INDOOR AIR QUALITY IN NEW ZEALAND OFFICE BUILDINGS

-STUDIES OF AIRBORNE BACTERIA AND FUNGI-

BY

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ABSTRACT

The aim of this thesis was to investigate the levels of indoor airborne bacteria and fungi in fully sealed mechanically ventilated offices in New Zealand. One of the main objectives was to examine the indoor airborne bacterial and fungal levels in Auckland and Wellington offices and to compare the quality of indoor air in offices in both cities. Examining the differences in indoor airborne bacterial and fungal levels between complaint and non-complaint offices as well as comparing those levels with those of similar indoor environments overseas was also one of the main objectives of this thesis.

Indoor and outdoor air data used in this thesis were recorded during commercial investigation of 235 offices in Auckland and Wellington by the Institute of Environmental Science and Research (ESR) and Advanced Building Services (ABS). This data included measurements of indoor microclimatic parameters (temperature and relative humidity), indoor and outdoor airborne bacterial and fungal concentrations and indoor carbon dioxide levels.

Statistical analyses showed the indoor bacterial levels in Auckland offices were significantly higher than those of Wellington offices. Indoor fungal levels in Auckland offices, on the other hand, were significantly below those of Wellington offices despite the fact that outdoor fungal levels in Auckland were at least three times higher than those of Wellington.

No significant differences have been observed between airborne bacterial and fungal levels in complaint and non-complaint offices. Indoor airborne bacterial and fungal levels in New Zealand offices appeared also to be within the levels of those of overseas offices. However, as the bacterial and fungal sampling techniques used by ESR and ABS were different from those used

in overseas studies and this can affect airborne bacterial and fungal absolute counts significantly, care is needed in making such comparisons.

Finally, an evaluation tool has been developed to overcome the difficulties associated with comparison between indoor airborne fungal levels obtained using different measurements techniques. This tool can be used to establish whether elevated fungal problems exist in an office environment and the likely causes of these problems.

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ABBREVIATIONS

ABS	Advanced Building Services
ACGIH	American Conference of Governmental Industrial Hygienists
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning
BRANZ	Building Research Association of New Zealand
BRE	Building Research Establishment
BRI	Building Related Illness
CFU/m^3	Colony Forming Units per cubic metre of air
CO_2	Carbon Dioxide
DNA	Deoxyribo Nucleic Acid
EPA	US Environmental Protection Agency
ESR	Institute of Environmental Science and Research
HVAC	Heating, Ventilation and Air Conditioning systems
IAQ	Indoor Air Quality
ISOR	Institute of Statistics and Operations Research
NIWA	National Institute of Water and Atmospheric Research
ppm	parts per million
SBS	Sick Building Syndrome
VOCs	Volatile Organic Compounds
WHO	World Health Organization

STATISTICAL DEFINITIONS

A- LINEAR REGRESSION ANALYSIS

Regression analysis is a statistical tool used to model and test for linear association between two or more variables (dependant and independent variables).

R^2 is a statistic that measures the goodness of fit of a linear relationship. It ranges up to 1, with 1 being a perfect fit. It measures how close the dependant and independent values tested to a linear fit. This statistic is useful for comparing different models that have the same number of variables.

No. of observations is the total number of dependent values or, equivalently, the number of values for any of the independent values.

X Coefficient (s) are the coefficients of the independent variables in the model tested.

Std Err of Coef. is an estimate of the standard error of the independent variables coefficient.

X Coef. /St Err of Coef. is the standardised coefficient of the independent variables.

The following symbols are used in this thesis:

► significant linear association (x Coefficient/ Std Err of Coef. > 2- 0r 1.96 if the number of variables tested is large).

♦ insignificant linear association (x Coefficient/ Std Err of Coef. < 2 - 0r 1.96 if the number of variables tested is large).

B- TWO WAY TABLE ANALYSIS (PEARSON CHI-SQUARE TEST/ FISHER'S EXACT TEST).

Tests for association between two variables.

Probability value (P) — The null hypothesis for Pearson chi-square and Fisher's exact probability (P) test is that the table variables are independent. This hypothesis can be rejected if $P < 0.05$.

C- MANN-WHITNEY TEST

Tests for significant shifts in the centre of two independent variables (tests whether two variables come from identically distributed populations).

Probability value (P) — The null hypothesis for Mann-Whitney probability (P) test is that there is no significant shift in the centre of the two independent variables. This hypothesis can be rejected if $P < 0.05$.

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CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

> *"We have little control over most bacterial and fungal species in the outdoor environment. We can, however, control their presence and/or concentrations in an indoor environment. Control may involve preventing entry of the outdoor aerosol, preventing contamination of indoor substrate, or removing sources (eg; contaminated materials)".* [1]

1.1 BACKGROUND

Buildings are designed, constructed and operated to provide safe and healthy environments that are conductive to productivity and well-being of occupants. Many buildings, however, fail to perform adequately and cause productivity losses and illness. Several studies have shown a consistent pattern of higher prevalence of work-related symptoms in buildings with air-conditioning and mechanical ventilation than in buildings with natural ventilation [2,3,4]. The specific causes of incidences of elevated complaints are related to indoor air pollution.

Among the various sources of indoor air pollution, microorganisms are considered to be the most complex and least investigated. When high concentrations of airborne bacteria and fungi are found in fully sealed mechanically ventilated buildings, it is difficult to determine to what extent these are due to outdoor pollution, the ventilation system itself or the occupants and their activities.

High indoor concentrations of airborne bacteria can result in bacterial upper respiratory infections and lung diseases such as tuberculosis, legionnaires' disease and pneumonia [5]. High levels of airborne fungi may cause allergic reactions and asthma, and have been implicated in humidifier fever and hypersensitivity pneumonitis [6]. Up to now, no attempt has been made toward developing guidelines for human exposure to such pollutants in the New Zealand office environment. Therefore, this thesis was undertaken

to identify the main factors that affect their concentrations in New Zealand fully sealed mechanically ventilated offices.

The outdoor and indoor measurements used in this thesis were carried out commercially in 235 fully sealed mechanically ventilated offices[1] between 1990 and 1995 by the Institute of Environmental Science and Research (ESR) and Advanced Building Services (ABS). Measurements were made either as part of annual routine checks of indoor air quality in office buildings, initiated by building owners, or in response to complaint situations. The 235 offices examined in this study were located in 58 fully sealed mechanically ventilated buildings (46 in Auckland and 12 in Wellington). Around two thirds of these buildings (30 buildings in Auckland and 12 buildings in Wellington) have been measured by ESR while the remaining 16 Auckland buildings have been measured by ABS. These buildings were less than 15 years old.

The indoor and outdoor air measurements of the 235 offices examined in this thesis are presented in full in a separate volume (Appendixes 1 and 2).

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1 Some examples of ventilation and air-conditioning systems are presented in Appendix1.

1.2 AIM AND OBJECTIVES

The aim of this thesis was to identify the type and investigate the levels of indoor airborne bacteria and fungi in fully sealed mechanically ventilated offices in New Zealand and to determine the impact of a number of indoor and outdoor parameters on those levels.

The main objectives were:

1. To investigate the indoor airborne bacterial and fungal levels in Auckland and Wellington offices and to compare the quality of indoor air in offices in these cities.

2. To determine whether seasonal variations of airborne bacterial and fungal levels occur in fully sealed offices.

3. To examine the differences in indoor airborne bacterial and fungal levels between complaint and non-complaint offices, in order to determine whether the complaints reported were associated with indoor airborne bacterial and fungal levels.

4. To gain an indication of how indoor air quality in New Zealand offices (in terms of airborne bacterial and fungal levels) compare to that of overseas offices.

1.3 METHODOLOGY

This thesis was based on statistical analyses of measurements recorded during commercial investigation of 235 offices in Auckland and Wellington. These measurements were:

1. Indoor air temperature
2. Indoor relative humidity
3. Outdoor airborne bacterial levels
4. Indoor airborne bacterial levels
5. Outdoor airborne fungal levels
6. Indoor airborne fungal levels
7. Indoor carbon dioxide levels

These data were measured by the Institute of Environmental Science and Research (ESR) and Advanced Building Services (ABS).

Two statistical analysis tools have been used to test for association between indoor microclimatic parameters (air temperature and relative humidity), outdoor bacterial and fungal levels and airborne bacterial and fungal levels in New Zealand offices surveyed.

The first tool was linear regression analysis which measures linear association between two variables (the significance of linearity[2] ►) .

The second tool was the two-way table analysis (Pearson chi-square test and Fisher's exact test) which was used to test for associations between two variables ($P < 0.05$ was considered significant).

In addition to these analyses, another statistical tool (the Mann-Whitney U test) has been used to test for significant differences between two sets of data ($P < 0.05$ was considered

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2 The degree of linearity is considered significant if the X coefficient / Std Err of Coef. > 2 (►), see the Statistical definitions Section.

significant). This tool has been used in Chapters 4, 5 and 6 to determine any significant differences in indoor air parameters between Auckland and Wellington offices, offices surveyed during summer and winter and complaint and non-complaint offices.

All statistical analyses were performed using QUATTRO PRO and SYSTAT for Windows. A summary of the statistical analyses is presented in Appendixes 3, 4, 5 and 6. The actual (detailed) statistical outputs are presented in full in separate volume.

1.4 LIMITATIONS

There are four limitations associated with the analyses and interpretations of the results presented in this thesis. These limitations are summarized as follows:

1. Interpretation and comparison of indoor air data are often hampered by the use of different types of sampling methods. The procedures used for collecting and analysing airborne bacterial and fungal samples in the 235 offices surveyed were[3] the settle plate method with sampling time of 18 minutes [7] and the incubation method (based on drawing 0.6 cubic metre of air)[4] [8]. Most of the overseas research studies consulted were based on different sampling techniques (see Chapter 7). Yang et al. [6] pointed out that comparison can only be made between results derived from samples taken with the same technique, medium and duration, as the variations in sampling technique may cause differences in bacterial and fungal absolute counts. Therefore, care is needed in making any comparison between indoor airborne bacterial and fungal levels presented in this study and any similar studies based on data accumulated by using different measurement methods.

Several overseas studies have reported significant differences in airborne bacterial and fungal absolute counts caused by the use of different sampling techniques [9,10]. Furthermore, significant differences have been observed between ABS and ESR data

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3 It should be noted that ESR and ABS were contacted in order to provide information on the sampling techniques used in measurements after significant differences in airborne bacterial absolute counts between ESR and ABS were observed (Mann-Whitney P = 0.000 - see Appendix 1). No significant differences in fungal absolute counts between ESR and ABS data were found (P = 0.272 - see Appendix 1).

4 The incubation method is based on drawing a known volume of air through a gelatin filter, usually for approximately eight hours. The filter is then submitted to a consulting microbiological laboratory for microbiological analysis. The gelatin filter is removed from the filter cassette holders and dissolved in a spore recovery solution. Aliquot of the solution is then plated and from the analysis of this plate, the total number of bacteria and fungi is determined. The eight time weighted average concentration is subsequently calculated using the total number of bacteria or fungi and the total air volume sampled.

(airborne bacterial[5] absolute counts in Auckland offices - see Appendix 1)[6]. Therefore, additional statistical analyses have been carried out using ESR and ABS separately to insure the validity of the statistical analyses (see Chapters 3 and 4).

2. The indoor air measurements which were conducted by ABS and ESR were limited in time. The ESR indoor bacteria and fungi measurements, for example, were carried out once for eight hours, while ABS measurements in some cases were taken only once over 18 minutes. Indoor air measurements should be monitored over a significant period of time (over a week, a month or season) to establish the impact of indoor air temperature, humidity and outdoor bacterial and fungal fluctuations on indoor bacterial and fungal levels [11]. Furthermore, an American study reported significant differences between airborne bacterial and fungal absolute counts collected over various periods of time [12].

3. The measured data in offices located in the same building has been treated in this thesis as separate records despite the fact that these offices were located 'physically' in the same structure[7]. This assumption has been made as no data has been provided, by either ESR or ABS, regarding the type of ventilation system used in the offices /buildings surveyed (whether these offices are being served by the same air handling unit, whether these offices had the same ventilation rate and percentage of recirculated air....etc).

It should also be noted that limited number of offices/buildings presented in this thesis

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5 No significant differences in airborne fungal absolute counts have been observed between ESR and ABS data (see Appendix 1).

6 These differences resulted from the use of different sampling techniques (see the methodology section).

7 This means that from the ventilation system point of view, these offices (which located in the same building) have been regarded to be served by separate air handling units and therefore have been treated as separate records.

were measured twice as part of annual routine checks of indoor air quality. These measurements were also treated in this thesis as data of separate offices as no indications were provided on the identification of the offices/buildings which were measured twice. Very limited data were provided regarding the type of activity in the office spaces in which the measurements were made and the conditions at the time of measurements (eg ; office's fabric and furnishing).

4. The 235 offices measured by both ABS and ESR and presented in this thesis may not be representative of New Zealand office populations. They were measured either in response to complaint situations or as a part of routine checks of indoor air quality. Therefore, these 235 offices do not represent a random selection of mechanically ventilated fully sealed offices throughout New Zealand.

Despite these limitations, The statistical analyses of the data used in this thesis have provided the first published information on the levels of airborne bacteria and fungi and highlighted the main factors affecting their concentrations in New Zealand fully sealed mechanically ventilated offices.

1.5 SYNOPSIS

This thesis consists of eight chapters and seven appendixes. These Appendixes provide the detailed statistics to support the analysis described in each Chapter.

