is that the behaviour of the e-building cannot be distinguished from that of a building that has already been established to be "real". This final chapter hypothesizes what this reality test might be like in digital simulation. The goal is to develop a description of a prototype reality test. A QA process incorporating the reality QC test necessitates the development of the following pre- and post-simulation tools:

1) databases of default values defining what typical input values are for all standard building elements in a range of different situations: building size, type, construction, country of origin etc. These are not default values for simulation input programs, but typical values for buildings. None of these elements is independent of the other. The combinations of materials in schools for example will differ from country to country or between primary and secondary education. They will also differ within a single country between regions or across time. "This database, to be any significant improvement over current practice reported in Detailed Study 2 will have to be developed as a web-based interface. The user of the simulation program will as their first step in building an e-building search for a building "like" the one they are working on. This needs a system for searching and for organising the database which does not provide simple answers. Rather, it will allow the individual user to construct complex answers through their own queries. For example, it requires a search to be able to find a 'daylit, primary school in a Temperate climate' which has available an e-building representation in the simulation software that created the search." A recent MSc thesis by Shengjiang Lu has developed a prototype of such a search that might be added to a Simulation QA web site. It is a system which not only matches ebuilding "features" [1] but which also allows those features to be fuzzily defined: 'like' does not mean 'equal to'.
2) a building performance database that can provide benchmarks of performance for particular e-buildings. The goal here is to develop a set of performance benchmarks that provide early

feedback to the design team and hence the client of the likely environmental performance of their building. Careful construction of the database will build a set of data entries which will enable the design team to state with confidence that the daylit primary school they have designed is sufficiently "like" several of the buildings in "similar" climates in the database that the energy use for lighting will be between the minimum and maximum measured or simulated performance figures in the database.

3) If the e-building performance and the performance of a building in the database are indistinguishable under the reality test, then the e-building is also deemed to be 'real'. The nature of this QC test for comparing building performance is described later in this chapter. It cannot be merely a comparison of the total annual energy use, or of the light levels attained in the building. Were these values indistinguishable, the buildings themselves would necessarily be indistinguishable. The QC test is intended to determine whether when subjected to the same external stimuli the buildings behave in an indistinguishable manner. "The search for the 'default' buildings may well create a basis for just such a benchmark of performance. Again, to be effective, this search must be not only for in-house exemplars, but also for on-line web assisted searches of (eventually) thousands of other consultants."

4) a simulation process analyser which not only prepares the new design e-building as a set of input files for the digital simulation but also sets up the QC reality test. It will create standard variants to the new design to test the sensitivity of the building performance to these design variations. These variations will help in the assessment of the reality of this new e-building. If the new e-building responds to these variations in the same manner as a real or another verified e-building, then it has passed the reality test. "This QC reality test should also be web-enabled. Its web interface must automate the process of uploading new exemplars back into the reality test database." The result of this uploading will be not only a database of building performance standards that is web-accessible, but also an ever-growing collection of these standards. It should eventually be possible to find relevant real as well as simulated performance in the database for the building being simulated with uploaded documentation of the performance of real and simulated variations in the design.

This four step QA process really requires only one database. Access to standardised building performance information is what each step in the QA process requires, including the QC reality test. To be an effective simulation QA process, the means of analysing the database should be incorporated into the simulation programs' GUI[2] interfaces. Ideally, the interface will be an "Agent[3]" or "Bot" working with the simulation software on the users' behalf. Thus, when a **thermal** simulation of a new school in a Temperate climate is planned, and the designer asks the agent in their CAD program to assist :

1) The agent finds similar buildings in local databases such as Building Design Advisor[4] datasets, or ESP-r[5].
2) Using the internet, the agent searches the Building Performance Database for buildings in a similar (see below) climate with a similar (see below) function which also have **thermal** performance data available.
3) The agent also searches these same databases for input data for the **thermal** simulation program that is to be used by the designer.
4) The agent presents the designer with the **thermal** design precedents it has gathered and any associated performance analysis data.
5) The agent responds to the designer's query by suggesting a close match building as a design reference. This will form the benchmark against which the performance of the new building design will be measured. Whether this is one of the buildings from the datasets or is a hybrid of one of them with local code minima for thermal insulation applied is for the designer to decide.

6) The agent will offer the designer a thermal simulation program input file based on the design reference. Some designers may use this as the starting point for constructing the input data file for their own design. Others may want the agent to provide an input file which matches the CAD data they have input. This latter option will probably have to await the introduction of a fully functional Building Product Model[6].

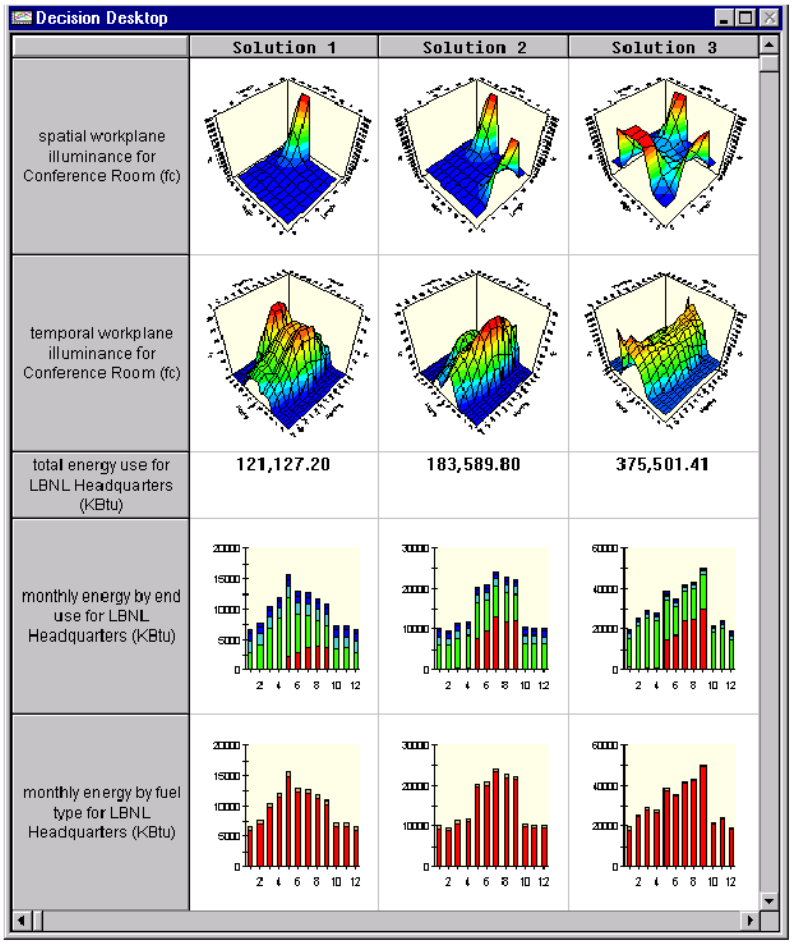


Figure 7 Building Browser interface from BDA program allowing comparison of performance of various ebuildings

7) The designer will simulate the performance of their e-building. However, this command to "run" the simulation program is actually stated as an instruction to answer a question or series of questions. Rather than "run" an annual calculation of the energy required to heat and cool the building, the Agent will be instructed to:

- calculate the seasonal suitability of the building to the activities planned; e.g. if it is a house in a temperate climate it might explore how cold the house gets on a winter morning when the heating system is turned off overnight.

- calculate the size of the heating or cooling or ventilation plant required in suitably understandable increments: e.g. in a school in New Zealand, this might be how many of the designer specified opening windows would be needed to cope with the excesses of February sunshine, pupils and days with no wind.
- perform a cost benefit analysis on one or other particular element in the building: e.g. in a tall deep plan commercial building in a cool climate, contrast the heating energy reduction against the cooling energy increase as a result of installation of wall insulation.

8) The Agent will report the simulation results in a format that identifies not only the simple answer to the question but also which of the myriad input parameters has a significant influence on the answer. This will require the Agent to create a parametric input file which runs the simulation many more times than just the once to answer the direct question being posed: for the low winter temperature question above it may run the simulation once for the whole winter, then a hundred times on the two coldest days varying just one parameter significantly each time. Iain MacDonald's thesis provides clear examples of the application of this stochastic approach to simulation[7].

9) The Agent will typically report all these results measured against the precedent(s) identified by the designer at the start of the analysis process.

10) Graphing, reporting and data export functions will be required of all analysis agents at this point. But they will also be asked to conduct a QC "veracity" test. The goal will be to establish that this new simulation is behaving in a manner that is consistent with reality. This test will be achieved by comparing the input and output data for the ebuilding with standard data from the web performance database. Without this final Turing style test of the reality of the simulation, and the internet data to make it happen, the simulation will have little credibility.

11) The agent will incorporate or use the types of data presentation technique being explored in the Building Design Advisor[8] and ESP-r[9] computer programs (see **Figure 8** and **Figure 7**).

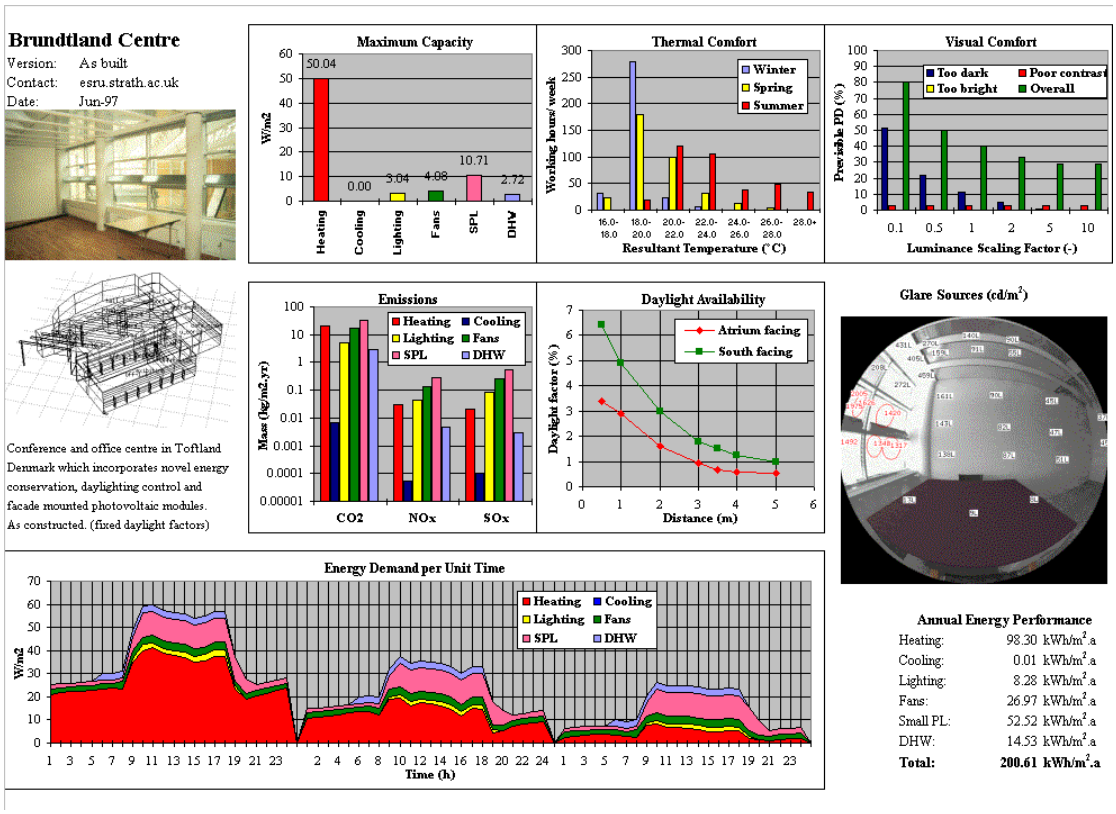


Figure 8 Illustration from ESRU web site of ESP-r integrated design view (http://www.esru.strath.ac.uk/Courseware/Design_tools/ESP-r/ESP-r.htm) Last accessed May 2003

12-2 *finding data on the web: url's & the cddb*

> INFORMATION IS STIMULI THAT HAS MEANING IN SOME CONTEXT FOR ITS RECEIVER. SOME (IF NOT ALL) KINDS OF INFORMATION CAN BE CONVERTED INTO DATA AND PASSED ON TO ANOTHER RECEIVER. RELATIVE TO THE COMPUTER, WE CAN SAY THAT: INFORMATION IS MADE INTO DATA, PUT INTO THE COMPUTER WHERE IT IS STORED AND PROCESSED AS DATA, AND THEN PUT OUT AS DATA IN SOME FORM THAT CAN BE PERCEIVED AS INFORMATION.
>
> HTTP://WWW.WHATIS.COM DEFINITION OF INFORMATION

The key to the whole process outline above is that the database is web accessible. The building performance data held in the database will not only be used by all people with simulation software, it will be added to by these people as well.

The following paragraphs describe how a web-accessible database of building performance information might be constructed so that it can function as the essential core of the QA process and QC reality test described above. In order to provide an internet[10] based resource for the storage of building performance information that is accessible through familiar computer technologies, it will be necessary to respect the overarching goal for the most widely used part of the internet - the World Wide Web[11].

In the words of the www.whatis.com information server:

> The Web was designed as an information space, with the goal that it should be useful not only for human-human communication, but also that machines would be able to participate and help. [12]

The data that is available on the web is accessed through the http[13] protocol. A key part of this protocol is the Uniform Resource Identifier (URI) - a standard identifier of points of content. The web page address is the most common form of URI. It is normally referred to as a URL: a Uniform Resource Locator. It is expected that all sites on the internet where building performance information is served[14] will have a URI capable of being found in the standard way by their URL's and normally possessing Uniform Resource Names conforming to the rules of syntax established by the managers of the World Wide Web. This will ensure that finding the resource will be a process or technique that can grow and adapt to the changes that occur in web engineering.

The URL under http identifies resources such as html pages, image files, programs such as CGI applications or Java applets, and so on. It contains: 1) the name of the protocol required to access the resource; 2) a domain name that identifies a specific computer on the Internet; and 3) a hierarchical description of a file location on the computer. This is however a mere subset of what may be found on the web and that web browsers are being developed to do. For the building simulation QA process the most interesting aspect of these web-enabled technologies is that tools are being developed to permit the web to attain its creator's original vision: the web as a tool for collaborative development of information[15] rather than merely passive viewing of the work of others. People accessing the web database will not only be able to use it, they will be able to add to it. For standard web pages, programs like AMAYA[16] and JIGSAW[17] have been developed to facilitate just such internet collaboration. They work together to permit the person browsing a document to make

changes to it while maintaining both the integrity of the original version, the names and contact details of the person making the changes and also permitting subsequent people browsing to have access to each contributor's view of the document. What is proposed is a system for doing much the same thing with the building simulation QA web data.

What is needed more than anything else is for this building performance database to stay small. If it became a massive searchable database of all building performance data available in the world, or even in the English speaking world, it would soon outgrow its usefulness. Response times would slow to a crawl. Maintenance of data integrity would become ever more complex so the database itself would be forever out of date. What is needed is a means of finding all web-accessible databases with QC tested building performance data in them. A URI that is in the form of a Universal Building Locator (UBL) that describes the location of specific building performance data on the internet is required. It must contain the URL locating the computer and the file in which the data is stored somewhere on the internet as well as a unique building identifier. What would be stored centrally - the core of the QA process database - would be a description of the content of the many databases on may web sites that had relevant building performance information, not the building performance data itself.

The inspiration for this web accessible database of databases was the unique means of identifying individual CD's created by the CDDB (Compact Disk DataBase) developers: their Disk Recognition Service (DRS). This calculates a unique ID for each music CD on the basis of the table of contents of the disk in minutes:seconds:frames format. The minutes and seconds are the track lengths for each track on the CD and the frames are the track position on the CD. This data is formatted in an 8 bit[18] number in hexadecimal[19]. A variant on this format exists in the CDINDEX [20] approach. Essentially this latter index calculates a larger base 64 number and then converts this string to a unique string of ASCII[21] characters.

If we were to follow this DRS approach, then we would develop a standard database format for the labelling - the description - of the building performance data, not a format for the storage of the data itself. The UBL unique identifier will then be generated from the values of the labels in that standard format. The major advantage of this approach is that it is decentralised. There is no need for a central registry allocating numbers. If you wish to submit your data set to the world wide pool, you put it in the required format, and the system automatically allocates it a unique id number that would be the same unique id number calculated by anybody else in the world. To quote from the documentation of the CDDB system:

> The cddb_discid function computes the discid based on the CD's TOC (Table Of Contents) data in MSF (Minutes, Seconds, Frames) form. The frames are ignored for this purpose. The function is passed a parameter of tot_trks (which is the total number of tracks on the CD), and returns the discid integer number.
>
> It is assumed that cdtoc[] is an array of data structures (records) containing the fields min, sec and frame, which are the minute, second and frame offsets (the starting location) of each track. This information is read from the TOC of the CD."[22]

The following example data is taken from the documentation of the CDINDEX system. It is the Table of Contents from a CD-Extra disc. It has mostly music on it, plus a little video clip in CD-ROM format, such as a computer can read. Hence the CD-Extra label, rather than CD-ROM or Audio CD.

Starting track = 1, ending track = 15, TOC size = 4 bytes

track	start	duration	block	length	type
1	0:02.00	4:10.41	0	18641	audio
2	4:10.41	3:35.51	18641	16026	audio
3	7:44.17	4:51.08	34667	21683	audio
4	12:33.25	4:37.31	56350	20656	audio
5	17:08.56	6:29.63	77006	29088	audio
6	23:36.44	4:23.60	106094	19635	audio
7	27:58.29	5:22.56	125729	24056	audio
8	33:19.10	4:16.50	149785	19100	audio
9	37:33.60	3:49.00	168885	17025	audio
10	41:20.60	4:27.44	185910	19919	audio
11	45:46.29	5:26.13	205829	24313	audio
12	51:10.42	3:42.17	230142	16517	audio
13	54:50.59	4:14.55	246659	18955	audio
14	59:03.39	5:20.15	265614	23865	audio
15	64:21.54	8:05.28	289479	36253	data
170	72:25.07	-	325732	-	-

Essentially this is a measure of how much data there is on the disk. It does not differentiate between Pavarotti and Presley. Nor does it describe the music as Classical or Rock and Roll. It merely notes that Track 1 is 4:10:41 Minutes:Seconds:Frames in length, and so on for as many tracks as are on the disk. Because the combination of tracks will never be duplicated except by an exact replica of the data disk, this data can be combined into a single id number. Should the number generated be too short, then a series of leading zeros are added to ensure it is long enough. So long as we use the same calculation formula, we will always calculate the same unique index number for a music CD no matter whether we are using a five year old copy of the CD player program on an old computer with a new copy of the music CD, or a second hand copy of the CD on a brand new computer. To be able to automate the submission of buildings to the database and to automate the accessing of the data from uniquely identified buildings, the proposed QA system will require a similar system of assigning a unique ID number to each building.

The singular advantage of the DRS system for music CD's is that not only can a machine read the acoustic data - the music - but it can access automatically the database. The user of the program does not even know the unique id number for the CD. The program they are using works it out. It then goes to a single repository of such information on the web to find the data describing the qualities of the music data on the CD. At some point in time an individual has typed this data into the database: they have read the CD label and typed the data into their computer: artist's name, classification of the music, name of each track and name of the disk. However, the process of entry of this latter data is only done once for each unique CD, as once it is in the database linked to the

unique identifier, then it is accessible in an automated fashion by all who subsequently read the CD. The downloading of the music content is not precluded by this system, it is just not necessary in a world where people buy their own copies of CD's. Within the limits of copyright, with web based music downloads, this same system could be used to associate a link on the web to a source on the web where the music from that particular CD could be downloaded.

The parallel for buildings is not exact. There is no large industry pressing hundreds of thousands of identical copies of disks with the building performance data on them in the way the music industry does with its data. In fact the likelihood is that each building will only have a record of a few published measurements of real or simulated performance. In fact, the building performance data may not all be in machine readable form. The input files for computer simulation programs will obviously be machine readable. The readings from monitored data are increasingly likely to be. What is required is a data description which is as neutral as the Table of Contents of the CD-Audio disk.

The following Table proposes such a format for the Building Performance Data that will be stored on this web database and which would be used to create a unique id for each building. The next section of this chapter examines more closely the nature of the QC 'reality' text. The section following that critiques this whole web-accessible database idea using principles suggested by Tim Berners-Lee[23] the 'inventor of the internet'.

The Building Performance Data format is a description of the space occupied by the content. In the same way that the DRS system data is a description of the music data, not the music itself, this Building Performance Data is not the content. It is planned so that with this definition standardised, each new database entry will have a unique identifier. This will be able to be associated with the descriptive data about the entry. It is not a description of the content. Instead of using the country where the building is located, the type of building (commercial, residential, institutional etc) and the type of data (lighting, acoustic, thermal) to create a unique id number, it defines only the space occupied by this location and type data. The space is defined in terms of separate types or sets of data (analogous to tracks in CD-Audio, and these might well be lighting, acoustic or thermal data) plus the number of rows and columns and total number of bytes of data in each set.

Type	Rows:Columns	Total Bytes
Set 1	m(1) :n(1)	
Set 2	m(2) :n(2)	
Set 3	m(3) :n(3)	
...		
Set *x*	m(*x*) :n(*x*)	

This data should be enough to create a unique number identifying the building performance data within the UBL. A possible problem may arise with data input files to some analysis programs

because they are essentially a line oriented text file. They are therefore x rows in length but only one column wide. If all files were of fixed line length then the data here is insufficient to create a sufficiently unique identifier.

There is an obvious missing element here: the data describing the building itself. We have a means of generating a unique ID for the building; we have many people putting building performance data into a standard reporting format on their own web sites all over the world: we need a central data repository which described the building and which identifies where on the web the actual performance data can be found. The following list describes the database descriptor (field type: country code, building type, etc) and gives examples of the values that these descriptors might take:

Level 1: **country code locating the building itself**, e.g. nz, us
Level 2: **building type** (rationale for this split developed for Energy Performance of Buildings book[24]):
- com commercial office
- ret shops, banks and similar public activity oriented business places
- pro restaurants, fast food, and other process intensive retail activities
- res residential (small and large scale, domestic)
- hot residential (small and large scale, commercial)
- ind industrial (manufacturing process excluded)
- agr agricultural (farm industry, not farm houses)
- inst institutional (hospitals, council facilities, halls, museums, gymnasiums)
- edu educational (schools, universities, colleges)

Level 3: **datatype**
- light lighting
- therm heating or cooling
- sound acoustics
- air ventilation (mechanical or natural)
- poe Post Occupancy Evaluation
- bpm Building Product Model[25]

Level 4: **analysis type**
- anal analytical performance evaluation - simulation program input or output
- monit monitored performance evaluation - measurements of real building(s)

Level 5: **data units**
- lux lux - illuminance on a working plane
- cd candela per square metre - brightness of reflected light
- C Degrees Celsius - room temperature
- GJ Heating Energy need / year
- kW Heating / Cooling Plant size
- dB deciBels of sound pressure

Level 6: **environment**
- xillum external lighting "climate" classification (see Appendix M for proposal)
- xcli external thermal climate classification (Cold, Cool, Temperate, Hot-Arid, Hot-Humid)
- xacou external acoustic environment (Industrial, Urban, Suburban, Country)
- xwind external air flow climate (Urban, Suburban, open Country)
- illum internal lighting standard (Probably a two part scale made up of quantity and glare components. Quantity: Casual seeing, Large detail, Standard tasks, Fine detail, Prolonged duration fine detail, Minute and prolonged. Glare: Low risk, Large item assembly, Normal tasks, Precision, High Risk, Severe Risk)
- cli internal thermal comfort requirements (degree of control: Floating temperature, Heating only, Ventilation for cooling plus heating, Cooling and heating)
- acou internal acoustic comfort requirements (Factory, Office, Lecture room, Music)

Level 7: **identification**
the unique identification number like the cddb DRS number described above

Further levels that might be added are:
- organis the web address of the organisation that developed the data
- name name of building
- addr address of building
- pers name of person who did analysis
- addr web address of analyst
- type name of datalogger OR name of computer analysis program (e.g. *Campbell Scientific* OR *Radiance*)

This data should be stored and reported by the web-based "central" repository of building performance data. This data store should be able to be added to by anyone with new building performance data they wish to have listed. The goal is to make the information as machine readable

and automatically accessible as possible. In the spirit of the world wide web, the goal is to encourage evolution and hence growth and change whilst maintaining interoperability which makes the data useful now.

In this design, each building that passes the QC "reality" test, has the results of its test automatically recorded in the central repository. Whether or not the performance data becomes web accessible, the intention is that the basic performance metrics are recorded to assist the development of the overall database. The goal is to make the early design question about precedents for Daylit Schools in Temperate Climates generate many answers, not just a handful.

12-3 *speculations on what is 'real'*

The research has thus far defined a development path for the next generation of environmental design decision support tools (eddst's). It hypothesises that this next generation of design tool will be digital simulation programs like ENERGYPLUS, SUNREL, DOE2. It also demonstrates that if they are increasingly to be a part of the building designer's repertoire, then Quality Assurance processes will be a significant part of that future.

A key component of a Quality Assurance process will be the Quality Control "reality" test proposed in the previous chapter. What is posited is an automated test that establishes that the building being simulated behaves in a "realistic" manner. The key concept in this QC technique is that the definition of "realistic" is behavioural: the ebuilding must behave like a real building. The behaviour to be tested is not the absolute performance of the building. If that was shown to be the same as another building then the simulation would have been a waste of time as it would not show the designer anything new. The behaviour to be tested is whether the ebuilding performance changes in response to a design change in the same way that the 'real' building performance changes in response to real design changes.

The major problem with creating a database of real building environmental performance behaviour of this type will be immediately obvious: it is next to impossible to obtain comprehensive performance studies of real buildings where the influence has been documented of significant single-variable design changes such as doubling of thermal insulation thickness, or halving of window transparency. Single variable design changes are necessary to guarantee that each performance change is a result of a particular design change.

Abandoned to another thesis (or three) is a full definition and evaluation of all aspects of the fully developed reality test. To undertake that research is to embark on several more years research, and thousands more pages of text. A minimum specification for the test has been constructed as follows:

- Build a computer model of a building - an ebuilding - whose design specification matches exactly that of buildings in a dataset of performance standards - such as a test "cell" typically used for computer program validation purposes.
- Ensure that the ebuilding's simulated performance matches the test cells' performance. Typically test cells are one room buildings containing large numbers of sensors

connected up to a comprehensive data logging facility.
- Design a set of variations to the ebuilding and document the performance changes that result from these variations.
- Test that these same variations in performance are associated with the same design changes when one is modelling or measuring a more complex ebuilding - say one representing a real house.
- Build the report of the changes into a web accessible database that a lighting / acoustics/thermal/airflow program can access automatically to determine whether a new ebuilding simulation model is "behaving" in the same manner as the norms established by the test cell and the standard ebuilding.
- Establish a system for using these newly tested buildings as part of the web accessible database.

Two small pilot projects have been undertaken of how one might take this performance documentation of a test-cell and of an actual building and use it as the basis for a QC technique in an eddst based on simulation. Each research project undertaken under my supervision in recent years[26,27] has demonstrated how time consuming and painstaking the early development phases of the database development will need to be. One project examined how one might construct a "reality" test for daylight simulation programs, and the other a "reality" test for thermal simulation programs. In each case, the test based itself on simple monitored data. The lessons learned in general from the two research projects are discussed in the following paragraphs and then the projects are described in detail in the subsections entitled daylight reality (page 14) and thermal reality (page 16).

It is not intended that the bulk of the building performance data in the proposed QC tool is real data for real buildings. This is because of the inherent difficulty of obtaining the type of behavioural performance data that is at the heart of the QC test. There are very few datasets available that describe the measurement of the performance of a building and then document measurements of how that performance changes as the building itself is changed. Very few people have the sort of financial resources required to make that type of building performance study possible. However, there are a few datasets of this type available for 'real' buildings: these buildings are the 'test cells' whose performance is documented by building scientists in studies typically used as part of computer simulation software validation exercises[28].

As the name implies, test cells measured in this way are typically one room (cell) buildings. While not a necessary property of every case in the QC reality test database it seemed from the experience of these two pilot research projects that it was essential that some of the foundation datasets in the database were measurements of real projects. Thus each of these projects established the following logic in the creation of an embryo QC reality test database:

- Step ONE: find some measurements of real buildings where the design was changed and the resultant performance change ('behaviour') was documented;
- Step TWO: construct an ebuilding in the appropriate simulation software whose performance behaviour matches that measured;
- Step THREE: preferably have two different people working independently construct the same ebuilding and observe it behaviour with design changes - this has the benefit of 'calibrating' the user as well as the software;
- Step FOUR: create a more complex and 'realistic' ebuilding of more than one room and

model its behaviour subjected to the same design changes;

- Step FIVE: extrapolate the performance behaviour of the test cell model for a more extensive range of design changes than have been measured and contrast these with the performance behaviour when these same design changes are incorporated into the more complex ebuilding.

The most important step in the above process is Step Three. This is because it suggests how the QA process and its associated QC reality test database might be viable without a massive ongoing financial contribution for the maintenance and internal Quality Control. It suggests a mechanism by which one might allow automatic addition of data from simulation programs to the database whilst avoiding a possible distortion of the veracity of the data by sloppy simulation, or deliberate "hacking". It is a 'voting' model for how the QA process might be self-policing and maintained by automated processes, rather than by an oversight committee. Only when there were sufficient confirming 'votes' comprising submissions of similar performance data for suitably matching buildings from completely independent people would a particular new data point be added to the database.

This last approach is suggested as a means not only of publishing the QC data, but also of publishing validation data for new computer simulation programs. There is a risk with the establishment of a QC reality test database of the type proposed that it will appear to favour the simulation programs that have been around the longest and thus have the most case lore established. If this QC reality test is to work, then it must be founded upon the work of international simulation validation research groups such as the BESTEST[29] and CIE Technical Committee 333[30]. The publication on the QC reality test database of the means of validating a new computer simulation package means that the package could be 'validated' on-line. The reality test database could allow the viewing of comparative performance scores of different computer packages - how well do their results match the validation dataset.

Even with a new computer simulation program, the process of submission of the data demonstrating validity could be semi-automated. Submission of a validation dataset from the program developers could count to 10% of a reliability score for the data. Submission by the first independent simulationist would contribute 60% to a reliability score. The second independent submission would add a further 15%. Recommended reliability scores should be over 80%. With the standard QC reliability test a similar reliability score would need to be published: only when the performance behaviours exhibited by a particular new submission are matched by three or more independently produced simulations would their reliability score be sufficiently high that the data could be added.

12-3.1 a qc daylight reality test

For the daylight test, Ben Masters measured and simulated daylight distribution in a simple one-window room[31], then recorded the building "behaviour" given certain design changes. This was interpreted as measuring and simulating how that distribution changes with design changes such as changed room reflectivities and changed window size. For example, reflectivities were changed by

making the walls and roof all the same white colour for test one; then for test two the walls had equal width black and white stripes - essentially halving the reflectivity. The time needed for design changes like this to be measured meant that most of the behaviours recorded were for simulated design changes.

Recent work in which I am involved has expanded this concept into a more systematic evaluation of lighting simulation programs. It is part of the validation work of Subtask C of the International Energy Agency Solar Heating and Cooling Programme Research Task 31[32] **Daylight for the 21st Century**. Its goal is to create a means by which people can undertake systematic evaluation not only of the analytical formulae in their simulation programs but also of the match between their simulation programs and measured or monitored performance data.

There are two completely separate types of test currently being developed as part of this suite of tests. The first type of test is obvious: empirical data measured in the UK by John Mardaljevic[33] and others[34]. The second type of test is a set of analytical tests devised by Fawaz Maamari[35]: ebuilding 'test cases' where the actual values of measured light can be calculated exactly by a simple formula, rather than the complicated photon mapping usually employed by lighting simulation software. These latter reveal how well the digital renderer's complex photon mapping replicates reality in simple limited extreme cases such as illuminance at a point on the floor immediately below a single light source in a perfectly black completely non-reflective room. They are being developed as a means of providing an objective test of the ability of a photon mapping program to render reality. They will be published as such by the CIE[36] and the IEA[37]. Both these tests have a place at the foundation level of the QC reality test. However, to be fully useful in lighting simulation QA, the bulk of the test must be the inclusion of many widely different building types and lighting performance results - a database.

Two basic forms of data from which this type of database might be constructed have already been compiled. One is at www.aecsimqa.net, the web site set up to test the ideas in this thesis. There it is possible to find a searchable list of a wide range of computer models of daylit art galleries. These ebuildings have been constructed in my Digital Craft course for architecture, building science and interior design students at the Victoria University School of Architecture[38]. The other form of data is the case study of the SFMoMA in Volume B.

In order to ensure the integrity and relevance of a web-accessible qc reality test in lighting, this database will therefore be founded on empirical and analytical data for test cells, and expanded with Masters' 'behaviour' data. To remain relevant it must include an increasing number of buildings that have been subjected to the test and have been made web-accessible. The one-off simulations of my Digital Craft class illustrated on the www.aecsimqa.net web site (see **Figure 9**) cannot therefore be anything other than illustrative at present. Whilst as digital models of real art gallery buildings these meet half the requisite qualifying criteria, they have not been subjected to the qc test, so do not qualify.

What is required for this web-accessible database system to work is an automated means for ebuildings that have been qc tested to be submitted to www.aecsimqa.net.. Development of a reliable mechanism for this submission is I believe more a Computer Science than a Building Science problem. Individually refereeing every submission would not permit the database to grow quickly enough to ever make it useful. What is required is some form of user-based quality control system like the cddb referred to on page 8.