Chapter 1 summarises the aim and objectives of this thesis and outlines the statistical tools used to reach these objectives. Appendix 1 presents some examples of ventilation and air-conditioning systems and explains, in graphs, one of the limitations resulting from combining ESR and ABS data in the statistical analyses.

Chapter 2 presents the most common bacterial and fungal species identified in the office environment and evaluates the potential health risks associated with exposure to such species. Appendix 2 gives examples of fungal species found in similar indoor environments overseas.

Chapter 3 evaluates and discusses the impact of indoor air temperature, indoor relative humidity and outdoor bacterial and fungal levels on the indoor bacterial and fungal levels of the 235 New Zealand offices surveyed. Appendix 3 contains the outputs of the statistical analyses used in Chapter 3.

Chapter 4 Compares the indoor airborne bacterial and fungal levels of Auckland and Wellington offices and analyses in detail the effects of several indoor and outdoor factors on the bacterial and fungal levels in offices in both cities. Appendix 4 contains the statistical analysis outputs used in Chapter 4.

Chapter 5 discusses in detail the impact of summer and winter seasonal variations on indoor airborne bacterial and fungal concentrations in Auckland and Wellington offices. It also examines the impact of seasonal variations on indoor/outdoor bacterial and fungal ratios in offices in both cities. The output of the anayses used in Chapter 5 are contained in Appendix 5.

Chapter 6 examines the differences between nine indoor air parameters in complaint and non-complaint offices surveyed. Appendix 6 presents the statistical analyses outputs used in Chapter 6.

Chapter 7 presents indoor airborne bacterial and fungal levels found in similar office environments overseas. It also evaluates the indoor bacterial and fungal levels found in New Zealand offices against three guidelines developed overseas and proposes an evaluation tool which can be used to detect any fungal problem in the office environment. Appendix 7 evaluates outdoor air temperature and relative humidity levels in both Auckland and Wellington in terms of its suitability for fungal growth and presents in graphs indoor air temperature and indoor/outdoor fungal ratios as possible causes for complaints in New Zealand offices.

Chapter 8 summarises the general conclusions and recommendations.

A diagram illustrating the structure of the thesis is presented in Figure 1.1. This diagram shows the type of analysis used in each Chapter and the degree of significance each Chapter has on the following Chapter and the final conclusions and recommendations (Chapter 8).

The separate volume contains the actual statistical analyses' outputs.

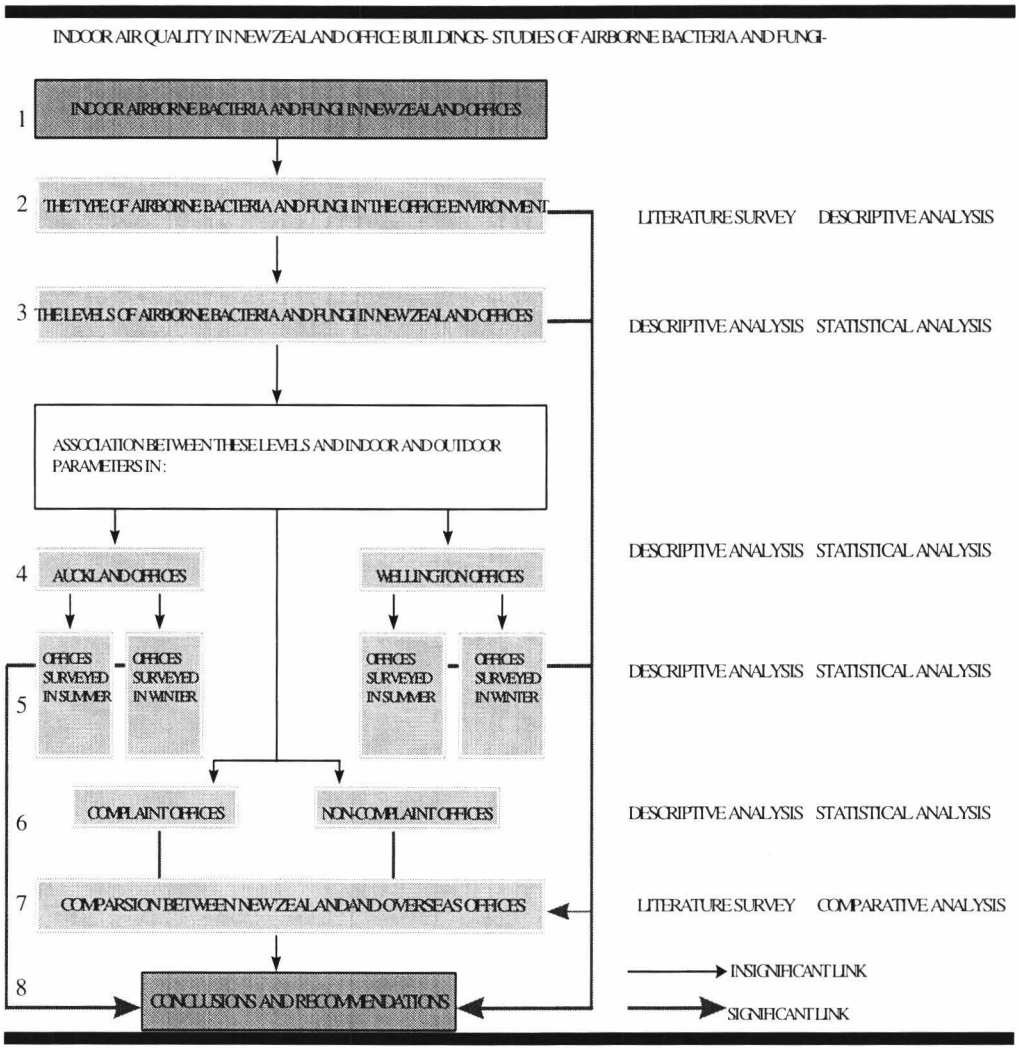

Figure 1.1: The structure of the thesis

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CHAPTER 2

ASSOCIATION BETWEEN THE COMMON AIRBORNE BACTERIAL AND FUNGAL SPECIES IDENTIFIED IN THE OFFICE ENVIRONMENT AND HUMAN HEALTH

- LITERATURE SURVEY
- DESCRIPTIVE ANALYSIS

CHAPTER 2

ASSOCIATION BETWEEN THE COMMON AIRBORNE BACTERIAL AND FUNGAL SPECIES IDENTIFIED IN THE OFFICE ENVIRONMENT AND HUMAN HEALTH

> *"Bioaerosol sampling should be undertaken only in cases in which positive evidence exists for diseases related to biological contamination: humidifier fever, hypersensitivity pneumonitis, allergic asthma and allergic rhinitis. For complaints in other organ systems (e.g. skin, reproductive system), no evidence exists to support microbial aerosols as etiologies."*[1]

2.1 INTRODUCTION

Airborne bacteria and fungi are always present in the ambient air. Their variety and quantity depend on the environment. Exposure to airborne bacteria and fungi in a contaminated environment results in allergic reactions in susceptible individuals but poses a very limited risk to 'normal' individuals. A significant amount of airborne bacteria and fungi with toxic potential in the ambient air can pose a greater health hazard, however. Therefore, determining the impact of different bacterial and fungal species on human health is an important step towards identifying microbial pollution in the air and then applying effective correction measures to eliminate or reduce their occurrence in the indoor environment.

Illnesses caused by poor indoor air quality have been defined by Godish [2] as a unique set of symptoms which may be accompanied by clinical signs, laboratory findings and identifiable pollutants. Exposure to high levels of airborne bacteria and fungi can cause a wide variety of symptoms. Some of these symptoms include hay fever, skin, nose and eye irritation and upper respiratory illness. In this chapter, the major bacterial and fungal species found in the Auckland office environment will be identified[8]. The health

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8 No data have been provided by ESR regarding the concentration level of the identified bacterial and fungal species presented in this thesis. Therefore, no link will be made in this Chapter between bacterial and fungal species and the level of concentrations which might be considered (through literature review) hazardous.

implications caused by these species will be assessed through literature survey to evaluate the risks involved with the exposure to such species.

The bacterial and fungal species presented in this chapter were based on ESR data[9] collected from 33 offices in Auckland City[10]. The identification of bacterial and fungal species has been carried out in these 33 offices because of the existence of elevated levels of airborne bacteria and fungi. The symptoms reported in some of these offices included eye and skin irritation and 'flu-like' symptoms.

9 ABS data has no records regarding the type of bacterial and fungal species found in the offices surveyed.

10 No data regarding the type of airborne bacterial and fungal species were available for the rest of Auckland offices and in all Wellington offices.

2.2 MOST COMMON BACTERIAL SPECIES IDENTIFIED IN THE OFFICE ENVIRONMENT (DESCRIPTIVE ANALYSIS)

Bacteria are defined by Kowalski [3] as single-celled organisms about one micron in diameter. They have a cell membrane, DNA and some subcellullar components. They are ubiquitous in both indoor and outdoor air.

The identification of bacterial species is far more complex than the identification of fungi. Little data exists regarding the health effects of exposure to high levels of airborne bacteria whereas many, though not all, health problems caused by fungi are well defined.

There were two major bacterial species found in the Auckland office environment. *Flavobacterium* was the most common bacterial species identified. It has been found in 60% of offices with airborne bacteria. *Flavobacterium* has been found also in approximately 75% of all outdoor samples taken. This would imply that this particular species is more likely to exist outdoors.

Pseudomonas was the second most common bacterial species identified in Auckland offices. It has been identified in around 40% of all indoor samples with bacterial existence. In the outdoor environment, on the other hand, 25% of all measurements with bacterial existence had *Pseudomonas* as the predominant species. This means that *Pseudomonas* is more likely to be an indoor genus.

The most common bacterial species and the percentage of their occurrence in the office environment are presented in Figure 2.1.

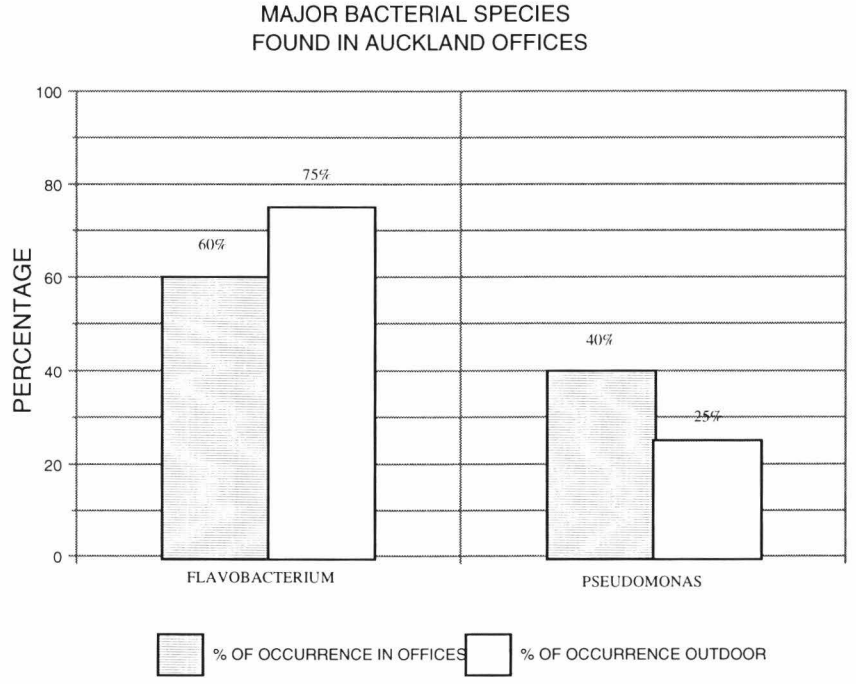

Figure 2.1: The common bacterial species identified in indoor and outdoor samples of Auckland offices

2.3 MOST COMMON FUNGAL SPECIES IDENTIFIED IN THE OFFICE ENVIRONMENT (DESCRIPTIVE ANALYSIS)

Fungi are organisms containing membraneous organelles. They can be unicellular like *Yeasts* or multicellular like moulds [3]. Most fungi produce spores which can become airborne. Only a few fungi invade living cells to cause infectious disease. However, most fungi produce metabolic products which can cause antigenic reaction in those who are hypersensitive.

There were five major fungal species found in the Auckland office environment. The most common species was *Penicillium* which was identified in 46% of the offices surveyed. *Penicillium* was also found in 31% of total outdoor samples with fungal existence.

The second most common fungal species found were *Yeasts*. These have been found in 18% of the offices surveyed. They also existed in 11% of total outdoor samples with fungal existence.

Cladosporium has been found in 14% of all indoor samples with fungal existence. It has been found in 42% of the total outdoor samples. This means that *Cladosporium* is more likely to survive in the outdoor environment.

Aspergillius and *Paecilomyces* were the least common fungal species identified in the office environment. They have been found in 11% of the indoor air samples whereas in outdoor samples, *Aspergillius* and *Paecilomyces* have been found in 5% and 11% respectively.

The most common fungal species and the percentage of their occurrence in the office environment are presented in Figure 2.2.