My working hypothesis for this aspect of the ongoing work is "that it is possible to create a web accessible database of building performance data where the votes of the users of the database create a live reliability indicator for the data integrity." One would obviously need to provide tools for people to observe trends in the available data so 'outliers' could be readily identified. One would need to provide means of 'normalising' the data so that differences in climate, occupancy and size did not mask trends. One might also rank the reliability votes in terms of the origin of the data.

For example, if one were adding to the database more results from use of Maamari's analytical tests to evaluate a particular rendering program might be used not only for qc in digital lighting simulation, but could also be used in promoting the program, then one would rank results submitted by the program developers as only 10% of the value as a vote for integrity as results submitted by a country's national research laboratory. One would also rank results for two buildings of similar type in similar climate from the same simulationist as only half the value of results for two buildings of similar type in similar climate from two different simulationists.

12-3.2 a qc thermal reality test

For the thermal test a complete simulation set was created for the BESTEST[39] building test sets.

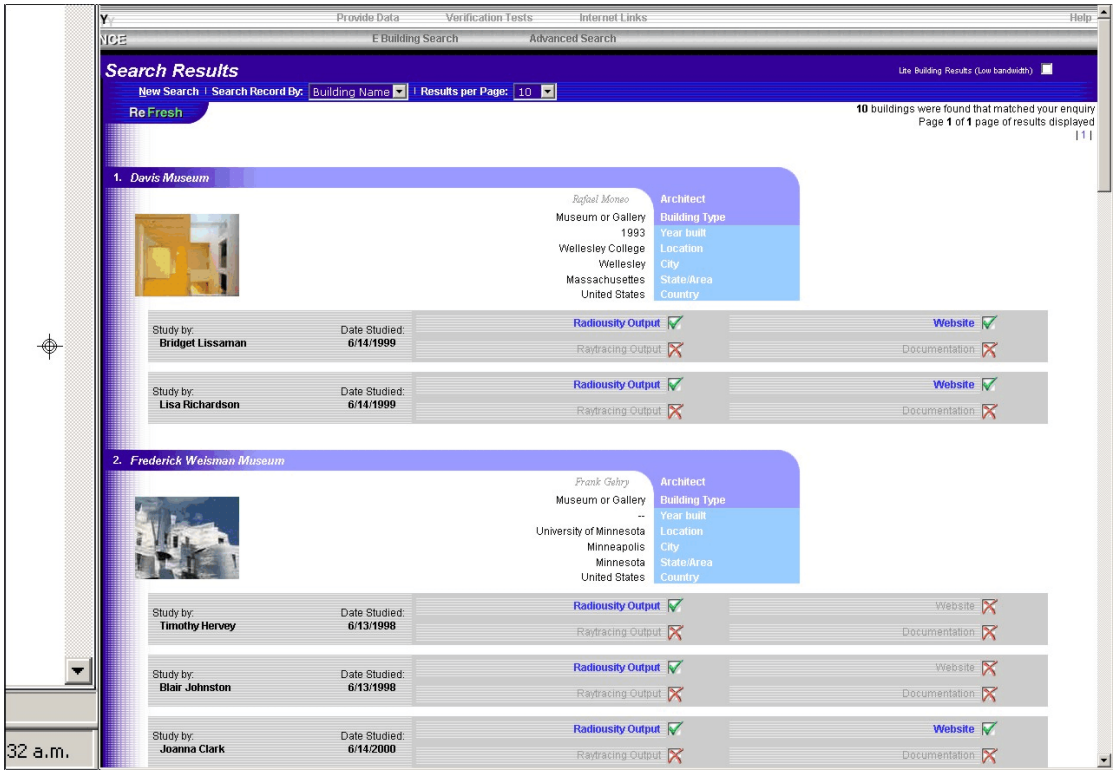


Figure 9 Screen capture of www.aecsimqa.net web site Daylit Museum search

These are essentially single room test cells that have been devised to evaluate building simulation programs. Ideally, there would be an even earlier first step which is to create some ebuilding simulation models which replicate real test cells for which monitored data is available.

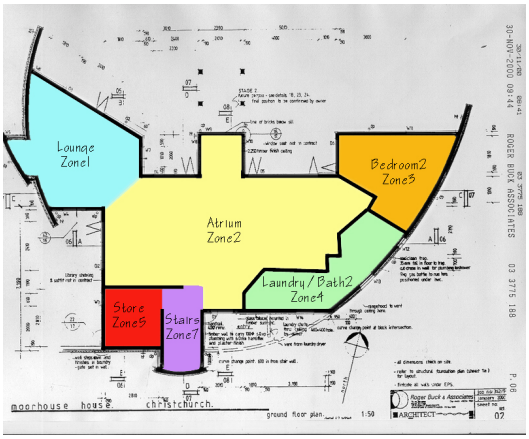


Figure 10 Ground floor of Moor house - Architect Roger Buck

Figure 11 'Eco' House, Wellington - Architects: Red Design

The simulation set was created by two independent people. Once the thermal simulation program had been calibrated against these 'measured' BESTEST data points, it was possible to compare how well it modelled design "changes" from one test cell to the next. There were only a few of these monitored "behaviours" against which to compare the simulations. The next step was to simulate a lot more design changes (doubling and halving window size, and insulation levels and amounts of mass in the building). These then formed the basis for a first exploration of the automated "reality" test: two real solar houses were modelled with the matching design changes and then these simulated "behaviours" were compared to the standardised behaviours established by the test cell simulations and measurements.

Once the model was found to fall into the acceptable range of output established by the other reference programs, the model could be thought of as 'real'. A virtual model was then sought in order to compare against the 'real model'. One research assistant used 'the Moor house' in Christchurch designed by architect Roger Buck. This house conforms to all standard solar design strategies and a very high proportion of its structure is thermal mass. The other used the so-called 'Eco House' in Wellington, designed by Red Design.

Once both spaces were modelled carefully, standard changes were performed to both models and the output was compared. The Moor house was compared to the BESTEST heavy weight Case 900 ebuilding. As the test cell with the largest amount of concrete in its construction it was the BESTEST test cell closest in design to the Moor house. The following table shows the basic environmental design parameters of the two ebuildings:

SITE	BESTEST model	Moor House
Longitude	104.9 degrees West	172.6 degrees East
Latitude	39.8 degrees North	-43 degrees South
Altitude	1609m	<100m
Shading	Flat unobstructed	Flat unobstructed
Ground Temperature	- 10C	Summer - 17.3C Winter - 7.6C
Ground Reflectivity	0.2	0.2
STRUCTURE		
Floor area	48m2	161m2
Wall height	2.7m	2.7m
Wall construction	100mm concrete block R - 1.537 insulation	100 - 190mm concrete block 12mm gypsum plaster finish to interior 40mm - 60mm XPS insulation to exterior walls Brick exterior finish to south curved walls
Floor construction	80mm concrete floor slab R - 25.175 floor insulation	200mm concrete floor slab Clay tiles to all flooring 50mm EPS insulation"
Roof construction	10mm plasterboard ceiling R - 2.794 fibreglass quilt Two windows on South wall 2 x 6m2	200mm insulform blocks to roof

To compare the results, some of these parameters had to be made the same in the two models. These were:

- Longitude, latitude values
- Orientation (exterior surfaces)
- Weather file
- Infiltration rate (ACH)
- Ground temperature, reflectivity
- Terrain and shield class values

A total of eight tests were developed. For the Moor house study they looked like this:

TEST	BESTEST model	Moor House
Total thermal mass volume doubled	Concrete block walls: 100mm to 200mm Concrete floor slab: 80mm to 160mm,	Concrete block walls: 190mm to 380mm, 140mm to 280mm Concrete floor slabs: 200mm to 400mm, 150mm to 300mm Concrete ceilings: 150mm to 300mm, 100mm to 200mm.
Total thermal mass volume halved	Concrete block walls: 100mm to 50mm. Concrete floor slab: 80mm to 40mm,	Concrete block walls: 190mm to 95mm, 140mm to 70mm Concrete floor slabs: 200mm to 100mm, 150mm to 75mm Concrete ceilings: 150mm to 75mm, 100mm to 50mm.
Total window area doubled	$12m^2$ to $24m^2$ (NB: to achieve this, the model geometry was increased slightly: North and south facing walls increased from 8m to 9m in length and floor and roof dimensions were adjusted accordingly).	$78.16m^2$ to $156.32m^2$
Total window area halved	$12m^2$ to $6m^2$	$78.16m^2$ to $39.08m^2$
Air infiltration increased	to 5	to 5
Air infiltration Decreased	to 0.25	to 0.25
Insulation R-value doubled Wall Floor Roof	 R-1.537 to R-3.074, R-25.175 to R-50.35, R-2.794 to R-5.588.	 R-2.1 to R-4.2, R-1.75 to R-3.5 R-1.4 to R-2.8 R-3.2 to R-6.4.
Insulation R- values halved Wall Floor Roof	 R-1.537 to R-0.7685, R-25.175 to R-0.38425, R-2.794 to R-1.397	 (Exterior) R-2.1 to R- 1.05, R-1.75 to R- 0.875, R-1.4 to R-0.7 R-3.2 to R-1.6.

Figure 12 shows the effect of doubling the mass on total energy use of the two buildings.

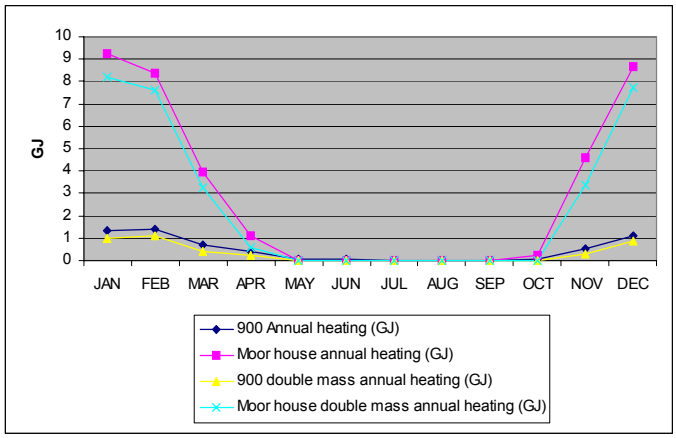


Figure 12 Graph showing the effect of doubling the thermal storage 'mass' in the test cell and the Moor house

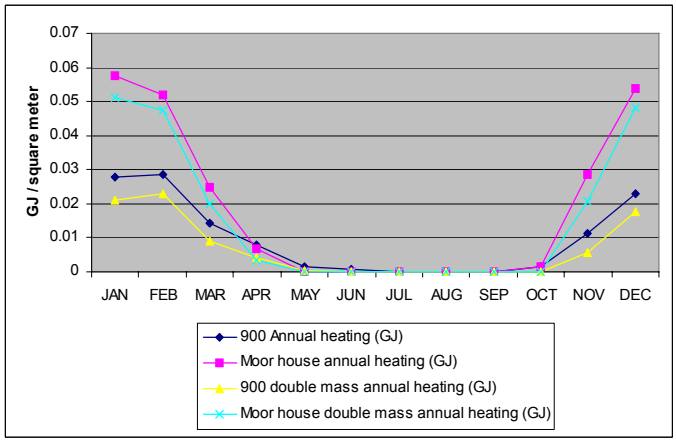


Figure 13 Monthly energy use per square metre for standard and double mass versions of test cell and Moor house ebuildings

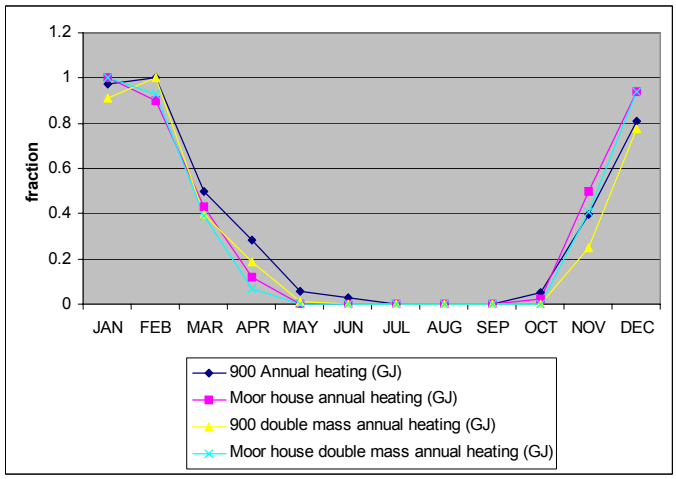


Figure 14 Monthly energy use as a fraction of the highest month's energy use for standard and double mass ebuildings

normalising the data to facilitate comparison

Comparing these results merely reveals that the Moor house is much bigger than the test cell. Some form of normalisation is required to enable the effects to be compared simply between the two very different sizes of ebuilding. The two graphs immediately following **Figure 12** show alternative normalisation approaches to analysis of the data in **Figure 12**.

Figure 15 is the closest of the sequence above to a depiction of the likely form of the QC reality test because it graphs the differences in energy use between the standard and the double thermal mass versions of the two ebuildings. Similarity in the line traces is present in all these graphs. However, there is still a huge amount of development work to be done to evaluate the most appropriate normalising factor and to determine how close the line traces should be to confirm 'reality'. Another approach commonly tried in comparative studies is dividing the energy use by the total floor area (**Figure 13**) is of no great benefit in this exercise.

Normalising of free floating temperatures is also necessary. Comparing changes in temperatures rather than in energy use is an equally valid means of evaluating performance. However, dividing internal temperature by floor area serves no useful "scaling" purpose. Subtracting each average

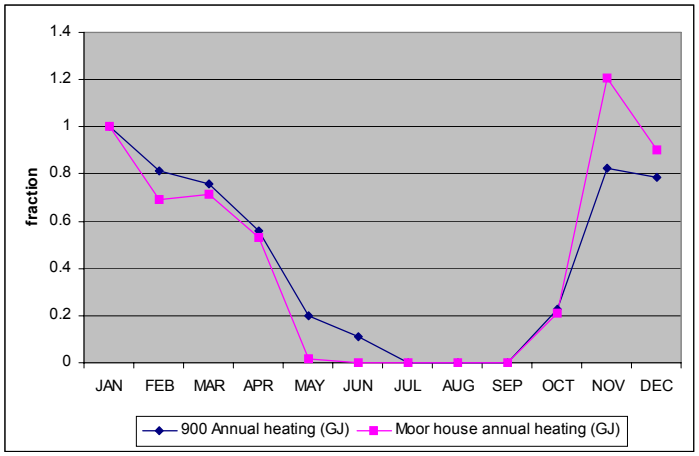


Figure 15 Difference between standard and double mass ebuildings' energy use per month as a fraction of the difference for January

monthly temperature of the double mass option from each monthly temperature for the standard option is a measure of the effect on temperature of mass, but possibly not useful for comparisons between ebuildings. It may well be better to compare the average difference between maximum and minimum temperature over each month with the changes in this as the building design changes.

12-3.3 a qa process in practice

The following paragraphs summarise a simple QA process in a set of simulation studies for the Cement and Concrete Association of New Zealand and for Standards New Zealand. **Figure 16** shows the building whose performance was documented by a digital simulation program in order to develop a text-based eddst - **Designing Comfortable Homes**[40]. The simulations follow a stylised pattern of low, medium and high 'levels' of Insulation, Glass (area) and Mass (total amount of thermal storage in concrete construction materials). In all, this made 9 ebuildings for each of 3

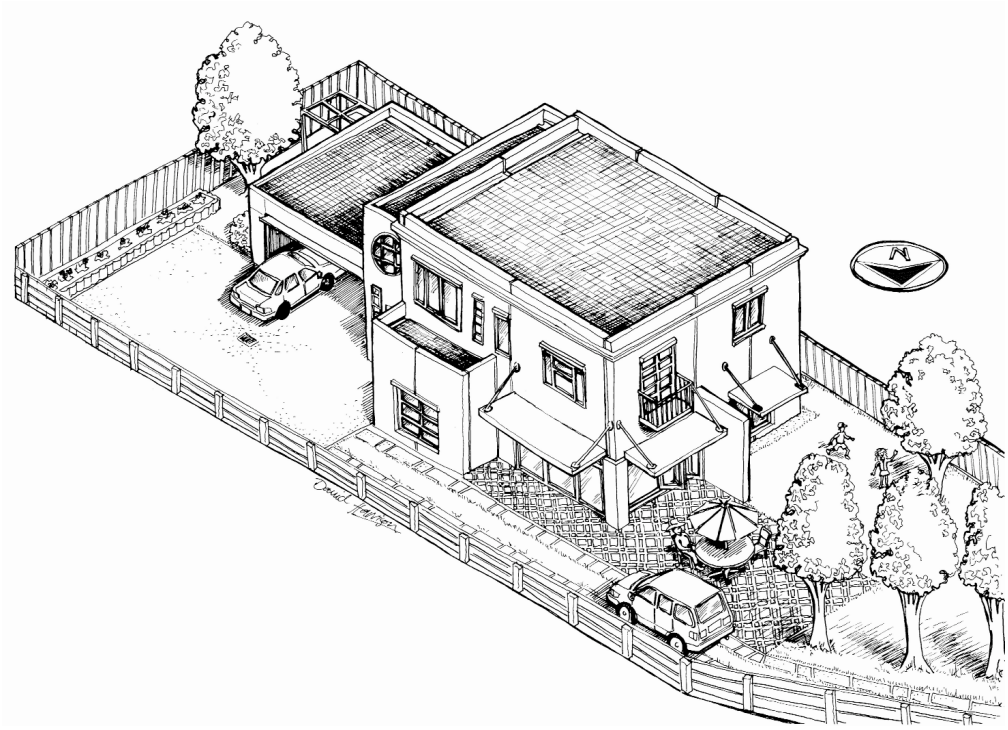


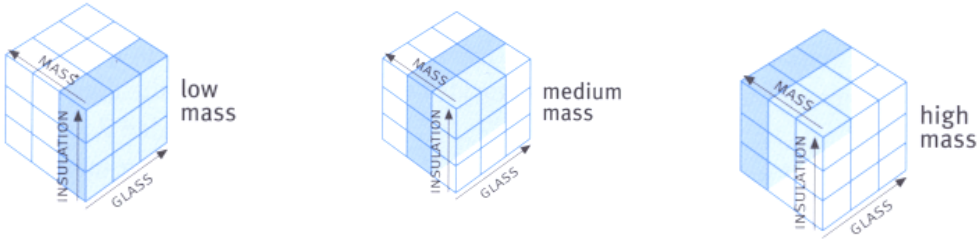
Figure 16 CCANZ 2 Storey House used as basis for development of text based passive solar design tool: ***Designing Comfortable Homes***

locations: 27 simulations.

AUCKLAND Best Practice: High mass/ high insulation			Rsi	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Rso	Total R Value	
Walls	Exterior	200 series concrete block + 60mm eps to exterior		cement plaster	concrete block all filled	60eps	cement plaster				
			0.09	0.01	0.13	1.70	0.01		0.03	**1.97**	Total exter walls
	Interior	100mm conc interior walls with paint finish		concrete							
			0.09	0.07					0.03	**0.19**	Total inter wall
Floors	Ground	Concrete 100mm slab with 50mm area eps and carpet		carpet	concrete	50eps area					
		Slab 90% to 1m earth	0.09	0.21	1.40	1.40			0.03		
		Footing 10% to ambient	0.09	0.21	1.40	1.40			0.03	**3.13**	Total ground floor
	Intermediate	Unispan concrete 75+90mm with carpet		carpet	unispan concrete						
			0.09	0.21	0.11				0.03	**0.44**	Total second floor
Roof	Skillion roof	200mm rafter		gib	190mm pink batts	airgap	rafters	longrun steel			
		Structure 20%	0.09	0.06		0.00	1.54	0.0004	0.03		
		Cavity 80%	0.09	0.06	5.00	0.15		0.0004	0.03	**4.60**	Total roof
Glazing	R = 0.31	(Al TB Al IGU)		system							Total windows
	SuNREL file	ALTBDOUBLECLEAR	0.10	0.18					0.03	**0.31**	
				5.56							Total area total R Value

Example Spreadsheet from a CBPR Quality Assurance exercise: R_{SO} and R_{SI} represent respectively the Outside and Inside surface resistances.

The table above illustrates part of the QA process for the development of **Designing Comfortable Homes**. It illustrates the type of careful building documentation that is necessary in any systematic digital simulation study. The proposed QA web site will publish standard checklist versions of this in order to encourage the development of an international agreed minimum documentation of eddst simulations.



Low Mass building: First set of graphs presents energy use, comfort scores for each combination of low medium and high Insulation and Glass.

Medium Mass building: This set of graphs presents energy use, comfort scores for each combination of low medium and high Insulation and Glass.

High Mass building: This set of graphs presents energy use, comfort scores for each combination of low medium and high Insulation and Glass.

Figure 18: 3D Graph of the stylised pattern of low medium and high 'levels' of Insulation, Glass and Mass.

The eddst text itself follows the classic pattern: it contains a number of graphs of likely building energy performance costs and benefits for set combinations of Glass in the Windows; Thermal Storage (Mass) in the Walls and Floor; and overall Thermal Insulation. A further set of simulations were performed for the single storey building shown in **Figure 17**. What is interesting about these simulations is that they follow the pattern advocated for the development of the QC "reality" test: they are systematic variations where, within the realms of practical construction the environmental

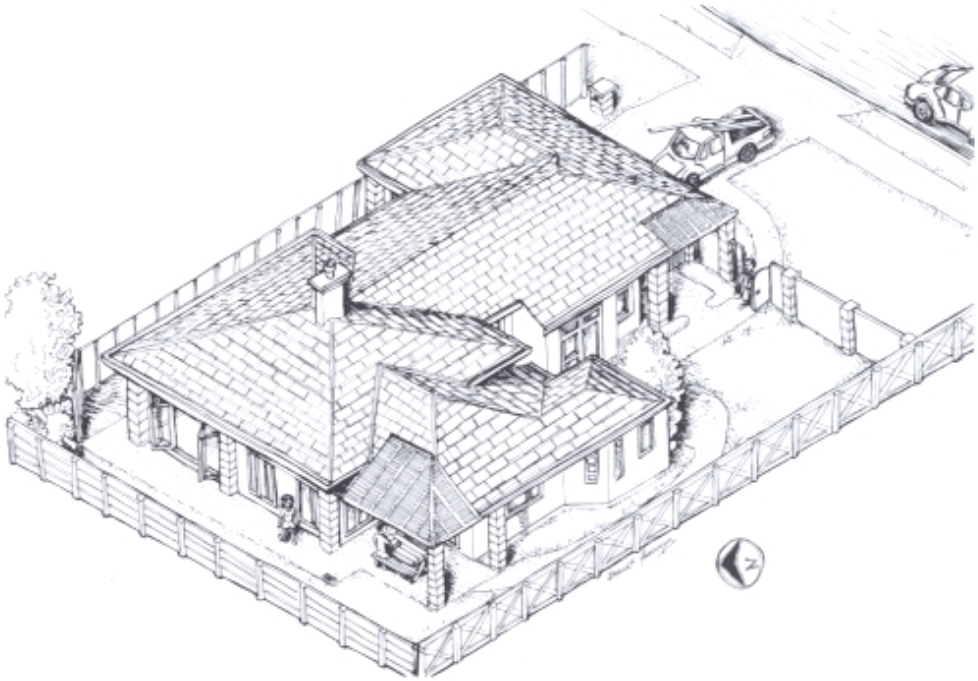


Figure 17 CCANZ One Storey House used to supplement 2 storey house results in development of text based passive solar design tool: ***Designing Comfortable Homes***

design parameters are made larger and smaller.

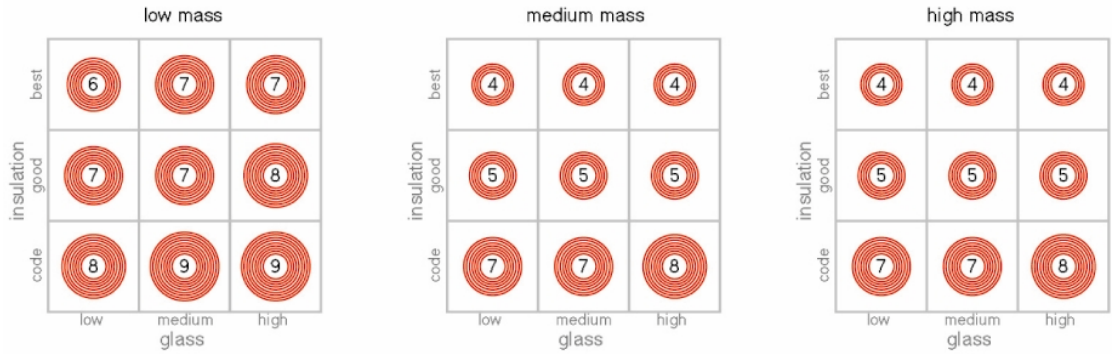


Figure 20 Size of heater in Wellington

The results of that systematic variation are presented in the book as a series of graphs. The annual energy use (**Figure 18**); the hours of over and under heating (**Figure 19**); and the heater size (**Figure 20**), for the three 'slices' of the 3D graphs - the three stylised low/medium/high levels of Insulation and Glass for each Mass level.

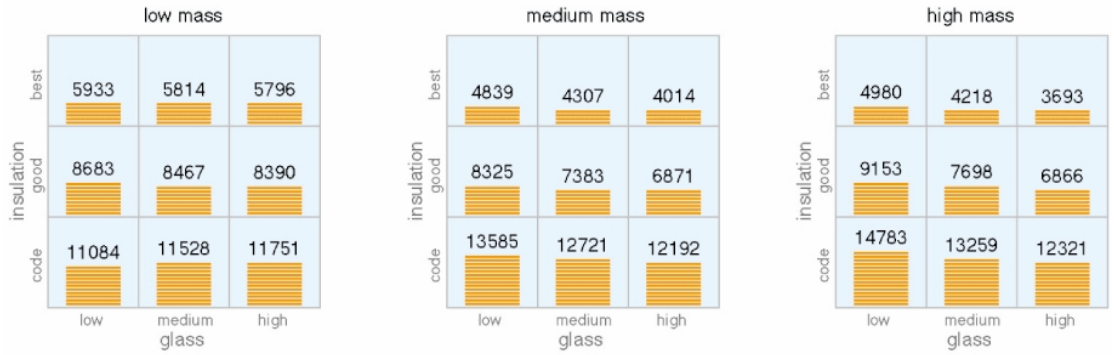


Figure 18 Annual Energy Use for various combinations of Insulation, Glass and Mass in Wellington

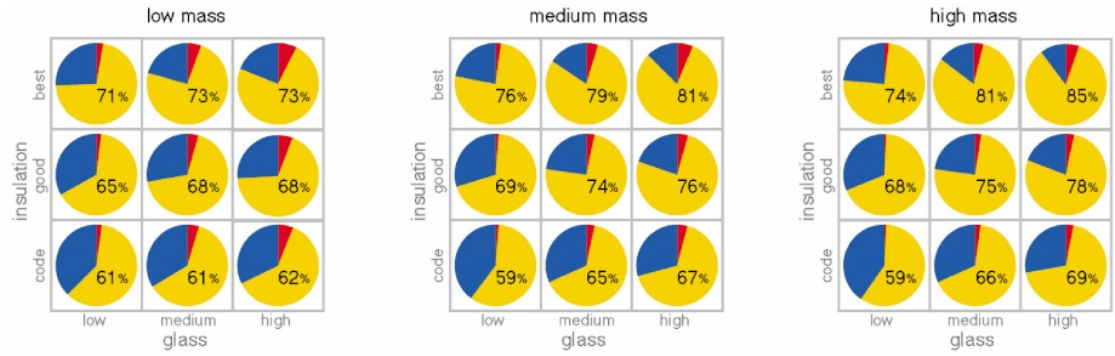


Figure 19 Hours of Overheating (red) and Underheating (blue) in Wellington - no HVAC system installed

Parametric variations like this are exactly what the QC reality test is intended to have. However, these results will not be presented in this manner when incorporated into the QC test. For example: what is not of interest in the QC reality test is the total number of hours per year that a building is acceptably comfortable because it "floats" between an overheating and an underheating set point

(**Figure 19**); rather, what is of interest is the relative size of the change in this total as the building design changes. Thus, what is of interest is that the "Low Mass" building with high levels of glass changes from being in this 'comfort' range 62% of the year for code insulation, to 68% of the year for the 'good' insulation level defined in Designing Comfortable Homes.

As soon as we start to make these types of comparisons, we are left again with a need to normalise the data. Part of the future work for this project will be to complete a systematic evaluation of the best options for normalising the presentation of the data.

12-3.4 the reality test?

Based on experience of the thermal and the lighting pilot projects, the focus for future research into lighting and thermal performance behaviours should be on determining standardised measures of performance. This is even more important than establishing the appropriate set of tests themselves. For example, in thermal performance we need a means of standardising the energy use measure (energy use per square metre is not adequate) to account for size. We also need a means of standardising the behaviours, the energy use changes, to account for reasonable differences in a building design but expose any similarities or differences in the measures of behaviour that we consider a measure of "reality". The daylighting study showed similar scaling problems are likely. The exploratory research project was performed under overcast skies to establish as general a distribution as possible. This enabled the measurement of a dimensionless Daylight Factor (DF) ratio between inside and outside. Changes in light level became changes in DF. That research project determined that there are still questions remaining as to whether any further scaling might be needed to account for questions like room height to depth ratios and other building features that measure the relative significance of the reflections off the walls in the overall light distribution.

Figure 21 contains a proposed hierarchy of tests that future research will have to develop in order to create the required SimQA reality test suite. It starts with the types of analytical tests used in software validation exercises such as those developed in the IEA Task 12 BESTEST and the IEA Task 31 Render tests. In the final structure of the SimQA reality test, each ebuilding reality test lower in the hierarchy has to be calibrated against the test above it. It acquires the status of another standard of "reality" if its environmental behaviour as measured by changes in performance with changes in design is consistent with the behaviour documented for the ebuilding above it.

The plan is to determine behaviours that are "real" for the simple monitored data. Then build more and more complex e-buildings using these monitored e-buildings as calibration data. Only those wishing completing all tests can submit their building as a 'Reality Standard'.

12-4 *gedanken experiment - testing the qa idea*

The next step in formulating a web-based proposal of this type is to test it. Again, following Burner-Lee's approach, applying a set of principles in a thought (gedanken) experiment is adopted as the means of testing this idea. The approach systematically examines the proposal as a web technology,

using a series of tests drawn from the ideas presented by Berners-Lee on the W3 consortium web site[41]. The tests in particular focus on the issues raised by the idea of a database which is to be accessed more often by automated software than by software operated by people. This is an application of the principles of *the semantic web*[42]*:*

> The Web was designed as an information space, with the goal that it should be useful not only for human-human communication, but also that machines would be able to participate and help. One of the major obstacles to this has been the fact that most information on the Web is designed for human consumption, and even if it was derived from a database with well defined meanings (in at least some terms) for its columns, that the structure of the data is not evident to a robot browsing the web. Leaving aside the artificial intelligence problem of training machines to behave like people, the Semantic Web approach instead develops languages for expressing information in a machine processable form."

In the world of building performance, what is required is a store of data that can be drawn upon by building performance analysis programs around the world. A central repository provides the pointers to the myriad locations of the actual data. That data is machine readable, and the pointers are machine-readable, when a user places a particular type of request.

The following headings are drawn directly from Berners-Lee's paper on *Principles of Design*[43]:

Level	**Scale**	**Analytical tests**	**Empirical tests**
Basic software validation and user calibration. *INDEPENDENT of any other tests.*	Test cells.. 2 cell variants..	Many tests abound. With each, the important documentation is data to help user software to match performance of its "exemplar" buildings with the 'truth' calculated analytically.	
Base level SimQA test. *INDEPENDENT of any other tests.*	Test cell 2 cell variants		Some data sets exist. Key is to identify those which create an hierarchy of building performance. Goal is to document simple design steps from one case to the next, permitting identification of simple performance steps to be used as 'standards' against which to compare 'real' buildings.
"Reality Standards" ***MATCHED where possible to relevant tests further up the hierarchy.*** *Full range of analytical and empirical tests must be completed for a cell to acquire this status.*	Real buildings, monitored data..	Some tests may be available to permit as full as possible an evaluation of the suitability of an ebuilding for acquiring status as a published basis for a reality test. This requires the building to be monitored in a strangely analytical manner: e.g. in daylight, measurements in a completely black room with a single window on an overcast day. *Matching is against single analytical "truth" cases.*	Not only measured data is sought here, but documentation of measurements of performance changes as a result design changes. Some tests may be available to permit a full evaluation of the suitability of an ebuilding for acquiring status as a published basis for a reality test. *Matching would be against measured performance changes given changes in test cell designs.*

Figure 21 Hierarchy of tests forming the proposed SimQA 'reality test'

12-4.1 evolvability

> By "data" as opposed to "documents", I am talking about information on the Web in a form specifically to aid automated processing rather than human browsing. "Data" is characterised by information with a well defined structure, where the atomic parts have well defined types, such as numbers and choices from finite sets. "Data", as in a relational database, normally has well defined meaning which has rarely been written down. When someone creates a new database, they have to give the data type of each column, but don't have to explain what the field name actually means in any way. So there is a well defined semantics but not one which can be accessed. In fact, the only time you tells (sic) the machine anything about the semantics is when you define which two columns of different tables are equivalent in some way, so that they can be used for example as the basis for joining the two databases. [44]

The central issue here is that the design of the Building Performance Database is such that it can **evolve**. Evolution means:

i. that any new type of analytical document can be added: in the structure outlined above there is no restriction on a new simulation program's data type being used as the format for a new file stored on the web. The pointer in the central repository will find it. The more limiting classification system adopted to aid the machine search for building performance data (Level 1, 2 3 etc..) is extensible. Should other types of data be added at Level 3 for example, then one needs only to add another class to this list. There is nothing precious about the list, so long as the classifications of data within it do not change. Search engines with wild card searches could find all the buildings matching only one of the specified Levels, or just the buildings which match criteria with specified values for each Level.

ii. that the number of Levels in the classification system for finding data can be increased: while it would be difficult to maintain interoperability if some levels were to disappear altogether, adding Levels would not stop the search system from working.

iii. that the system should survive the birth and death of new internet technologies: nothing in the above definitions is dependent on a particular web browser or on a particular internet data format. The data files could be ASCII, binary, movie files, simulation program binary files - anything. All that the system guarantees is that they will be found.

iv. that the system should survive the birth and death of new computer software: Some data files which are input files for particular analysis programs will go out of date as the programs are updated or made obsolete by new developments. However, nothing in the above definitions is dependent on a particular analysis program format.

12-4.2 metadata

> What makes a cool URI?
>
> A cool URI is one which does not change.
>
> What sorts of URI change?
>
> URI's don't change: people change them.[45]

The key to maintaining reliable access to data is to develop an understandable, long term and unambiguous naming convention. The W3 consortium is encouraging people to develop web sites which do not change location on the web over time. Access restrictions may vary from hour to hour as files move from restricted internal drafts to fully unrestricted distribution final copies. Type of file may vary from year to year as the web technology varies. What is essential in all file naming on the web is that the document can be found in the same place this year as it was when last accessed five years ago. It may have been updated annually, but its location on the web is clear.

The key to all this is **Metadata**[46] - machine readable data about data. The central repository of information about building performance data is metadata. It is itself data and hence is as amenable to being manipulated, referenced and analysed as the basic data. In digital signatures in documents and graphics the metadata is the signature - it is distributed with the file. In the proposed building performance analysis database such additional data might be added to files if there was a concern about proprietary information. Normally however, the data describing the data would be held separately in the central repository.

> Metadata consists of assertions about data, and such assertions typically, when represented in computer systems, take the form of a name or type of assertion and a set of parameters, just as in the natural language a sentence takes the form of a verb and a subject, an object and various clauses.[47]

The information in Appendix N is extracted directly from the W3 consortium discussion paper on metadata. It describes the various levels at which machine readability might be achieved. The central repository of access data is in this scheme, exactly what is described by this paper. It seems that use of the XML "language" for the packaging of as much of the data as possible provides an added evolvability advantage. It provides a standardised system of self-documenting of the data format: at the top of each XML document is a pointer to the schema for the document. This effectively defines how machine reading will occur. Style sheets will define how the data is to be presented in readable form for people.

12-4.3 common syntax for structured documents: XML

> An examination of the needs for evolution of technology in a distributed community of developers shows that the language must have certain features:
>
> i) It must be possible to precisely define a language (the set of tokens, grammar, and semantics) as a first class object; ii) It must be possible to make documents in a mixture of languages (language mixing) iii) Every document should be self-defining by carrying the URI(s) of the language(s) in which it is written; iv) It must be possible to process a document understanding a subset of the languages (partial understanding).[48]

From reading this set of goals for XML as defined for the W3 Consortium, it seems that adoption of XML for the structured documents describing building performance will answer many of the potential problems associated with building performance documentation. It allows for mixing CAD and thermal simulation files in the one "document" describing a building's performance. Note: a first class object is one that can be identified by its name - its name is its Universal Resource Indicator (URI)[49].

12-4.4 simplicity

Simplicity of design of schema leads to reduction in potential for error, even though the expression of that simplicity may make data quite difficult to read at first. The above schema has very few classifications. It attempts to work at the broad level where large differences in building performance may be expected. Thus, while there may be differences in building performance in an individual country between towns, the fact that the whole country has a Temperate climate is what is seen to be important from the point of view of thermal performance analysis. Similarly, building type has a strong effect on thermal or lighting performance. But there will be little point served by creating a

database that differentiates between clothing and book stores in this classification because the buildings found will be quite similar in performance.

12-4.5 modular design

The key to modular design is the simplicity of the interconnection of the modules. Unless each individual module can be understood and worked on independently there is no advantage to dividing a system into pieces. The advantage of the modularity is that each individual module can be upgraded without affecting the others, allowing for incremental improvement in design and for smaller design or maintenance teams. The modules of the Building Performance Database are: i) specification of the local data storage protocols for the recording of each building's performance; ii) specification of each of the levels in the central repository classification of the building performance data; iii) the use of internet technologies for the communication between the database, each building's data and the users of the information.

12-4.6 tolerance

Be liberal in what you require but conservative in what you do[50]

As shown by the proliferation of non-standard HTTP which has led to web pages that can be read by one web browser and not by another, this principle has an inherent weakness: it can encourage a too liberal attitude on the part of the creators of building performance datasets. It still provides an essential guideline. Unless the system is tolerant of various ways in which files can be stored and delivered it will not work. It must be possible, for example, to store data as ASCII[51] or Binary a DOE2 file. Or, for a 3D CAD file of a building's geometry to be in one of the many different proprietary formats for Computer Aided Design programs.

There will inevitably be looseness in the characterisation of buildings into types and in the classification of the analysis available. Even when a universally accepted Building Product Model[52] exists, it will still be important to have the other building descriptions able to be stored and accessed. It should never be necessary to store only one building description such as a particular building product model format in order to use the Building Performance Database even if data exchange would be more efficient for those buildings where such a format was available.

12-4.7 decentralisation

The proposed system is highly decentralised. It is possible, though not likely that each building would be described on a different computer. Once the system was running well, even the "Central Repository" would be mirrored in a number of locations around the world to improve responsiveness. There is nothing inherently anti the principle of decentralisation in having a single standard for classifying and locating data. This is merely the principle of the URI - the "Central Repository" is the Universal Resource that one uses to access Building Performance Data. It has a single unique Identifier on the web.

12-4.8 test of independent invention

If someone else had already invented your system, would theirs work with yours?[53]

Berners-Lee notes we may assume we will be smarter in the future and thus should ensure that we work by a principle that version 4 of our system should always be able to read the data from version 5, even if it misses some of it. He then points out we cannot assume we will be the smartest. Someone else may well devise a system that is even better. What is important and indeed, essential about the proposed database of building performance is that all its pieces could be re-used by other better or different systems:

1. In the same way that the CDINDEX is an alternative generator of a unique identifier for audio CD's to the CDDB system, a new or different building identifier could be created to generate basically the same system as is proposed here, but with perhaps a more robust building identifier.
2. All the individual web locations with building performance data on them will be able to be used by any number of analytical systems.
3. The data in the proposed "Central Repository" is also accessible. It could be used either as a key to the translation between the proposed system and an alternate. As Metadata, and hence data it could also be used as just another data reference in an alternate system.

12-4.9 principle of least power

The rationale for this principle in web design is that the less powerful you make the language in which data is stored, the more each individual can do with the data stored in the language. As this system will be using the languages of the web, and as it seems unlikely that building performance analysts will be devising many new languages for the storing of data, this point needs only to be mentioned for completeness. However, if a building product model was to be used as the language to store the performance data, then it would be necessary to re-examine this issue.

I leave to others at this point the decision about the relationship between Building Product Models and the W3 organisation's published work on a Resource Description Framework (RDF) for Metadata[54,55].

12-5 *conclusion - putting qa pieces together*

This thesis concludes with a set of pictures illustrating the building blocks of a basic QA process in simulation. It shows how elegantly the XML[56] system separates the **content** of the SuNREL thermal simulation program input file (**Figure 22**)from its **presentation** with the use of a **data model** expressed as metadata in XML syntax in a DTD[57] file (**Figure 24**). Presentation of the content in a human-readable web page format or indeed any other format using an XSL[58] style sheet is routine. The XML content shown in standard SuNREL format could easily be written out by an automated XSLT process. In fact, given the power of XSLT(ransformation)s, style sheets can be used to transform data in one XML file format into another by relating the DTD's. With this approach, and the naming conventions that already exist on the web, all that is needed at present to establish a QA lookup system for the SuNREL program is a single working web site where such DTD metadata can

be found and hence referenced by all computers that wish to "understand" SuNREL thermal simulation data in XML format.

12-5.1 the semantic web

During the period of writing this thesis the concept of the semantic web has been suggested, debated, vilified and morphed into a range of possible technologies. In particular, the Semantic Web itself has gained some further credibility and a proposed operational form: "web services" [59]:

> The term Web services describes a standardized way of integrating Web-based applications using the XML, SOAP, WSDL and UDDI open standards over an Internet protocol backbone. XML is used to tag the data, SOAP is used to transfer the data, WSDL is used for describing the services available and UDDI is used for listing what services are available. Used primarily as a means for businesses to communicate with each other and with clients, Web services allow organizations to communicate data without intimate knowledge of each other's IT systems behind the firewall.
>
> Unlike traditional client/server models, such as a Web server/Web page system, Web services do not provide the user with a GUI. Web services instead share business logic, data and processes through a programmatic interface across a network. The applications interface, not the users. Developers can then add the Web service to a GUI (such as a Web page or an executable program) to offer specific functionality to users.
>
> Web services allow different applications from different sources to communicate with each other without time-consuming custom coding, and because all communication is in XML, Web services are not tied to any one operating system or programming language. For example, Java can talk with Perl, Windows applications can talk with UNIX applications.
>
> Web services do not require the use of browsers or HTML.
>
> Web services are sometimes called application services.

Web services make applications available over the Internet. One application of this technology posits a future where one might buy a web services enabled eddst very cheaply and have to be on-line all the time to run it because every time one wanted to use a never-before-used function in the program one would pay the vendor via the internet for the added service to be installed. The approach would use the internet TCP/IP protocols for the exchange of information but would not need web browsers like Netscape or Internet Explorer to function.

While not ruling out this possibility, the Simulation QA (SimQA) approach uses Web Services via an agent running in the eddst simulation program. The agent sends a request to a program running on another server (a web service) and uses that program's response to assist the QA process. The beauty of this approach is that the Simple Object Access Protocol (SOAP) lightweight XML-based messaging protocol used to encode the information in Web service requests and response messages are independent of any operating system or protocol. For example, they can be transferred as part of a Simple Mail Transfer Protocol (SMPT) email or a Hyper-Text Transfer Protocol[60] (HTTP) web page.

The SimQA web service described in this chapter is not a database. It is a database of databases. An eddst will generate a request to the web service for, say, an acoustic simulation of a primary school auditorium for a school of 500 pupils. This is passed to the web service which looks in its database for matches in the SimQA databases it "knows" about. This match has to be fuzzy. There will be

some difficult logic to be developed in the web service that interprets how closely gymnasium, hall and auditorium might be matched in the context of a primary school. This might well be learned behaviour from the linking of these terms by many other people (the equivalent of the book-selling web site www.amazon.com where they offer prospective purchasers with a list entitled "Customers who bought this book also bought:" [61]. There will be easier logic in matching size (down to half and up to twice the size seems a good starting point).

Even with a simple protocol like SOAP, we need a means of finding web services. The Universal Description, Discovery and Integration[62] (UDDI) project is planned to be the definitive directory to services over the web. There is also a need to use the Web Services Description Language (WSDL) to describe a Web service's capabilities ". WSDL describes four critical pieces of data:

" Interface information describing all publicly available functions
Data type information for all message requests and message responses
Binding information about the transport protocol to be used
Address information for locating the specified service

In a nutshell, WSDL represents a contract between the service requester and the service provider, in much the same way that a Java interface represents a contract between client code and the actual Java object. The crucial difference is that WSDL is platform- and language-independent and is used primarily (although not exclusively) to describe SOAP services.[63]

With WSDL one can embed functions into software that are web services aware. The SimQA process can be automated, can find the relevant data and present it in the most appropriate format for the eddst user.

What is attractive about the XML format and is so elegantly demonstrated here, is that the structured database format of input data describing a building for a thermal (or lighting or acoustic or air flow) simulation program is so readily translated into the structured XML format. In fact, the tags which convey meaning in the XML version of the SuNREL file are based directly on the tags used in the actual SuNREL input file.

As noted above, the essential requirement of a computer program that performs the role of being the intelligent "agent" advising the designer about each step in the design process is that the agent / program understand the data it is working on. In the "semantic web"[64] " most databases in daily use are relational databases - databases with columns of information that relate to each other, such as the temperature, barometric pressure, and location entries in a weather database. The relationships between the columns are the semantics - the meaning - of the data. These data are ripe for publication as a semantic web page ... the Resource Description Framework (RDF) which... is based

```
Infiltration/Natural ventilation sample building

Created by: Michael Deru
Created on: 7/7/1998 4:49:55 PM
Last modified by: Michael Deru
Last modified on: 4/15/1999 1:04:29 AM

&RUNS
LABEL = 'Sample'
STATION = 'Boulder'
RSTRTMN = 'jan'
RSTOPMN = 'dec'
PARAM = 'default'
RUNITS = 'e'
DDTYPE = 'US'
GREFL = 0.3
GTEMP = 50.
RSTRTDY = 1
RSTOPDY = 31
/

&ZONES
ZONENAME = 'living',  'attic',  'sunroom'
ZAREA = 1500.0, 1500.0, 300.0
ZHGT = 8.0, 2.5, 8.0
ZONEZ = 0.0, 8.0, 0.0
ZACH = 0.0, 0.0, 0.0
ZLEAK = 25.0, 0.0, 0.0
SOL2AIR = 0.05, 0.0, 0.0
SOLLOST = 0.02, 0.0, 0.05
GAINSENS = 0.0, 0.0, 0.0
GAINLAT = 0.0, 0.0, 0.0
/

&INTERZONES
IZSRCZONE = 'sunroom'
IZSINKZONE = 'living'
IZSOLTRN = 0.1
IZREVTRN = 0.0
/

&WALLS
...

...etc
```

Figure 22 Sample first few lines from SuNREL building description file (aecsim.blg)

```
<?xml version='1.0'?>
<?xml:stylesheet type="text/xsl" href="sunrel.xsl"?>

<!DOCTYPE sunrel_web_page SYSTEM "sunrel.dtd">

<title>Infiltration/Natural ventilation sample building</title>

<Created-by> Michael Deru </Created-by>
<Created-on> 7/7/1998 4:49:55 PM</Created-on>
<Last-modified-by> Michael Deru </Last-modified-by>
<Last-modified-on> 4/15/1999 1:04:29 AM </Last-modified-on>

<LABEL>Sample</LABEL>
<STATION>Boulder</STATION>
<RSTRTMN>jan</RSTRTMN>
<RSTOPMN>dec</RSTOPMN>
<PARAM>default</PARAM>
<RUNITS>e</RUNITS>
<DDTYPE>US</DDTYPE>
<GREFL>0.3</GREFL>
<GTEMP>50.</GTEMP>
<RSTRTDY>1</RSTRTDY>
<RSTOPDY>31</RSTOPDY>

<ZONENAME>living</ZONENAME>
<ZAREA>1500.0</ZAREA>
<ZHGT>8.0</ZHGT>
<ZONEZ>0.0</ZONEZ>
<ZACH>0.0</ZACH>
<ZLEAK>25.0</ZLEAK>
<SOL2AIR>0.05</SOL2AIR>
<SOLLOST>0.02</SOLLOST>
<GAINSENS>0.0</GAINSENS>
<GAINLAT>0.0</GAINLAT>

<ZONENAME>attic</ZONENAME>
<ZAREA>1500.0</ZAREA>
<ZHGT>2.5</ZHGT>
<ZONEZ>8.0</ZONEZ>
<ZACH>0.0</ZACH>
<ZLEAK>0.0</ZLEAK>
<SOL2AIR>0.0</SOL2AIR>
<SOLLOST>0.0</SOLLOST>
<GAINSENS>0.0</GAINSENS>
<GAINLAT>0.0</GAINLAT>

..... etc
```

Figure 23 Sample first few lines from XML version of SuNREL building description file (aecsim.xml)

on XML ... allows computers to represent and share data just as HTML allows computer to represent and share hypertext. ... In fact it is just XML with some tips about which bits are data and how to find the meaning of the data. ”

```
<?xml version=~1.0~?>
<!ELEMENT    Building      (BlgName, Address, BlgType, SimData+, MonitorData+,
                           ClimData+, DesignerData+)>

<!ELEMENT    BlgName       (#PCDATA)>

<!ELEMENT    Address       (Street+, City, Region?, Country, PostalCode?)>
<!ELEMENT    Street        (#PCDATA)>
<!ELEMENT    City          (#PCDATA)>
<!ELEMENT    Region        (#PCDATA)>
<!ELEMENT    Country       (#PCDATA)>
<!ELEMENT    PostalCode    (#PCDATA)>

<!ELEMENT    BlgType       EMPTY>

<!ELEMENT    SimData       EMPTY>

<!ELEMENT    MonitorData   EMPTY>

<!ELEMENT    ClimData      EMPTY>

<!ELEMENT    DesignerData  (Designer?, HVACEngineer?, StructEngineer?, Owner?,
                           Builder?)>
<!ELEMENT    Designer      (#PCDATA)>
<!ELEMENT    HVACEngineer  (#PCDATA)>
<!ELEMENT    StructEngineer (#PCDATA)>
<!ELEMENT    Owner         (#PCDATA)>
<!ELEMENT    Builder       (#PCDATA)>

<!ATTLIST    BlgType  Type     ResidentialSmall| ResidentialGroup|
                               ResidentialLarge| ResidentialCommercial|
                               SchoolPrimary| SchoolSecondary| SchoolTertiary|
                               RetailSmall| RetailLarge| RetailFoodService|
                               OfficeSmall| OfficeLarge| Recreation|
                               GoodsStorage| Institutional|                    #REQUIRED
                          Area     CDATA              #IMPLIED
                          NumberFloors  CDATA         #IMPLIED
                          AreaOverVol   CDATA         #IMPLIED>

<!ATTLIST    SimData  BldgDesc ENTITY          #REQUIRED
                          SimProgram    CDATA          #REQUIRED
                          SimType  (Light?, Heat?, Sound?)
                          OperatingSys  NMTOKEN        #IMPLIED
                          Variants NMTOKEN          #IMPLIED>

<!ELEMENT    Light         (Illuminance| Luminance| Reflectivity| LuminousFlux|
                           Glare)>
<!ELEMENT    Illuminance   (#PCDATA)>
<!ELEMENT    Luminance     (#PCDATA)>
<!ELEMENT    Reflectivity  (#PCDATA)>
<!ELEMENT    LuminousFlux  (#PCDATA)>
<!ELEMENT    Glare         (#PCDATA)>

<!ELEMENT    Heat          (Temperature| Energy| Power| Reflectivity| Resistance|
                           HeatCapacity)>
<!ELEMENT    Temperature   (#PCDATA)>
<!ELEMENT    Energy        (#PCDATA)>
<!ELEMENT    Power         (#PCDATA)>
<!ELEMENT    Reflectivity  (#PCDATA)>
<!ELEMENT    Resistance    (#PCDATA)>
<!ELEMENT    HeatCapacity  (#PCDATA)>

<!ELEMENT    Sound         (Intensity| Power| Reflectivity| Transmissivity)>
<!ELEMENT    Intensity     (#PCDATA)>
<!ELEMENT    Reflectivity  (#PCDATA)>
<!ELEMENT    Transmissivity (#PCDATA)>
```

Figure 24 Sample first few lines from XML version of Metadata describing SuNREL building description file (aecsim.dtd)

The key with the *semantic* web in this proposal is that a document contains not only the data but the links or references to the places on the web where a computer program can find "how to convert each term in the document it doesn't understand into a term it does understand.." With the appropriate RDF's an XML document describing lighting performance measurements in an office building in Los Angeles might be used to create a realistic Radiance daylight simulation for San Diego this week; and next week it might form the basis of a DOE2 analysis of the impact of daylight on cooling equipment energy use in a Los Angeles doctors' surgery.

There are many advantages to this web based approach. The most obvious is the accessibility of the data. Instead of a single database with a single structure which requires many years of negotiation to define, each time a person sets up a new Quality tested file or measures a new building, it can be put on the web as another "data point". All that needs to be done "centrally' is provide a means of finding the data. This is where the concept of the Uniform Resource Identifier[65] is extremely significant. "The most common form of URI is the Web page address, which is a particular form or subset of URI called a Uniform Resource Locator (URL). A URI typically describes: a)The mechanism used to access the resource b)The specific computer that the resource is housed in c)The specific name of the resource (a file name) on the computer." What is required for buildings is a URI that adds to the URL or web address of the institution storing the building's performance data. As the technology matures, the UDDI specification will need to be used, but in the short term, an enhanced version of the familiar web browser URL may well be sufficient.

If each dataset is placed in Cyber space with its own built-in RDF definitions, in an XML language document, then useful searches by a pre-processor could be constructed such as: "find all the mild climate office buildings monitored in the past 10 years for which lighting measurement and energy consumption figures are available" '. The computing processes associated with this type of search is the subject of a recent Auckland University Computer Science Masters thesis[66]. It has shown a prototype of how such a search mechanism might be added to the prototype SimQA web site www.aecsimqa.net that has resulted from this thesis proposal. (See **Figure 9** on page 16).

A similar search concentrating only on buildings for which energy use data is stored might be used by the energy performance simulation post processor to find information to calibrate its predictions. The simulation package authors do not need to have done a complete analysis of the knowledge representation required to construct a computer-based "'product' model of a building" [67] and hence of the translation of their input data into that model format. Rather, they need to provide a link from the program user to the RDF for their program. Inference engines[68] developed by them or by others will provide the link to relevant data in other people's data formats.

To paraphrase Berners-Lee: machines can give the appearance of thinking by answering questions that cause it to follow the links in a large database. The database of relationships might be structured like: "a building is a thing, a house is a building, a door is a thing, a building has at least one door" . To create a useful database of this type is a huge task and typically "has room for only one

conceptual definition of a house" . The web defines only one page at a time, not a whole system. The goal of the semantic web is to allow different sites to have their own definition of "house" and to develop an "inference layer" to allow machines to link definitions. RDF's are the inference layer.

qa approach not limited to particular simulation programs

A major advantage of the semantic web application of this approach is in Berners-Lee's terms: "evolvability" . If an RDF exists for the input files for a program like DOE2[69], then when an old version encounters a file from a newer version it can look up the relevant RDF for the new version to find the parts of the new file it can "understand". The process of expanding the use of these QA tools then is one of evolution, and requires very little in the way of international or inter-disciplinary standardisation. It carries within it the RDF tools that permit adaptation and machine learning. written in the only part that needs to be standardised - XML.

A considerable advantage also arises from the XML/RDF split in the presentation of data - on the web or anywhere else. This is the reasoning - the rules that define the relationships between parts of a building are explicitly removed from the simulation program revealing the reasoning behind the analysis very clearly. This separation has benefits when seeking to apply a QA process in simulation.

documenting the context in eddst ebuilding documentation

The split between content and presentation also deals with an aspect of simulation that the new analyst often finds puzzling: determination of the appropriate external environment to "apply" in a simulation. Analysts continue to debate how to characterise the 'typical' external environment.[70] Is it an average day/week/year? What might the risk to the building owner or operator be if the normally expected variations around the average occur from year to year?

Stochastically valid risk analysis is essential in all Quality Assurance procedures related to building performance simulation. In an XML system the weather data for a thermal or lighting simulation would contain the RDF definition of the meaning of its terms. This would enable a different XML-aware simulation to translate the columns of weather information to a format compatible with its own views of the world. It would also mean that each weather file would contain synoptic information on how typical it was which could then be used by the simulation package to construct atypical weather scenarios.

A second and often-overlooked aspect of the external environment is the operational environment. The designer needs to know just how vulnerable the simulated performance will be to variations in the way we occupy or operate the building. If we no longer operate the building as we assumed it would be, what might the performance consequences be? XML format data on the energy performance of other real or simulated buildings would contain data about the data (Metadata) in the file. This would describe the context for the measurements and hence permit the XML front end of the simulation package to *infer* how "typical" the usage patterns are and hence how much they might

be tweaked to test how sensitive the simulation output is to realistic variations in the assumed usage patterns.

12-6 *the full qa process*

The focus in this chapter on the development of a QC reality test should not be read to imply that this is all that is necessary to create an appropriate and robust QA process. As the GUI's for digital simulation programs become easier to use, so it becomes more necessary that experienced simulationists begin to develop and publish international norms for the simulation of building performance. This would include the minimum content of an in-house checklist that documents the ebuilding construction and the digital simulation eddst modelling parameters. **Figure 25** and **Figure 26** show for Lighting and HVAC equipment respectively the database entry form for just such a QC checklist. www.aecsimqa.net is an ideal venue for the support of an international effort focussed on the eventual development of this database into an international documentation standard for simulation.

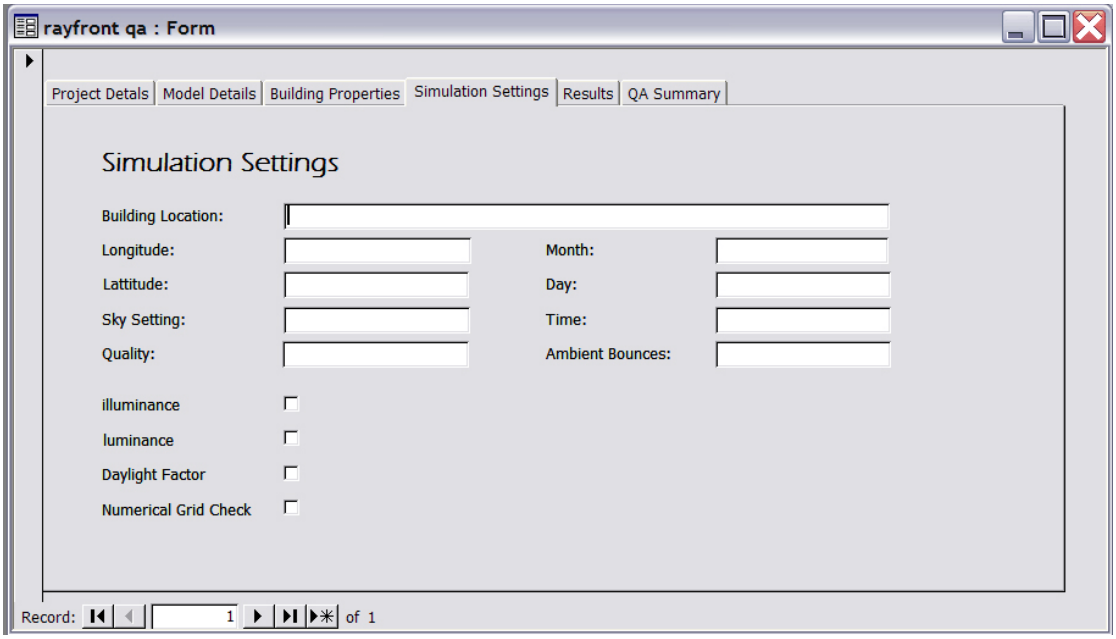


Figure 25 Database entry form devised by "Building Workshop Ltd" to document their lighting simulation service

12-6.1 the eddst 'holy grail': application early in design

Finally, the increased complexity of modern computer-based building performance simulation tools has not rid the design profession of its traditional problem with digital simulation based design tools: that they evaluate completed designs. The proposed web based database of ebuildings that have passed the 'reality test' has the potential to address this 'holy grail' of environmental design decision

support. It will do so by making web accessible to all designers a dataset of tested building designs and their associated performance measures. Guidance about how to move forward in improving a design typically only comes only from the informed user looking backwards at how their existing

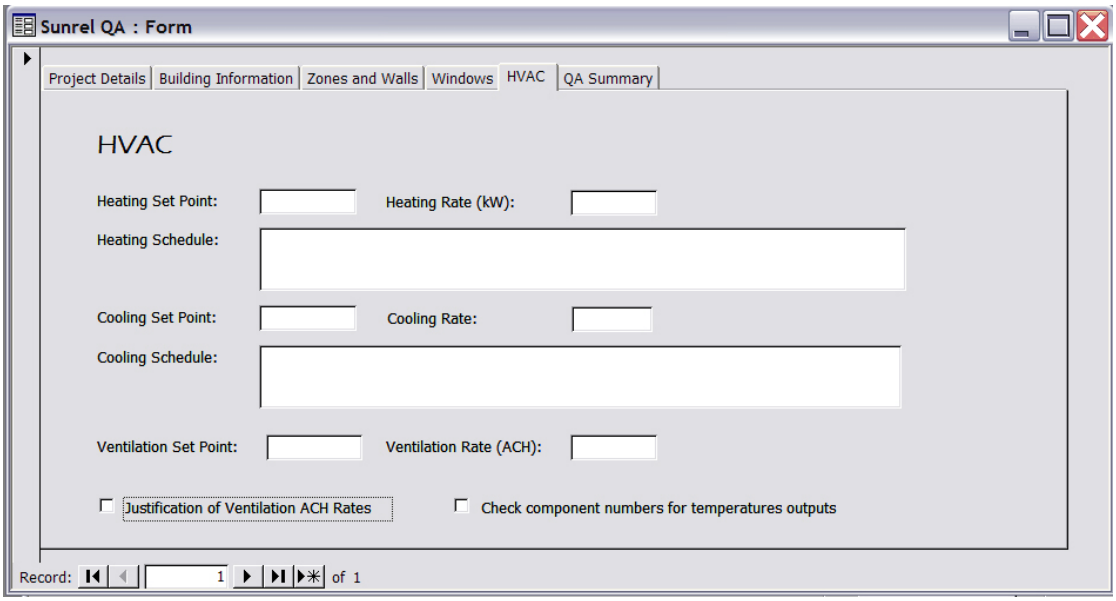


Figure 26 Database entry form devised by "Building Workshop Ltd" to document their HVAC simulation service

designs perform. An XML front end to a design process such as modelling a building in CAD would be able to look up Post Occupancy Evaluation (POE) contributions to the Internet database. It would also make available other people's calculations of the environmental performance of 'similar' buildings. This would place at the designer's fingertips a comprehensive set of data showing what might be expected of the current building design based upon its similarity to other buildings.

It might even be possible to generate initial design ideas that have a high likelihood of producing exciting and functional environments based on systematic study not merely of precedents in pretty pictures but of documented environmentally successful precedents!

12

Notes & References

1. Shengjiang, L. *Towards feature-based e-building matching in a Building Simulation Quality Assurance System.* Computer Science. Auckland, Auckland University**:** (2002). Pp140.

2. GUI (graphical user interface) A GUI (usually pronounced GOO-ee) is a graphical (rather than purely textual) user interface to a computer. ... The term came into existence because the first interactive user interfaces to computers were not graphical; they were text-and-keyboard oriented and usually consisted of commands you had to remember and computer responses that were infamously brief. Defined in: www.whatis.com/gui.htm Last accessed October, 1999.

3. Holloway, Marguerite **Patti**; Wired magazine, Dec 1997

   Agents *- small programs that do electronic tasks for their masters and that can, ideally, learn by watching their user's activities - have been dogged by hype for the past 20 years. The approach that AI researchers had generally used - the deliberative thinking paradigm - had not yielded serviceable autonomous agents, so the promise of the servile bots was never followed by the real thing.*

   Now, however, agents are finding their way into the world in large part because of [Patti] Maes's pioneering work. Her radical approach flew in the face of traditional knowledge-based AI research. This new generation of agents has found a niche as people flail around in information overload and crave personalized Web experiences - and as advertisers seek to reach out and touch just you and just you and just you, not just a homogenized lowest common denominator.

   Agents can work as technological machetes, clearing the lush data tangle of the Web. Some, such as Jango (née Bargain Finder and made by NetBot Inc.), scan through hundreds of Web sites and find the least expensive price for a toaster or a Toyota. Others, like Firefly, take stock of our buying and browsing habits and then offer purchase recommendations based on the behavior of like-minded people, while also facilitating the delivery of finely tuned ads.

   But far from being physical alter egos or butlers - as they were originally described by Media Lab director Nicholas Negroponte in the 1970s, and as they have been envisioned ever since - agents are manifesting themselves invisibly, blending into the network gestalt.

   Dehype, rebuild

   In some ways, agents seem a perfect American solution: create a bot in your own image and go back to sleep on the couch. If you can define your interests and have your agent serve them up, you have the potential to simplify the world, narrowing it down to comfortable ideas and people who think like you.

   But this is the antithesis of how Maes views agents. "Agents are a new way of thinking about software that is more proactive,' she explains, her Belgian accent lingering. 'Sometimes I envision an agent as having extra eyes, hands, or brains which are looking out for my interests. I am convinced that software will treat us in a more personalized way.' This has already happened with Microsoft Office 97, for example. The system observes what the user does and then gives recommendations that are context sensitive.

   *Her thoughts are echoed by many in the field of agent development, including Alper Caglayan, president of Open Sesame in Cambridge, Massachusetts. 'Agents by themselves as an entity will not happen, but there will be agents in the interface, so every application will be sort of agentized,' says Caglayan, coauthor of the Agent Sourcebook***.**

4. Papamichael, Konstantinos John La Porta & Hannah Chauvet **Decision Making Through Use of Interoperable Simulation Software** Proceedings of International Building Performance Simulation Association, Prague 1997.