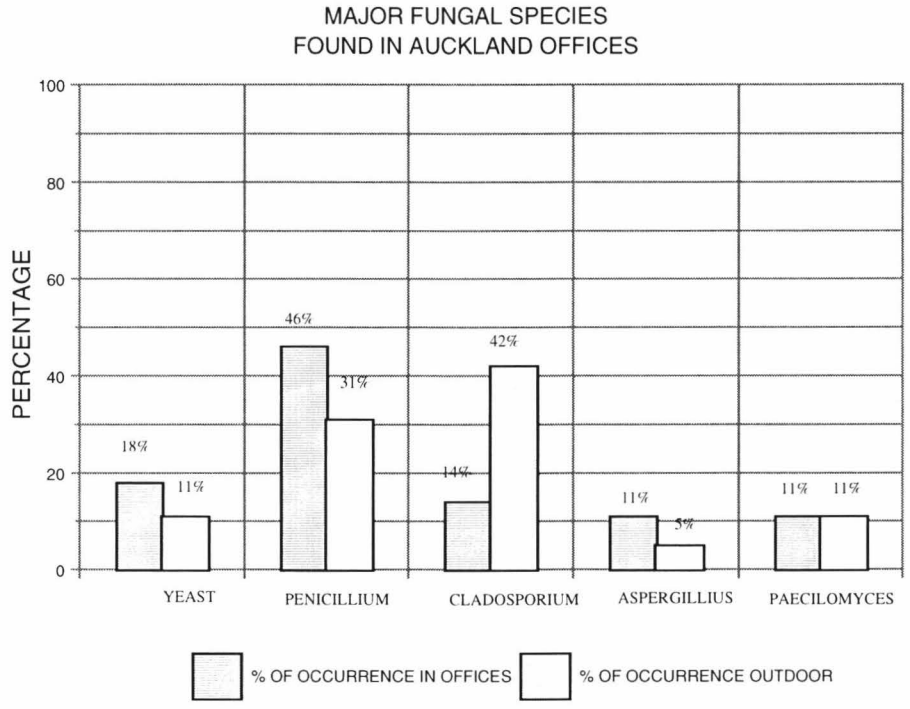

Figure 2.2: The common fungal species identified in indoor and outdoor samples of Auckland offices. *Yeast*, *Penicillium* and *Aspergillius* were the most common fungal species identified indoors while *Cladosporium* was the most common fungal species isolated from outdoor samples.

2.4 EFFECTS OF DIFFERENT BACTERIAL AND FUNGAL SPECIES ON HUMAN HEALTH (LITERATURE SURVEY)

It is important to evaluate the potential health risks associated with exposure to the seven major bacterial and fungal species identified in the Auckland office environment. This would be the first step towards developing guidelines for the levels of human exposure to such species in the office environment. Several overseas studies[11] have been carried out on some of these species which pose a health hazard to humans. These studies will be discussed and evaluated to assess the likely health hazards facing office occupants.

2.4.1 *FLAVOBACTERIUM*

Flavobacterium is rarely found in the indoor environment and the effect of this bacterial species on human health is not well documented. No evidence has been found to suggest any links between *Flavobacterium* and building-related illnesses. An American study [4] carried out to investigate health risks associated with microbial exposure in an industrial setting found no detectable increase in symptoms which could be related to the existence of *Flavobacterium* in the indoor environment.

Gallup [5] showed that in 326 offices, 155 classrooms and 23 homes in California, *Flavobacterium* was the third most frequent bacterial species identified. A study carried out on some naturally and mechanically ventilated buildings in Italy reported *Flavobacterium* as among the most common identified bacterial species especially during winter time. The study also reported *Flavobacterium* in higher frequencies in primary and secondary schools [6].

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11 These studies have been conducted in different indoor environments, not necessarily offices (eg. residential units, schools, libraries..etc).

2.4.2 *PSEUDOMONAS*

Pseudomonas has the ability to infect an individual through open wounds and to cause upper respiratory and pneumonia-like illness [4]. A study carried out on mouldy houses in Finland showed that *Pseudomonas* may be involved in some of the respiratory disorders caused by indoor mould exposures [7].

Another Finnish study showed that *Pseudomonas* is not part of indoor airborne flora but is a common genus in outdoor air. The study showed that this particular bacteria is common in waters, soil and plants and it might be generated in water reservoirs (such as contaminated humidifiers) [8]. A French study found *Pseudomonas* to be one of the bacterial species isolated from classrooms in 10 primary and nursery schools [9]. Furthermore, a Canadian study showed also that *Pseudomonas* was the most common bacterial species identified in a medical waste incinerator [10]. The study suggested the increase of air exchange rates as the most effective way to reduce the bacterial concentrations.

Maroni [6] pointed out that *Pseudomonas* was the most common bacterial species identified in 17 buildings (seven of them were mechanically ventilated) in Italy. Furthermore, Gallup [5] reported *Pseudomonas* as the most frequent bacterial species identified in offices and working areas in some 326 offices in 73 multistory buildings in California. The levels of *Pseudomonas* were particularly high near cooling towers.

2.4.3 *PENICILLIUM*

Penicillium has been found to be associated with allergic alveolitis[12] [11] and hypersensitivity skin test reactions in some allergic individuals [12] (cited in 24). A Canadian study found *Penicillium* to be the main fungus in the home of a family

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12 Alveolitis is an inflammation of the gas-exchanging parts of the lung resulting in breathlessness.

suffering from itching wrists and feet, pain in lower limbs, chronic sore throat and dryness of eyes and nose [13]. These symptoms were cured by eliminating the *Penicillium* moulds which were found on the basement ceiling. Furthermore, a study carried out in a library in response to complaints from regular visitors found that *Penicillium* was among the dominant fungal species. The main symptoms reported were irritation of eyes and nose, fever and headache [14].

Several studies have shown that *Penicillium* was a common fungal genus and was identified more frequently indoors than outdoors [15,16,17] (cited in 24). Kalliokoski [18] pointed out that *Penicillium* is the predominant fungal genus in Finnish homes and its high frequency in indoor air is due to the fact that *Penicillium* spores are released into the air 'more easily' than any other fungal spores. Furthermore, an Italian study found *Penicillium* to be one of the most frequent fungi recovered from houses with allergic complaints [19].

2.4.4 *YEASTS*

An Italian survey showed that the percentage of *Yeasts* occurrence in allergic people's homes was twice that found in non- allergic homes [17]. An American study carried out in some 150 homes found *Yeasts* to be significantly associated with the occurrence of hay fever symptoms [20].

A Japanese study [21] showed that *Yeasts* were isolated from different parts of air-conditioners in a number of dwellings. *Yeasts* were found most frequently in drain pans and they were not recovered from any other parts of the air-conditioners (eg; filters and air outlets). An American study conducted in commercial buildings, most with ongoing indoor air quality complaints, has found *Yeasts* in high levels in cooling coils. Most of the samples were taken from air-conditioning systems serving complaints areas [22].

2.4.5 *CLADOSPORIUM*

Cladosporium has been found to be associated with hay fever-type symptoms in children [20] (cited in 2). It has been found to cause hypersensitivity skin reaction in some allergic individuals [12,23] (cited in 24). Garrett [25] found a significant correlation between *Cladosporium* levels and respiratory symptoms, parental asthma, cough and wheeze. Garrett also indicated that *Cladosporium* is primarily an outdoor mould as the levels of *Cladosporium* were higher in homes with open windows at the time of sampling. Li [26] reported a significant association between *Cladosporium* levels and history of asthma in children. This species was very common mainly on decomposing vegetation and under certain conditions can have a toxic potential.

An American study [27] carried out on some 1200 fibreglass air ducts of HVAC systems of buildings with known indoor air quality complaints found *Cladosporium* to be the major fungal species existing. *Cladosporium* was also the major fungal genus recovered from several parts of HVAC systems[13] in Japanese homes [21] and from filtering devices of HVAC systems of a large congress centre in Berlin, Germany with a history of complaints [28] (Appendix 2). These finding indicate that *Cladosporium* is primarily an outdoor species. This observation was confirmed here in Auckland offices as *Cladosporium* was the major fungal genus found outdoors.

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13 These parts were filters and fresh air inlets (as these parts are the most HVAC systems devices which have direct contact with outdoor air).

2.4.6 *ASPERGILLIUS*

Aspergillius was found to be significantly associated with wheeze and/or asthma complaints in school-aged children [20]. A Finnish study [29] on houses with mould problems showed that airborne *Aspergillus* counts in mould problem houses were significantly higher than those of 'reference' houses (Appendix 2). Furthermore, Li [26] reported a significant level of *Aspergillus* in homes of atopic children and in schools with dampness problems in Taiwan. The concentrations of *Aspergillus* and *Penicillium* spores in particular were significantly higher in houses with mould problems. This means that the composition of fungal genera in the mould problem environment was significantly different from that of a 'normal' environment.

An American study indicated that *Aspergillius* was the fourth most frequent fungal species found in homes [30]. Another American study ranked *Aspergillus* as the third most frequent fungal species identified in around 2000 fungal samples of non-residential buildings across the U.S. [31]. This would suggest that Aspergillus is very adaptable and likely to flourish in the indoor environment.

2.4.7 *PAECILOMYCES*

In an Italian study, *Paecilomyces* has been recovered from allergic patients' homes along with *Penicillium* and *Aspergillus* [19]. Another Italian study showed that *Paecilomyces* was one of the identified fungal species in two different industrial areas with complaints. The levels of this fungal species were higher in an area devoted to carpentry [32] (Appendix 2).

Paecilomyces is found infrequently in the indoor environment as it rarely occurs below 95% relative humidity [33]. An American study showed that *Paecilomyces* is a thermotolerant fungal genus as high levels of *Paecilomyces* were observed in a building with damp furnishing and construction materials (in this case, water had been used to control a fire in the building three months earlier), although air temperature and relative

humidity at the time of sampling were 42°C and 70% respectively [34]. Furthermore, Chin [27] reported *Paecilomyces* in wetted parts of fibreglass air-duct liner (FGL) of HVAC systems in buildings throughout the U.S. *Paecilomyces* has also been found where liquid water is often present (such as in cooling coils and drain pans). This would suggest water damaged areas provide the most suitable conditions for the growth of this particular fungal species.

An American study [35] carried out on two mechanically ventilated office buildings presented *Paecilomyces* as the fifth most common fungal species identified in one of the buildings, although this species has not been found in outdoor samples. Meldrum [36], on the other hand, reported *Paecilomyces* at a very low frequency in 116 households surveyed in the U.S.

2.5 DISCUSSION

The aim of this chapter was to present the bacterial and fungal species found in the office environment and to evaluate the risks associated with exposure to such species. This has been achieved through the literature review. This review has been helpful in identifying bacterial and fungal species which might be associated with particular types of building problems. For example, just as a carbon dioxide reading over 1000 ppm is an indicator of under ventilation [37], the presence of airborne *Aspergillius* and *Penicillium* is an indicator of indoor mould problems (eg. mouldy, dirty or wet ceiling tiles, window sills/frames, slime or algae humidifiers, water leaks, damp odours, wet cooling/heating fan coils... etc.), while the presence of *Cladosporium* is an indicator of an outdoor source problem which suggests poor filter performance in fully sealed offices.

Penicillium and *Cladosporium* were the most common fungal species isolated from Auckland offices. These species were also the most common fungal species found in similar indoor environments overseas (Appendix 2). Likewise *Yeasts* and *Aspergillius* were more likely to flourish indoors. These species were identified in approximately 29% of all indoor samples, whereas in outdoor samples, these species were found in only 16%. This finding appeared to be confirmed in several overseas studies.

No thresholds, based on health risk, can be drawn as an upper limit for exposure to airborne bacterial and fungal species in the indoor environment. There are two reasons for this. The first is due to the fact that some people may be more susceptible to exposure to specific bacterial and fungal species than others. The degree of reaction to such exposure is highly dependent on age, sex and medical conditions of individuals [38]. The second reason is that the use of different sampling methods in measuring airborne bacterial and fungal levels often affects their absolute counts and this in turn will affect the reliability of any guidelines proposed for these particular indoor pollutants [9,36] (see Chapter1 and Appendix 1).

2.6 RECAPITULATION

Two bacterial species were the most common genera identified in Auckland offices. *Flavobacterium* was the most frequent bacterial species isolated from Auckland offices (approximately 60% of all indoor samples and 75% of all outdoor samples). *Pseudomonas* was the second most common bacterial species identified in Auckland offices. It was isolated from 40% of all indoor samples and 25% of all outdoor samples taken from the 33 offices surveyed in Auckland.

Penicillium was the most common fungal species isolated from Auckland offices. It was identified in almost half the indoor samples taken from the 33 offices surveyed. *Penicillium,* on the other hand, has only been found in around 30% of all outdoor samples. This appeared to be confirmed in several overseas studies which reported *Penicillium* as the most common fungal species identified more frequently indoors than outdoors. These studies also reported strong association between *Penicillium* and symptoms similar to those reported by some occupants in Auckland offices[14].

Yeasts were the second most common species identified in the 33 offices surveyed. They were found in indoor samples more frequently than outdoors. They were recovered more often in wet parts of air-conditioning units. Several overseas studies have linked the existence of *Yeasts* in the indoor environment with hay fever symptoms reported by the occupants.

Cladosporium was the third most common fungal species identified in the offices surveyed. However, it has been isolated more often from outdoor samples than indoors (14% of all indoor samples and 42% of all outdoor samples). This appeared to be confirmed in a number of overseas studies which reported *Cladosporium* as an outdoor species. It has been isolated from HVAC systems and in particular filtering devices

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14 These symptoms include eye and nose irritation and chronic sore throat (flu-like symptoms - see Section 2.1 and Chapter 6).