5. Citherlet, Stéphane. **Multi-view performance assessment of an office building**. Proc. 7th International IBPSA Conf, Rio de Janeiro, Aug. 2001. (And **Towards the holistic assessment of building performance based on an integrated simulation approach** EPFL thesis, Lausanne, 2001)

6. Augenbroe, Godfried. **COMBINE Final report**. CEC- DGXII report (1995) cited in **Communicating Performance Assessments of Intermediate Building Design States** Godfried Augenbroe and Sten de Wit Proc. of 1997 IBPSA Conference, Prague **OR** Bazjanac, V., and S. Selkowitz. 1997. **The International Alliance for Interoperability: Its Mission and Its Method,** LBNL, August 1997. Cited in **The Implementation of Industry Foundation Classes in Simulation Tools for the Building Industry** Vladimir Bazjanac, Drury B. Crawley. **Proc. IBPSA Conf.**, Prague 1997.

7. MacDonald, Iain. ESRU...Macdonald I A **Quantifying the effects of uncertainty in building simulation**, PhD Thesis, Dept. Mech. Eng. University of Strathclyde, 2002. http://www.esru.strath.ac.uk/publications.htm (Last accessed March 2003).

8. Papamichael, La Porta & Chauvet, Prague 1997. *op. cit.*

9. Citherlet, Stéphane. **Multi-view performance assessment of an office building**. Proc. 7th International IBPSA Conf, Rio de Janeiro, Aug. 2001. (And **Towards the holistic assessment of building performance based on an integrated simulation approach** EPFL thesis, Lausanne, 2001)

10. The Internet, sometimes called simply "the Net," is a worldwide system of computer networks - a network of networks in which users at any one computer can, if they have permission, get information from any other computer (and sometimes talk directly to users at other computers). www.whatis.com/internet.htm (Last accessed October, 1999).

11. "The World Wide Web is the universe of network-accessible information, an embodiment of human knowledge." Tim Burners-Lee quoted in http://www.whatis.com/www.htm (Last accessed November, 1999.)

12. Berners-Lee, Tim **The Semantic Web** http://www.w3.org:80/DesignIssues/Semantic (Last accessed September 1998).

13. "The Hypertext Transfer Protocol (HTTP) is the set of rules for exchanging files (text, graphic images, sound, video, and other multimedia files) on the World Wide Web" ". www.whatis.com/http.htm (Last accessed October, 1999).

14. "1) In general, a server is a computer program that provides services to other computer programs in the same or other computers. 2) The computer that a server program runs in is also frequently referred to as a server (though it may contain a number of server and client programs). 3) In the client/server programming model, a server is a program that awaits and fulfills requests from client programs in the same or other computers. " www.whatis.com/server.htm Last accessed October 1999.

15. Berners-Lee, Tim **Weaving the Web - the original design and ultimate destiny of the world wide web by its inventor** HarperCollins, New York, p57, 1999

16. " "An open source web browser editor from W3C and friends, used to push leading edge ideas in Web client design" " to quote Tim Berners-Lee; http://www.w3.org/Amaya/. (Last accessed October 1999).

17. " "Open source Web server of great modularity, written in Java. From W3C and friends" ." to quote Time Berners-Lee; http://www.w3.org/Jigsaw/ (Last accessed October 1999).

18. "A bit is the smallest unit of data in a computer. A bit has a single binary value, either 0 or 1" . www.whatis.com/bit.htm (Last accessed October 1999.)

19. "Hexadecimal describes a base-16 number system. That is, it describes a numbering system containing 16 sequential numbers as base units (including 0) before adding a new position for the next number. (Note that we're using "16" here as a decimal number to explain a number that would be "10" in hexadecimal.) The hexadecimal numbers are 0-9 and then use the letters A-F" . www.whatis.com/hexadeci.htm (Last accessed October 1999.)

20. http://www.cdin.org/proto/ (Last accessed October 1999).

21. "ASCII is the most common format for text files in computers and on the Internet. In an ASCII file, each alphabetic, numeric, or special character is represented with a 7-bit binary number (a string of seven 0s or 1s). 128 possible characters are defined." www.whatis.com/ascii.htm (Last accessed October 1999.)

22. **Use of CDDB Service in Your Software** Copyright (c) CDDB, Inc. @(#)cddb.howto www.cddb.com 1.27 98/12/09 (Last accessed October 1999).

23. " "The Web is by design and philosophy a decentralized system, and its vulnerabilities lie wherever a central facility exists. The URI specification raises one such general vulnerability, in that the introduction of new URI scheme is a potential disaster, immediately breaking interoperability.

Guidelines for new Web developments are that they should respect the generic definition and syntax of URI's, not introduce new URI schemes without due cause, not introduce any different scheme which puts itself forward as to be universal as a superset of URI's which would effectively require information apart from a URI to be used as a reference. Also, in new developments, all significant objects with any form of persistent identity should be "first class objects" for which a URI exists. New systems should use URI's where a reference exists, without making constraint on the scheme (old or new) which is chosen.

The principle of minimalist design requires that the URI super-space itself makes the minimum constraint upon any particular URI scheme space in terms of properties such as identity, persistence and dereferencability. In fact, the distinction between names and addresses blurs and becomes dangerously confusing in this context. (See Name myths). To discuss the architecture of that part of the Web which is served using HTTP we have to become more specific." http://www.w3.org:80/DesignIssues/Architecture (Last accessed October 1999).

24. Baird, George, Michael Donn and Frank Pool **Energy Demand in the Wellington Central Business District - Final Report,** NZERDC Publ 77. 1982.

25. Augenbroe, Godfried. *1995 op. cit* **OR** Bazjanac, V., and S. Selkowitz. 1997 *op. cit.*

26. Masters, Ben. **Quality control in daylight simulation** - a report submitted [to the Victoria University of Wellington] in partial fulfilment of the requirements for Bachelor of Building Science (Hons.) 2001, 105pp.

27. Masters, Ben and Christopher Furneaux. As yet, unpublished CBPR report of application of thermal simulation of building behaviours conducted as summer study 2000/2001. Supervised by Michael Donn.

28. **Task 22: Building Energy Analysis Tools** www.iea-shc.org/task22 - the web site of the IEA Solar Heating and Cooling Implementing Agreement Research Programme, (Last accessed, December 2003).

29. Judkoff, Ron and J. Neymark **Building Energy Simulation Test (BESTEST) and Diagnostic Method** NREL/TP-472-6231. Golden, Colorado, National Renewable Energy Laboratory, 1995

30. http://irc.nrc-cnrc.gc.ca/ie/light/docs/presmaamari.pdf *Benchmarks to validate lighting computer programs*; Presentation by Fawaz Maamari, chair of IES TC 333 (Last accessed December 2003).

31. Masters, Ben. **Quality control in daylight simulation** - *op. cit.*

32. www.iea-shc.org/task31 (Last accessed May 2003)

33. Mardaljevic, John. **PhD thesis.** http://www.iesd.dmu.ac.uk/~jm/thesis/ (Last accessed December 2003)

34. Mardaljevic, John. **A gold standard ′ dataset for the validation of illuminance predictions** http://irc.nrc-cnrc.gc.ca/ie/light/miniconf.html Lighting Research - 2002 IEA Task 31 and CIE Division 3 mini-conference held at NRC Canada. (Last accessed December 2003)

35. Maamari, Fawaz. **Benchmarks to validate lighting computer programs**. http://irc.nrc-cnrc.gc.ca/ie/light/miniconf.html Lighting Research - 2002 IEA Task 31 and CIE Division 3 mini-conference held at NRC Canada. (Last accessed December 2003)

36. CIE: Commission Internationale d'Eclairage: http://www.cie.co.at/doc/tcs.html (Last accessed December 2003).

37. http://www.iea-shc.org (Last accessed May 2003).

38. Http://studentwork.arch.vuw.ac.nz the on-line exhibition of digital craft based student work at the Victoria University School of Architecture (Last accessed January 2004).

39. Judkoff, Ron and J. Neymark **Building Energy Simulation Test (BESTEST) and Diagnostic Method** NREL/TP-472-6231. Golden, Colorado, National Renewable Energy Laboratory, 1995

40. Donn, Michael and Grant Thomas. **Designing Comfortable Homes.** Cement and Concrete Association of New Zealand, Wellington, ISBN 0-908956-13-4. 2001.

41. Berners-Lee, Tim **Principles of Design: Axioms of Web Architecture** http://www.w3.org:80/DesignIssues/Principles September 1999 (Last accessed October 1999).

42. Burners-Lee, Tim **The Semantic Web** http://www.w3.org:80/DesignIssues/Semantic September 1998. (Last accessed October 1999).

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45. Berners-Lee, Tim **URI Style Guide** http://www.w3.org/Provider/Style/URI March1998. (Last accessed October 1999).

46. "Metadata is machine understandable information about web resources or other things" in **Metadata Architecture** http://www.w3.org:80/DesignIssues/Metadata January 1997. (Last accessed October 1999).

47. Ibid.

48. Berners-Lee, Tim **Web Architecture from 50,000 feet** http://www.w3.org/Provider/Style/URI (Last accessed October1999).

49. " "URI (Uniform Resource Identifier) : To paraphrase the World Wide Web Consortium, Internet space is inhabited by many points of content. A URI (Uniform Resource Identifier; pronounced YEW-AHR-EYE) is the way you identify any of those points of content, whether it be a page of text, a video or sound clip, a still or animated image, or a program. The most common form of URI is the Web page address, which is a particular form or subset of URI called a Uniform Resource Locator (URL). A URI typically describes:
" The mechanism used to access the resource
" The specific computer that the resource is housed in
" The specific name of the resource (a file name) on the computer
"For example, this URI: http://www.w3.org/Icons/WWW/w3c_main.gif identifies a file that can be accessed using the Web protocol application, HTTP, ("http://") that is housed on a computer named "www.w3.org" (which can be mapped to a unique Internet address). In the computer's directory structure, the file is located at "/Icons/WWW/w3c_main.gif." Character strings that identify FTP addresses and e-mail addresses are also URIs (and, like the HTTP address, are also the specific subset of URI called a URL)." " In www.whatis.com/uri.htm (Last accessed November 1999).

50. Berners-Lee, Tim **Principles of Design: Axioms of Web Architecture** http://www.w3.org:80/DesignIssues/Principles (Last accessed October 1999).

51. "ASCII (American Standard Code for Information Interchange) ASCII is the most common format for text files in computers and on the Internet. In an ASCII file, each alphabetic, numeric, or special character is represented with a 7-bit binary number (a string of seven 0s or 1s). 128 possible characters are defined. UNIX and DOS-based operating systems (except for Windows NT) use ASCII for text files. " www.whatis.com/ascii.htm (Last accessed October 1999).

52. Augenbroe, Godfried. *1995 Op. Cit* **OR** Bazjanac, V., and S. Selkowitz. 1997 *Op. Cit.*

53. Berners-Lee, Tim **Principles of Design: Axioms of Web Architecture** http://www.w3.org:80/DesignIssues/Principles (Last accessed September 1999).

54. Lassila, Ora and Ralph R. Swick **Resource Description Framework (RDF) Model and Syntax Specification** http://www.w3.org/TR/WD-rdf-syntax/ January 1999. (Last accessed October 1999).

55. **aecXML™ - A Framework for Electronic Communications for the AEC Industries**; White Paper available at http://www.aecxml.com (Last accessed October 1999) supported by Bentley Systems (http://www.bentley.com - Last accessed December 2003) "aecXML™ is a framework for using the XML standard for electronic communications in the architectural, engineering and construction industries. " And: " The problem of creating data types and schemas to accurately reflect all of that information for the purpose of transferring a complete model from for transferring from one system to another has been addressed in other standards (for example, the IFC specifications created by the International Alliance for Interoperability (IAI) and the various STEP APs). This is not within the scope of aecXML."

56. "XML Short for E**x**tensible **M**arkup **L**anguage, a specification developed by the W3C. XML is a pared-down version of SGML, designed especially for Web documents. It allows designers to create their own customized tags, enabling the definition, transmission, validation, and interpretation of data between applications and between organizations. " From http://www.webopedia.com/TERM/X/XML.html (Last accessed, May 2003)

57. DTD "Short for **d**ocument **t**ype **d**efinition. A DTD states what tags and attributes are used to describe content in an SGML, XML or HTML document, where each tag is allowed, and which tags can appear within other tags. For example, in a DTD one could say that LIST tags can contain ITEM tags, but ITEM tags cannot contain LIST tags. In some editors, when authors are inputting information, they can place tags only where the DTD allows. This ensures that all the documentation is formatted the same way. Applications will use a document's DTD to properly read and display a document's contents. Changes in the format of the document can be easily made by modifying the DTD." From http://www.webopedia.com/TERM/D/DTD.html (Last accessed, May 2003)

58. XSL "Short for Extensible Style Language, a specification for separating style from content when creating HTML or XML pages. The specifications work much like templates, allowing designers to apply single style documents to multiple pages. XSL is the second style specification to be offered by the World Wide Web Consortium (W3C)(www.w3c.org). The first, called Cascading Style Sheets (CSS), is similar to XSL but does not include two major XSL's innovations -- allowing developers to dictate the way Web pages are printed, and specifications allowing one to transfer XML documents across different applications. W3C released the first draft of XSL in August 1998, and promotes the specifications as helpful to the Web's speed, accessibility, and maintenance. " From http://www.webopedia.com/TERM/X/XSL.html (Last accessed, May 2003)

59. Web Services From http://www.webopedia.com/TERM/W/Web_services.html (Last accessed, May 2003)

60. HTTP "Short for HyperText Transfer Protocol, the underlying protocol used by the World Wide Web. HTTP defines how messages are formatted and transmitted, and what actions Web servers and browsers should take in response to various commands. For example, when you enter a URL in your browser, this actually sends an HTTP command to the Web server directing it to fetch and transmit the requested Web page." From http://www.webopedia.com/TERM/H/HTTP.html (Last accessed, May 2003)

61. www.amazon.com (Last accessed May 2003)

62. www.uddi.org (Last accessed May 2003)

63. http://www.xmlpitstop.com/Articles/AmolJadhav/WebServices.htm (Last accessed May 2003) - the best, simple explanation of web services I have yet discovered.

64. Berners-Lee, Tim **Weaving the Web - the original design and ultimate destiny of the world wide web by its inventor**, HarperCollins, New York 1999.

65. http://www.whatis.com (Last accessed March 2003) "To paraphrase the World Wide Web Consortium, Internet space is inhabited by many points of content. A URI (Uniform Resource Identifier; pronounced YEW-AHR-EYE) is the way you identify any of those points of content, whether it be a page of text, a video or sound clip, a still or animated image, or a program.... For example, this URI: http://www.w3.org/Icons/WWW/w3c_main.gif identifies a file that can be accessed using the Web protocol application, HTTP, ("http://") that is housed on a computer named "www.w3.org" (which can be mapped to a unique Internet address). In the computer's directory structure, the file is located at /Icons/WWW/w3c_main.gif." Character strings that identify FTP addresses and e-mail addresses are also URI's (and, like the HTTP address, are also the specific subset of URI called a URL). Another kind of URI is the Uniform Resource Name (URN). A URN is a form of URI that has "institutional persistence," which means that its exact location may change from time to time, but some agency will be able to find it. The URI rules of syntax, set forth in the Internet Engineering Task Force (IETF) Request for Comments 1630, apply for all Internet addresses." In Tim Berner-Lee's original working document, URI stood for Universal Resource Identifier.

66. Shengjiang, Lu. 2002. *op. cit.*

67. COMBINE: http://erg.ucd.ie/combine/papers.html (Last accessed October 1999).

68. Berners-Lee, Tim. **Weaving the Web ...** Op Cit: "Inference languages allow computers to explain to each other that two terms that may seem different are in some way the same - a little like an English-French dictionary. Inference languages will allow computers to convert data from one format to another." P 185.

69. Crawley, Drury, Curtis O. Pedersen, Richard J. Liesen, Daniel E. Fisher, Richard K. Strand and Russell D. Taylor, Linda K. Lawrie, Frederick C. Winkelmann, W. F. Buhl, A. Ender Erdem, and Y. Joe Huang *Energyplus, a New-generation Building Energy Simulation Program*, Proc Sixth Intl IBPSA Conference, Kyoto, 1999.

70. Crawley, Drury, Jon Hand and Linda Lawrie *Improving the Weather Information Available to Simulation Programs* in Proc. IBPSA Conference, Kyoto, 1999.

PART D

APPENDICES

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abridged EECA design tool report

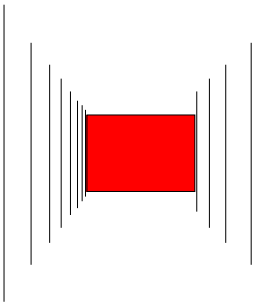
SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

nz_survey_abridged_no_style.wpd

NOTES:

I worked on the development of the questionnaire used in the NZ survey in consultation with CBPR manager Nigel Isaacs, and John Goodchild, the project manager for the sponsors of the work. A major contribution was also made by the contractor employed to conduct the surveys in person and by telephone throughout the country - Mr Chris Watson. The format and content of a series of questions that were part of this NZ survey were deliberately tailored to investigate design tool issues for this thesis. The lead contractor and project manager was CBPR, with assistance from C Watson Consultancy Ltd and Energy Research Otago Limited.



Centre for Building Performance Research

Energy Design Support Tools
A Survey of Their Use for Building Code Compliance

Michael Donn
Jacky Lee
Nigel Isaacs
CBPR
Paul Bannister
EROL

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EXECUTIVE SUMMARY

A. Conclusions and recommendations

1.1.1 Project overview

This report describes a project which forms part of the work programme for the revision of Clause H1 of the New Zealand Building Code. The terms of reference established that the required output was a two part report:

- Part 1 to describe existing practices; and
- Part 2 to describe in broad terms any additional support tools required.

  Part 2 was not funded. It was planned to include establishing which tools are suitable for use in each building category. It would also have explained the need for additional tools (if any) or revisions of present tools required from New Zealand or overseas sources. In Part 2 it was also planned that a performance specification for any new and/or revised tools would be developed.

In Part 1 it was proposed that definition of existing practices could be best achieved through a survey of present users of NZBC Clause H1.

For the purposes of this work "support tools" included (but were not solely limited to):

- technical tools - including nomographs (whether on paper or computerised), rules of thumb, handbooks, computer simulations, Standards, etc
- economic tools - calculation procedures, computer assistance, Standards etc.

The lead contractor and project manager was CBPR, with assistance from C Watson Consultancy Ltd and Energy Research Otago Limited.

The survey was designed to cover the range of present and possible future users of Clause H1, and their present and possible future use of support tools. Questions covered both design and building practice, along with attitudes to and experience of the Energy Efficiency Clause H1 of the NZBC.

The representative sample was selected with approximately equal numbers of designers (architects, engineers, draughtspeople) and builders classified as primarily working in "small" and "large" buildings. A small number of support organisations were also surveyed.

H1 User Groups	Number Surveyed **Personal** *& Telephone*	
	<300m^2	>300m^2
Designers (e.g. architects, engineers, etc)	**10** & *10*	**9** & *10*
Small scale builders (e.g. one or two person)	**7** & *5*	
Large scale builders (e.g. developers)	**4** & *2*	**5** & *5*
Inspectors	**5**&*5*	

Other (e.g. research, Q.S)	**1** & *2*
TOTAL SURVEYED	**41** & *39*

Table 1 Summary of 80 survey participants

1.1.2 SURVEY: Results

Energy efficiency and design decisions

Participants were asked to comment on the frequency with which energy efficiency considerations affect design decisions. Only 6 of the 67 said that passive solar considerations **never** affect their designs. 49% said that passive solar design **always** affects the design of their homes. This is high by comparison with other energy conservation activities that could be influenced by an altered H1 clause in NZBC; e.g. only 21% said that they chose efficient hot water cylinders and heating appliances every time. A picture emerged of professionals who believed that they understood the issues, and were responding to a general public that were actively demanding sun in their homes, and who wanted solar passive energy. Linked with these ideas was a strong belief that passive solar design worked.

[RECOMMENDATION DELETED]

Costs of energy efficiency and code compliance

Participants were asked to list their decision making priorities when choosing new space heating systems and water heating systems. The results show that efficiency is considered important, but purchase cost is considerably more important.

[FOUR PARAGRAPHS DELETED]

Typical size of buildings

It can be clearly seen in that, although many (50%) of the respondents work with a mixture of large and small buildings, a significant number work predominantly (48%) or exclusively (22%) with small buildings. While this separation of work is not as pronounced as anticipated, it is still relatively large.

[RECOMMENDATION DELETED]

Uptake of Energy Efficiency

The respondents were asked in how many of the 6739 buildings with which they had been involved over the past year were the following energy efficient devices installed:

- double glazing
- 'A' grade hot water cylinders
- shading devices

[FIVE PARAGRAPHS DELETED]

Design Tools

59 of the respondents said that they used design tools such those recommended in H1: ALF, NZS2418P and NZS4220, or other aids such as books, manufacturers information, computer programmes, or attendance at a seminar. There was no real correlation between their assessment of ease of use of a design tool and the amount of training they had received.

A clearer pattern was found when the methods used were compared with ease of use, and training. Most people who used only NZS4218P and/or manufacturers information found them easy to use but also had no training!

[RECOMMENDATION DELETED]

[SEVEN PARAGRAPHS DELETED]

Compliance checking

86% of all respondents (including building inspectors) said their buildings' Energy Efficiency features were checked for being built in accordance with the design.

[FOUR PARAGRAPHS DELETED]

Types of design tools

With the exception of the engineers, most professional groups show preference for checklist type design support tools. Manual calculations were least favoured, with computer calculations coming second. The engineers favoured computer calculation over the checklist. The designers were equally divided in preference for checklists and computer tools. In summary people realise the multitude of factors which are relevant to a building's energy efficiency and wish to address them. However, some people want greater simplicity while others want more sophistication in design support tools.

Taking CAD use as an indicator of high level computer use, 83% of the engineers use CAD and thus could be expected to be able to utilise complex computer based design support tools with most ease. However, the overall industry use of CAD is only 42.5%. At the other end of the scale, 89% of all practices surveyed did some kind of computing.

[RECOMMENDATION DELETED]

7 people used tools specifically for calculating air conditioning requirements. There was little commonality in the tools used. The ACADS and CIBSE tools were each used by two people;

the other 3 people used in house programs, the Australian standard and the "Amazon" program respectively.

[RECOMMENDATION DELETED]

Respondents were asked at which stage of design they would like tools to be applicable. Preference was very clearly towards tools that could be used early in the design process. Preference was also clearly expressed for tools that could inform the energy design process rather than just produce code compliance reports. The only exception was the building inspectors who expressed a differing view, asking for code compliance checking tools.

[RECOMMENDATION DELETED]

Answers were sought as to the likely users of design tools to provide indicators of the level of skill and field of expertise that the user might have. However these replies reflected a very conventional view of an hierarchical design structure with the architect "at the top" doing the design.

[RECOMMENDATION DELETED]

Lighting

The survey results suggest that there is very little involvement by any of the people we surveyed in the installation of energy efficient lighting. Most of the engineers interviewed were however HVAC engineers rather than electrical engineers who are more commonly involved in lighting design.

[RECOMMENDATION DELETED]

1.1.3 REVIEW: Validity of support tools.

The work reported below was undertaken by Energy Research Otago Limited.

The design support tools have been grouped into three categories, being input tools, such as manufacturers' data; rules of thumb; and output tools (such as DOE2.1E, ALF and SERI-RES). **[FOUR PARAGRAPHS DELETED]**

2 INTRODUCTION

2.1 Research background

This report describes a project which forms part of the work programme for the revision of Clause H1 of the New Zealand Building Code. It was approved as *Contract No 7* in this programme following presentation of a Work Statement outlining proposed work to the Building Industry Authority (BIA) and the Energy Efficiency and Conservation Authority (EECA). It follows the brief and terms of reference contained in a letter to CBPR from Mr. J. Goodchild dated 13 May 1994.

2.1.1 Project description

For the purposes of this work "support tools" included (but were not solely limited to):

- technical tools - including nomographs (whether on paper or computerised), rules of thumb, handbooks, computer simulations, Standards, etc
- economic tools - calculation procedures, computer assistance, Standards etc.

The lead contractor and project manager was CBPR, with assistance from C Watson Consultancy Ltd and Energy Research Otago Limited.

The Terms of Reference established that the required output was a two part report:

- Part 1 to describe existing practices; and
- Part 2 to describe in broad terms any additional support tools required. Part 2 was to be completed based on other BIA/EECA contracts presently under way.
-

[PARAGRAPH DELETED]

2.1.2 Phase II

[SIX PARAGRAPHS DELETED]

2.2 Report contents

This report is organised into two major sections representing the two major thrusts of the research: the Design Support Tool SURVEY, and the Design Support Tool REVIEW. The titles of the chapters of the report reflect this division. Chapters 2-6 inclusive report the results of the survey of the building industry use of design support tools. Chapter 7 reports the review.

[PARAGRAPH DELETED]

2.3 Acknowledgements

[TWO PARAGRAPHS DELETED]

3 SURVEY: Research Background

The data presented in this chapter describes the survey design process, the application of the survey, and the nature of the people and firms selected for interview.

3.1 The survey

The Energy Efficiency section of the New Zealand Building Code is at present (1994 -1995) in the process of being rewritten. For Proof of Compliance, the new code will require some kind of Verification Method or design support tool. Thus it was seen to be important to find out about the building industry's current experience with support tools and their needs for new tools. A survey was conducted of a representative range of members of the building industry.

[TWO PARAGRAPHS DELETED]

3.2 Survey design

Clause H1 is used by a range of people involved in the creation of buildings to which it applies. Examples of users and their specific interests include:

- Architects: design the building whilst ensuring the requirements of H1 are met;
- Engineers: design energy using services (e.g. HVAC) to meet H1 requirements;
- Draughtspeople: draw, and in many cases design, the building to meet the requirements of H1;
- Builders: construct the building envelope to meet the requirements of H1;
- Developers: ensure investment meets the relevant legal requirements;
- Suppliers: demonstrate product(s) permit compliance with requirements of H1;
- Support organisations e.g. BRANZ in the development of Appraisal Certificates
- Energy efficiency consultants: assist in the design of energy efficient buildings.

Of this list only suppliers were not surveyed.

[THREE PARAGRAPHS DELETED]

The survey itself was carried out by C Watson Consultancy Ltd.

3.3 Questionnaire

The first stage of writing the survey was to clarify the key issues where we required industry feedback. Within each of these categories individual questions were formulated which were designed to provide quantifiable answers. The wording and ordering of these questions was carefully considered. For clarity in the interview they were not strictly grouped by issue in the Questionnaire.

Preliminary interviews with three people were undertaken. After these interviews, identified problems were resolved. Next a pilot survey consisting of one personal and two telephone interviews was conducted.

[TWO PARAGRAPHS DELETED]

3.4 Participants

From the outset it was clear that the survey could not be undertaken for a large number of each of the different types of "player" in the building "game". A careful selection was therefore made of what was considered to be a representative sample.

[TWO PARAGRAPHS AND A TABLE DELETED]

3.5 Survey method

The final survey was completed over a period of around 2 months from October to September 1994. A selection of the interviewees (41) from all the locations was interviewed in person. The remainder were interviewed by telephone (39). The questions were the same for both interview types, with the exception of two of the more complex questions which involved ranking preferences, which were deleted from the telephone survey. The cost of telephone interviews were significantly lower than the cost of personal interviews, yet it was thought important to do a large number of personal interviews as they were likely to yield more reliable results and thus could be used as a control for the telephone interviews.

One interviewer was used for all the interviews whether by phone or in person. This made it unnecessary to add in extra control questions for variations between interviewers.

3.6 The survey "Attitudes Towards Energy Efficiency Among Specifiers"

[PARAGRAPH DELETED]

4 SURVEY: Characteristics of the Survey Group

Some general background of the interviewees was required in order to link answers to types of practice. This was necessary to establish whether different practice types have different attitudes or needs. These background questions included the individual's Role in the company (Q2); the company's Activities (Q3) (e.g. Architectural, Engineering, Developer); and the Size of the company in terms of: number of employees (Q6), Number of buildings and the Size of those buildings built in last 12 months (Q4 &5), and the total Value of those buildings (Q7).

The respondents to the questionnaire fall into two distinct groups: the construction industry participants, that is the builders, developers, architects, engineers and the designers; and the building inspectors and 'others'. The 'Others' were 2 building industry support people and one quantity surveyor.

These two groups were often separated in the analysis of data. There were 67 construction industry participants and 13 inspectors and others (10 inspectors).

[TABLE AND PARAGRAPH DELETED]

4.1.1 Number of staff employed in the organisations interviewed

[TABLE AND PARAGRAPH DELETED]

4.1.2 Number of buildings built

[FIVE PARAGRAPHS DELETED]

4.1.3 Size of building

It had been hypothesised that different sized buildings were built by different contractors, "Energy Efficiency in the N.Z. Building Code - a New Structure" (Isaacs, Lee and Donn 1995) If this were true then several conclusions regarding different skill levels and different levels of code complexity could be justified as appropriate for the two different building size categories.

[FIGURE AND SEVEN PARAGRAPHS DELETED]

4.1.4 Cost of buildings built

[TWO TABLES AND TWO PARAGRAPHS DELETED]

4.1.5 Building type

[TABLE AND SIX PARAGRAPHS DELETED]

4.2 Attitudes to energy efficiency

The following two questions were asked in order to establish the "market" for energy efficiency within which the construction industry people that we interviewed were operating.

[PARAGRAPH DELETED]

Question 12: In the last 12 months, did your clients place some importance on the energy efficiency characteristics of the buildings?
-Yes
-No

Question 13: Could you make your buildings more energy efficient?
-Yes
-No
-Inspector
If yes: What deters you from doing so?

70% of Practitioners said that their clients were interested in energy efficiency, 28% said their clients were not. Only 50% of the inspectors believed that clients were interested in energy efficiency.

With the exception of one builder and of the building inspectors all survey participants said that they could make buildings more efficient.

Reasons given for not making buildings more efficient are as follows:

- 42 gave cost as the predominant reason
  of these 3 mentioned their competitive position
  and 5 mentioned an unsatisfactory return on investment.
- 20 mentioned client perception
  of these 8 quoted client resistance to capital cost
  and 3 said clients did not get good enough return on investment.
- NOTE: 13 of the 80 respondents gave no reply to this question.

[THREE PARAGRAPHS DELETED]

These results are very similar to those found by the EECA Attitudes Towards Energy Efficiency Among Specifiers report (Shaw 1993) which says: "In all types of projects, architects place more importance on energy efficiency than their clients". The report also divides client interest by type saying that institutional and industrial clients were most likely to ask for energy efficiency. These clients are more likely to be long term occupiers of a building and are increasingly cost and profit orientated. Commercial and retail clients were less likely to ask for energy efficiency. Attitudes of clients for residential projects were more varied.

[FOUR PARAGRAPHS DELETED]

4.3 Computer Use

Question 9: What does your firm use a computer for?

-Word processing
-Accounts
-CAD
-Schedules
-Games
-Design analysis

The question about computer use was designed to determine whether or not it is realistic to require the use of computer based energy efficiency compliance programmes. Questions regarding software use give an indication of the level of expertise possessed within each company, and give an indication of the difficulty that they would experience if asked to use software packages for energy efficiency compliance.

The type of computer applications the industry claimed to be using were:

- 9 (13%) **Did not** use computers
- 56 (83%) used **Word processing** packages
- 51 (76%) used computers for **Accounts**
- 31 (46%) used **Computer Aided Drafting**
- 26 (38%) used the computer for **Schedules**
- 21 (31%) admitted to, among other things, playing **Games** on their computers,
- 22 (32%) used the computer for **Design Analysis**

[FIGURE AND SIX PARAGRAPHS DELETED]

5 SURVEY: Code Compliance Actions Over Past 12 Months

This chapter deals with code compliance in relation to energy efficiency as opposed to energy efficiency in general, which is covered in Section ? on Survey Design. Questions were asked about aspects of code compliance such as cost (Q10) and support tools used in the last 12 months (Q11).

5.1 Compliance with NZBC compared with old regulations

Question 10: Did your firm have to do anything more to comply with energy efficiency requirements of the Building Code than it did before its introduction?

[THREE PARAGRAPHS DELETED]

5.2 Use of different compliance methods

Question 11: For buildings designed over the last 12 months, which of the following clauses of the Building Code were used?

B1 Structural
-Acceptable (eg NZS3604)
-Verification (eg Specific design)

H1 Energy Efficiency
-Acceptable (eg NZS 4218P - the insulation code for houses)
-Verification (eg The Annual Loss Factor method from BRANZ)

The question was asked about the structural section of the code in order to give an indication of the individuals' willingness or resistance to using specific design in other parts of their work...

[THREE PARAGRAPHS AND TWO TABLES DELETED]

An example of frequently used thermal efficiency Verification Methods is found in California. where "Currently it is estimated that 80% of houses use the computer methods, and only 5% use the prescriptive packages."(Goldstein 1988). Goldstein explains that an industry of small practices doing computer simulations consult to designers, promising a reduction in construction costs well in excess of their fees. This is usually achieved by locating more insulation in areas where it is cheaper to apply (for example the prescriptive Approved Solutions require wall insulation greater than can be achieved in standard thickness wall construction). Other designers use the simulation methods to overcome the prescriptive constraints on window area

5.3 Opinions of Clause H1 of the Building Code

Question 22: Have you read the energy efficiency clause H1 of the Building Code?

How do you think it could be improved?

22 out of the 80 respondents chose to comment on clause H1 of the building code:

[EIGHT PARAGRAPHS DELETED]

5.4 Opinions of NZS4218P Table 2

Question 23: Have you used Table 2 of the house insulation standard referred to in the code which allows you to trade off insulation in the walls against insulation in the roof?
How do you think it could be improved?

[THREE PARAGRAPHS DELETED]

5.5 Design aids and tools use

A large part of the purpose of the survey was to find out which tools people were already using and their assessment of: their suitability to the task; the ways in which they were used; the kinds of training the users had; and how easy they were to use.

Because some of the respondents had very different answers depending on their concept of how the tool was to be used, it was decided during the pilot stage that there should be two separate questions about I) tools used for code compliance (Q15); and, ii) tools used for energy efficiency in general (Q17):

Question 15: Which of the following design aids/tools were used to help you comply with Clause H1 of the Building Code in the last 12 months?
-Books
-NZS4218P (the insulation standard for houses)
-NZS4220 (the energy standard for commercial buildings)
-ALF
-Other programmes
-Manufacturers information
-Attendance at seminars
-Other people

Question 17 asked the same question as Question 15 but this time about tools used to support Energy Efficiency design choices as opposed to proving compliance with code requirements.

The answers to question 17 were very similar to those for Question 15 . We wished to distinguish between the use of tools for energy efficiency design and their use for code compliance. However, only for the "use of NZS4220" and the "attendance at seminars" responses are there significant differences. In both cases they were used more for code compliance than design.

NZS4220 was reported to be used by 7 out of 12 engineers for code compliance in the last year but only 2 of this 12 said that they used it for more general energy efficiency information. This means that despite the apparent lack of commitment to checking Clause

H1.3.2 (the Part of H1 that applies to commercial buildings and refers to NZS4220) shown in Question 28 more than half of the engineers had used NZS4220. It must be remembered that NZS4220 was written as a recommendatory code not a mandatory one. If NZS4220 is to be used as a requirement for H1 it must be substantially rewritten, as the present clauses selected for H1, it must be substantially rewritten as the clauses used for the Verification Method from the present version have no specific criteria by which compliance can be judged.

[THREE TABLES AND TWO PARAGRAPHS DELETED]

Of all the design support tools, ALF is used the least; only 6 (9%) of the 67 people from the construction industry have used it in the past year. (3 of these were architects).

[TWO PARAGRAPHS DELETED]

5.6 Stage of design where energy efficiency is considered

Question 14: At what stage in the building process were the energy efficiency requirements of the Building Code dealt with?
-Preliminary design
-Developed design
-Working drawings
-TA Building Consent check
-Construction
-None

The nature of information available to the design team is a crucial determining factor of the type of design decision tool that they might wish to use. This information varies tremendously between design stages. A designer can be less certain of sizes of components like windows and ventilation openings in the early stages of design than they can be later in the design process. We sought to determine at which stage of the design process practitioners were currently thinking about energy efficiency. Later in the future tools section we asked at which stage they would ideally like to use design tools.

When Companies were questioned regarding their normal code compliance practice, many respondents listed several stages of the design process as involving work towards compliance with H1. There is no single design support tool that could provide energy efficiency guidance at all these stages of the design process.

23 (28%)of the respondents listed only one stage of the design process where H1 was considered

21 (26%) of the respondents listed two stages of the design process where H1 was considered

[TABLE AND TWO PARAGRAPHS DELETED]

The table shows that most of the Architects and Engineers tend to deal with energy efficiency in the first two stages of design. The designers were more likely to deal with it at the working

drawing stage. Builders and developers also said energy efficiency code compliance was dealt with in the three earliest stages of design. A smaller percentage of all groups said it was dealt with at the time of building consent and construction.

This question did not give a clear indication that any one stage should be targeted in preference to the others. The different design stages are often blurred and do not necessarily take place in a clearly defined chronological sequence. While this result does not give a conclusive mandate for a particular type of tool when participants were asked which stage of design they would like to use tool the strong reply was that tools were preferred for the early stages of design. (See ?) This is a clear request for design assistance which points the designer in the "right direction". By contrast the compliance Verification Methods which are available internationally are normally far better at evaluating performance after the design is complete.

6 SURVEY: Energy Efficiency Actions Over Past 12 Months

This chapter looks specifically at support tools used for the design of efficient buildings. It also addresses questions about tools used to design other energy-using features of the building such as lighting (Q31) and air conditioning (Q32)

6.1 Lighting design tools.

Question 31: How did you design the daylighting and lighting system?
(eg NZS 6703, supplier support, books, rules of thumb, experience, calculations)

[SIX PARAGRAPHS DELETED]

6.2 Air conditioning design tools

Question 32: What air conditioning design aids/tools did you use? (eg Carrier/DOE2/ESP/ASHRAE/CIBSE)

When questioned about designing air conditioning, only 12 people responded. The rest are presumed to be involved only minimally in buildings with air conditioning.

[TWO PARAGRAPHS DELETED]

6.3 Energy efficiency impacts on design.

The next set of questions attempted to gain a more objective indication of how much energy issues actually affected the practices of individual designers and builders.

Participants were asked which parts of buildings were actually changed because of energy efficiency requirements (Q16) and what was the average effect this had on the capital cost of the building. (Q20)

[TABLE FIGURE AND TWO PARAGRAPHS DELETED]

It is noteworthy that only 5 people said that they never use passive solar design. 75% said that they always or sometimes use it. 41% said that passive solar design always affects the design of their homes. This is indeed a high figure compared with only 21% who said that they choose efficient appliances every time. Any clause that made passive solar design mandatory would serve purely to bring reluctant adopters into line with typical good practice. For more analysis of the widespread uptake in the belief in solar design refer to the report "Sustainable Energy and the Building Code" (Bannister 1994) and Appendix ? which summarises the survey responses to questions regarding sustainable energy sources.

6.4 Decision making priorities

Participants were asked to list their decision making priorities when choosing new space heating systems (Q36) and water heating systems (Q35). Outside of the building envelope, these two appliances probably make the most difference to the energy bills of domestic buildings, (Wright and Baines, 1986). These questions recognise that there are other considerations in building design besides energy efficiency. It was intended to produce a ranking of energy efficiency relative to these other design priorities.

[PARAGRAPH DELETED]

6.4.1 Hot water cylinder selection

Question 33: What was the most important consideration in selecting water heating systems?

[SEVEN PARAGRAPHS AND SIX GRAPHS DELETED]

6.4.2 Space heating selection

Question 35: What was the most important consideration in selecting space heating systems?

[EIGHT PARAGRAPHS FIVE GRAPHS ONE TABLE DELETED]

6.5 Energy efficiency measures used in the last 12 months

As opposed to opinions of what the designer / builder thinks is important, these questions asked in how many buildings the following energy efficient devices were installed:

- Double glazing (Q24),
- 'A' grade hot water cylinders (Q25),
- Shading devices (Q26).

Participants were also asked on how many buildings some life cycle costing was performed, and then in how many cases that life cycle costing included energy (Q27).

[PARAGRAPH DELETED]

6.5.1 Double glazed buildings

[FIVE PARAGRAPHS DELETED]

6.5.2 'A' grade water cylinders

[FIVE PARAGRAPHS AND ONE TABLE DELETED]

6.5.3 Shading devices

[TWO PARAGRAPHS DELETED]

6.5.4 Life cycle costing

We asked participants in how many buildings had they performed some life cycle costing. Table ? shows how many respondents undertook life cycle costing which included energy costs. The purpose of this question was to see how many building professionals already use life cycle costing, because one possible approach to establishing a Verification Method would be to require use of a life cycle costing calculation method. There were 102 buildings which had some life cycle costing undertaken out of the total sample of 2573 buildings.

[TABLE AND THREE PARAGRAPHS DELETED]

Just under half of all people surveyed had done some form of life cycle costing on some of their buildings in the last year. Thus life cycle costing is not too difficult, or too time consuming to be of use to the building industry. It is concluded that it would not be unrealistic to include it as a Verification Method.

7 SURVEY: User Assessment of Support Tools.

The survey sought to establish respondents' assessment of those design tools that they did use by asking questions about ease of use and training. It also sought to gauge current quality control practices (checking) with regards to the features of the building that affect energy efficiency.

7.1 Training and ease of use

Some respondents said that they used design tools such those recommended in H1, ALF, NZS2418P and NZS4220, or other aids such as books, manufacturers information, computer programmes, or attendance at seminar. Only those who used tools (62 people) were asked questions regarding the use of those tools.

Question 18: What training has the user had in the design aids/tools?
-None
-Course
-Colleague

Out of those 56 members of the construction industry who responded, their answers are as follows.

- 28 (50%) of those using tools had no training
- 6 (11%) had been trained by a colleague in use of the tools
- 12 (21%) said they had been on a course
- 10 (18%) said they had received 'other' training

of the 13 Inspectors and Others only 6 replied, they said:

- 4 of those using tools had no training
- 1 had been trained by colleagues
- 1 had been on a course.

It would appear that training is at best randomly used for most design tools currently in use in New Zealand. All together half of the respondents had no formal training in the correct use of design tools.

Question 19: How easy was it to use the above aids/tools?
-Easy
-Fair
-Difficult

Of those 62 who used the tools 56 were directly involved in the design and construction of buildings

- 6 (11%) made no comment as to how easy the tools were to use
- 25 (44%) described them as easy
- 24 (43%) described then as fair
- 1 (2%) described them as difficult

Of the 6 inspectors and others

- 1 made no comment as to how easy the tools were to use
- 4 described them as easy
- 1 said they were fair
- 1 said they were difficult.

There was no real correlation between ease of use and amount of training received. The impression from the comments was that those with less training used predominantly the simpler methods thought the methods were easier. Most people who used only NZS4218P and/or manufacturers information found them easy to use and also had no training

Issue Respondent Numbers	Use	No training	Thought it easy
NZS4218P and/or Manf info only	12	10	9
People using NZS4220, ALF and/or other programmes	33	7	18

Table 2 Ease of use and training compared with tools type.

It can be seen that those using only NZS4218P and/or manufacturers' information find it easy to use (75%). Most of these people (83%) have no training. However, those using more complicated tools have more training. Only 20% have no training in the use of these tools and 54% of users find these tools easy to use.

Simple prescriptive tools require little training and are easy to use. Where possible this type of tool should be used to demonstrate compliance for most buildings. More complex tools require more training which may deter some people from using them.

7.2 Compliance checking for energy efficiency

Question 29: Are the energy efficiency features of your buildings specifically checked to confirm that they are installed in accordance with the design? For example, are houses checked to confirm that insulation is installed in accordance with specification?

-Yes
-No
-Not applicable

If yes, By whom?
-Designer
-Builder
-TA
-.....

Question30: *[If there are any mechanical heating and cooling appliances installed during construction]* Are they checked to confirm that they initially operate in accordance with the design?

-Yes
-No

If yes, By whom?
-Designer

-Builder
-Engineer
-.....

How often are they operated in accordance with the design?
-Always
-Usually
-Sometimes
-Rarely
-Never
-NA

Even a well designed building may be rendered inefficient if it is not built according to the design. Previous work has shown that if equipment is not commissioned correctly in a new building, efficiency can be severely affected (Baird, et al. 1984).

[THREE PARAGRAPHS DELETED]

7.2.1 Checking of installation

[TWO PARAGRAPHS AND TWO TABLE DELETED]

7.2.2 Checking of commissioning

Question30: [If there are any mechanical heating and cooling appliances installed during construction]
Are they checked to confirm that they initially operate in accordance with the design?
-Yes
-No

If yes, By whom?
-Designer
-Builder
-Engineer
-.....

[FIVE PARAGRAPHS AND TWO TALES DELETED]

7.2.3 Building operation

Question 30: How often are they operated in accordance with the design?
-Always
-Usually
-Sometimes
-Rarely
-Never

[TWO PARAGRAPHS, ONE GRAPH AND ONE TABLE DELETED]

7.3 Territorial Authority checking of Clause H1.3.2

Question 28: With non-residential buildings, how does the TA check for compliance with the Building Code clause H1.3.2?

[ONE PARAGRAPH ONE TABLE DELETED]

8 SURVEY: Future Energy Efficiency Trends

Participants were asked about the energy efficiency trends that they envisioned in the future.

[TWO TABLES AND FOURTEEN PARAGRAPHS DELETED]

8.1 Future design tool possibilities

The final part of the questionnaire surveyed preferences as to the kinds of design tools which respondents might find useful.

Issues included:

- The level of complexity (checklist / manual / computer) (Q45)
- The place of tool in the design process (initial design / final design) (Q46)
- The purpose of the design tools (code compliance / general energy efficiency) (Q47)
- The relationship to other packages (integrated / stand alone) (Q48)

Respondents were also asked who the users of the tools were likely to be for different areas of design:

- The building envelope (Q49)
- The lighting (Q50)
- The heating and cooling services (Q51)
- The planning (Q52)

These question where important because different professions have different concerns and different levels of expertise and are thus likely to wish to use tools in quite different ways.

8.1.1 Preferred type of tool

> Question 45: If you had the choice, would you prefer to use an energy efficiency design aid tool which involved :- checklist, manual calculation, computer calculations, or other.

[TABLE AND PARAGRAPH DELETED]

Most participants (95%) answered this question. With the exception of the engineers, most professional groups show preference for checklist type tools. Manual calculations were least favoured, with computer calculations coming second. The engineers favoured computer calculation over checklist tools. The designers were equally divided in preference for checklists and computer tools.

> Question 46: If you had the choice, would you prefer to use an energy efficiency design aid/tool which:- Is only able to be used once all the dimensions of the building are known, or Contains sufficient best guess data that it can be used very early in the design process (when only building size and type may be known).

Respondents were asked at which stage of design they would like tools to be applicable. Preference was very clearly towards a tools that could be used early in the design process

[TABLE DELETED]

Question 47: If you had a choice, would you prefer to use an energy efficiency design aid/tool which;
-Produces only code compliance reports,
or-Can be used to study general building energy and efficiency questions.

Preference was also clearly for tools that could inform the energy design process rather than just produce code compliance reports. The only exception to this was building inspectors who normally use design tools primarily for compliance checking.

[TWO TABLES AND TWO PARAGRAPHS DELETED]

In summary most of the respondents wanted tools that could be used to study the energy efficiency of their buildings especially at early stages of design. They were divided as to whether these tools should be 'stand alone' or could be linked to something like CAD. It is likely that a CAD linked tool could not be used at the earliest stages of design as CAD drawings would not be available. We recommend that these preferences be taken into consideration when assessing the provision of support tools for the code.

[TWO PARAGRAPHS DELETED]

8.2 Users of energy efficiency design support tools

Questions 49 to 52 were intended to identify who the users of tools would be. Answers were to be used as indicators of the level of skill and field of expertise that the user might have. We expected to find some diversification from traditional roles, particularly with regards to builders who might do their own designs. While there was some indication of this with respect to building structure, most replies reflected a very traditional design process with the architect making most design decisions. It is difficult to determine how much this answer reflected reality and how much it reflected answers the respondents thought we wanted to hear.

Participants were asked to relate their replies to buildings over 300m^2 or under 300m^2 or both depending on their type of experience and expertise. Many more people responded with regards to small buildings than to large buildings.

8.2.1 Design of thermal envelope

Question 49: Who would be the primary users of energy efficiency design aids/tools which affect building construction? (i.e. relating to thermal mass air leakage, solar gain, insulation, double glazing)

-Architect, designer
-Engineer
-Energy Consultant
-Builder
- . . . . .

For small buildings 93% (73) of the people who answered thought that this tool would be used by the architect or designer. 11 (14%) people thought that the engineer might use the tool 12 (15%) people thought that builders would also use it. 6 (8%) thought that an energy consultant may use it. Some people gave more than one answer.

When the same question was asked with respect to large buildings, only 63 of the respondents answered. 42 (66%) people said the architect or designer would use these tools and 33 (52%) said that an engineer would use them; 18 (29%) thought a specialist energy consultant would use them, while 3 (5%) thought that a builder would use it.

Thus a tool for designing the construction of a building would be expected to be used mostly by architects but also by engineers and builders of small buildings. In large buildings the engineer or the energy consultant may also become involved.

Question 52a: Why would this person be the primary user of energy efficiency design aids/tools which affect building construction?

Almost every participant answered this question about design of the thermal envelope, Most answers contain more than one reason. Listed below is an indicative selection of some of the answers given (referring, as the respondents most often did to the architect as "he").

- 'this is the way we do it', 'traditionally his role', 'that is their role'
- 'not large enough to bring in consultants', 'small jobs architect does all', 'only have a consultant for large jobs'
- 'because they design it'
- 'because it is an integral part of the design'
- 'because it has to be decided early on in the design stage'
- 'that's where those things are addressed'
- 'they are the people with the expertise'
- 'greatest influence'
- 'most client contact'

8.2.2 Design of lighting

[SEVEN PARAGRAPHS DELETED]

8.2.3 Design of heating and cooling

Question 51 Who would be the primary users of energy efficiency design aids/tools which affect heating and cooling services? (ie finding optimum combination of building mass and heating plant)

In buildings under 300m^2 (small buildings), 57% of participants thought that it was the architect's responsibility to use design aids for the heating and cooling services; 32% believed that engineers would be the primary users; 6% saw builders and 17% energy consultants as being the users of these tools in small buildings.

In large buildings, 24 (38%) people believed that it was the architects responsibility; 44 (71%) thought that the engineer would use heating and cooling design tools; 20 (32%) people thought that an energy consultant would use them, and 3 (5%) saw a builder using them.

Question 51A Why would this person be the primary user of tools for designing heating and cooling services?

Again, many of these answers were repeats of the reasons given for previous questions. A selection of answers that seem significant to heating and cooling are as follows:

Those who said that architects did the job claimed that it was because the"heating and cooling was an integral part of the design", and that these things had to be considered at the beginning of the design process.

Those who said the engineer did the job said that the engineers were the specialists or "that the engineers are more involved in the calculations". Some who saw the job as the engineer's or consultant's responsibility believed that it was "the energy consultants' job because it doesn't impact the design of the building so much".

There also appeared to be an opinion that, in smaller buildings, heating and cooling was a more integral part of the building and therefore designed by the architect, whereas with a larger building a specialist was required.

One architect expressed "reluctance to let HVAC engineers make all the decisions as they had a tendency to over design. It is advantageous having the designer there to moderate their design"

8.2.4 Design of building plan

> Question 52 Who would the primary users of energy efficiency design aids/tools which affect building planning? (eg grouping living areas on the warm side of the house)

As expected, this was seen by most (92%) as the domain of the architect whether in large buildings or small. However, most of the other professions were selected by a small number of the respondents. The reason for the selection of the architect was that spatial planing is "their job" and is fundamental to very early design choices.

8.2.5 Tool users conclusion

Questions 49-52 showed that architects were considered to be the major potential users of all these tools except for heating and cooling plant in large buildings. In these the engineer is perceived to be the most likely user. 15% of respondents envisaged builders using tools that dealt with building construction, but only 6% of them believed builders were likely to use tools related to lighting or heating and cooling, in those same small buildings. These responses imply that architects and perhaps builders are expected to be involved in use of verification Methods associated with clause H1. If this is so then from earlier data in section ?, it is likely that the design support tools used as VMs will have to have simple easy to use interfaces and avoid manual calculations.

The use of engineering or energy consultants is most significant in larger buildings. While some respondents feel that they may use the tools in smaller buildings, most also listed the architect or designer as the most likely user in small buildings.

9 REVIEW: Validity of Support Tools

The work reported in this chapter was under taken by Energy Research Otago Limited.

9.1 Introduction

[SEVEN PARAGRAPHS DELETED]

9.2 Input tools

It is noted from the survey that nearly all respondents used manufacturers data as a support tool in the design process. This is a fairly broad ranging category, as it could be interpreted to mean everything from a fan curve to a relatively complex simulation tool such as CALCULUX. For the purposes of this discussion, the category will be limited to simpler information such as equipment and construction component ratings and performance data.

[EIGHT PARAGRAPHS DELETED]

9.3 Rules of thumb

9.3.1 Equipment design

[FIVE PARAGRAPHS DELETED]

9.3.2 Other rules of thumb

[SIX PARAGRAPHS DELETED]

9.4 Design tools

[ELEVEN PARAGRAPHS DELETED]

9.5 Validation experiments on computer design tools

[TWELVE PARAGRAPHS DELETED]

9.6 The validity of computer simulation models in code compliance procedures

[ELEVEN PARAGRAPHS DELETED]

9.7 Conclusions

[TWO PARAGRAPHS DELETED]

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B

NZ survey questionnaire

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

nz_survey.wpd

Introductory notes;

This is a small part of the **revision of the energy efficiency section** of the building code. The Building Industry Authority wants to find out about the **range of experience** in the building industry of energy efficiency of buildings.

This questionnaire refers to buildings your office/firm worked on in **last 12 months** which and are completed or are expected to be built. My notes from this interview will remain **confidential** to the Centre for Building Performance Research at Victoria University and C Watson Consultancy Ltd. An **anonymous summary and analysis** will be used for development of the Building Code and in a study of the useability of design tools/aids. If you do not understand something please ask for **clarification**.

1☐-telephone 2☐-personal consent to interview ..... (signed) 1994

Your Firm

1 Please advise if there are any errors in the contact details above.

2 What is your primary role in the firm?
1☐-Owner
2☐-Manager
3☐-Designer
4☐-Inspector
5☐-Solo
6☐-.....

3 How would you describe the activities of your firm?
1☐-Property Developer
2☐-Builder
3☐-Engineer
4☐-Architect
5☐-Designer
6☐-Inspector
7☐-.....

4 How many new buildings < 300 m^2 did your firm work on in the last 12 months?
.... 0m^2 - 300m^2

5 How many new buildings > 300 m^2 did your firm work on in the last 12 months?
.... 300m^2 +

6 On average how many full-time equivalent people were involved in your firm?

7 What was the total construction cost of building projects your firm turned over in the last 12 months?
1☐-$0 - $1m
2☐-$1m - $5m

3□-$5m - $50m
4□-$50m +

8 What types of buildings was your firm involved with?
1□-Detatched dwelling
2□-Multi-unit dwelling
3□-Group Dwelling
4□-Communal residential
5□-Communal non-residential
6□-Commercial
7□-Industrial

9 What does your firm use a computer for?

1□-Word processing

2□-Accounts

3□-CAD

4□-Schedules

5□-Games

6□-Design analysis

7□-.....

Approach to Energy Efficiency

10 Did your firm have to do anything more to comply with energy efficiency requirements of the Building Code than it did before its introduction?

1□-Yes

2□-No

11 For buildings designed over the last 12 months, which of the following clauses of the Building Code were used?

B1 Structural

1□-Acceptable (eg NZS3604)

2□-Verification (Specific design)

H1 Energy Efficiency

1□-Acceptable (NZS 4218P - the insulation code for houses)

2□-Verification (The Annual Loss Factor method from Branz)

12 In the last 12 months, did your clients place some importance on the energy efficiency characteristics of the buildings?

1□-Yes

2□-No

13 Could you make your buildings more energy efficient?

1□-Yes

2□-No

3□-Inspector

If yes: What deters you from doing so? .....

Design Aids/tools to comply with the Building Code Clause H1

14 At what stage in the building process were the energy efficiency requirements of the Building Code dealt with?

1☐-Preliminary design

2☐-Developed design

3☐-Working drawings

4☐-TA Building Consent check

5☐-Construction

6☐-None

15 Which of the following design aids/tools were used to help you comply with Clause H1 of the Building Code in the last 12 months? *(NZS 4220 Energy Conservation in Non-Residential Buildings)*

1☐-Books

2☐-NZS4218P (the insulation standard for houses)

3☐-NZS4220 (the energy standard for commercial buildings)

4☐-ALF

5☐-Other programmes

6☐-Manufacturers information

7☐-Attendance at seminars

8☐-Other people

9☐-.....

16 In the last 12 months, how often did energy efficiency considerations influence the following design choices?

Choices in the fabric of the building

1□-Every time

2□-Seldom/sometimes

3□-Never

Specialist passive solar features (trombe walls, sun spaces etc)

1□-Every time

2□-Seldom/sometimes

3□-Never

Other passive solar features (window orientation, thermal mass, shading)

1□-Every time

2□-Seldom/sometimes

3□-Never

Choice of efficient appliances

1□-Every time

2□-Seldom/sometimes

3□-Never

17 Did you use any of the following design aids/tools to help you with these energy efficiency design choices?

1□-NZS4218P

1□-NZS4220

3□-ALF

4□-Other programmes

5□-Manufacturers information

6□-Attendance at seminars

7□-Other people

8□-.....

18 What training has the user had in the design aids/tools?

1☐-None

2☐-Course

3☐-Colleague

4☐-.....

19 How easy was it to use the above aids/tools?

1☐-Easy

2☐-Fair

3☐-Difficult

20 How often did the energy design choices affect building costs?

.... (No.)

How much?

$ +/- ....

+/- ....%

21 What would help you produce more energy efficient buildings?

1☐-General guidance (eg rules thumb, design guides, textbooks)

2☐-Savings estimates (manual calculations, computer calculations)

3☐-Examples (standards eg NZS 4218P, Approved Solutions, Case studies)

4☐-Other .....

22 Have you read the energy efficiency clause H1 of the Building Code?

1☐-Yes

2☐-No

How do you think it could be improved? .....

23 Have you used table 2 of the house insulation standard referred to in the code which allows you to trade off insulation in the walls against insulation in the roof?

1☐-Yes

2☐-No

How do you think it could be improved? .....

24 On how many buildings did you install double glazed vertical windows?

....

25 How many of the electric hot water cylinders in your buildings are the A grade Watermark type?

....%

Why not more? .....

26 On how many buildings did you use shading devices to reduce energy consumption of cooling equipment?

....

27 On how many buildings was some life cycle costing undertaken?

.... (No.)

If so, was energy included in the life cycle costs?

1☐-Yes

2☐-No

28 With non-residential buildings, how does the TA check for compliance with the Building Code clause H1.3.2? *(Expand on H1.3.2)* .....

29 Are the energy efficiency features of your buildings specifically checked to confirm that they are installed in accordance with the design? For example, are houses checked to confirm that insulation is installed in accordance with specification?

1☐-Yes

2☐-No

3☐-Not applicable

If yes, By whom?

1□-Designer

2□-Builder

3□-TA

4□-.....

30 *[If there are any mechanical heating and cooling appliances installed during construction]*
Are they checked to confirm that they initially operate in accordance with the design?
1☐-Yes
2☐-No

If yes, By whom?
3☐-Designer
4☐-Builder
5☐-Engineer
6☐-.....

How often are they operated in accordance with the design?
1☐-Always
2☐-Usually
3☐-Sometimes
4☐-Rarely
5☐-Never
6☐-NA

Other Energy Efficiency Design Aids/Tools

31 How did you design the daylighting and lighting system?
(eg NZS 6703, supplier support, books, rules of thumb, experience, calculations)

.....

32 What air conditioning design aids/tools did you use? *(eg Carrier/DOE2/ESP/ASHRAE/CIBSE)*

.....

33 What was the most important consideration in selecting water heating systems?
☐.....

34 **[PERSONAL INTERVIEW ONLY]** Please rank the following in order of importance for selecting water heating systems? (1 most 5 least)

☐-Equipment cost

☐-Fuel cost

☐-Equipment efficiency

☐-Fuel availability

☐-life cycle cost

☐-Service (eg volume/capacity)

35 What was the most important consideration in selecting space heating systems?

☐.....

36 **[PERSONAL INTERVIEW ONLY]** Please rank the following in order of importance for selecting space heating systems? (1 most 5 least)

☐-Equipment cost

☐-Fuel cost

☐-Equipment efficiency

☐-Fuel availability

☐-Life cycle cost

☐-Aesthetics

☐-Comfort

Sustainable Energy

37 The Building Code is worded in a way which seeks to encourage the use of sustainable energy. Have you used any of the following energy sources?

1☐-Solar water heating

2☐-Wood fuelled heating

3☐-Wind power

4☐-Photovoltaic generators

5☐-Micro-hydro generators

6☐-Passive solar design *(eg north facing windows, trombe wall, sun space)*

7☐-Geothermal heating

If so, why did you use them? .....

Were there any of these options that you decided against? Why .....

38 Has the Building Code encouraged you or assisted you in the use of these sustainable energy sources?

39 If you had to produce buildings with less purchased energy consumption, would you prefer to make them use less energy or replace the purchased energy with energy from sustainable sources such as the sun, wind, water etc.

1☐-Use less energy

☐2-Sustainable sources

Future Design of Energy Efficiency Features

40 Apart from the Building Code, do you expect to experience any pressures to produce more energy efficient buildings?

1☐-Yes

2☐-No

From whom? .....

41 What change in your building designs would be the best one to improve energy efficiency of buildings up to 300 m^2?

.....

42 Please score the following for improvement of energy efficiency in buildings up to 300m^2?

1 Extremely 2 Very 3 Quite 4 Important 5 Not important

☐-Use of sustainable energy (eg sun, wind, water)
☐-Improved equipment (eg better insulated HWC)
☐-Improved building fabric (eg insulation, double glazing)
☐-Improved building orientation
☐-Improved building operation (eg better controls)
☐-Other .....

43 What change in design would be the best one to improve energy efficiency of buildings more than 300 m^2?

.....

44 Please score the following for improvement of energy efficiency in buildings over 300m^2?

1 Extremely 2 Very 3 Quite 4 Important 5 Not important

☐-Use of sustainable energy (eg sun, wind, water)
☐-Better equipment, improved equipment
☐-Improved building fabric (eg insulation, double glazing)
☐-Improved building orientation
☐-Improved building operation (eg better controls)

45 If you had a choice, would you prefer to use an energy efficiency design aid/tool which involved;
1☐-Checklist
2☐-Manual calculation
3☐-Computer calculations
4☐-.....

46 If you had a choice, would you prefer to use an energy efficiency design aid/tool which;
1☐-Is only able to be used once all the dimensions of the building are known
2☐-Contains sufficient best guess data that it can be used very early in the design process (when only building size and type may be known).

47 If you had a choice, would you prefer to use an energy efficiency design aid/tool which;
1☐-Produces only code compliance reports,
2☐-Can be used to study general building energy and efficiency questions.

48 If you had a choice, would you prefer to use an energy efficiency design aid/tool which;
1☐-Is integrated with other office design tools eg CAD, quantities,
2☐-Stand alone.

Users of Energy Efficiency Design Aids/Tools

49 Who would be the primary users of energy efficiency design aids/tools which affect building construction?
(eg tools/aids which relate to thermal mass air leakage, solar gain, insulation, double glazing)

Buildings <300m^2	Buildings >300m^2
1□-Architect, designer	11□-Architect, designer
2□-Engineer	12□-Engineer
3□-Energy Consultant	13□-Energy Consultant
4□-Builder	14□-Builder
5□-.....	15□-.....

Why? .....

50 Who would be the primary users of energy efficiency design aids/tools which affect lighting?
(eg sizing windows for daylighting, planning electric lighting, lighting controls)

Buildings <300m^2	Buildings >300m^2
1□-Architect, designer	11□-Architect, designer
2□-Engineer	12□-Engineer
3□-Energy Consultant	13□-Energy Consultant
4□-Builder	14□-Builder
5□-.....	15□-.....

Why? .....

51 Who would be the primary users of energy efficiency design aids/tools which affect building heating and cooling services? *(eg finding the optimum combination of building mass and heating plant)*

Buildings <300m^2	Buildings >300m^2
1□-Architect, designer	11□-Architect, designer
2□-Engineer	12□-Engineer
3□-Energy Consultant	13□-Energy Consultant
4□-Builder	14□-Builder
5□-.....	15□-.....

Why? .....

52 Who would be the primary users of energy efficiency design aids/tools which affect building planning?
(eg grouping living areas on the warm side of houses)

Buildings <300m^2	Buildings >300m^2
1□-Architect, designer	11□-Architect, designer
2□-Engineer	12□-Engineer
3□-Energy Consultant	13□-Energy Consultant
4□-Builder	14□-Builder
5□-.....	15□-.....

Why? .....

C

USA questionnaire

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

usa_survey.wpd

Simulation Case Studies: a Survey of Users' Experiences

Michael Donn

September 1996

This "interview" form is designed to elicit responses which will help us all understand better the role of simulation in design. It is planned to use the analysis of the responses to develop three products:

- better data for those undertaking improvement and development of simulation design tools
- a report for simulation program users describing quality control procedures in simulation
- a brief for improvement of education of new users' of simulation programs

Our questions refer to a particular building your office or firm has worked on which has been recommended as worthy of closer examination in a case study of the influence of simulation on design. The notes from this survey form will be held in confidence by the Centre for Building Performance Research at Victoria University and the Windows and Lighting Group at Lawrence Berkeley National Laboratory. As the case study will require publication of details of the design of the building, we ask your permission to publish information about it in the summary reports of the analysis. If you do not understand something please ask for **clarification** at any time of the author Michael Donn. Your individual responses to the survey, where they do not relate directly to the design of the building will only be published in anonymous form.

1□-Permission to publish description of the building and impact of simulation on its design?

1 . . . . . (signed) ..... (date).....

---

1 Name . . . . . .

2 Address . . . . . .

3 Contact 'Phone number . . . . . .

4 Code Number . . . . . .

CODE NUMBER.....

Screening questions

1 To your knowledge, which of the following simulation programs were used as design aids/tools to help you with energy efficiency design choices in the design of . . . ? (READ ALL AND CHECK THOSE THAT APPLY)

DoE2 . . . . . ☐-1

a commercially available PC version of DoE . . . . . ☐-2

BLAST . . . . . ☐-3

a PC version of BLAST . . . . . ☐-4

TRACE or other TRANE product . . . . . ☐-5

HAP or other Carrier Product . . . . . ☐-6

ESP from APEC . . . . . ☐-7

Other (SPECIFY_____)..... . . . . ☐-8

IF MORE THAN ONE SIMULATION PROGRAM IS IDENTIFIED AS BEING USED IN DESIGN, GO ON TO QUESTION 2, ELSE GO TO QUESTION 3.

2 Of the programs you listed, which would you say was most used for design of the building envelope as opposed to HVAC services design? THE REST OF THE QUESTIONS IN THIS INTERVIEW ARE ABOUT USE OF THIS PROGRAM.