(especially during the growing season[15]). Several studies have linked *Cladosporium* with respiratory symptoms and parental asthma.

Aspergillius and *Paecilomyces* were the least common fungal species identified (only 20% of all indoor samples and 15% of all outdoor samples). *Aspergillius* was more common indoors. This has been confirmed in a number of overseas studies carried out in houses with mould problems which presented *Aspergillius* as very adaptable to and likely to flourish in the indoor environment. *Paecilomyces*, on the other hand, has been isolated more often in wet areas such as drain pans, cooling coils and water damage areas.

A summary of the common bacterial and fungal species found in the 33 Auckland offices surveyed and the potential health hazards associated with the exposure to such species is presented in Table 2.1.

In the following Chapter, the indoor air profile in the 235 fully sealed mechanically ventilated offices will be investigated and statistical analysis will be used to test for association between indoor microclimatic parameters (indoor air temperature and relative humidity), outdoor airborne bacterial and fungal levels and indoor airborne bacterial and fungal concentrations.

15 Mainly during spring and summer.

TABLE 2.1: SUMMARY OF THE MOST COMMON BACTERIAL AND FUNGAL SPECIES IDENTIFIED IN THE OFFICE ENVIRONMENT AND THE POTENTIAL HEALTH HAZARDS ASSOCIATED WITH EXPOSURE TO SUCH SPECIES.

	OCCURRENCE IN THE OFFICE ENVIRONMENT	**POTENTIAL HEALTH HAZARD ASSOCIATED WITH EXPOSURE TO SUCH SPECIES (LITERATURE REVIEW)**
FLAVOBACTERIUM	Found mainly outdoors. It is also the major bacterial species identified indoors.	- Unknown
PSEUDOMONAS	Found mainly indoors.	- Upper respiratory and pneumonia-like illness
PENICILLIUM	It is the most common fungal genus identified indoors.	- Hypersensitivity skin reaction in some individuals - Allergic alveolitis - Irritation of eyes and nose, headache
YEASTS	It is one of the common fungal species identified indoors.	- Hay fever symptoms
CLADOSPORIUM	It is one of the major fungal species identified outdoors.	- Hypersensitivity skin reaction in some allergic individuals - Hay fever-type symptoms in children - Respiratory symptoms - Cough and wheeze
ASPERGILLIUS	The least common fungal species identified both indoors and outdoors, more likely to exist indoors.	- Identified as a casual agent for asthma and allergic alveolitis - associated with wheeze and asthma
PAECILOMYCES	Found both indoors and outdoors.	- Allergic manifestation and positive skin reaction

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CHAPTER 3

INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN THE NEW ZEALAND OFFICE ENVIRONMENT

- DESCRIPTIVE ANALYSIS
- STATISTICAL ANALYSIS

CHAPTER 3
INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN THE NEW ZEALAND OFFICE ENVIRONMENT

"Indoor environmental microorganisms and their secondary metabolites are considered by some to pose a greater risk than the other notorious environmental pollutants such as asbestos and VOCs from non-organic sources".[1]

3.1 INTRODUCTION

The number of offices included in this research was 235 (186 offices in Auckland[16] and 49 offices in Wellington). The indoor and outdoor measurements were carried out by the Institute of Environmental Science and Research (ESR) and Advanced Building Services (ABS). There were seven measurements conducted for most of the offices surveyed. These measurements were:

1. Indoor air temperature (°C)
2. Indoor relative humidity (%)
3. Outdoor airborne bacterial levels (CFU/m^3)
4. Indoor airborne bacterial levels (CFU/m^3)
5. Outdoor airborne fungal levels (CFU/m^3)
6. Indoor airborne fungal levels (CFU/m^3)
7. Indoor carbon dioxide levels (ppm)

This chapter examines the associations between indoor air temperature, indoor relative humidity, outdoor airborne bacterial and fungal levels and indoor airborne bacterial and

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16 116 offices, out of the 166 Auckland offices, have been measured by Advanced Building Services (ABS).

fungal levels in fully sealed mechanically ventilated offices[17]. The aim of these analyses is to determine to what extent indoor air temperature, relative humidity, outdoor airborne bacterial and fungal levels affect the indoor levels in fully sealed mechanically ventilated offices in New Zealand.

Two different statistical methods have been used to examine whether the indoor microclimatic parameters (temperature and humidity) and the outdoor bacterial and fungal concentrations affect the indoor airborne bacterial and fungal concentrations. The first method was linear regression analysis which tests for significant linear association between two variables. A test for linearity is performed and the degree of linearity is considered significant if X Coef./ Std Err of Coef. > 2 - ►. The second method was the Pearson chi-square analysis which tests for association between two variables (The null hypothesis of the Pearson chi-square test (P) is that the two variables tested are independent). This hypothesis can be rejected if (P) value < 0.05 (see Section 1.3 Methodology).

17 Not necessarily air-conditioned.

3.2 INDOOR AIR PROFILE IN THE NEW ZEALAND OFFICE ENVIRONMENT (DESCRIPTIVE ANALYSIS)

Statistical analyses of the 235 sets of indoor air data showed that the mean indoor air temperature and relative humidity were 21°C and 47% respectively. The indoor bacterial levels were significantly higher than the outdoor levels. As mentioned previously in Chapter 2, the main bacterial species found outdoors were *Flavobacterium* and *Pseudomonas* and the predominant indoor species was *Flavobacterium*. The indoor fungal levels, on the other hand, were significantly lower than those found outdoors. The predominant outdoor fungal species were *Cladosporium* and *Penicillium* whereas indoor species were predominantly *Penicillium* and *Yeasts*. The mean, median, and range of indoor microclimatic parameters, outdoor and indoor bacterial and fungal concentrations and indoor carbon dioxide levels are listed in Table 3.1.

TABLE 3.1: THE MEAN, MEDIAN AND RANGE OF MEASURED PARAMETERS IN NEW ZEALAND OFFICES.

	Indoor temperature °C	Indoor humidity %	Outdoor bacteria CFU/m³	Indoor bacteria CFU/m³	Outdoor fungi CFU/m³	Indoor fungi CFU/m³	Carbon dioxide ppm
New Zealand offices (ESR+ABS data, all outdoor measurements are ESR data only) [18]							
Mean	21	47	22	68	139	38	584
Median	21	48	13	23	41	20	557
Range	19-24.2	27-69	0-292	0-621	14-1382	0-470[19]	200-1100
Count	203	202	99	138	99	121	173

18 Outdoor bacterial and fungal data presented here were ESR measurements as ABS had no records regarding outdoor measurements.

19 There was one record of 470 CFU/m³ in one office(measured in Wellington by ESR) which is a very high level (considering the rest of indoor fungal levels in New Zealand offices - see Appendix 1 of the accompanied report). The second highest value reported was just 254 CFU/m³ (measured in an Auckland office by ABS). Therefore, the indoor airborne fungal range of **0-254** might reflect more accurate range.

In the following Sections, a number of statistical analyses will be carried out to find out to what extent indoor air temperature, indoor relative humidity and outdoor airborne bacterial and fungal levels affect the indoor airborne bacterial and fungal levels.

3.3 ASSOCIATION BETWEEN INDOOR AIR TEMPERATURE AND INDOOR AIRBORNE BACTERIA AND FUNGI (STATISTICAL ANALYSIS)

As shown in Table 2, the indoor air temperature at the time of measurement ranged from 19°C to 24 °C. Indoor bacterial concentrations were found to have no significant association with indoor air temperature ($R^2 = 0.17$ ► in the case of using ESR and ABS data combined in the analysis and 0.04 ♦ in the case of using ESR data only). The probability value (P) for the Pearson chi-square test confirmed this finding (P= 0.001 and 0.870 - see Appendix 3)[20]. The relation between indoor air temperature and indoor airborne bacterial concentrations is shown in Figure 3.1.

Indoor airborne fungal concentrations were also found to have no significant correlation with indoor air temperature (R^2= 0.003 ♦). The Pearson chi-square test confirmed this finding (P=0.935- see Appendix 3). This would suggest that indoor air temperature within the 19-24°C range had no association with indoor airborne fungal concentrations (see Figure 3.2). This agrees with a Japanese study, carried out on five residential units, which suggested that airborne fungal levels and indoor air temperature were not likely to be correlated within the range of 15-20°C [2].

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It should be noted that the R^2 value was 0.04 (♦) and Pearson chi-square test (P) was 0.870 without the use of ABS data (see Appendix 3). This means that the use of ESR data only in the statistical analyses showed no association between indoor airborne bacteria and temperature whereas the use of (ESR+ABS) data showed a relatively significant association ($R^2 = 0.17$ (►) and P = 0.001- see the Limitation section of Chapter 1). As mentioned previously in Chapter 1, the reasons for these differences is due to the fact that different measurement techniques have been used by ESR and ABS which in turn affected the airborne bacterial absolute count (ABS bacterial counts were in general five times higher than those of ESR (P = 0.00 - see Appendix 1 and Chapter 1). Therefore, data distributions will be affected by these differences (high values for ABS data and relatively low values for ESR data - see Appendix 1). The differences in results affect only two statistical analyses :

indoor bacteria vs indoor air temperature and indoor bacteria vs indoor relative humidity.

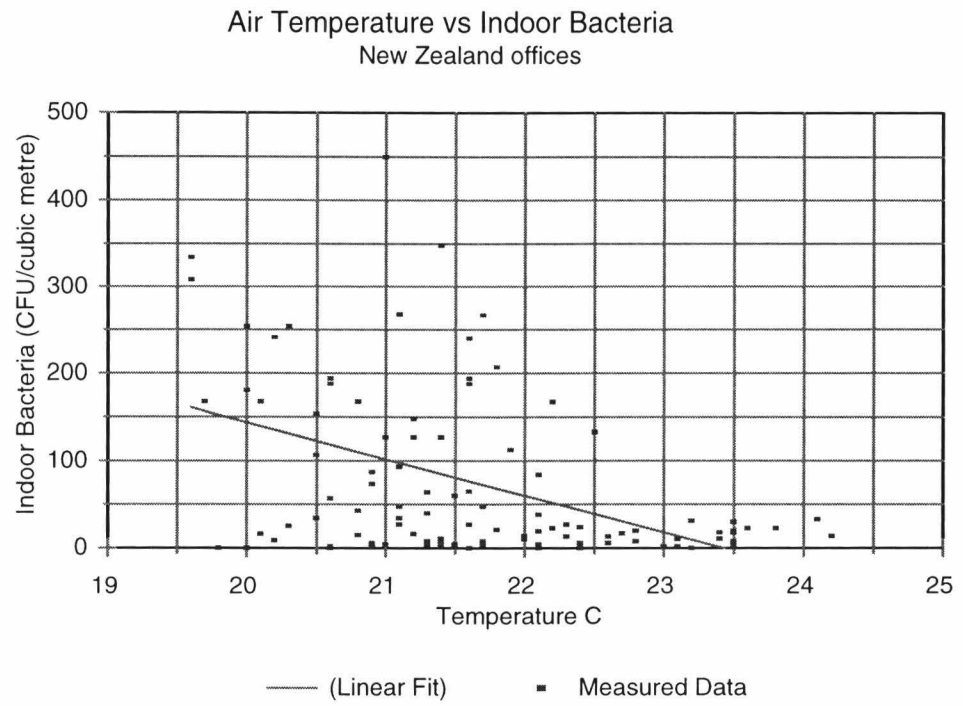

Figure 3.1: Indoor air temperature and indoor airborne bacterial levels in New Zealand offices. Most indoor airborne bacterial records above 100 CFU/m^3 were ABS measurements (see Appendix 1). Therefore, additional analysis has been carried out using ESR data separately.

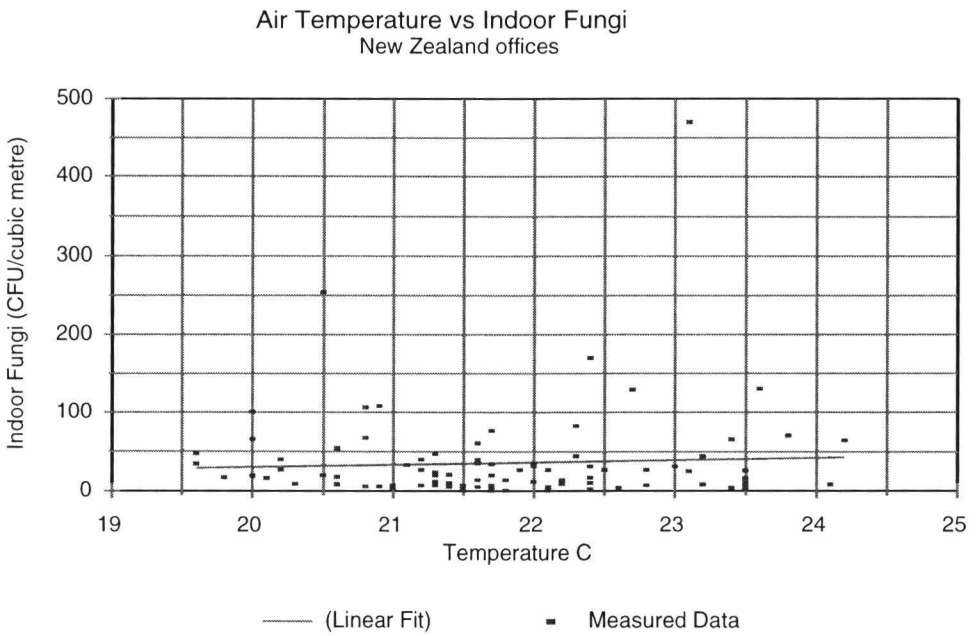

Figure 3.2: Indoor air temperature and indoor airborne fungal levels in New Zealand offices. No significant differences in indoor airborne fungal levels between ESR and ABS data have been found (see Appendix 1).

3.4 ASSOCIATION BETWEEN INDOOR RELATIVE HUMIDITY AND INDOOR AIRBORNE BACTERIA AND FUNGI (STATISTICAL ANALYSIS)

Indoor relative humidity levels during the time of measurements ranged from 27% to 69%. Statistical analysis indicated that indoor bacterial levels and indoor relative humidity were not associated ($R^2 = 0.06$ ► in the case of using ESR and ABS in the analysis and $R^2 = 0.00$♦without the use of ABS data- see Footnote 21 and Figure 3.3). The Pearson chi-square probability (P) values were 0.029 in the case of using ESR and ABS in the analysis and 0.487 without ABS data. This would suggest that the relative humidity within the above range was not associated with indoor bacterial concentrations (see Appendix 3). This appears to be confirmed in a German study [3] which reported that most bacterial species are more viable indoors at high humidity levels than at low levels[21].

Indoor airborne fungal levels appeared to have no association with indoor relative humidity ($R^2= 0.003$ ♦ - see Figure 3.4). The Pearson chi-square probability test confirmed that indoor relative humidity and indoor airborne fungal levels were independent (P=0.634 - see Appendix 3).

Kalliokoski et al.[4] reported, in a Finnish study, that fungal growth requires high relative humidity levels (76%-96%). The study showed that a number of common indoor fungal species such as *Cladosporium* and *Stachybotrys* existed to a significant degree only in the relative humidity range 96%-98%. A study published by Health Canada reported that in most Canadian cities, "*ideal*" indoor relative humidity levels range from 35% to 50%. Higher humidity levels can lead to condensation which may cause moulds to grow [5]. Furthermore, a Nordic guideline for indoor relative humidity suggested that indoor relative humidity levels should be maintained at 40-70% to avoid microbiological growth [6]. A study carried out on a building in the southeastern United States which had

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21 High relative humidity in this study was around 77% while the low relative humidity was 33%.

a history of elevated relative humidity reported visible fungi on interior surfaces [7]. A WHO study, on the other hand, suggested that low humidity can also promote the survival of several fungal species and enhance the release of fungal spores [8]. In around 88% of the New Zealand offices surveyed, the indoor relative humidity ranged from 35-70%.

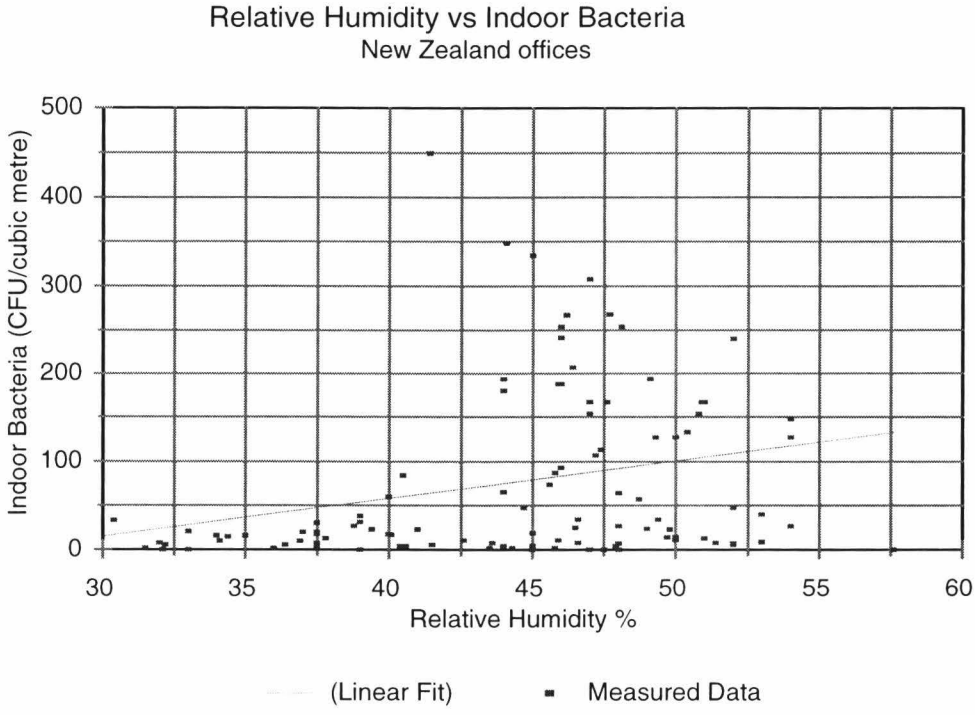

Figure 3.3: Indoor relative humidity levels and indoor airborne bacterial levels in New Zealand offices. In this graph, most indoor airborne bacterial records above 100CFU/m^3 were ABS data. Therefore, additional analysis has been carried out using ESR data separately.

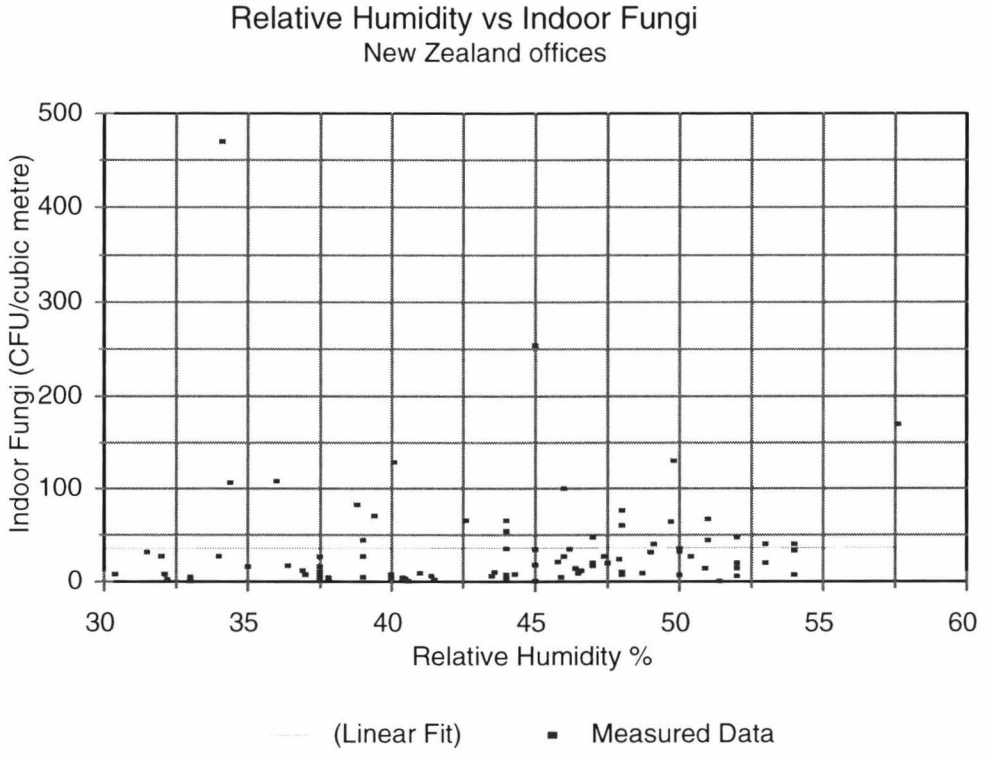

Figure 3.4: Indoor relative humidity levels and indoor airborne fungal levels in New Zealand offices. Indoor relative humidity and indoor airborne fungal levels were not associated.

3.5 ASSOCIATION BETWEEN INDOOR AND OUTDOOR AIRBORNE BACTERIA (STATISTICAL ANALYSIS)

The linear regression analysis of indoor and outdoor bacterial levels showed that there was significant linear association between the two variables (R^2= 0.17 ►- see Figure 3.5)[22]. The Pearson chi-square probability (P) value showed also significant association between indoor and outdoor levels (P= 0.014). A WHO study indicated that outdoor airborne bacteria is an important source for indoor airborne bacterial contamination [9].

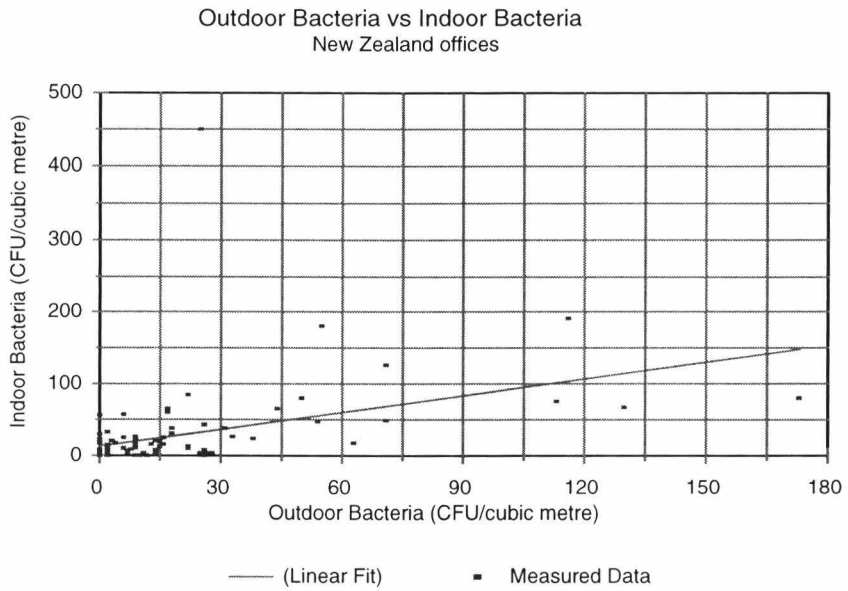

Figure 3.5: Outdoor and indoor airborne bacterial levels in New Zealand offices. The graph shows that the association between indoor and outdoor airborne bacteria is a linear one.

22 All the data used in this case were ESR measurements as no outdoor measurements were provided by ABS.

3.6 ASSOCIATION BETWEEN INDOOR AND OUTDOOR AIRBORNE FUNGI (STATISTICAL ANALYSIS)

Linear regression analysis showed no significant association between indoor and outdoor fungal concentrations. The R^2 value for this relation was 0.01 ♦. The Pearson chi-square analysis, on the other hand, showed a significant association between the two variables (P=0.029[23] - see Appendix 3). Figure 3.6 shows that the relation between indoor and outdoor airborne fungi is a non-linear one. Therefore, the P value would be a more reliable measure in this case.

An American study showed that high outdoor airborne fungal levels had a strong impact on the indoor levels. This study reported that a sudden increase in outdoor fungal levels (during a demolition project) resulted in a significant increase in indoor fungal levels in a nearby hospital after a time lag [10]. Walsh et al. [11] reported that indoor fungal levels in summer were consistently higher than in winter. An Australian study reported that outdoor airborne fungal levels contributed to indoor levels in around 20% of the buildings surveyed [12]. Furthermore, a WHO report indicated that outdoor sources were important contributors to indoor levels [8]. Statistical analysis indicates that outdoor air infiltration was a strong source of indoor airborne fungal contamination in New Zealand offices.

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23 Pearson chi-square test (nonlinear analysis) is a more reliable measure as linear regression is only valid for simple linear relationships which may be suspected. Furthermore, Figure 3.6 shows that the relationship between indoor and outdoor airborne fungi is a nonlinear one.

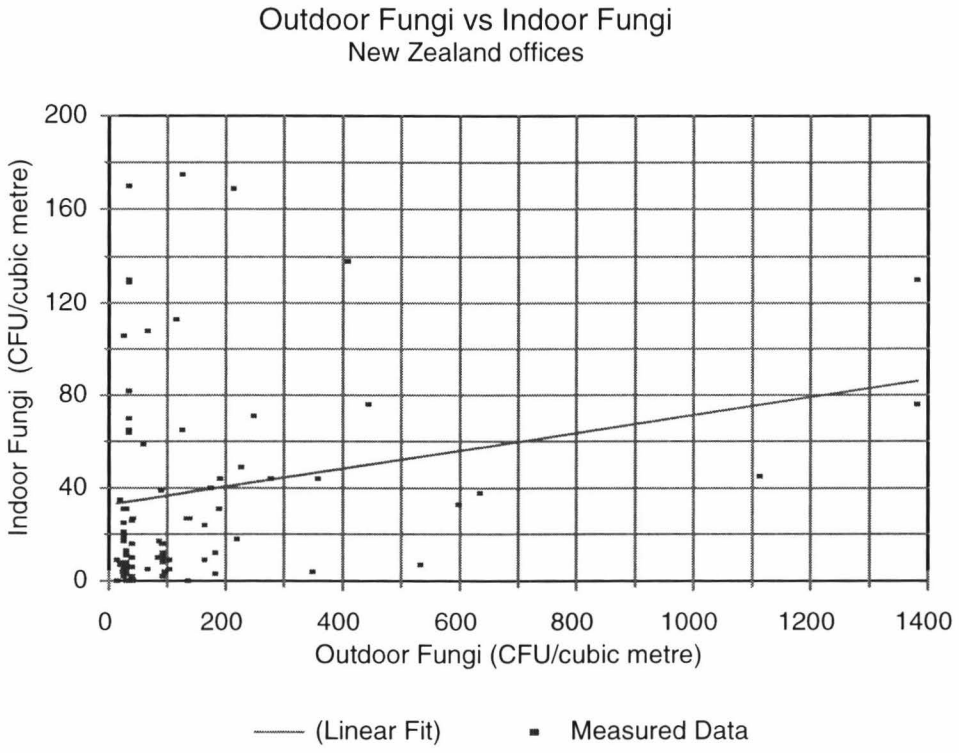

Figure 3.6: Outdoor and indoor airborne fungal levels in New Zealand offices. This graph shows that the relationship between indoor and outdoor airborne fungi was a non-linear one (low outdoor levels coincided with both low and high indoor levels).