. . . . . ☐-1

3 Here are some situations where energy efficiency considerations might influence your design choices. I would like you to state how often they have influenced the design of buildings you have worked on in the past 12 months. Have (OPTION**) Always, Frequently, Sometimes or Never influenced your choice?.**

	Always	Frequently	Sometimes	Never
Building envelope alternatives	1		2	34 . . . . . -1
Specialist Solar features (sunspace, Trombe wall, ...)	1		2	34 . . . . . -2
Passive solar features (Orientation, mass, shading)	1		2	34 . . . . . -3
Selection of HVAC equipment	1		2	34 . . . . . -4

Your Firm

The next few questions help us establish the nature and character of your firm for comparison with those firms surveyed in the 'phone and mail surveys of simulationists earlier this year..

4 Would you describe your firm's role in the building industry as primarily HVAC Engineer, Architect, or Simulationist

HVAC Engineer . . . . . ☐-1

Architect . . . . . ☐-2

Simulationist . . . . . ☐-3

Utility support group . . . . . ☐-4

5 How would you characterise your own (primary) role in the firm - owner, manager, designer, a sole practitioner, or what?

Owner . . . . . ☐-1

Manager . . . . . ☐-2

Designer . . . . . ☐-3

Solo . . . . . ☐-4

Analyst . . . . . ☐-5

Other (SPECIFY_____) . . . . . ☐-6

6 As You read each of the following, please tell me whether your firm used a computer for that purpose during the past 12 months.

Word processing . . . . . ☐-1

Accounts . . . . . ☐-2

CAD (Computer Aided Drafting/Design) . . . . . ☐-3

Scheduling (Project management etc) . . . . . ☐-4

Design analysis (Structural, thermal, lighting calculations) . . . . . ☐-5

Any other way (SPECIFY_____) . . . ☐-6

Your Use of Information from Simulation Programs

7 What type of environmental simulation did you as architectural designer do (in-house) in the EARLY PHASES OF DESIGN of the case study building:

Use simple formulae to estimate allowable insulation thickness or glazing area . . ☐-1

Make simple (card) model of windows for shading or lighting studies . . . . . ☐-2

Run simple ("Energy 10" or "Energy Scheming") computer program . . . . . ☐-3

Other (SPECIFY_____) . . . . . ☐-4

8 What type of environmental simulation did you as architectural designer do (in-house) DURING DESIGN DEVELOPMENT for the case study building:

Use simple formulae to estimate allowable insulation thickness or glazing area . . ☐-1

Make simple (card) model of windows for shading or lighting studies . . . . . ☐-2

Run simple ("Energy 10" or "Energy Scheming") computer program . . . . . ☐-3

Run a complex computer thermal simulation program (e.g. DOE2, BLAST) . . . ☐-4

Run a complex computer lighting program (e.g. Radiance, Lightscape) . . . . . ☐-5

Other (SPECIFY_____) . . . . . ☐-6

9 How easy was it to use the simulation program in design, to explore the impact of design alternatives, and even to suggest ways in which the design might be improved (in other words as a design "tool"): *very easy; fairly easy; fairly hard; very difficult?*

Very easy . . . . . ☐-1

Fairly easy . . . . . ☐-2

Fairly hard . . . . . ☐-3

Very difficult . . . . . ☐-4

10 What type of environmental simulation did you as architectural designer have done by consultants in the EARLY PHASES OF the

DESIGN:

Use simple formulae to estimate allowable insulation thickness or glazing area . . ☐-1

Make simple (card) model of windows for shading or lighting studies . . . . . ☐-2

Run simple ("Energy 10" or "Energy Scheming") computer program . . . . . ☐-3

Run a complex computer thermal simulation program (e.g. DOE2, BLAST) . . . . ☐-4

Run a complex computer lighting program (e.g. Radiance, Lightscape) . . . . . ☐-5

Other (SPECIFY_____) . . . . . ☐-6

11 What type of environmental simulation did you as architectural designer have done by consultants DURING DESIGN DEVELOPMENT:

Use simple formulae to estimate allowable insulation thickness or glazing area . . ☐-1

Make simple (card) model of windows for shading or lighting studies . . . . . ☐-2

Run simple ("Energy 10" or "Energy Scheming") computer program . . . . . ☐-3

Run a complex computer thermal simulation program (e.g. DOE2, BLAST) . . . . ☐-4

Run a complex computer lighting program (e.g. Radiance, Lightscape) . . . . . ☐-5

Other (SPECIFY_____) . . . . . ☐-6

12 Read this list of four different levels or types of design aid / tool which could be provided to assist you to produce more energy efficient buildings. Please tell me how helpful they might be to you personally. On a scale from Would they help *a lot*; Help *a little*; *Not* help *much*; and *Never* help.

	A lot	A little	Not much	Never
General guidance (e.g. rules of thumb, design guides, text books)	1	2	34	-1
Savings estimators (e.g. charts and tables for use with calculators or their spreadsheet equivalents)	1	2	34	-2
Simulation programs	1	2	34	-3

(Computer programs which simulate a building's environment)

Examples 1 2 34 . . . . . -4
(e.g. Case studies, standards)

Other Energy Efficiency Design Aids/Tools

13 How often do you try to integrate the daylighting and/or the lighting system design with the thermal design: please answer this question on a scale of *Always, Frequently, Sometimes, Never*?

Always . . . . . ☐-1

Frequently . . . . . ☐-2

Sometimes . . . . . ☐-3

Never . . . . . ☐-4

The Principal Simulation Program Itself

14 Approximately how many years have you been a designer of energy efficient large scale buildings: less than a year; at least one year but less than 3; 3 years or more?

Less than a year . . . . . ☐-1

At least one year and less than 3 . . . . . ☐-2

3 years or more . . . . . ☐-3

15 About how often do you use simulation (directly or through consultants) : very occasionally; regularly, but not on every project; or on every project?

Once or twice a year . . . . . ☐-1

Regularly, but not on every project . . . . . ☐-2

On every project . . . . . ☐-3

16 When you do use it, how often is it because of the factors in this list? (FOR EACH**): Is that your reason on most buildings, some, very few, or none of your buildings?**

	Most	Some	Few	None
Compliance with State Energy Codes	1	2	34	-1
Because you're working on Government (FEMP) projects	1	2	34	-2
Because you're receiving a Government subsidy	1	2	34	-3
Because you want to optimise the Design for the client or architect	1	2	34	-4
Because you're part of a Utility DSM programme	1	2	34	-5

. . . . . .

. . . . . .

. . . . . .

The Impact of the Simulation Program

17 Were there questions or issues that you found simulation could not resolve, that you had expected it to?

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

18 Are there questions that you would like answered by simulation that would improve the design of buildings?

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

19 Did Simulation improve the quality of your design?

Yes . . . . . ☐-1

No . . . . . ☐-2

IF THE ANSWER TO THIS QUESTION IS NO, THEN SKIP THE NEXT QUESTION TO QUESTION 21.

20 How did the simulation improve the quality of your design?

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

21 If you can, please describe the form or format of the output of the THERMAL SIMULATION that you felt was most useful to you during the design process.

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

22 If you can, please describe the form or format of the output of the LIGHTING SIMULATION that you felt was most useful to you during the design process.

. . . . . .

. . . . . .

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23 In your opinion, did the THERMAL SIMULATION analysis for the case study building improve the design?

Yes, definitely . . . . . ☐-1

Yes, probably . . . . . ☐-2

No . . . . . ☐-3

. . . . . ☐-4

IF THE ANSWER TO THIS QUESTION IS NO, THEN SKIP TO QUESTION 24.

24 Could you please describe briefly what in particular was improved in the design of the cae study building.

. . . . . .

. . . . . .

. . . . . .

. . . . . .

25 In your opinion, did the LIGHTING SIMULATION analysis for the case study building improve the design?

Yes, definitely . . . . . ☐-1

Yes, probably . . . . . ☐-2

No . . . . . ☐-3

. . . . . ☐-4

IF THE ANSWER TO THIS QUESTION IS NO, THEN SKIP TO QUESTION 27.

26 Could you please describe briefly what in particular was improved in the design of the case study building.

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. . . . . .

27 The building industry is currently discussing a building product model which will permit all members of the building design team to exchange computer data describing a building. This raises the prospect of "Clicking" the analyse button on the CAD program menu. Given this prospect, would you prefer to

Click a button to produce the lighting output for analysis in-house . . . . . ☐-1

Click a button to forward the data to the lighting consultant for analysis . . . . . ☐-2

Click a button to produce the energy performance output for analysis in-house . ☐-3

Click a button to forward the data to the energy analyst for review . . . . . ☐-4

. . . . . ☐-5

28 When you do simulations, at what stage(s) in the design process do you seek results that you can use in design: during the preliminary design phase; during design development; while working drawings are being produced or at some other point? (CODE ALL THAT APPLY)

Early or preliminary design . . . . . ☐-1

Design Development . . . . . ☐-2

Working Drawings . . . . . ☐-3

None of the above, design process different . . . . . ☐-4

Thank You!

M.R. DONN

D

USA survey brochure & letter

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

usa_brochure.wpd

BACKGROUND

Computer programs that simulate building performance can provide accurate answers to design questions. However, in successive New Zealand case studies simulating daylight or heating energy use with different programs, I have observed that designers wish to ask questions other than those the software is designed to answer. The case studies described below involved an art gallery, a library, a museum, an office, and a police station.

Figure 1

Simulation programs are made accurately to represent the performance of buildings. But: the designer often wants quantitative information with this qualitative picture. Merely simulating what a building might look like (Figure 1) is not enough. For example, *in an art gallery*, adding into the simulation a single spotlight illuminating a surface in the gallery to 150 lux gave the picture a physical scale relevant to the curator(Figure 2).

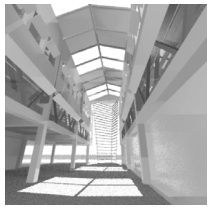

Figure 2

Similarly, *in a public library*, the principal concern of the librarian was not energy use but the potential risk of overheating with a natural ventilation cooling system using sea breezes.

In a major museum the concern was how much sun and daylight would spill from circulation areas into the galleries. Nothing short of an animation could have shown the client how brief or long some exposures might be. (Figure 3)

Figure 3

BACKGROUND continued...

In an atrium lit office, ray- traced pictures provided some credibility to the design, and graphs of temperatures some reassurance that the analysis was rigorous. But the architects sought reassurance about performance changes as they varied their design from the simulated "optimum". Such sensitivity questions are at the heart of design decision making.

Finally , *in a regional police station* an appropriate level of detail was used in the models such that answers were produced quickly at the start of the design process. But, the process was constrained to creating models that could be used in the higher level of complexity required later in the design process.

In each of the above cases the essential requirement is for an expert simulationist. The expert's role is to:

- Record data from one simulation so that it is available and consistent with the data for another.
- Maintain consistency between "versions" of the building as its design develops.
- Provide advice on interpretation of the output of the simulation - what does it "mean".

Better early design decisions imply better overall building performance. Simulation offers a way to improve the design team's understanding of the building. But, making simulation programs usable by architects is more than just adding a user friendly interface. This research aims to document how today's designers use simulation so future building simulation tools can be written to support these activities.

GOALS and BENEFITS

I plan to interview as many people as possible about their use of computer simulation in building design to learn how they are using it and what they are using it for.

The principal outcomes from this exercise are planned to be:

- better data for the improvement and development of simulation programs as design tools
- a report for simulation users describing how others maintain quality assurance in their simulations
- a brief for improvement of the education of new users of simulation programs

My premise in this project is that while architects and clients are interested in environmental design, the simulation programs currently available do not directly address their specific design tool needs.

Simplification of the simulation program input or output, or worse still of its rigorous model of reality, too often ends up trivialising the issues to the point where the designer often sees no relevance in the remote or abstract information produced.

Expert users or advisers also can hinder the design process as their interests are different than the designer's. The project explores the role that simulation may have in improving design through involvement of designers directly in evaluation of the performance of their buildings.

This study has identified your firm as a user of a simulation program. I would like to arrange a time to interview you, or another appropriate employee of your firm. I shall 'phone to arrange an appropriate telephone interview date within the next 2 weeks. With your help during the interview I would also like to identify a small number of projects to document in detail as case studies. The larger survey of simulationists, mostly conducted by telephone, will provide a context for these cases.

The Interview

The questions will identify the different ways in which simulation is used in your practice to assist the design of new and the retrofit of existing buildings.

Duration

It is anticipated that general interviews will take about half an hour. The longer case studies will involve my non-participatory attendance at some site meetings.

Analysis

The analysis will consist of reporting the words of the interviewees in a structured manner. The analysis techniques will identify the commonalities and the differences among the cases and seek to link these to the types of simulations and questions being asked by the design teams interviewed.

Privacy

No reports and papers arising out of this research

will contain information through which the persons interviewed could be identified.

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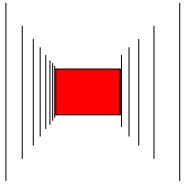
Email mrdonn@lbl.gov

Computer Based Environmental Design Tools



A survey of their use in practice

A survey of their use in practice

A survey of their use in practice

E

LBNL previous survey results

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

winkelmann_comments.wpd

Date: Mon, 8 Jan 96 10:49:47 PST
From: fcw@pegasus.lbl.gov (Fred Winkelmann)
To: mrdonn@lbl.gov
Subject: Re: DOE2 Users' Survey

Mike, here are the survey results. The "11111"'s are a count of number of responses in each category.

DOE-2 1995 SURVEY
Summary of 105 responses from 1200 questionnaires sent out
7/24/95

Type of organization
consulting engineering 11111111111111111111111111111
university/research 1111111111111111111111
A/E 1111111111111111
university/teaching 111111111
federal government 11111111
utility 1111111
R&D consulting 111111
manufacturer 11111
city/state energy department 1111
ESCO 111
state research 11
architect 11

Why DOE-2 chosen
flexibility, range of modeling options 1111111111111111111111111111111
recognition 111111111111111
accuracy 111111111
best available 1111111
industry standard 111111
validated 11111
client preference 1111
availability 111
support 111
equipment configurations 11
reliability 11
hourly 11
not a black box 111
hourly reports
ability to compare complex energy systems
project requirement
peer acceptance
whole building
parametric run capability

large user community
completeness
required for gov't jobs
can save loads for systems parametrics
continuously improving
speed
plant program
IEA credibility
accessibility on PC as well as UNIX
"other programs considered self serving"
unbiased
approved by California Energy Commission

DOE-2 Applications
commercial buildings 1111111111111111111111111111111111111111111111111111
institutional buildings11111111111111111111111111111111111
research 11111111111111111111111111
residential buildings 1111111111111111111
retail stores 111111111111111111
industrial buildings 1111111111111
teaching 111111111
DSM programs 1111
agricultural buildings

Extent of use of DOE-2 on actual buildings ([extrapolated sf] = (1200/105) x [respondees sf])

New buildings to date, US: respondees = 166 million sf, extrapolated = 1903 million sf

Retrofits to date, US: respondees = 348 million sf, extrapolated = 3977 million sf

New buildings last year, US: respondees = 20 million sf, extrapolated = 230 million sf

Retrofits last year, US: respondees = 82 million sf, extrapolated = 933 million sf

Percent energy savings using DOE-2: average = 21.8%

[10-63,10-20,10-40,12-30,10,10-50,10-30,35,10,5-40,5-25,5-10,15,15-30,5-20,10-30,25,15-20,0-65,20-30,35,15-25,20,30,5-15,10-15,15,10-40,20-50,15,6-25,20-25,10,10-35,20-40,15,70,10-25,10,50,10-20,25,20-30,20-40,20-35,35,10-30,15,5-40,10-35,8-35,10-45,20-50

,10-15,10,10-20]

Suggested calculation improvements (italicized items will be available in PowerDOE 1.0)

heat balance loads 11111111111

more system and plant options 11111111

user-configured systems and plant from components 1111111

improved ground heat transfer 11111

improved system sizing calculations 11111

improved daylighting for complex geometries (light shelves, etc.) 11111

air flow network (zone-zone air transfer, air transfer between infiltration and exhaust, natural ventilation) 1111

more system and plant types 1111

smaller time step for electrical demand calculation 1111

smaller time step for equipment simulation 1111

higher limit on number of zones, systems and schedules 111

radiant cooling 111

primary and secondary pumping 111

more pump and fan detail 111

IAQ simulation 11

radiant heating 11

ground source heat pump 11

PLANT input functions 11

scheduling of hot and chilled water pumps

auto-sizing of pumps

user-defined component models

zone-zone interaction improvement

zone-to-zone air transfer

comfort calculation including radiant temp

improved window blind thermal modeling

increased number of allowed layers in constructions

natural ventilation option in all system types

VAV with terminal cooling

remove restriction in some systems that supply air temperature from main heating coil cannot exceed MIN-SUPPLY-T

allow PIU system to draw air from same zone to increase circulation

fan-powered terminal box with terminal cooling

Allow constant volume systems to have DATR

mixed air reset

residential system with baseboards and mechanical ventilation but no air conditioning

earth coupling for outside air

radiant barriers

floating temperature and ventilation load in LOADS

ECONOMICS runnable with user-defined energy/demand profile

parasitics based on state of simulation (e.g., 20W/ton if fan on and chiller off)

dual-fan dual-duct system type

SYSTEMS load component breakdown, including ventilation

higher limit on number of walls and windows

more air-to-air heat recovery system types
more flexible modeling of system and plan controls
vary interior window film coefficient with flow rate from under-window registers
active solar systems
easier input functions and macros
easier modeling of multiple buildings on single plant
better modeling of multiple chillers/cooling towers
more cooling tower types
multiple chillers of same type and different performance curves 11
multiple chillers with dedicated cooling towers
cooling tower with variable-speed fan
easier functions and macros
easier specification of animal heat and moisture production
HVAC systems for livestock buildings
dynamic envelopes
combined electric lighting and daylighting illuminance calculation
better simulation of space temperatures and HVAC performance when plant is undersized
electric heating in fan coil
more temperature control options
swimming pool
more than one plant on same meters
demand limiting
moisture absorption/desorption
more controls options
input function hooks to external programs
more robust metric version
better supermarket case load simulation
model systems run in non-standard way
model systems in disrepair
supplemental zone cooling
dhw heating from steam boilers
zone/subzone pressurization
inducing air from plenums and zones
occupancy controlled ventilation
better modeling of non-residential natural ventilation
vary supply cfm by schedule (time controlled VAV)
ECONOMICS input functions
zone-level humdity calculation
better life-cycle cost program
make it easier to match plant to actual configurations
faster calculation
optimization routines
more than one system per zone
reengineer code rather than patch
better modeling of ventilation of atria and large buildings
system sizing: SS-J and SS-H often report conflicting capacity predictions
portable to any PC or mainframe

interactive setup to maximize performance on any platform
common return air plenum for multiple systems
ability to modify weather file to baseline year parameters
ability to enter actual billing data and compare with predicted billing
integrate LOADS and SYSTEMS
integrate SYSTEMS and PLANT
account for power factor, power conditioning and transformer losses
fix bugs quickly
model everything available to current technology
assure upward compatibility of new versions or provide translators from old to new versions
Loads is good, Systems is OK, Plant is pretty rough--concentrate on Systems and Plant (Tuluca)

Suggested user interface improvements (italicized items will be available in PowerDOE 1.0)
Windows front end 11111111111111111111111111111111111111111111111111
3-D building view 111111111111
easy switch between menu driven and BDL formats 111111
on-line help 1111
library of prepackaged systems 1111
expanded materials and constructions library 111
library of prepackaged plants 111
interface version for Mac 111
better input error checking 11
parametric analysis manager 11
library of actual manufacturer's equipment 11
ability to start from a scalable building template 11
engineering design assistance module 11
digitizing of plans for geometry input 11
set of "building blocks" from which to assemble a model 11
graphical display of equipment part load curves
library of operation schedules
library of space types
ability to enter different types of plug loads in a space
graphics of systems and plant layout
map and hooks for shell development
library of rate schedules
easier way than curve fit to enter part load performance
more realistic systems and plant defaults
better reporting of equipment default values
worldwide weather availability
show seldom used variables on secondary menus
alternative inputs: per_zone, per_person, per_installed_tons, etc.
more realistic default for DHW tank loss coefficient
use standard engineering input units (e.g., tons instead of MBtuh)
automatically adjust building model for code compliance
standard weather profiles for days, weeks and years with comfort as target
automatic determination of adjacencies

graphical grouping of rooms into zones

Suggested results display improvements (italicized items will be available in PowerDOE 1.0)

graphical output 1111111111111111111111111111111111

easy link to spreadsheet 111111111111

user-customized report formatting 11111111

graphical comparison of base case and alternatives 111

ability to print reports without rerunning 111

scatter plots 11

cut and paste results to other applications

display execution status

option to print no reports

end use energy and demand summary

finer disaggregation into end uses

include heat pump supplemental heating in electric heating hourly report variable

graphic display of system and plant showing how loads effect operation for typical days (useful for presentations and learning)

output macros to calculate custom results from standard results

standard hourly, monthly, annual graphic display pallet

easy method of choosing hourly report data

make reports fit in standard width screen

custom units for reporting (e.g. tons instead of Btuh)

real-time plots of selected variables with auto-suspend when value exceeded

color coding of space conditions, like temperature

comparison of simulation to monitored or utility data

checksum outputs (sqft/ton, cfm/ft2, kw/ton, etc.

"rulers" to measure relative size of output values

report with utility usages, peaks and costs on one page

Suggested documentation improvements

combine Reference Manual and Supplement 11111111111111111111111111111111111

index 1111111111

update Engineering Manual 11111111

on-line documentation 11111111

tutorial manual 11111

more examples of commands 1111

put on CD-ROM 1111

hypertext 111

Web site for documentation updates 111

separate start-up, tutorial and full doc 11

more advanced simulation examples 11

better definition of output variables 11
more examples of real engineering problems 11
cookbook with input for most popular loads, systems and plant configurations
tutorial starting with a CAD drawing and showing input steps and simplifications
more explanation and examples of input parameters
separate engineering description and progrmming description in Engineers Manual
make topic based
have Hewlett-Packard do it
faster response from NTIS
more system type examples
better overview of calculation methodology
better organization and overview
lite version for residential modeling
better description of dehumidification for different systems
make language more consistent with current terminology
sample run for each building type

Other energy programs used
TRACE 600 11111111111111111111
BLAST 11111111111111
Carrier HAP 1111111111111
ASEAM 111111111111
Micro-AXCESS 111111111111
Carrier E20 11111111
TRNSYS 11111111
Energy Scheming 11111
ESP-r 11111
FSEC 111
HOT-2000 111
SERIRES 111
ADM-2 11
Market Manager 111
MicroPAS 11
TARP 11
TrakLoad
QUICK (South Africa)
KAREN (Korea)
HELIOS (Switzerland)
CECDOE2
Softdesk Energy
LoadShaper
SPARK
CHVAC
HEVACOMP
COMTECH
WATSUN (active solar)

EEDO
SEA
Wilkes attic model coupled with DOE-2
ESPRE
CALPAS
Cheetah (Australia)
Benchmark
SUNCODE
HVACSIM+

Other design tools used
AutoCAD 11111111111111111111111111
other CAD 1111111111111111111
Lighting design 1111111111111111
Radiance 111111
ENVSTD 1111
Window-4 11111
Code compliance 1111
SuperLite 111
Comply-24 111
Equipment selection software 11
WaterSim
ESP+
Sweet source CD-ROM
BuilderGuide
Lighting survey spreadsheet
Solar 5
Sun Path
Sun Spec
Model View
Duct sizing
Spreadsheets 111
Trane Load calc.
Frame 3.1
RESFEN
Manual J
BLCC4
APEC HCCV
APEC SuperDuct
APEC PSA
AES Loads
AES Ducts
Elite design packages
Load analysis
Phoenics
Flow3D

FloVent

Airnet

Contam93

Exposure

Caline3 (air pollution)

CFAST, FIRST, CCFM.VENTS, ASET, FIRECALC (fire simulation)

BOSE (acoustics)

Integration of DOE-2 with other programs useful?

connect to CAD for geometry input 1111111111111111111111111111111111111111

connect to lighting program 11111111111111111111

connect to compliance software 111111111111111

connect to standard building description 111

don't want integration 11

connect to daylighting program 11

connect to equipment sizing program 11

connect to airflow program

connect to active solar program

connect to WaterSim

connect to Radiance

connect to spreadsheets

connect to window program

connect to life-cycle costing

connect to piping and duct design

"input data once should be the name of the religion"

integrate AutoCAD, Radiance, energy and compliance software

Other recommendations (italicized items will be available for PowerDOE 1.0)

better promotion

better user support

establish technical training center

lower cost for US than foreign

industry-wide use of DOE-2 would save resources supporting lesser programs

make User News monthly and expand

A/C contractors get mad because DOE-2 gives lower equipment tonnage than Manual J so they lose profits

F

CBPR analysts' comments

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

cbpr_analysts.wpd

F-6.2 Analyst 1

No Opportunity to present findings in person.

i..e. talk to group

explain tests/results

Discuss questions

Suggest options in conjunction with engineer / architect

Clear brief made known to ourselves, architect, client

Discussion of our design modifications with architect rather than written / faxed correspondence. Opportunity to discuss problems, design requirements, reasons why things have or have not been done a certain way ... explaining benefits of recommendations.

No clear communication channel established with engineer / architect.

Report and recommendations prepared in a rushed manner. Standard probably OK for oral presentation / explanation, but probably difficult to understand as a stand alone document.

I get the feeling the report received minimum "airplay" at the meeting. Also, the meeting may have been too late for our recommendations to be considered.

The questions or feedback from architect not helpful, probably as a result of this poor communication.

F-6.3 Analyst 2

– The architect needs to be aware of the role of CBPR. Needs to be identified as an interactive process in that changes in either must be acknowledged by the other.

Regular meetings. CBPR must be seen as a sub-consultant. Possibly funding to come from the architect. Client pressure on them to utilise CBPR.

Accountability; architect needs to be accountable to client. Problem is that funding provided by someone with their own interests at heart (ECNZ) which may not have been important to the architect.

Tightness of time schedule. Perhaps it was impossible task. Bulleyment-Fortune could not vary their design due to pressures of working drawings, etc.

Perception of role of CBPR not viewed as important in the process of completing the building at cost, and on time - minimal emphasis on quality.

CBPR should have been involved prior to the design stage re planning / construction / materiality. The results of the CBPR analysis should have been seen more in the light of design rather than pure servicing which may be easy to brush aside and deal with later on.

CBPR was not utilised as a knowledgeable consultant. The architect may not have been aware of the skill / expertise available.

It was necessary for the architect to lay down some concrete deadlines for submission by CBPR after which design work would cease. The process undertaken was no more than a retro-reflective look at a fixed design which may or may not have the ability to influence any further design decisions, any more than would have simple tables for lighting / heating.

Simply, the design process was not two way. Nor was it interactive. Should the people who were involved in doing the work have been able to meet with the architects to create a dialogue for each party to establish the position of the other.

CBPR required to clearly define what would be provided to enable dis-association if breach occurs.

Key points:

- identification of role of CBPR to architect
- regular meetigs. CBPR must be seen as sub-consultant
- definition of accountability
- identification of time schedule. Critical dates. This would clarify tasks of CBPR
-
- Involvement of CBPR - defined and participate early.

Analyst 3

- The architect did not appear to be very interested in cooperating with us. His lack of interest seemed to directly influence everyone else as the architect is the primary coordinator
- Mainly lack of interaction at all levels with people who were committed to getting an energy efficient structure and putting the time in for that output.
- Regular meetings with all concerned may have helped as well as regular communication with those we were directly working with / against - especially with respect to the architect
- Possibly having Electricorp more dominant rather than just reported to as to progress. Are they interested in the actual result? And are they prepared to put some time commitment in? Same with the Police station - very little interaction with them. Is this a reflection of the way Bulleyment

Fortune communicate with their clients or is it that the distance they were away made a difference?

- Getting more specific about what they actually wanted to achieve would have made our job easier. i.e. were they interested in more clerestorey glazing, reduced lighting during daylight hours, tinted glazing or more storage material? Getting no feedback from the changes we made did not help!

In conclusion, what struck me the most as being missing was clearly establishing with all parties exactly what you al intend to achieve and having a close cooperation between all parties throughout the whole process.

G

CBPR client comments

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

becker_architect_interviews.wpd

G-6.4 Climate

The architects identified our benign climate as having facilitated the use of tinted glazing as the environmental filter in our commercial buildings. However, this has not been an option in countries with a more extreme climate. "Thick friendly walls" usually cost more than glazed curtain walls, so they are currently not being utilised by architects in their commercial building designs.

One architect commented: New Zealand is unusual because it has very little variations between seasons, so the environmental control problems don't arise to the same degree as in other countries.

Our climate lets the developer get away with a lot, because of the benign climate. In other countries, these buildings would be uninhabitable. ... Since the 1972 oil crisis, energy hasn't been a problem ... overseas these energy issues have always been there, because of the extremes in climate.

One architect said: Glazing has had huge technological breakthroughs, so you can minimise the old [environmental control] problems by just using a sheet of glass. While the other thought: Architects ask too much of the glass and too much of the air conditioning systems".

G-6.5 Cost

New Zealand's commercial building industry is mostly financed by developers, who, the architects felt, are interested in constructing buildings as cheaply as possible. They are not generally concerned with spending extra to reduce running costs in a building or to provide a high standard of indoor environment, which are the benefits that "thick friendly walls" offer.

Many of the literature case study buildings were in countries that have tight energy efficiency regulations, requiring more than a glazed curtain wall as the environmental filter. Often the projects were government subsidised to provide examples of environmentally friendly buildings.

In most commercial developments, the occupant is not important, it is dollar driven. Because the benefits of "thick friendly walls" are of advantage to building users, not the developer, the likely increase in construction cost will make developers uninterested in the "thick wall" options. Another disadvantage of "thick friendly walls" suggested from the

develpers' point of view is the lettable space in a building, therefore they desire walls of a minimum thickness.

One architect suggested a tax rebate: Setting an energy consumption level for a certain size building and giving a rebate if the building comes in under that level.

The architect for the Schools of Architecture and Design building gave the example of a project budget being split up into discrete smaller budgets. Therefore, the quantity of glazing in the building was partially determined by the size of the glazing budget. The area of glazing could not have been increased by cost savings made elsewhere in the building.

Quantifying information is important. Dollars are something the client can understand.

G-6.6 Economics

Both architects identified recent economic conditions in New Zealand resulting in dramatic reductions in architects' fees as an obstacle to designing "thick friendly walls". The reduced fees mean that architects can't afford the time required to experiment with the design and detailing of "thick friendly walls".

One architect said that the number of jobs for which he is having to tender is increasing, and this is pushing fees down and making it uneconomic to design "thick friendly walls". [We] had limited funds, therefore we had to produce a design quickly to come within the fees we were being paid. [Because of the] minimum fee we weren't interested in pursuing alternatives unless we were paid for it.

Low fees, resulting in limited design time, affected how advantageous both architects found the services of the Centre for Building Performance Research. The computer modelling done by CBPR was considered useful, but the information was not available immediately enough, to keep pace with the required design speed. The architects indicated that the extra time required to fully consider the options put forward by the CBPR would have put them behind schedule and they couldn't afford to do that because the short design time was necessary to ensure the architects didn't lose money on the job. Another problem with using CBPR to do computer modelling in the scenario of low architect's fees, was that there wasn't adequate money to pay for it. One architect felt that minimum fees are discouraging architects in New Zealand from experimenting with non-conventional ideas because of the risk involved. Although used overseas, "thick friendly walls" are still unusual in the New Zealand context and architects' unfamiliarity with them produces a situation of increased risk. Architects already have one of the highest risk factors of all professionals in New Zealand and they would need to be paid a good fees before they were willing to experiment with ideas and technologies which were new to them.

G-6.7 Regulations

The architects felt that because some regulations in New Zealand are very strict, such as fire safety and disability access, the money spent to meet these requirements, cannot be spent in other areas. This means that other issues which are not regulated so stringently, for instance healthy work environments and energy efficiency, receive less priority.

One of the architects felt that the New Zealand Building Code is very strict in terms of how buildings must be constructed and how long they must last. He thought it is unfortunate that the Building Code is not backed up by regulations stating that a building must be designed to be flexible enough to be able to be used for that length of time. He thought that any careful design of natural systems facilitated by "thick friendly walls" becomes a waste of money, when the next tenant moves in and partitions off the whole interior, rendering the passive systems useless.

G-6.8 Client Expectation

Both architects though that clients usually have an expectation of what they want in terms of a building design from an architect. This is usually based on what they see elsewhere and especially in the case of a developer the maximum price they want to pay.

Clients need to be shown. Often they only see as far as what they see elsewhere. Clients need to be taken beyond their experience. This architect thought that inexperienced clients don't fully appreciate how being aesthetically driven as well as cost driven can improve a building. These clients would find it difficult to weigh up the advantages of "thick friendly walls" against the cost.

Clients requirements dictate going in a certain direction. Both architects identified two very different types of client, the developer and the building end user. One of the architects' opinion of most developers was that, the end user was not a high priority. [The developers] know what they want and the cheapest way to get it. Even when the client is the end user, the other architect felt that the internal environment of the building was not of great concern. New Zealand people don't seem to care too much about their internal environments. Mostly now only Government employees get good internal environments .. because the user has more clout, but with the decline of the unions, this is less the case.

G-6.9 User Participation

Although not specific to the New Zealand context, both architects and the literature surveyed, identified relying on user participation to operate adjustable elements in "thick friendly walls" can be a problem.