3.7 DISCUSSION

There were significant differences between results obtained by the use of ESR data only and results obtained by the combined use of both ESR and ABS data. For instance, the Pearson chi-square probability value (P) for indoor airborne bacteria and indoor air temperature was 0.001 (which suggests indoor airborne bacterial concentrations were affected by indoor air temperature levels) in the case of the combined ESR and ABS data, but increased to 0.870 (which means indoor airborne bacterial concentrations were not affected by indoor air temperature levels) when only ESR data was used (see Footnote 21 and the Limitations Section of Chapter 1). This is due to the fact that ABS bacterial counts were significantly higher than those of ESR and this in turn has affected the overall data distribution. Therefore, care should be used in conducting analyses using data obtained by using different measurement techniques.

The analytical results which have been affected by the use of different sources of data were limited to indoor airborne bacteria analyses with indoor air temperature and indoor relative humidity. The statistical analyses of indoor airborne fungi with indoor air temperature and relative humidity were not affected as no significant differences existed between the fungal absolute counts of ABS and ESR (P = 0.272 - see Appendix 1). The indoor and outdoor airborne bacterial and fungal analyses were also not affected as only ESR data was used in these analyses (no data regarding outdoor measurements has been provided by ABS).

Statistical analyses suggested a strong association between indoor and outdoor airborne bacterial and fungal levels. The R^2 value for indoor and outdoor airborne bacteria was 0.17 ► and the Pearson chi-square (P) value was 0.014. This means that there was association between indoor and outdoor airborne bacterial concentrations (see Figure 3.5). The R^2 value for indoor and outdoor airborne fungi was 0.01 ♦ and the Pearson chi-square (P) value was 0.029 (the Pearson (P) value is more reliable in this case as the association between indoor and outdoor airborne fungi was not a linear one - see Figure

3.6). This means that outdoor bacterial and fungal levels were more important factors affecting indoor airborne bacterial and fungal levels than indoor microclimatic parameters (temperature and relative humidity).

3.8 RECAPITULATION

There was strong statistical evidence of an association between indoor airborne bacterial and fungal levels and outdoor levels in fully sealed mechanically ventilated offices in New Zealand. The statistical analyses of 235 offices produced the following results:

1- There was no association between indoor air temperature and indoor airborne bacterial and fungal levels (see Footnote 21).

2- There was no association between indoor relative humidity and indoor airborne bacterial and fungal levels (see Footnote 21).

3- Indoor airborne bacterial levels were significantly associated with outdoor levels.

4- Outdoor airborne fungal levels had a strong impact on the indoor levels. Statistical analyses showed a significant association between the two variables.

A summary of the results of the statistical analyses of various factors affecting indoor bacterial and fungal levels in New Zealand offices is presented in Table 3.2.

In the next chapter, a detailed statistical analysis of indoor air data in Auckland and Wellington offices will be examined. The aim of this analysis is to identify to what extent outdoor airborne bacteria and fungi in both cities affects the indoor levels in fully sealed mechanically ventilated offices.

TABLE 3.2: SUMMARY OF LINEAR REGRESSION AND PEARSON CHI-SQUARE ANALYSES OF INDOOR AIR TEMPERATURE, INDOOR RELATIVE HUMIDITY, INDOOR AND OUTDOOR AIRBORNE BACTERIA AND FUNGI IN THE NEW ZEALAND OFFICES SURVEYED.

	LINEAR REGRESSION (R^2)	PEARSON CHI-SQUARE TEST (P)
TEMPERATURE vs INDOOR BACTERIA	0.17*▸ (0.03)** ♦	0.001* 0.870**
HUMIDITY vs INDOOR BACTERIA	0.06*▸ 0.00** ♦	0.029* 0.487**
TEMPERATURE vs INDOOR FUNGI	0.00▪♦	0.935▪
HUMIDITY vs INDOOR FUNGI	0.00▪♦	0.634▪
OUTDOOR BACTERIA vs INDOOR BACTERIA	0.17**▸	0.014**
OUTDOOR FUNGI vs INDOOR FUNGI	0.01**♦	0.029**

Significant association (Pearson chi-square < 0.05).

Insignificant association (0.05 <Pearson chi-square < 0.1).

Further analyses have been performed, without the use of ABS data, as the validity of the initial analyses (through the combined use of ESR and ABS data) was inconclusive.

▸ Significant linear association (X Coef./ Std Err of Coef. > 2)

♦ Insignificant linear association (X Coef./ Std Err of Coef.< 2)

* Results affected by the combined use of ESR and ABS data (see Footnote 21, Chapter 1 and Appendix1).

** Only ESR data have been used.

▪ Both ABS and ESR data have been used (results not affected, see Chapter 1 and Appendix1).

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CHAPTER 4

INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN AUCKLAND AND WELLINGTON OFFICES

- DESCRIPTIVE ANALYSIS
- STATISTICAL ANALYSIS

CHAPTER 4

INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN AUCKLAND AND WELLINGTON OFFICES

"Although mechanical ventilation of buildings is seen as a solution to the problem of IAQ, some studies have shown that naturally ventilated office buildings have two to five times fewer complaints of air related problems than sealed buildings. This seems to be a situation where technology has not kept up with design needs, and where human health and overall productivity are suffering". [1]

4.1 INTRODUCTION

Indoor air data of 186 offices in Auckland and 49 offices in Wellington have been analysed[24]. The aim of this analysis was to identify the indoor airborne bacterial and fungal profiles in Auckland and Wellington offices. The main objective was to determine to what extent indoor microclimatic parameters and outdoor airborne bacterial and fungal levels affect indoor levels in the office environment in both cities.

The comparison between indoor airborne bacterial and fungal levels in Auckland and Wellington offices was expected to lead to better understanding of the factors affecting indoor airborne bacteria and fungi in the office environment. Comparison between indoor airborne bacterial and fungal levels in Auckland and Wellington offices with those found in similar environments overseas will also be useful[25]. Although the 235 offices surveyed were not randomly selected and may thus not be representative of New Zealand office populations, it was felt worthwhile to determine how indoor air quality in these offices were compared to their overseas counterparts.

Statistical analysis of indoor/outdoor airborne bacterial and fungal ratios was also

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24 116 offices in Auckland have been measured by ABS (see chapter 3 and Appendix 1). All Wellington offices presented in this thesis were measured by ESR.

25 These comparisons will be made in chapter 7.

expected to provide useful information on the performance of the ventilation system in offices in both cities. It will also determine the major sources of airborne bacteria and fungi in the indoor environment.

4.2 INDOOR AIR PROFILE IN AUCKLAND AND WELLINGTON OFFICES (DESCRIPTIVE ANALYSIS)

The mean indoor air temperature in Auckland offices was slightly lower than that of Wellington. The mean indoor relative humidity was 20% higher in Auckland than in Wellington offices.

Indoor bacterial levels were above 100 CFU/m^3 in approximately 53% of Auckland and just 3% of Wellington offices. Indoor bacterial levels were below 10 CFU/m^3 in 33% and 57% of Auckland and Wellington offices respectively. The mean outdoor airborne bacterial levels of Auckland were at least five times higher than those of Wellington and the maximum outdoor levels were 10 times higher in Auckland than in Wellington. These significant differences in outdoor bacterial levels between the two cities are reflected in the indoor airborne bacterial levels, as the mean indoor airborne bacterial levels in Auckland offices was almost five times higher than that of Wellington offices.

Indoor fungal levels were above 100 CFU/m^3 in approximately 6% and 17% of Auckland and Wellington offices respectively. Indoor fungal levels were below 10 CFU/m^3 in 37% and 43% of Auckland and Wellington offices respectively. The mean outdoor fungal level in Auckland was almost seven times higher than that of Wellington. This could be explained by the fact that outdoor climatic conditions in Auckland are more suitable for fungal growth [2,3], especially in summer[26] (see Appendix 7).

The mean, median and range of indoor air temperature, relative humidity, outdoor and indoor airborne bacterial and fungal levels and indoor carbon dioxide levels in Auckland and Wellington offices are listed in Table 4.1.

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26 Based on climatic data published by NIWA [4].

TABLE 4.1: THE MEAN, MEDIAN AND RANGE OF INDOOR AIR TEMPERATURE, INDOOR RELATIVE HUMIDITY, INDOOR AND OUTDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS AND INDOOR CARBON DIOXIDE LEVELS IN AUCKLAND AND WELLINGTON OFFICES.

	Indoor temperature °C	indoor humidity %	outdoor bacteria CFU/m³	indoor bacteria CFU/m³	outdoor fungi CFU/m³	indoor fungi CFU/m³	carbon dioxide ppm
Auckland offices (ESR+ABS data)[27]							
Mean	21	49	35	92	229	34	597
Median	21	49	17	53	104	27	576
Range	19-24	32-69	0-292	0-621	14-1382	0-254	200-1100
Count	166	165	53	92	53	75	143
Wellington offices (ESR data only)[28]							
Mean	22.4	40	7	20	45	46	521
Median	22.7	38	2	7	34	12	490
Range	20-24.2	27-57	0-26	0-450	24-214	0-470[29]	367-851
Count	37	37	46	46	46	46	30

27 Outdoor bacterial and fungal data presented here were ESR measurements as ABS had no records regarding outdoor measurements.

28 No Wellington offices have been measured by ABS.

29 As mentioned previously in Chapter 3, The 470 CFU/m3 is a very high value (considering the rest of indoor airborne fungal levels of Wellington offices). The second highest fungal level recorded in a Wellington office was just 175 CFU/m3 (see Appendix 2 of the separate report). Therefore, the indoor airborne fungal range of **0-175 CFU/m3** might reflect more accurate range. This is also the case in the 0-450 CFU/m³ range of indoor airborne bacteria in Wellington. The second highest level in a Wellington office was just 56 CFU/m³. Therefore, the indoor airborne bacterial range of **0-56 CFU/m3** might also reflect more accurate range.

4.3 ASSOCIATION BETWEEN INDOOR AIR TEMPERATURE, INDOOR RELATIVE HUMIDITY, OUTDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS AND INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN AUCKLAND AND WELLINGTON OFFICES (STATISTICAL ANALYSIS)

Indoor air quality depends on many factors. The existence of diverse potential indoor sources of microbial pollutants, ventilation efficiency and outdoor air quality are among the factors of greatest interest. Therefore, linear regression analysis and the Pearson chi-square test (a nonlinear analysis) have been used to test for associations between indoor microclimatic parameters (temperature and relative humidity), outdoor airborne bacterial and fungal levels and indoor airborne bacterial and fungal concentrations.

4.3.1 ASSOCIATION BETWEEN INDOOR AIR TEMPERATURE AND INDOOR AIRBORNE BACTERIA

The linear regression analysis of indoor airborne bacteria and temperature data for Auckland showed no association between the two variables. The R^2 value was 0.16 ▸ in the case of using both ESR and ABS data and 0.04 ♦ in the case of using ESR data only (Figure 4.1). The Pearson chi-square test showed also no significant association between indoor airborne bacterial concentrations and indoor air temperature. The P value was 0.018 in the case of using ESR and ABS data in the analysis whereas the P value was 1.00 in the case of using ESR data only- see Appendix 4 and the Recapitulation section).

In Wellington offices, the statistical evidence suggested also that indoor airborne bacteria and indoor air temperature were not associated (Figure 4.2). The R^2 value was 0.03 ♦. The Pearson chi-square test also showed that indoor airborne bacteria and indoor temperature were not associated (P = 0.61).

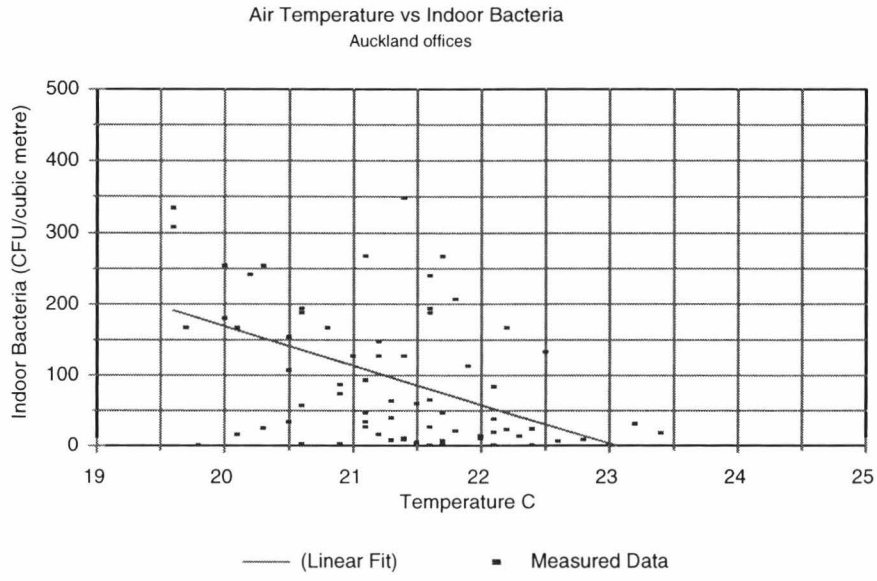

Figure 4.1: Indoor air temperature and indoor airborne bacterial levels in Auckland offices. This graph illustrates clearly the impact of using both ESR and ABS data on the analysis. The combination of high values of airborne bacteria (ABS data) and the relatively low values (ESR data) creates the effects of strong negative linear association between indoor airborne bacterial level and indoor air temperature.