People will only adjust louvres by necessity. They need to be simple to use and easily adjusted. One architect also felt that educating the user was important, not only in the use of the "thick friendly wall" but also to the advantages of them. He said that people were so used to stable, artificially controlled environments that they complain about drafts in naturally ventilated buildings, even if is just a perceived draft...

Both architects identified maintenance as a problem with "thick friendly walls", since, for example, light shelves have to be clean to work to their full potential. Both said that ease of access was an important design consideration.

G-6.10 Information

Both architects said that technical literature on environmental control was available in New Zealand, but was aimed at scientists and researchers, not architects. They felt that a text written especially for architects and their clients on "thick friendly walls" would be useful. They felt that the periodicals, while reviewing new buildings incorporating "thick friendly walls" were failing to give sufficient information. Most articles do not discuss environmental control, or provide psot occupancy evaluations to show success or failure of the "thick wall" designs.

The architects thought that the testing of "thick friendly wall" options by the CBPR could be useful to architects, but currently the service is not fulfilling their requirements. The speed with which results can be produced is too slow for today's tight building schedules and information is arriving too late to be of use. CBPR is also not marketing itself effectively. The gap between CBPR, as researchers and the client in the market place is not being adequately bridged. Ideas of "thick friendly walls" need to be sold to clients and architects and the CBPR is currently failing to do this.

G-6.11 Aesthetics

Both architects felt that the way "thick friendly walls" impact aesthetically on a building design is important. This issue was not discussed in the literature, but both architects'

negative reactions to the aesthetic of one of the case study buildings indicates that this is probably an obstacle overseas as well.

You don't want buildings which look as though they have been designed around the environmental control issues. Thick walls are scientifically driven and science and aesthetics can be difficult to come together. You need to look at the macro and the micro - the overview. [How well this is done] depends on the skill of the architect to combine many different factors. At the end of the day you can't compromise the aesthetic quality or an engineer could have designed the building... The other architect though that A good architect should be able to play within any system and make it look good..

Combing technical and aesthetic issues was seen as the main design difficulty with utilising "thick friendly walls". Both architects cited Norman Foster as an architect who does this particularly well.

H

WCC wind ordinance text

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

OBJECTIVE

12.2.2 To maintain and enhance the amenity values of the Central Area and any nearby residential areas.

POLICIES

To achieve this objective, Council will:

12.2.2.4 **Ensure that the buildings are designed to minimise wind problems that they create.**

METHODS

- Rules
- Information (Wind design guide)

Tall buildings can induce wind changes at ground level. This can make activities on the ground uncomfortable, difficult and even dangerous. Wind rules will therefore be enforced to ensure that adverse effects are avoided or reduced.

The environmental result will be that the adverse effect of wind around buildings is minimised.

13.1.2.11 **Wind (except in the operational port area)**
Refer to policy 12.2.2.4

New buildings or structures above 4 storeys in height shall be designed to comply with the following standards:

Existing wind speeds	Wind speeds resulting from development proposal	Requirements on developer
	If exceeding 10m/sec in any public space	Reduce to 10m/sec in the public space
Up to 15m/sec	If exceeding 15m/sec	1. Reduce to 15m/sec 2. Although other directional speeds may be increased towards 15m/sec, overall impact is to be no worse than existing
15-18m/sec	If exceeding 15m/sec	Reduce to max 15m/sec
Above 18m/sec	If more than 18m/sec	Reduce to max 18m/sec

To show that a proposed development complies with these standards, a wind report must be supplied which includes the results of a wind tunnel test.

The test or tests must examine the effects of the proposed building upon areas open to the public, such as adjacent roads, parks, malls, plazas, public carparks, the immediate forecourt area and entranceways to proposed buildings.

The tests must also be operated on the following basis:

- maximum annual occurrence within daylight hours;
- simulated 3 second gusts at a 2 metre height;
- the proposed development must be tested against the existing situation except where the site is currently cleared. If the latter is the case, the proposal must be tested against the building which

For the form and content of reports on wind tunnel tests, refer to Appendix 7.

The wind rules are designed to encourage a safe and pleasant environment by decreasing the worst effects of wind. The standards work to ensure that no development makes the environment around buildings dangerous or makes the existing wind environment significantly worse.

For information, the effects of wind at various speeds are:

10 metres/second - Generally the limit for comfort when standing or sitting for lengthy periods in an open space.

15 metres/second - Generally the limit of acceptability for comfort whilst walking.

18 metres/second - Threshold of danger level.

23 metres/second - Completely unacceptable for walking.

Assessment Criteria

In determining whether to grant consent and what conditions, if any, to impose, Council will be guided by the following criteria:

Wind *Refer to policy 12.2.2.4*

13.3.2.22 whether a proposed development makes the environment dangerous or makes the existing wind environment significantly worse. Under this rule any reduction in the specified standard will only be considered where it can be shown that every reasonable alternative building design has been explored. A full wind report must be supplied in support of the application;

Council aims is to encourage a safe and pleasant environment by ameliorating the worst effects of wind. In some limited cases, some reduction in the standards may be justified.

APPENDIX 7: WIND

This Appendix details the form and content of reports on wind tunnel tests as required by Rule 13.1.2.10.

1. Aims of the wind tunnel test

The aims of a standard wind tunnel test are:

1.1 to examine a building proposal in order to quantify any wind problems and to test alternative solutions to them; and

1.2 to provide documentary evidence, of the proposed building's positive effect on the wind environment emphasising measures taken to improve the wind environment, and describing other options for development that have been tested.

2. Form of the wind tunnel test

A standard wind tunnel test must meet these conditions:

2.1 The wind tunnel used in this procedure must reproduce the wind speed variation with height observed in the atmospheric boundary layer, at the model scale used for the model of the building proposal to be tested. A simple power law relationship may be used for this variation, such that:

$$\text{Velocity at height } H = V_G \, (H/H_G)^{\varphi}$$

where H_G is the height above the city at which the shear forces of the atmospheric boundary layer give way to the pressure forces driving the wind; where V_G is the (gradient) velocity of the wind above this gradient height; and where φ has a value between 0.3 and 0.45 in Wellington.

Other expressions for the relationship between height and wind speed may be accepted if their derivation is adequately documented in each wind report.

2.2 The wind tunnel model of the velocity profile of the atmosphere must model the turbulence at scale heights between 0 and 200 metres in the wind tunnel, namely:

- between 30 percent and 40 percent at a scale height of 10 metres; and
- between 10 percent and 25 percent at a scale height of 100 metres.

2.3 The model scale used in the wind tunnel test must not produce models that are smaller than those obtained using a 1:500 scale.

3. Wind tunnel procedure

The following checklist is offered as a guide to the steps to be followed in order to produce the material needed to complete the WCC standard wind tunnel test report described in Section (4) of this Appendix.

The checklist is divided into phases which it is expected will be sequential. However, the points within each phase may well be performed in a different order from that listed, depending on the type of building project to be investigated.

Is the criteria of acceptability only to be pedestrian safety or are there other considerations of comfort to be applied to particular areas? What parts of the proposed building are fixed in bulk/size and what parts may be changed, moved or added to improve the wind environment.

Phase I

Book time at a wind tunnel facility capable of making the detailed measurements required in a wind tunnel test report. As the test itself could take at least a week to complete, book well in advance.

It is important to ensure that the wind tunnel is capable of meeting the requirements set out in Section (2) above.

Phase II - The Model

3.1 Provide model details and/or model(s) of the proposed and existing buildings to the wind tunnel facility which is to perform the test.

Phase III - The Wind Tunnel Test

3.2 Identify the areas around the proposed building which experience the highest wind flows. Measure and record the wind speed at these locations for wind from the following points of the compass (degrees clockwise with respect to true North) 340°, 360°, 20° (Northerlies); 160°, 180°, 200° (Southerlies).

3.3 Measure and record the wind speeds occurring in the high wind areas around the existing buildings for the 340° and 200° directions, and for other directions identified as problematic for the proposed building.

3.4 Assess the need for alterations to the form of the proposed building. If alterations would be useful, test those that would be acceptable to the proposer of the building. If no alterations are needed, examine other alternatives for improving the ground level wind environment, such as wind-breaks, trees, walls, canopies and verandahs. The recording and measurement of wind speeds here should only be for those areas on the proposed building causing problems and for the problem plus the 340° and 200° directions.

3.5 Summarise the physical measurements and qualitative observations made during the tests in a way which clarifies:

3.5.1 the cause(s) of the observed problems;
3.5.2 the ways in which these problems might be avoided; and
3.5.3 the ways in which shelter against these wind problems might be provided.

At its simplest this might mean stating (for example):

- that the root cause is the downwash caused by the building being very much bigger in scale than its neighbours;

SFMoMA archive material

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

SFMOMA_archive_list_wpd

SF MOMA Material collected from Archives

References collected to be obtained (as of 18/11/96)

A + U 1995 No 302, pp 18-33 has excellent section on page 23 -	method
SF MOMA press release kit - complete copy	Greg Johnson to obtain
New museum campaign drawings	Greg Johnson to obtain
Creating the SF MOMA - how did it happen? AIA/SF seminar proceedings	Andres Grechi to obtain
AD #94 1991; pp78-79	from VUW library
Domus N767, Jan 1995, pp7-18 & 19-23	from VUW library
Time Jan 30 1995 p 48	from VUW library
Arch Record 11/1994	from VUW library
a+u 95.11	purchased
Contemporary European Architects III	from VUW library

From SF MOMA (Archives & Greg Johnson)

Index of all the drawings held by the SF MOMA archive listing

accession number, Botta office code, general description, and date

Photocopies of drawings

SF1	no label	section	
SF2	no label	section	
SF3	no label	section	
SF4	no label	wall/cove	
SF5	no label	section	
SF6	no label		
SF7	no label	section	
SF8			entry stairs
SF9			lighting section
SF9a			ditto - different exposure
SF10	B8.1		
SF11	A3		
SF12	A4		
SF13	A5		
SF14	E1		
SF15	E1.1		
SF16	E1.2		
SF17	E2		
SF18	E3		
SF19	E4		
SF20	E5		
SF21	E5.1		

SF22	E6	
SF23	E7	
SF24	E8	
SF25	E9	
SF26	E9.1	
SF27	E9.2	
SF28	E13	
SF29	E13.1	
SF30	E14	
SF31	E14.1	
SF32	B1	
SF33	B2	
SF34	B3	
SF35	B9	
SF36	B4	
SF37	B5	
SF38	B6	
SF39	B6.1	
SF40	B6.2	
SF41	B6.3	X I 89
SF42	B6.4	
SF43	B7	
SF44	B8	
SF45	B10.1	
SF46	B11	
SF47	B12	
SF48	B12.1	
SF49	B12.2	
SF50	B12.3	
SF51	B13	
SF52	B14	
SF53	B15	
SF54	B15.1	
SF55	B15.2	05/01/91
SF56	B16	
SF57	B17	
SF58	B18	
SF59	“B18"	
SF60	B19	
SF61	B20	
SF62	B20.2	10/89
SF63	D1.1	
SF64	D1.2	
SF65	D2	
SF66	D3	
SF67	D3.1	
SF68	D3.2	

SF69 D4
SF70 D5
SF71 D5.1
SF72 D6
SF73 D7
SF74 D9.2
SF75 D13.4
SF76 C7
SF77 C5
SF78 C9
SF79 C1
SF80 C4
SF81 C6

Sent by Greg Johnson 8 November 1996

Three survey forms completed by SF MOMA staff

Three pages from the programme for the SF MOMA building defining the lighting means and conditions

Light readings on 76 separate occasions in the galleries on level from March 19 1995 through June 24 1996.

From HOK Archives

Drawings

Bound set of construction drawings.

4.2.1	Lower level floor plan	
4.2.2	Ground floor plan	
4.2.3	Second floor plan	
4.2.4	Third floor plan	
4.2.5	Intermediate roof plan	
4.2.6	Fourth floor plan	
4.2.7	Fifth floor plan	
4.2.8	Mechanical penthouse plan	
4.2.9	Mechanical penthouse mezzanine plan	
4.2.10	Roof plan	
4.3.7	Partial plans at stair no 5	
4.5.1	West elevation	
4.5.2	North elevation	
4.5.3	East elevation	
4.5.4	South elevation	
4.5A.1	Building section	
4.5A.2	Building section	
4.7.5	Exterior wall sections	
4.7.9	Exterior wall sections	
4.7.10	Exterior wall sections	
4.7.11	Exterior wall sections	
4.8.4	Section/ Elevations at stair no. 5	
4.20E.4	Panel Elevations	
4.20E.5	Panel elevations details	
4.20E.6	Panel joint details	
4.20E.9	Misc details	
4.40E.1	Interior details	
4.40E.2	Interior details	
4.40F.7	Interior details	Section of skylight
4.40F.8	Interior details	
4.40F.10	Interior details	
4.40F.11	Interior details	

Specifications

07820	1-12	Metal framed skylights (acrylic covers) June 1992
08800	1-12	Laminated Pattern glass/ Glass & glazing / AFG Pattern #62, film of 0.60 clear polyvinyl butyral & uv inhibitor interlayer between (09.2 shading coeff) / G-7 Insulating glass at gallery skylights AFG Pattern #62 film of 0.60 ....(0.92 SC) for

			inner pane, clear outer pane	
08960	1-		Sloped glazing system	
12520			Fabric shades	

Articles and cuttings photocopied from Andres Grechi personal archive 17-9-96

H1	1991	What's on newsletter from SF MOMA	Botta's design "An extraordinary work of architectural humanism	
H2	Sept / Oct '90	"At the Modern"	Cover + Bold modernist design for Museum's future home	
			Multimedia studies brochure	
H3	Fall '92	SF State Uni	Swiss on high	
H4	Jan 1994	Elle/Decor	Two tombs & a laboratory	Paolo Polledri
H5	Jan 10 1991	Artweek		Britton Schlinke
H6	May 17 1993	SF Chronicle	Graceful Triad taking shape in Yerba Buena	Allan Temko
			Under Construction	
H7	Jan 30 1994	San Jose Mercury News		David L Beck
		SF Examiner	Structuring a sense of place	
H8	Jan 22 1992			Gerald D Adams
H9	Jan 20 1994	SF Chronicle	A bridge to the new world of modern art	Chris Stewart
H10	Sept 13 1990	New York Times	For SF, a new museum with its own signature	Paul Goldberger
			News	
H11	Feb 1991	Interior Design	New Home for SF's Modern Art	
H12	Sep 12 1990	SF Chronicle	Labors of love in Sand	Michael McCabe
H13	Sep 24 1990	SF Chronicle	It's a fright wig - letter to ed.	April Lynch
H14	Sep ?? 1990	SF Chronicle	Wild Start for SF Museum and Museum dedicates site with a bang	Barnaby Conrad III
H15	1991??	SF Chronicle	The architects of transformation	
			Powerful, humanistic concept for	

1991 ??

Jan 19 1994

1991??

1992? Day of Ground breaking

1991??

Sundry other material

Set of slides of hand-coloured original presentation drawings.

Complete set of 22 11x17 prints from 1990 - paper copies of pictures on slides

Personal photograph of M Botta on the building site for SFMOMA by Andres Grechi

Set of photographs of wall material option models (complete with modulor) by Andres Grechi

From Botta Archives

Drawings

1	E1	02/89		Scale of "skylight" concept - services beside
2	E1.1	02/89		And options ...
3	E1.2	02/89		
4	E2	02/89		
5	E2	02/89	zoom+	(Same as #4)
6	E3	02/89		
7	E4	01/90		
8	E5	01/90		How concepts might come together in galleries
9	E5.1	01/90		- including sections and perspectives
10	E6	01/90		
11	E7	01/90		Vaulted gallery, not just vaulted skylight?
12	E8	01/90		
13	E9	01/90		
14	E9.1	08/91		Details of daylighting concept
15	E9.2	08/91		
16	E10	11/9/91		
17	E10.1	09/91		Sawtooth sections through galleries

18	E10.2	09/91	- including artificial lighting placement
19	E10.3	12/9/91	
20	E10.4	09/91	
21	E10.5	09/91	
22	E11	12/9/91	Gallery perspective
23	E12	09/91	
24	E12.1	12/9/91	Gallery perspective
25	E12.2	3/10/91	
26	E13	10/91	Spotlight placement under skylight
27	E13.1	10/91	Striplight placement in skylight
28	E14	11/11/91	Artificial lighting concept - gallery vaults
29	E14.1	11/91	

Photographs of construction (Perretti & Park progress Photo)

id	PP#	date	Content
1	34	May 4 1993	Looking southeast
2	33	Mar 30 1993	Third St elevation, looking southeast
3	24	Jan 5 1993	Looking southeast
4	25	Jan 29 1993	Looking southeast
5	27	Feb 2 1993	Third St elevation
6	28	Mar 2 1993	Looking southeast
7	31	Mar 30 1993	Looking southeast
8	37	Jun 2 1993	Looking southeast
9	47	Aug 31 1993	Aerial looking SE
10	52	Sep 29 1993	4th Floor Gallery, Looking east
11	48	Aug 31 1993	2nd floor west gallery
12	42	Jul 2 1993	Looking SE, pre-cast topped off
13	55	Nov 1 1993	4th floor gallery, looking NE
14	60	Dec 29 1993	Hardwood floor, 4th floor gallery N
15	63	Jan 31 1993	Hardwood floor, 4th floor gallery N
16	66	Feb 28 1993	Partitions, 4th floor gallery S

Bibliography and selected references

The Botta office maintains folders of cuttings and articles about the SF MOMA building. Currently three "lever arch" files contain the articles published during the gestation and occupation of the building project. The Bibliografia specifica runs to 9 pages each with 8-9 articles per page.

The following articles from the collection were photocopied during my visit:

B1	Jan 1995	SF Focus; pp 42-49	Art & Soul	Allan Temko
B2	Jun 1 1992	Christian Science Monitor	Architect puts his mark on SF	Olivia Snaije
B3	Feb 12 1995	New York Times	An emporium for art rises in the West	Herbert Muschamp

B4	1991	Edizioni Electa-Milano (Italia); pp 48-51 of 48-63	Botta, Eisenman, Gregotti, Hollein: Mesei	Pippo Ciorra
B5	Apr 2 1996	SF Examiner	Year-old SFMOMA is a big draw, and a fine landmark	David Bonetti
B6	May 1995	Art in America, pp 92-97		Eleanor Heartney
B7	1995	Lotus Intl #86; pp7-29		Janet Abrams
B8	Mar-Apr 1995	Flash Art, VXXVIII, # 181, pp49 & 58		Francesco Bonami
B9	#43 1995	Parkett, pp139-146		Daniela Salvioni
B10	Vol 20	Hinge - design in focus; pp 46-49		

Bay Area Modern

Mario Botta: il museo d'arte moderne di San Francisco

Sacred and profane lands

Cumulus from America

SF Museum of modern art

]

wind tunnel users´ survey

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

typed-papers.wpd

WELLINGTON WIND ORDINANCE - ARCHITECT INTERVIEWS
SUMMARY OF INTERVIEW RESPONSES

Architects interviewed:

A	no interview, notes from telephone conversation
B	24 Jan 91
C	25 Jan 91
D	28 Jan 91
E	11 Feb 91
F	11 Feb 91
G	12 Feb 91
H	12 Feb 91
I	13 Feb 91
J	13 Feb 91
K	14 Feb 91
L	14 Feb 91
M	
N	14 Feb 91
O	16 Feb 91
P	17 Feb 91

Questions and responses:

Do you feel the Ordinance has made the wind environment in Wellington City better or worse? Are there specific locations you are thinking of in your answer?

General response: "don't know" / "hard to tell".

Reasons/comments: Hasn't made any worthwhile difference. [A]

Don't know which buildings have been influenced by Ordinance. Recent buildings have not been sufficiently problematical for the Ordinance to have a noticeable effect. Buildings on the Terrace have caused little change in wind regard. Time will tell for effect of Majestic development, more likely to be affected because of size, location. Don't think Ordinance has made a difference. [B]

Aren't aware of which buildings have been affected by the Ordinance so can't really comment. Haven't had direct contact with the Ordinance so don't know any particular examples. Expect that it would have improved the city. [C]

Feel designers are designing the "most appropriate building" for each site, so Ordinance is not making the changes, designers are. [DK]

"Probably improved". [E]

No effect. [DH]

In practical terms it has made no difference. Majestic - "net effect has been unfortunate". BNZ - public opinion not ordinance had effect. [H]

"Hard to assess if it has improved things. I guess on balance it probably has". [I]

In certain parts it has: open spaces that the Council has created are sheltered, grow trees that never used to be able to grow in Wellington. [J]

Development in the city in the last five years has had a major effect on the city environment, hard to quantify what impact the Ordinance has had. Believes it has had a beneficial effect, particularly in the malls and courtyards and the like. [K]

Must have improved the city. I don't think any clients or developers or architects dispute that the Ordinance has improved the environment for Wellington. [WM]

"Has made it better in terms of it would have been worse if it [the ordinance] hadn't been there. I don't know that the Ordinance has made it any better on what has been there in the past. Without the Ordinance it would have been even worse still". [L]

For the better. [A, M]

Are there particular problems or issues with the wind environment in Wellington that you feel the Ordinance does not address? List.

General response: "no", some list problems later in interview.

Reasons/comments: Feels speeds have been set, testing applied to cover Wellington-specific wind issues - expect Central Labs to cover that. Main problem is changing shape of the city, if buildings are coming down/going up, how to measure wind speed, how many development proposals to consider in test, what happens when problems are the result of another building? [D]

Building environment changes, buildings pulled down, new buildings built, alter wind effect on a building. Proposed new buildings used in test may be changed or may not be built. [B]

Ordinance only deals with new projects. Some problem areas exist on sites where redevelopment is not likely to happen for a long time, if ever. [E]

Accuracy of model, moving building slightly on site changes wind speeds measured, margin of error makes some of the assumptions questionable. [I]

Council requires property owner to rectify problem that is not of his making, passes responsibility on to most recent development. [J]

Doesn't allow for effects of trees and landscaping or effects of building detailing such as balconies which you would expect to moderate the wind, but the margin of error in the testing is sufficient for it not to be able to register those sorts of things. Relationship between wind tunnel and built environment. "Some situation you can't do anything they [the Council] don't quite expect the impossible but not far off it". [K]

Only covers the central business district, doesn't cover other shopping centres. Johnsonville, Tawa or Karori shopping centres might benefit from wind testing in those localised areas. Housing should be looked at, particularly for worst residential areas. Testing available is not sufficiently detailed, it is not very accurate, "pretty much a hit and miss affair". [WM]

"Not strong enough. Wind is a really negative aspect of our environment. Having chosen to live in a windy environment we should be prepared to spend quite a lot of money protecting ourselves from the wind". "Not strong enough in writing or in enforcement". [L]

Ordinance doesn't allow for initial development in an area where further development is going to change the environment significantly.

Points of concern that show up on the tests may be irrelevant to the use of the area.

The time taken to get a response back from Council after testing has been carried out is too long in terms of commercial necessity, building world moves much faster and delays may mean the end of a project. [M, A]

Do you find the Ordinance easy to understand?

General response: yes

Summarise the main requirement of the Ordinance.

Reasons/comments: preparation of model, take model to WORKS testing, observe test, evaluate report, modify building if required. [B]

standard wind report, test proposed building against existing building, wind speeds and erosion testing. [D]

pre-design test, test model at Central Labs, test modifications until satisfactory result is found. [E]

effects of wind on building and immediate environment, a wind speed problem. [WM]

performance, effectively add or alter verandahs or add wind screens. [L]

Followed town planning requirements [M, A]

Do you feel the Ordinance is easy to work with? Examples?

General response: yes

Reasons/comments: As long as other factors are taken into account. If wind is treated as paramount with no regard to sun/aesthetics/height/plot-ratio etc the Ordinance would become unworkable. Must be recognised that this is just one set of requirements among many. There must be room for flexibility and common sense. [D]

Some ridiculous solutions proposed. Wind requirements must be balanced against aesthetics and other considerations. [E]

In terms of procedures it is easy to follow. [H]

"Some of the problems arise when you start getting pedantic about certain speeds that have been tested" [I]

Found it interesting to follow. Problems lies in Council adherence to wind speeds set out in Ordinance, without regard to individual situations. [J]

Council interpretations of the Ordinance is the problem, "Often we are at variance over the interpretation of the reports with the Council ... The planners tend to work like engineers with numbers, and unless the numbers work they are not interested". Town Planners are "gutless" in approach when something is not within the requirements, prepared to sit down and talk about changes and amendments to bring the building into an acceptable form, but not prepared to give approval that building meets the conditions, instead they send it off to a committee to a hearing to appeal and so on. Are not prepared to accept trade-offs. Town Planning process in working with the Ordinance is at fault. [WM]

"As easy or as difficult to work with as you decide to make it. Just another technical aspect of construction and design. Everybody in the design team and everybody with responsibility has to realise you've got a difficult problem and you've got to knuckle down and solve it." [L]

No problem with the Ordinance. "It's really the interpretation of the results". "The procedure is fine ... but no time in the building design process for the time required for a pre-design test, for instance". Fringe area is not covered, intermediate stage between CBD and outside city. Council expects each building to solve problems created over years, often impossible to do. Many years to cause the problem, have to recognise that may take years to cause the problem, have to recognise that may take years to rectify the problems. [M, A]

Do you use particular design techniques to improve the wind effects on your buildings? List.

General response: "no", but indicate awareness of several techniques during interview.

Reasons/comments: "driven by economics", aware of tower-podium as positive effect on wind [B]

tower-podium, curved/aerodynamic shape, verandahs [D]

"Don't have any rules of thumb, but we're aware of the general things that do affect wind and take those into account". [C]

landscaping, wind baffles, rounded corners. [E]

wind breaks, canopies, screening, elements protruding from building to deflect wind. [F]

rounded corners, curved facade, verandahs, canopies. Keep wind effects in mind while designing. If wind looks like being a serious problem, call on experts to advise. [G]

just what was taught at school. Use consultant when necessary. [H]

not in a conscious way. Modulate form of building to break up wind flow. If architect is sensitive and responsible then not concerned only with visual architectural historical and social impact of building but also performance issues. [I]

verandahs to stop downdrafts [J]

aerodynamic shapes, aerofoils to deflect the wind [WM]

awareness of where wind comes from and aware of increasing wind speeds with height, basically try to solve the problems before they start, and go from there and think in terms of verandahs and what's happening at pedestrian level. [L]

use Council guide for designing with wind, try to avoid troublesome building forms. [M, A]

Have you ever had to alter or redesign a building proposal because of the Ordinance?

Comments: Mostly yes, but only minor changes, such as extending verandahs or adding porous screens.

Have particular problems or opportunities arisen as a result of this?

Comments: Designers are aware of wind environment factors, so aren't really affected by the Ordinance. [D]

"Thought of it as an interesting obstacle ... designing a building not a pure thing in itself, really an exercise to take all the aspects and try and resolve them all". Opportunity to consider other aspects of design "subtle argument for the accountants." [E]

Can work to advantage, justification to client for additional ornamentation. [F]

Ordinance provides opportunity to vary building form, gives architects some leverage over clients. [I]

"The big opportunity is that a large number of people have to look at the wind and think about is constructively, if they are doing that in a positive sense they will reconsider Ordinances such as the tower-podium bonus and they will look at building height and building form and make it more streamlined. Another very large positive outcome could be that the local authority takes a much more responsible attitude towards provision of roofs over street spaces". [L]

Have you ever observed or taken part in wind tunnel testing of a building proposal?

B:	yes
C:	no
D:	yes
E	yes
F	yes
G:	yes
H:	yes
I:	yes
J:	yes
K:	yes
L:	no

Do you think taking part in a wind tunnel test helps/would help you in the design process?

General response: yes

Reasons/comments: If problems had come up, would have got a lot more out of it. [B]

Provides increased awareness of problems and a feel for why they happen. Indicates ways of dealing with problems. [D]

We haven't had any experience with that in this office but certainly that's the way I'd like to see it done". [C]

Reinforced some preconceptions on what works well and what doesn't work well". [E]

Useful to involve client as well, interactive approach. [F]

In pre-design stage, not so much at later stages. [H]

"realise where potential problems are ... usually only reinforce what was expected anyway, particularly at that level if accuracy." [I]

Found it very interesting to see what was happening. Need to be in the laboratory to see what it is all about. [J]

Report is comprehensive so no need to observe each test. "Once you've seen how one operates the report is probably sufficient." [K]

"Not unless you're pretty dumb and you can't see the results from photographs and take the word of a few people: if you have a problem with trust of other people, you'd have a problem - you shouldn't have to get involved in it." [L]

What practical difficulties are there in carrying out wind tunnel tests yourself? Eg pre-design tests as set out in the Ordinance?

Reasons/comments:

Client resists spending money before building is ready for Council approval. If wind test is all that stands between them and approval, will do it to get it out of the way. Not prepared to meet such a cost at an early stage when the design may undergo a lot of change in later design stages anyway. Architect will build model and observe testing as part of fee but not pay for testing or analysis. If costs were lower situation could change. [B]

Lack of expertise in the office. If there are experts, might as well use them. Accuracy of tests is questionable, need to know how certain results are. [D]

Expensive, once time, models and analysis taken into account. Better that designers be taught in the School of Architecture to be aware of wind effects and ways to design with it. [C]

Time. Not enough people in the office to spare someone for that time. Not confident to have done it efficiently and to have come out with good report. [E]

No problems, great idea. Should be more emphasis on pre-design approach. [F]

Best approach. Don't carry out testing personally, hire someone to do it, but very favourable to pre-design approach. [G]

Cost of losing floor area. Client generally works to Town Planning bulk and location limits and is very resistant to anything that will detract from that. [H]

Getting accuracy of model to satisfactory level. Facility is not widely known. Time may be a problem, process is intuitive anyway so appears an unnecessary hold-up to carry out pre-design test. If Council is serious about Ordinance they should enforce pre-design step. [I]

Time. Design time is usually quite short, and anything adding to that is an obstacle. [K]

Not impartial, acting for developers, believe if case went to Council or court wind report would be thrown out as a biased document. Believe it should be independant. "A lawyer would work through that and say well your consultants have produced a report that provides the condition you want. Town planners will dispute that, so the client is going to be disadvantaged. It's a legal question." Time, expertise, cost all have an effect - testing takes much longer than it should as a result of the lack of experience, wasting time, costing money while gaining experience, not economical or time efficient for developer. "Dreaming about buildings" [WM]

Time - is it necessary, why can't others do it? [L]

How easy to understand do you find the report on the wind tunnel testing?

General response: Good

Comments:

Results could be presented in a clearer way, although no serious problems with it - can be difficult to communicate results to clients. [C]

Fairly long but very clear. [E]

Difficulty lies in recommendations, other solution available to those proposed by WORKS report, can make suggestions but shouldn't only be in 2-D, should be thinking in 3-D. [F]

Question the recommendations, don't feel that "experts" have enough knowledge to say what should be done, and shouldn't be taken as absolutes. [G]

Disputable, but easy to understand. [H]

Set out fairly comprehensively, good to follow. Take a reasonable approach in the recommendations, don't expect the impossible. [J]

No problems, have a good rapport with Central Labs. Often go back to them for clarification or retesting. [K]

"More general than specific, can't get into detail that you may sometimes want". "General overall picture". Can't get more detailed with techniques used. Reports no problem at all, straightforward, no nonsense. [WM]

No problem. [L]

Do you have any suggestions for how the Ordinance might be improved?

Comments:

Rewrite it to remove portions currently ignored/overlooked. If overlooked but important should be enforced now, if not important, shouldn't be included. Reduce to workable minimum, don't incorporate unworkable points that are not necessary. Allow for flexibility and common sense. [D]

Objectivity must be maintained; while negotiation is necessary there should be limits to what is conceded. Levels of tolerance for areas and occupations should be made clear from the outset. Designers should be aware of the degree of flexibility in the Ordinance and be shown that it is not going to bend further. Set out what is a reasonable attempt to improve the wind environment, what extent additional tests/modifications should be taken to. (Noted that the Ordinance may contain this but isn't familiar with the Ordinance's workings except that seen in the building industry as a whole). [C]

Need to follow-through to show that the testing has been justified, that the finished result is successful. [F]

Good. Agree with findings in general, disagree with attention given to minor detail such as planting. Recommendations made solely in reaction to wind condition, no consideration given to other aspects affected by recommendations. [I]

Needs to be simplified, has been over complicated in the administration. Needs administrators with greater knowledge of wind design requirements and design needs. Would be helpful to have someone in Council who can look over early plans and indicate areas where problems could occur, who would take responsibility for accepting plans or referring them on for wind tunnel testing. [J]

Prepare a wind contour map of Wellington city so designers know in advance which areas will require particular attention. [K]

Increase the accuracy and level of detail that can be achieved if you require it. Map of the wind speeds. Speed up time taken by wind testing facilities. "A better testing system would be an advantage". Relate test results to what you actually get down in the street. [WM]

Remove bonuses for tower-podium developments, public amenity bonuses should only be awarded where the spaces are useful/useable ("three of the sides around the BNZ are a waste of spaces") If public spaces are put beside a building they should have a glass roof over them. [L]

General attitude towards Ordinance:

B: positive
C: positive
D: positive
A: negative
E: positive
F: positive
G: neutral/positive
H: neutral
I: positive

J:	negative/neutral
K:	positive
WM:	positive
L:	negative

General comments:

Good to have Central Labs doing the analysis as a neutral party. Have to keep the process on a negotiative rather than adversarial ground. Problem with testing, accuracy, reliability of results. [D]

If costs were lower it would encourage designers/clients to have more wind tunnel tests through the course of design. Objections come largely from the client not the designer. The cost benefit of a solution has to be considered before the money is spent (for example the wind gate idea). If difference is not going to be great or if problem has been managed for a while without problems then there seems little point to changes. [B]

The whole thing is a joke in Wellington. Buildings will create wind, nothing can be done about it. People will adapt to a changing environment. Can't stop progress. Waste of time and money to keep someone in a job. [A]

The Ordinance is important in Wellington, essential that safety is required from developers, not unreasonable that comfort be required in some locations as well. If designers leave it until last minute to get approval for wind environment, they should be prepared to pay the price of redesign etc if required, no matter how long/expensive the process. Should be encouraged to get early approval and made aware of the consequences if they don't. [C]

Good idea to have the Ordinance in a windy place like Wellington. Can't take it too seriously, too extremely or Wellington will be in a big dome, end up pretty boring. Wind can be exciting/add interest.