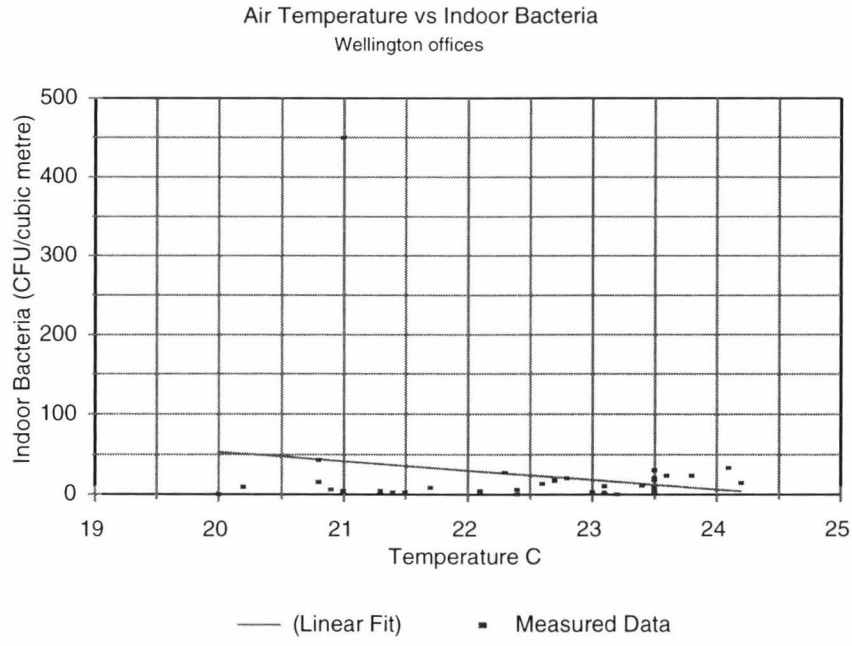

Figure 4.2: Indoor air temperature and indoor airborne bacterial levels in Wellington offices. The data used in this case were collected from a single source (ESR).

4.3.2 ASSOCIATION BETWEEN INDOOR AIR TEMPERATURE AND INDOOR AIRBORNE FUNGI

Statistical analysis of indoor airborne fungi and indoor air temperature in Auckland offices showed no association between the two variables (Figure 4.3). The R^2 value for this relation was 0.07 ♦ . The Pearson chi-square analysis confirmed this finding (P = 0.56).

Similarly, linear regression analysis of Wellington data showed no association between indoor airborne fungi and indoor air temperature (R^2 = 0.02 ♦ - see Figure 4.4). Again the Pearson chi-square analysis confirmed this finding (P = 0.80 - see Appendix 4).

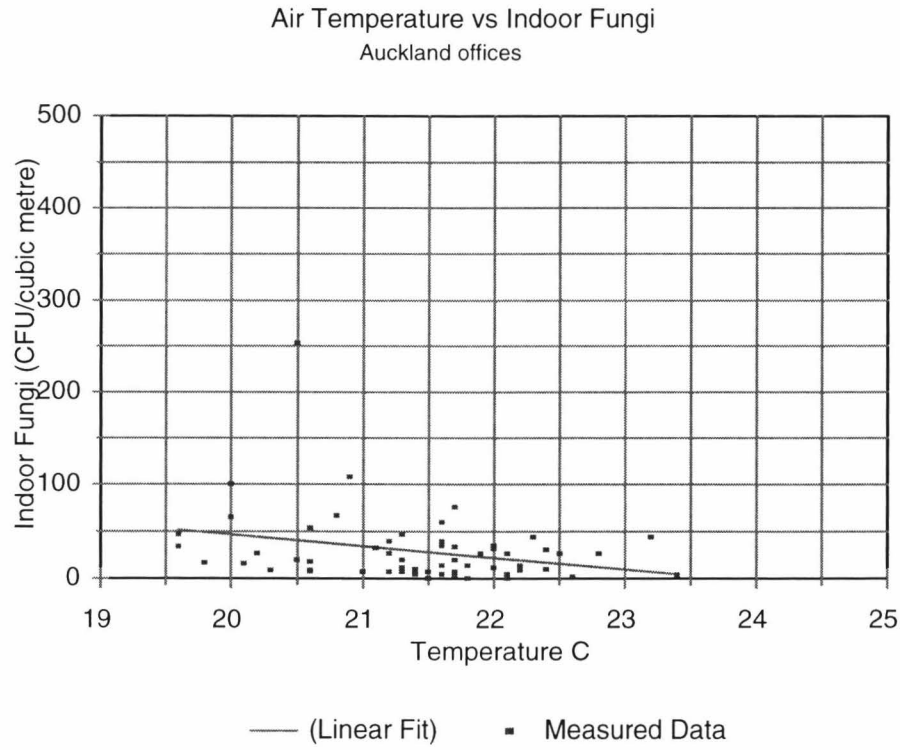

Figure 4.3: Indoor air temperature and indoor airborne fungal levels in Auckland offices

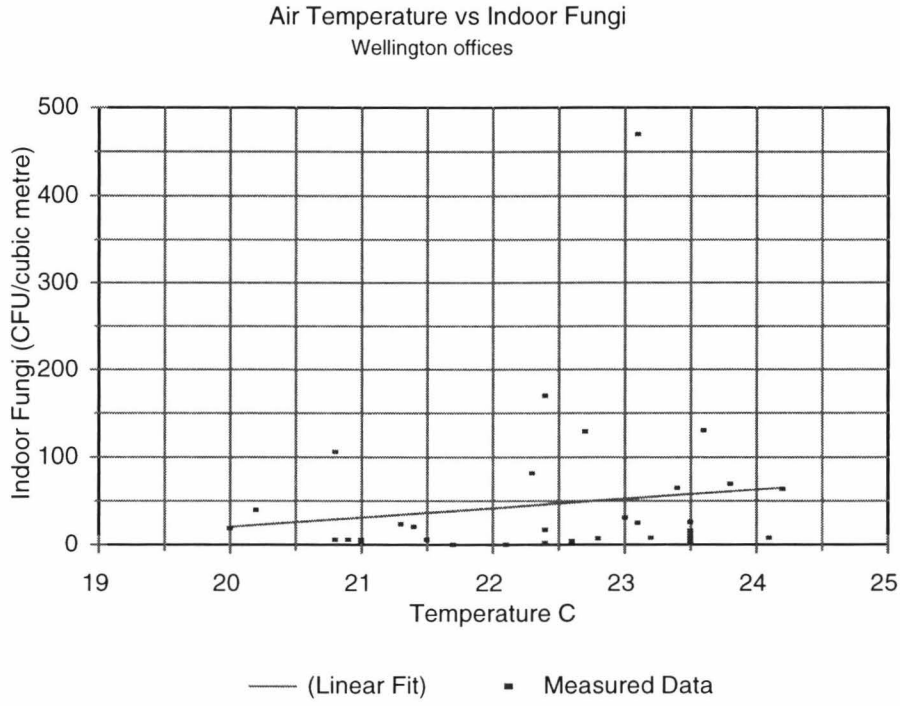

Figure 4.4: Indoor air temperature and indoor airborne fungal levels in Wellington offices

4.3.3 ASSOCIATION BETWEEN INDOOR RELATIVE HUMIDITY AND INDOOR AIRBORNE BACTERIA

Statistical analysis in both Auckland and Wellington offices showed that indoor airborne bacteria and indoor relative humidity were not associated. The R^2 value for this relation was 0.05 ♦ for Auckland offices in the case of using ESR and ABS data in the analysis and 0.00 ♦ in the case of using ESR data only in the analysis (see Figure 4.5 and the Recapitulation section). The R^2 value was 0.00♦ for Wellington offices (Figure 4.6). The Pearson chi-square test confirmed this finding. The P value was 0.192 for Auckland offices in the case of using ESR and ABS data in the analysis and 0.65 in the case of using ESR data only. The P value was 0.35 for Wellington offices - see Appendix 4 and the Recapitulation section).

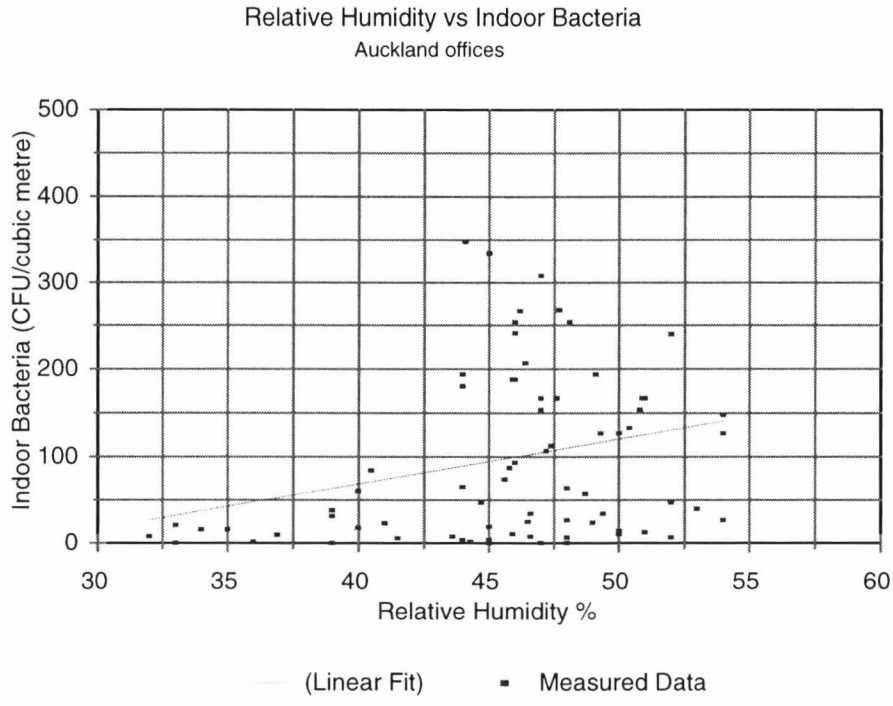

Figure 4.5: Indoor relative humidity and indoor airborne bacterial levels in Auckland offices. Again, the combined use of ABS and ESR data made the interpretation of the analysis more complicated.

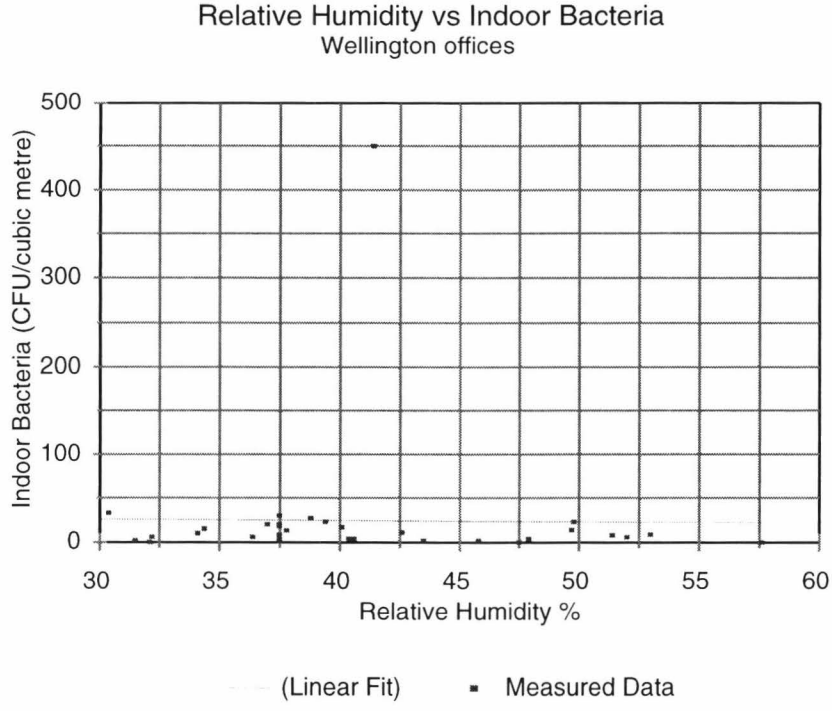

Figure 4.6: Indoor relative humidity and indoor airborne bacterial levels in Wellington offices. This shows no clear pattern in the data distribution to suggest association between indoor airborne bacterial levels and relative humidity.

4.3.4 ASSOCIATION BETWEEN INDOOR RELATIVE HUMIDITY AND INDOOR AIRBORNE FUNGI

Indoor airborne fungi in Auckland and Wellington offices appeared to have no association with indoor relative humidity. Linear regression analysis showed no association between indoor fungal levels and indoor relative humidity (R^2= 0.005 ♦ and 0.003 ♦ in Auckland and Wellington respectively - see Figures 4.7 and 4.8). The Pearson chi-square test analysis confirmed this finding (P = 0.228 in Auckland offices and 0.824 in Wellington offices - see Appendix 4).