"As long as it's viewed from the fact that it's looking after pedestrians, that's important, that looking after the pedestrian in the street is the main thing, that is doesn't cripple the rest of the building". "As long as it's not over elaborated, as long as it's kept fairly basic and it's realized that the results are only a guide ... the parameters should be relatively open, rather than tightened up". [F]

Need more expert consultants, no confidence in recommendations at present - a very inexact science, has no confidence in accuracy of wind tunnel testing or conclusions drawn from results. [G]

Large part of Wellington's wind problem stems from street grid pattern - straight and unobstructed street. "Not that I think that the wind gates proposed for Courtenay Place are a good idea at all". Council has more scope for improving the wind environment through selected closing of streets and planting. Don't believe that the wind tunnel simulation is accurate enough for some sites to give sensible solution to the problem. Dixon Towers development required a "fence" along the top of the adjacent building to improve wind conditions. Developer went bust before completion of project and fence was never built, but the area is none the worse for it. Don't believe carparking building behind was adequately modelled, not a solid block but open floors. Only isolated buildings that it affects. For anything in the

CBD it's really not relevant. [H]

Ultimately the Ordinance is a good thing as long as kept in its place along with all the other factors that affect the city. Wind can't become the dominant concern at the expense of other things that are important in the city. [I]

Like to see whole thing reviewed to find some simpler method, preferably to be usable at an early stage in the design process. [J]

Governed by programme of testing facility. May not fit in with timing of project. Timing of wind tunnel testing is difficult, can't happen earlier in project as building has not bee approved by the client prior to that, but at late stage it is generally carried out the building design is almost completely determined.

"We all benefit from it, even though it is a bit of an imposition at times, one of the factors of building in Wellington". "Better to have a pleasant environment around your building than one that's unpleasant. It's not seen as being a high priority in terms of building owners and developers, not at the initial stage. They expect it in the end, that's for somebody else to solve, it's a consultants' problem".

Developers see the Ordinance as a disincentive to moving to Wellington, more criteria to conform to. [WM]

"Tower-podium concept for wind is really bad. By very strong local body inducement the wind situation in Wellington is being made very much worse as they are granting a bonus for tower podium development ... that's going to mean a building of nearly twice the height of what could normally have been built. On one hand the Council says they want wind tunnel tests and they want wind speed reduced, and on the other hand they grant tower-podium bonuses". "Verandahs should be continuous and should be across intersections on the main pedestrian routes especially from the railway station; wide, broad verandahs from the railway station to Courtenay Place". [L]

24 Jan 91

25 Jan 91

28 Jan 91

no interview, notes from telephone conversation

Question:

Do you feel the Ordinance has made the wind environment in Wellington City better or worse? Are there specific locations you are thinking of in your answer?

General response: "don't know/hard to tell".

Reasons/comments: Aren't aware of which building have been affected by the Ordinance so can't really comment. Haven't had direct contact with the Ordinance so don't know any particular examples. Expect that it would have improved the city. [C]

Don't know which buildings have been influenced by Ordinance. Recent buildings have not been sufficiently problematical for the Ordinance to have a noticeable effect. Building on the Terrace have caused little change in wind regard. Time will tell for effect of Majestic development, more likely to be affected because of size, location. Don't think Ordinance has made a difference. [B]

Feel designers are designing the "most appropriate building" for each site, so Ordinance is not making the changes, designers are. [D]

Hasn't made any worthwhile difference. [A]

Are there particular problems or issues with the wind environment in Wellington that you feel the Ordinance does not address? List.

General response: "no", but list problems later in interview.

Reasons/comments: Feels speeds have been set, testing applied to cover Wellington-specific wind issues - expect Central Labs to cover that. Main problem is changing shape of the city, if buildings are coming down/going up, how to measure wind speed, how many development proposals to consider in test, what happens when problems are the result of another building? [D]

Building environment changes, buildings pulled down, new buildings built, alter wind effects on a building. Proposed new buildings used in test may be changed or may not be built. [B]

Do you find the Ordinance easy to understand?

General response: yes

Summarise the main requirements of the Ordinance.

Reasons/comments: preparation of model, take model to WORKS testing, observe test, evaluate report, modify building if required. [B]

standard wind report, test proposed building against existing building, wind speeds and erosion testing. [D]

Do you feel the Ordinance is easy to work with? Examples?

General response: yes

Reasons/comments: As long as other factors are taken into account. If wind is treated as paramount with no regard to sun/aesthetics/height/plot-ratio etc the Ordinance would become unworkable. Must be recognised that this is just one set of requirements among many. There must be room for flexibility and common sense. [D]

Do you use particular design techniques to improve the wind effects on your buildings? List.

General response: "no", but indicate awareness of several techniques during interview.

Reasons/comments: "driven by economics", aware of tower-podium as positive effect on wind. [B]

tower-podium, curved/aerodynamic shape, verandahs. [D]

"Don't have any rules of thumb, but we're aware of the general things that do affect wind and take those into account". [C]

Do you feel the Ordinance restricts the way you design? Examples?

General response: no

Reasons/comments: Designers are aware of wind environment factors, so aren't really affected by the Ordinance. [D]

Have you ever had to alter or redesign a building proposal because of the Ordinance?

General response: no

Reasons/comments: only minor changes, extending verandahs or adding porous

screens, for example. [D]

Have you ever observed or taken part in wind tunnel testing of a building proposal?

B:	yes
C:	no
D:	yes

Do you think taking part in a wind tunnel test helps/would help you in the design process?

General response:	yes
Reasons/comments:	If problems had come up, would have got a lot more out of it. [B]
	Provides increased awareness of problems and a feel for why they happen. Indicates ways of dealing with problems. [D]
	We haven't had any experience with that in this office but certainly that's the way I'd like to see it done"

What practical difficulties are there in carrying out wind tunnel tests yourself? Eg pre-design tests as set out in the Ordinance?

Reasons/comments:	Client resists spending money before building is ready for Council approval. If wind test is all that stands between them and approval, will do it to get it out of the way. Not prepared to meet such a cost at an early stage when the design may undergo a lot of change in later design stages anyway. Architect will build model and observe testing as part of a fee but no pay for testing or analysis. If costs were lower situation could change. [B]
	Lack of expertise in the office. If there are experts, might as well use them. Accuracy of tests is questionable, need to know how certain results are. [D]
	Expensive, once time, models and analysis taken into account. Better that designers be taught in the School of Architecture to be aware of wind effects and ways to design with it. [C]

Do you have any suggestions for how the Ordinance might be improved?

Comments:	Rewrite it to remove portions currently ignored/overlooked. If overlooked but important should be enforced now, if not important, shouldn't be included. Reduce to workable minimum, don't incorporate unworkable points that are not necessary. Allow for flexibility and common sense. [D]
	Objectivity must be maintained; while negotiation is necessary

there should be limits to what is conceded. Levels of tolerance for areas and occupations should be made clear from the outset. Designers should be aware of the degree of flexibility in the Ordinance and be shown that it is not going to bend further. Set out what is a reasonable attempt to improve the wind environment, what extend additional tests/modifications should be taken to. (Noted that the Ordinance may contain this but isn't familiar with the Ordinance's workings except that seen in the building industry as a whole). [C]

General attitude towards Ordinance:

B: positive

C: positive

D: positive

A: negative

General comments: Good to have Central Labs doing the analysis as a neutral party. Have to keep the process on a negotiative rather than adversarial ground. Problem with testing, accuracy, reliability of results. [D]

If costs were lower it would encourage designers/clients to have more wind tunnel tests through the course of design. Objections come largely from the client not the designer. The cost benefit of a solution has to be considered before the money is spent (for example the wind gate idea). If difference is not going to be great or if problem has been managed for a while without problems then there seems little point to changes. [B]

The whole thing is joke in Wellington. Buildings will create wind, nothing can be done about it. People will adapt to a changing environment. Can't stop progress. Waste of time and money to keep someone in a job. [A]

The Ordinance is important in Wellington, essential that safety is required from developers, not unreasonable that comfort be required in some locations as well. If designers leave it until last minute to get approval for wind environment, they should be prepared to pay the price of redesign etc if required, no matter how long/expensive the process. Should be encouraged to get early approval and made aware of the consequences if they don't. Results could be presented in a clearer way, although no serious problems with it - can be difficult to communicate results to clients. [C]

ARCHITECT INTERVIEWS

Wellington has had an Ordinance regarding wind for over 10 years. Initially it was merely a requirement to have a wind tunnel test performed, but in 1985 this was altered to require changes to be made to the building design if the test showed unacceptable wind conditions. This questionnaire aims to address two issues: the impression the Ordinance has made on the wind environment in Wellington; and the use and application of the Ordinance.

1 Do you feel the Ordinance has made the wind environment in Wellington city better or worse? Are there specific locations you are thinking of in your answer?

2 Are there particular problems or issues with the wind environment in Wellington that you feel the Ordinance does not address? List.

3 Do you find the Ordinance easy to understand? Summarise the main requirements of the Ordinance.

4 Do you feel the Ordinance is easy to work with? Examples

5 Do you use particular design techniques to improve the wind effects on your buildings? List.

6 Have you ever had to alter or redesign a building proposal because of the Ordinance? Have particular problems or opportunities arisen as a result of this?

7 Have you ever observed or taken part in wind tunnel testing of a building proposal? Do you think taking part in a wind tunnel test helps/would help you in the design process?

8 What practical difficulties are there in carrying out wind tunnel tests yourself?

9 How easy to understand do you find the report on the wind tunnel testing?

10 Do you have any suggestions for how the Ordinance might be improved?

11 How would you describe your attitude towards the wind Ordinance?

CHECKSHEET

1 Wellington wind conditions

[ ] better

[ ] worse

[ ] no different

[ ] don't know

location

2 problems with wind environment not addressed by Ordinance:

3 easy to understand?

[ ] yes

[ ] no

main requirements of Ordinance

[ ] pre-design wind report

[ ] standard wind report

[ ] full wind report

[ ] wind speeds

[ ] test proposed building against existing situation

[ ] flow visualisation

4 easy to work with

[ ] yes

[ ] no

examples _____

5 particular wind design techniques

[ ] yes

[ ] no

[ ] verandahs/canopies

[ ] landscaping

[ ] tower/podium arrangement

[ ] stepped back facades

[ ] building orientation/line of major axes

[ ] size in relation to neighbours

[ ] rounded/aerodynamic forms

[ ] chamfered corners

6 Alter or redesign building proposal?

[ ] yes

[ ] no

Provide opportunity or restricts design?

[ ] opportunity

[ ] restriction

examples _____

7 taken part ion wind tunnel testing?

[ ] yes

[ ] no

does/would help?

[ ] yes
[ ] no

8 practical difficulties in conducting testing pre-design?

[ ] cost
[ ] time
[ ] knowledge/expertise
[ ] presenting to client
[ ] access to wind tunnel equipment

9 [ ] easy to understand reports
[ ] difficult to understand

10 suggestions

11 Attitude is:

[ ] positive

[ ] negative

[ ] neutral

comments

MEETING with Town Planners, Wellington City Council

20 December 1990

1 Comments on the implementation of Ordinance 3B.5.

2 Where the Town Planners stand; answer relevant questions from questionnaire.

3 Working with architects in the implementation process; answer questions from architect's point of view.

4 Improvement on questionnaire.

The purpose of this questionnaire is to assess the effectiveness of the wind environment Ordinance in Wellington, Ordinance 3B.5. The questionnaire aims to address two issues: the impression the Ordinance has made on the wind environment in Wellington; and the use and application of the Ordinance.

1 Do you feel the Ordinance has improved the wind environment in Wellington city?

2 Are there specific locations you are thinking of in your answer in Question 1?

3 Are there particular problems or issues with the wind environment in Wellington that you feel the ordinance does not address?

4 Do you find the Ordinance easy to understand?

5 Do you feel the Ordinance is easy to work with?

6 Do you feel the Ordinance restricts the way you design?

7 Have you ever had to alter or redesign a building proposal because of Ordinance 3B.5?

8 Have you ever observed or taken part in wind tunnel testing of a building proposal?

9 Do you think taking part in a test helps/would help you in the design process?

10 Do you have any suggestions for how the Ordinance might be improved?

Discussion at Wellington City Council Town Planning Office

Two planners plus Urban Designer, Mike Donn

20 December 1990

Ordinance as it stands meets legal needs of the Council. Original form of Ordinance said that should be done but included no mechanism for enforcement. Implementation is improved with a legal footing.

Wind Ordinance provides a handle for the City Council to negotiate with a designer/developer over issues not in the planning requirements - aesthetics, building form, redesign of details.

Wind requirements don't fit comfortably with height limits. Possibilities for improving the wind environment are lost because there is no room to negotiate on height issues. Ordinance could be reworded to allow more discretion in setting heights when wind environment is affected. If every case is discretionary, approval process becomes much longer and more complicated. (Stuart Niven - time/cost of developer of little significance against long-term effects on the city. If controls are set, developers will meet them).

Performance vs prescription.

Architect's response to Ordinance is of a little difficulty to be dealt with after the serious design is completed, a tiresome hurdle rather than a creative constraint. Don't like to go back a step to amend a completed design to improve wind effects. Wind in a conceptual sense is not addressed while designing.

Town planners emphasise pre-design test with architect involvement.

Drawbacks

- if done by architect, comes out of fee. Outside agency eg Works Central Labs becomes an extra charge, passed onto client.
- legal aspect, architects don't feel they have the expertise to determine good/bad wind environment
- don't want to disagree with client, rather be told by outside
- time required to explore alternatives, can't work to a formula

Ordinance implementation has achieved a lot in short period of operation. Planners have learned what to look for, more thoughts on good/bad wind environment. Have gained confidence, understanding. Can take a stand, argue. Need this conviction to have strength to negotiate. Consultant adds strength to position.

Comfort/Safety: Wellington too windy to require comfort levels throughout city. As an incentive to provide open, comfortable urban amenity, precincts, open space, zones - comfort requirements could be useful. Detail quality of off-street spaces, social/environmental factors. City Council design?

Urban design approach to wind requirements, early involvement in development of an area, integration of developments. Total picture, not series of one-off developments.

Difficult to get developers to negotiate, not prepared to rely on other developers, suspect deliberate delays, interference.

Linking of design knowledge with wind criteria, suggestion, not just advice. Integration of design possibilities with wind requirements. Possibly needs a step-wise process, lead designer through preliminary approval before design is cut and dried. Too much pressure on Council that design is complete and contracts etc ready to go, too late to alter design. Need flexibility in design process.

K

Berners Lee´s Definition of Metadata

SIMULATION: Lightscape simulation of SF MoMA Atrium: http:\\viewbyview.com (2003)- cloudy

SF MoMA atrium - photograph - sunny: **REALITY**

web_architecture_metadata.wpd

Tim Berners-Lee

Date started: January 6, 1997

. Status: personal view, but corresponds generally to the W3C architecture for metadata.

Additions are at the end about consistency in label/metaset/collection syntax and semantics.

The syntaxes used in this document are meant to illustrate the architecture and be clear but are otherwise random. This note was written before the more general Semantic Web (http://www.w3.org/DesignIssues/Semantic.html) note.

Up to Design Issues

Axioms of Web Architecture: Metadata

Metadata Architecture

Preface

This document was written before the Semantic Web Roadmap, but is an introduction to the same ideas. Both introduce the world of machine-readable data on the web. This document introduces the concepts in the historical sequence at W3C, where the first driving applications of semantic web were metadat, and the first driving metadata applications were endorsement labels (PICS).

Documents, Metadata, and Links

The thing which you get when you follow a link, when you de-reference a URI, has a lot of names. Formally we call it a **resource**. Sometimes it is referred to as a document because many of the things currently on the Web are human readable documents. Sometimes it is referred to as an object when the object is something which is more machine readable in nature or has hidden state. I will use the words document and resource interchangeably in what follows and sometimes may slip into using "object".

One of the characteristics of the World Wide Web is that resources, when you retrieve them, do not stand simply by themselves without explanation, but there is information about the resource. Information about information is generally known as **Metadata**. Specifically, in the web design,

Definition

Metadata is machine understandable information about web resources or other things

The phrase "machine understandable" is key. We are talking here about information which software agents can use in order to make life easier for us, ensure we obey our principles, the law, check that we can trust what we are doing, and make everything work more smoothly and rapidly. Metadata has well defined semantics and structure.

Metadata was called "Metadata" because it started life, and is currently still chiefly, information about web resources, so data about data. In the future, when the metadata languages and engines are more developed, it should also form a strong basis for a web of machine understandable information about anything: about the people, things, concepts and ideas. We keep this fact in our minds in the design, even though the first step is to make a system for information about information.

For an example of metadata, when an object is retrieved using the HTTP protocol, the protocol allows information about its date, its expiry date, its owner, and other arbitrary information to be sent by the server. The world of the World Wide Web is therefore a world of information and some of that information is information about information. In order to

have a coherent picture of this, we need a few axioms about metadata. The first axiom is that :

Axiom

metadata is data.

That is to say, information about information is to be counted in all respects as information. There are various parts of this.

One is that metadata can be stored regarded as data, it can be stored in a resource. So, one resource may contain information about itself or about another resource. In current practice on the World Wide Web there are three ways in which one gets metadata. The first is the data about a document contained within the document itself, for example in the HEAD part of an HTML documents or within word processor documents. The second is that during the HTTP transfer the server transfers some metadata to the client about the object which is being transferred. This, during an http GET, is transferred from the server to the client and, during a PUT or a POST, is transferred from the client to the server. One of the things which we have to rationalize in our architecture of the World Wide Web is who exactly is making the statement. Whose statement, whose property is that metadata. The third way in which metadata is found is when it is looked up in another document. This practice has not been very common until the PICS initiative was to define label formats specifically for representing information about World Wide Web resources. The PICS architecture specifically allows for PICS labels which are resources about other resources to be buried within the resource itself, to be retrieved as separate resources, or to be passed over during the http transaction. To conclude,

Metadata about one document can occur within the document, or within a separate document, or it may be transferred accompanying the document.

Put another way, metadata can be a first class object.

The second part of the above axiom is:

Metadata can describe metadata

That is, metadata itself may have attributes such as ownership and an expiry date, and so there is meta-metadata but we don't distinguish many levels, we just say that metadata is data and that from that it follows that it can have other data about itself. This gives the Web a certain consistency.

The Form of Metadata

Metadata consists of assertions about data, and such assertions typically, when represented in computer systems, take the form of a name or type of assertion and a set of parameters, just as in the natural language a sentence takes the form of a verb and a subject, an object and various clauses.

Axiom

The architecture is of metadata represented as a set of independent assertions.

This model implies that in general, two assertions about the same resource can stand alone and independently. When they are grouped together in one place, the combined assertion is simply the sum (actually the logical AND) of the independent ones. Therefore (because

AND is commutative) collections of assertions are essentially unordered sets. This design decision rules out for example, in simple sets of data, assertions which are somehow cumulative or later ones override earlier ones. Each assertion stands independently of others.

We will see below how logical expressions are formed to combine assertions in more varied ways, and syntactic rules which allow the subject at least of the assertion to be made implicit. But neither of these change the basic operation of combining assertions in unordered AND lists.

Attributes

Assertions about resources are often referred to as attributes of the resource. That is, the type of assertion is an assertion that the object, the resource in question, has a particular named property such as it's author, and in that case the parameter is the name or identity of the author. Similarly, if the attribute is the document's date of expiry then the parameter is that date.

Often, a group of assertions about the same resource occur together, in which case the syntax generally omits the URI of that resource as it is implicit. In these cases, when it is clear from the context about which resource the assertion is being made, the assertion often takes the form of a list of attributes and values. In RFC822 format messages, such as mail messages and HTTP messages, metadata is transferred where the attribute name is an RFC822 header name and the rest of the RFC822 line is the value of the attribute, such as Date: and From: and To: information. The attribute value pair model is that used by most activities defining the semantics of metadata today.

I use the word "assertion" to emphasize the fact that the attribute value pair when it is transferred is a statement made by some party. It does not simply and directly imply that the resource at any given time has that value for the given attribute. It must be seen as a statement by a particular party with or without implicit or explicit guarantees as to validity. Throughout the World Wide Web, as trust becomes an important issue, it will be important for software -- and people -- to keep track of and take into account who said what in terms of data and metadata. So, our model of data of a resource is something about which typically we know the creator or the person responsible, and typically the date of which the information was created, which implies, in the case of a piece of information which makes an assertion, the date at which the assertion was made.

An assertion

(A u1, p, q...)

typically has as explicit parameters,

- the URI of the resource about which the assertion is made (u1).
- some identifier (A) for the type of assertion being made, such as author or date or expiry date.
- other parameters (p, q,...) according to the type of assertion.

As implicit or explicit or implicit parameters,

- The party making the assertion
- The date/time of the assertion
- etc...

We can often make an analogy with programming languages. An assertion in metadata can be compared with a function call in a programing language. In object oriented languages, the

object of the function has a special place among the parameters just as the subject of an assertion does in metadata. In object oriented languages, though, the set of possible functions depends on the object, whereas in metadata the set of assertion types is more or less unlimited, defined by independent choice of vocabulary. Anyone can say anything about anything.

A space for attribute names

It is appropriate for the Web architecture to define like this the topology and the general concepts of links and metadata. What about the significance of individual relationships? Sometimes, as above, these are special, defined in the architecture, and having an architectural significance or a significance to the protocols. In other cases, the significance of relationships or indeed of attributes is part of other specifications, other design, or other applications, and must be defined easily by third parties. Therefore, the set of such relationship and attributes names must be extremely easily extensible and therefore extensible in a decentralized manner. This is why

the URL space is an appropriate space for the definition of attribute names.

We have already (1997) several vocabularies of attribute names: for example, the HTML elements which can occur within the HEAD element, or as another example, the headers in an HTTP request which specify attributes of the object. These are defined within the scope of particular specifications. There is always pressure to extend these specifications in a flexible way. HTTP header names are generally extended arbitrarily by those doing experiments. The same can also be true of HTML elements and extension mechanisms have been proposed for both. If we look generically at the very wide space of all such metadata attribute names, we find something in which the dictionary would be so large that ad hoc arbitrary extension would be just as chaotic as central registration would be stifling.

> **Aside: Comparison with Entity-Relationship models**. This architecture, in which the assertion identifier is taken from (basically) URL space differs from the "Entity-relationship" (ER) model and many similar models like it, including most object-oriented programming systems. In an ER model, typically every object is typed and the type of an object defines the attributes can have, and therefore the assertions which are being made about it. Once a person is defined as having a name, address and phone number, then the schema has to be altered or a new derived type of person must be introduced before one can make assertions about the race, color or credit card number of a person. The scope of the attribute name is the entity type, just as in OOP the scope of a method name is an object type (or interface)By contrast, in the web, the hypertext link allows statements of new forms to be made about any object, even though (before anything other than syntax checking) this may lead to nonsense or paradox. One can define a property "coolness" within one's own part of the web, and then make statements about the "coolness" of any object on the web.

This design difference is in essence a resurfacing of the decision to make links mondirectional, sacrificing consistency for scalability.

An advantage of ER systems is that they allow one to work, in the user interface for example, with a set of properties which "should" be defined for each entity. You can define these in the Metadata's predicate calculus by defining an expression for a "well specified" object. ("For all X such that X is a customer X is well-specified if there exists n such that n is the name of X and there exists t such that t is the telephone number of X and...)

end of aside.

Metadata ("Entity") headers in HTTP

In the above it is important to realize that the HTTP headers which contain what can be considered as metadata ("entity headers") should be separated quite distinctly from HTTP headers which do not. HTTP headers which contain metadata contain information which can follow the document around. For example, it is reasonable for a cache to pass such information on without treatment, it is reasonable for clients or other programs which

process data to store those headers as metadata with the document for later processing. The content of those headers do not have to be associated with that particular HTTP transaction. By contrast, the RFC822 headers in HTTP which deal specifically with the transaction or deal specifically with the TCP link between the two application programs have a shorter scope and can only be regarded as parameters of the HTTP method. To make this separation clear will be to make it easier not only to understand HTTP and how it should be processed, it will also make it clear which pieces of HTTP can be used easily and transparently by other protocols which may use different methods with different parameters. The clarification of the architecture of HTTP such that both the metadata and the methods can be extended into other domains is an important part of the work of the World Wide Web Consortium. The Internet protocols SMTP and NNTP and HTTP as well as many new and proposed protocols share much of the semantics of the RFC822 headers. Formalizing the shared space and making it clear that there is a single design for a particular header, rather than four designs which are independent and happen to look very similar, requires a general architecture, some careful thought, and is essential for the future design of protocols. It will allow protocol design to happen in small groups which can take for granted the bulk of previous work and concentrate on independent new design.

Authorship of HTTP entity headers

It may be possible to remove or at least encompass the apparent anomaly of metadata transferred from an HTTP server by creating a special link type which links the document itself to the set of attributes which the server would give in the HTTP headers. In other words, the server would be able to say, "here is a document, here is some metadata about it, and the metadata about it has the following URL". This would allow one, for example, request a signed copy of the HTTP headers. It would allow one to ask about the intellectual property rights of those headers, and the authorship of those headers.

It is important to be completely clear about the authorship of the HTTP headers. The server should be seen as a software agent acting on behalf of a party which is the publisher or document author: the definer of the URI to resource identity mapping. The webmaster is only an administrator who is responsible for ensuing that (through an appropriately configured server) the transactions on the wire faithfully represent the statements and wishes of that party.

Links

An assertion of relationship between two resources is known as a **link**.

In this case, it is a triple

(A u1 u2)

of:

- the type of assertion being made, that is, the relationship which is being asserted,
- the first URI,
- and the second URI.

These sorts of assertions, links, are the basis of navigation in the World Wide Web; they can be used for building structure within the World Wide Web and also for creating a semantic Web which can express knowledge about the world itself. That is to say, links may be used both for the structure of data, in which case they are metadata, but also they may be used as a form of data.

Links, like all metadata can be transferred in three ways. They can be embedded in a document, which is one end of the link, they can be transferred in an HTTP message, for example what is called the header of the document, and they can be stored in a third document. This latter method has not been used widely on the World Wide Web to date.

Goal: Self-describing information

A critical part of the design of the whole system is the way that the semantics of metadata or indeed of data are defined. The semantics of metadata in our RFC822 headers in mail messages and in http messages are defined by hand in english in the specifications of those protocols. The PICS system takes this to one stage further in terms of flexibility by allowing a message to contain a pointer to the document which defines, in human readable terms, the semantics of each assertion made within a PICS label. In the future we would like to move toward a state in which any metadata or eventually any form of machine readable data carries a reference to the specification of the semantics of all the assertions made within it.

For example, suppose that when a link is defined between two documents, the relationship which is being asserted is defined in a such way that it can be looked up on the World Wide Web (i.e. using some form of URI), and someone or some program, which has not come across that relationship before can follow the link and extend its understanding or functionality to take advantage of this new form of assertion.

In the case of PICS, one can dynamically pick up a human readable definition of what that assertion really means. In PICS (and in theory in SGML using DTDs), one can also pick up a machine readable definition of what form that assertion can take, what syntax, what types of parameters it can take. This allows a human interface to a new PICS scheme to built on the fly. To go one step further, one could, given a suitable logic or knowledge representation language, pick up a machine readable definition of the semantics of that assertion in terms of other relationships.

The advantages of such self describing information is that it allows development of new applications and new functionality independently by many groups across the web. Without self-describing information, development must wait for large companies or standards committees to meet and agree on the commonly agreed semantics.

Of course a pragmatic way of extending software to handle new forms of information is to dynamically download the code to support a software object which can handle such data for one. Whereas this is a powerful technique, and one which will be used increasingly, it is not sufficient. It is not sufficient because one has to trust the implementation of the object, and the state.

Goal

As much as possible of the syntax and semantics should be able to be acquired by reference from a metadata document.

Building Applications using Link Relationships

It turns out that a very large number of applications both built on top of the web and also built within the infrastructure of the Web can largely be built by defining new relationship types. Examples of these are the document versioning problem which can be largely solved by defining link values relating documents to previous and future versions and to lists of versions; intellectual property rights, distribution terms, and other labeling which can be solved by making a link from one document to the document containing the metadata.

Summary so far

1Metadata is data

2Metadata may refer to any resource which has a URI

3Metadata may be stored in any resource no matter to which resource it refers

4Metadata can be regarded as a set of assertions, each assertion being about a resource (A u1 ...).

5Assertions which state a named relationship between two resources are known links (A u1 u2)

6Assertion types (including link relationships) should be first class objects in the sense that they should be able to be defined in addressable resources and referred to by the address of that resource A in { u }

7The development of new assertion types and link relationships should be done in a consistent manner so that these sort of assertions can be treated generically by people and by software.

Rough from here on down

Label syntax: Assertions about a common subject

When labeling information, it is often useful to make a lot of statements about the same object. It is also useful to be able to make the same set of statements about a set of resources. For example, the assertions

```
(A1 u1  a b ... )
 (A2 u1  c d )
 (A2 u1  a f g h )
```

might be written

```
(for u1
 (A1 a b ... )
 (A2 c d )
 (A3 a f g h )
 )
```

Therefore in the syntax of an actual assertion the subject is implicit. This is just the case with RFC822 headers which implicitly refer to the following body, and with HTML "HEAD" element contents which implicitly refer to the containing document. (Though notice there is a fundamental difference, discussed below , between a general label and a message header because the message header is definitive.)

So it is wise to recognise the label as case which it is wise to specifically optimize in the syntax. [In RDF this indeed the case, that the subject is established as a context, and then many properties are given within that context. -2000/9]

Assertions, when the subject is implicit, are known as attribute-value pairs as discussed above. Let's use the term "label" for a set of assertions with the subject extracted. Like the label on a jam jar, it contains information but there must be something else (in this case if its placement on the jar) which tells you to what it applies. (The PICS label in fact contained other information too, including the subject and meta-meta-data about the authorship of the label.)

Local definition:

A label is a set of assertions with a common implicit subject. In this architecture it is a set of attribute-value pairs

(There is a convention that you can write "Jam" on a jam jar label. You don't write "Jam jar" or "Jam Jar label". Even though I once saw a label on a cardboard box with the words "Equipment shipping box label" on it!)

Authorship of Metadata

It follows from the fact that metadata is data that here can be metadata about it. Some of this metadata becomes crucial when we consider a trust model. The logic we need includes the author of metadata

p1: (A u1 . . .)

where p1 is ,in a system with low trust, the author as stated, but in a cryptographically secure system is a principle represented by a key.

On the web, the granularity of information is the resource. Authorship and access control genrally use this granularity. Therefore, typically, the trust one places in an assertion is function the document which asserted it, and the metadata about that document. However, when information is then combined from many resources, one needs a language which allows the source of the original to be recorded. Like blockquote in HTML, this separates the data itself from the resource, so the resource does assert the data directly but asserts that it was asserted.

Analysing labels

See Analysing PICS labels as generic Metadata

where we look at PICS labels and try to sift out the actual semantics of them. This is a thought experiment generating requiremnts. The conclusions are that information such as authorship and date information in fact form a tree of assertions about assertions, and it is important to be clear about the structure of that tree. The notion of a message is brought up there too, but not followed up as it is not germaine to the discussion at this point.

Algebraic Manipulations

If you can make assumptions about the properties of labels then you can manipulate them, possibly without knowing everything about their meaning. Properties such as commutativity, transitivity and associativity would be very useful to have easily available: perhaps in the syntax, or failing that in the schema.

[See Semantic Web roadmap for higher levels of logic]

For example, given a label saying a pair of jeans has a 32 inch waist and a price of $28, I can deduce a label which just has the price of $28. But given a label which says that the punishment for the crime is a 2 month in jail and a fine of $3000, I can't deduce one that says that that the punishment is 2 months in jail.

A typical use of metadata will be to provide a statement along with its proof to be verified by another party. Being able to process these things efficiently and with limited knowledge will be crucial.

The most practical way to do this is to create a basic commonvocabulary for the logical functions. Sometimes known as the "RDF upper layers", these are mentioned in the note on the Semantic Web.

Ordered/Unordered

The axiom of independence of assertions above gives us that in any set of assertions, as assertions are independently true, specific assertions may be removed or reordered, leaving the document just as valid (though possibly less informative).

Examples of unordered things currently are: RFC822 message header lines, SGML attributes. Examples of ordered things are: HTTP header lines and SGML elements.

Do we need a form in which we can make an assertion which has many parameters which are in fact not mutable in any way?

Summary of Requirements

There are ways of representing the above things: messages, labels, specifying labels, and statements and distinguish between them.

As much as possible of the syntax and semantics should be able to be acquired by reference from a metadata document.

It must be possible to mix multiple vocabularies within the same scope.

The syntax and structure should be such that as many manipulations as possible can be done without having to know the semantics of the vocabulary in use.

A common voabulary for basic logic and knowledge representation functionality will be required.

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Tim BL, January 1997

Last edit $Date: 2000/09/21 15:54:40 $

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