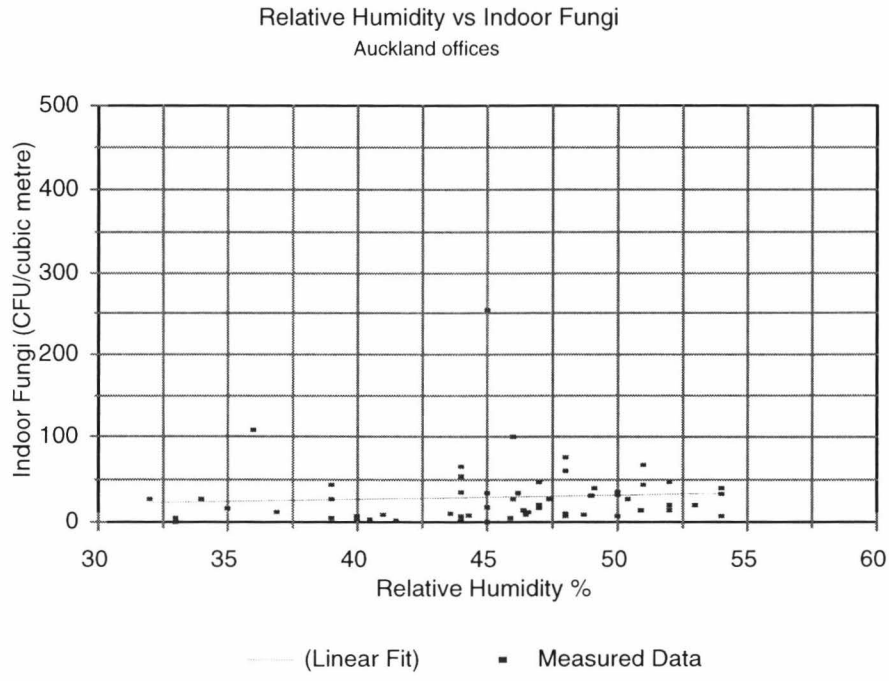

Figure 4.7: Indoor relative humidity and indoor airborne fungal levels in Auckland offices

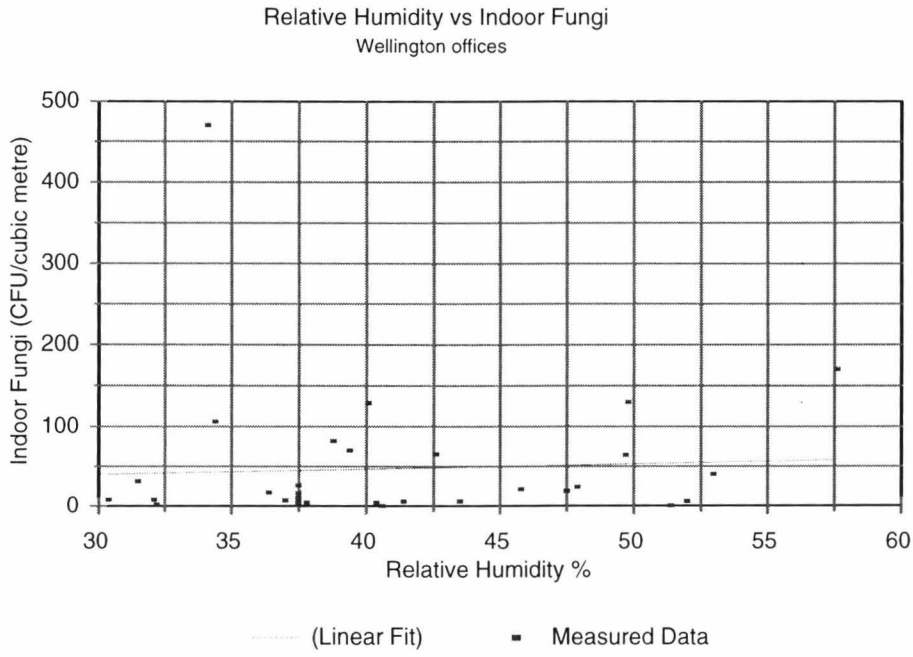

Figure 4.8: Indoor relative humidity and indoor airborne fungal levels in Wellington offices. No clear pattern can be observed to suggest association between indoor airborne fungi and relative humidity.

4.3.5 ASSOCIATION BETWEEN INDOOR AND OUTDOOR AIRBORNE BACTERIA

Linear regression analysis of indoor and outdoor airborne bacterial concentrations in Auckland offices showed strong association between the two variables ($R^2 = 0.39$ ▸ - see Figure 4.9). The Pearson chi-square test confirmed this finding ($P = 0.003$).

In Wellington offices, on the other hand, the association between outdoor and indoor airborne bacteria appeared to be less significant ($R^2 = 0.08$ ♦ - see Figure 4.10). The Pearson chi-square test also showed a relatively weak association ($P = 0.082$). Figures 4.9 and 4.10 show also that the measured data in Auckland offices were more widely distributed (in both the horizontal and vertical axes) than those of Wellington offices. This illustrates the significant differences in outdoor and indoor airborne bacterial levels between Auckland and Wellington offices.

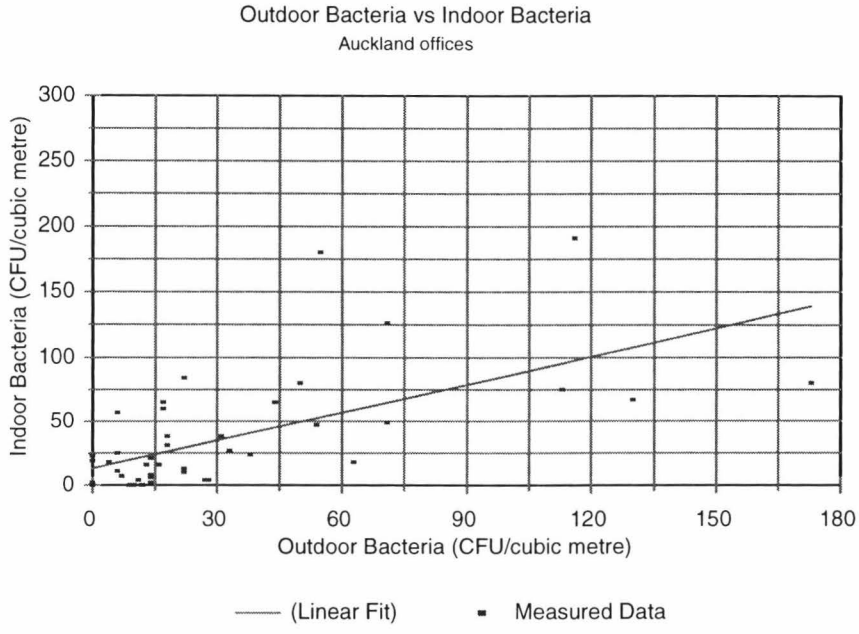

Figure 4.9: Indoor and outdoor airborne bacterial levels in Auckland offices. This graph shows that the association between indoor and outdoor levels was a linear one.

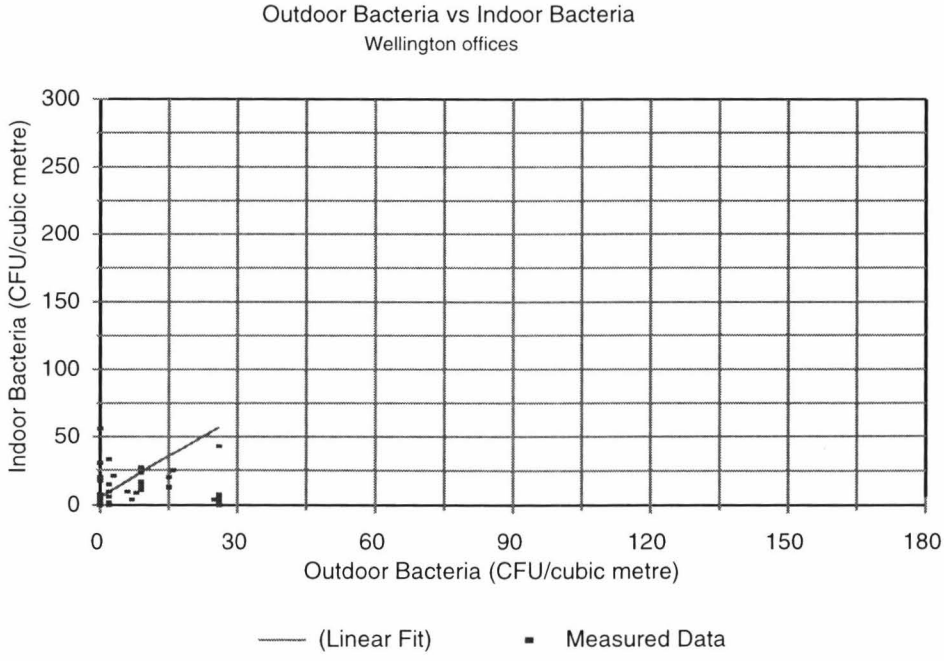

Figure 4.10: Indoor and outdoor airborne bacterial levels in Wellington offices. Figures 4.9 and 4.10 show that high indoor airborne bacterial levels in Auckland offices were due to elevated outdoor levels whereas in Wellington offices, indoor airborne levels were significantly lower as outdoor levels in Wellington were at low level.

4.3.6 ASSOCIATION BETWEEN INDOOR AND OUTDOOR AIRBORNE FUNGI

Statistical analysis of indoor and outdoor fungi data collected from Auckland offices indicated that there was a strong association between the two variables. Linear regression analysis showed that indoor airborne fungal levels were associated with outdoor levels ($R^2 = 0.27$ ▸ - see Figure 4.11). The Pearson chi-square test confirmed this finding (P = 0.00 - see Appendix 4). In Wellington, on the other hand, the linear regression showed no association between indoor and outdoor fungi (R^2=0.01♦ - see Figure 4.12). The Pearson chi-square test confirmed this finding (P=0.16).

Outdoor fungal levels exceeded the 100 CFU/m^3 level in 55% of outdoor measurements in Auckland whereas in Wellington, only 11% of outdoor measurements exceeded this level. However, indoor fungal levels exceeded 100 CFU/m^3 in 6% of Auckland offices and 17% of Wellington offices. In Auckland, indoor fungal levels exceeded outdoor levels in only 2% of offices, whereas this percentage in Wellington was 28%. Indoor fungal levels were 10 times less than outdoor levels in 48% of offices in Auckland, but only 8% of Wellington offices. This would suggest that in Wellington offices, indoor airborne fungal levels are more likely to be generated from internal sources[30].

In 88% of Auckland offices with outdoor fungal concentrations above 100 CFU/m^3, indoor concentrations were less than 100 CFU/m^3. This suggests that in most of the offices surveyed in Auckland, indoor airborne fungal levels were not likely to be generated from internal sources.

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30 In Auckland offices, on the other hand, indoor fungal levels higher than 100 CFU/m^3 were in general due to elevated outdoor levels.

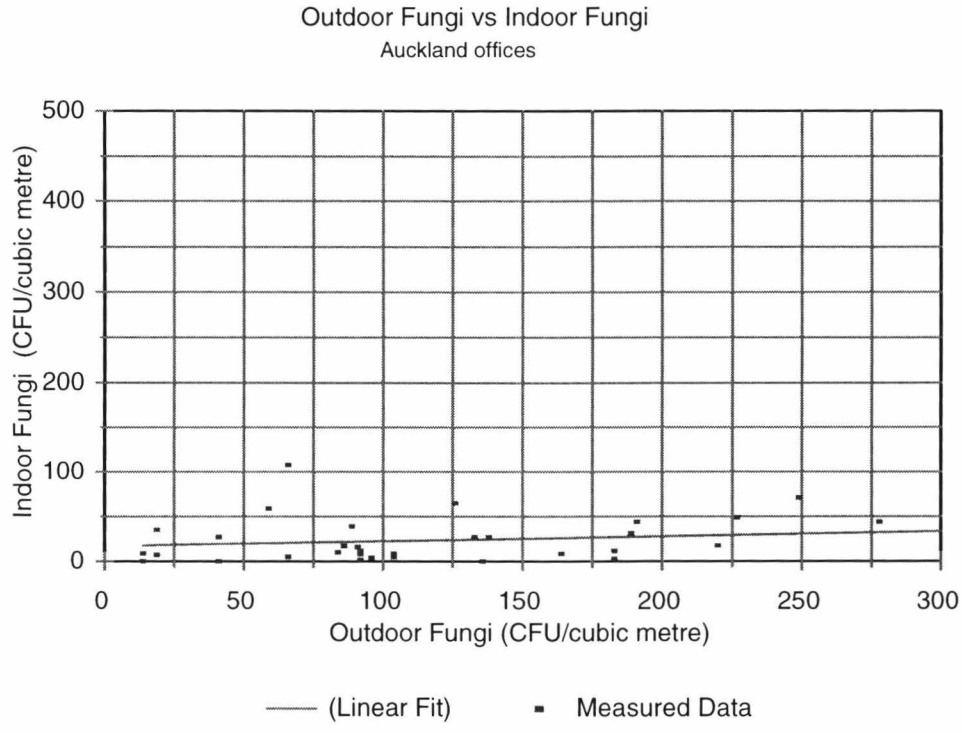

Figure 4.11: Indoor and outdoor airborne fungal levels in Auckland offices. Indoor airborne levels were in general low despite the fact that outdoor levels were much higher.

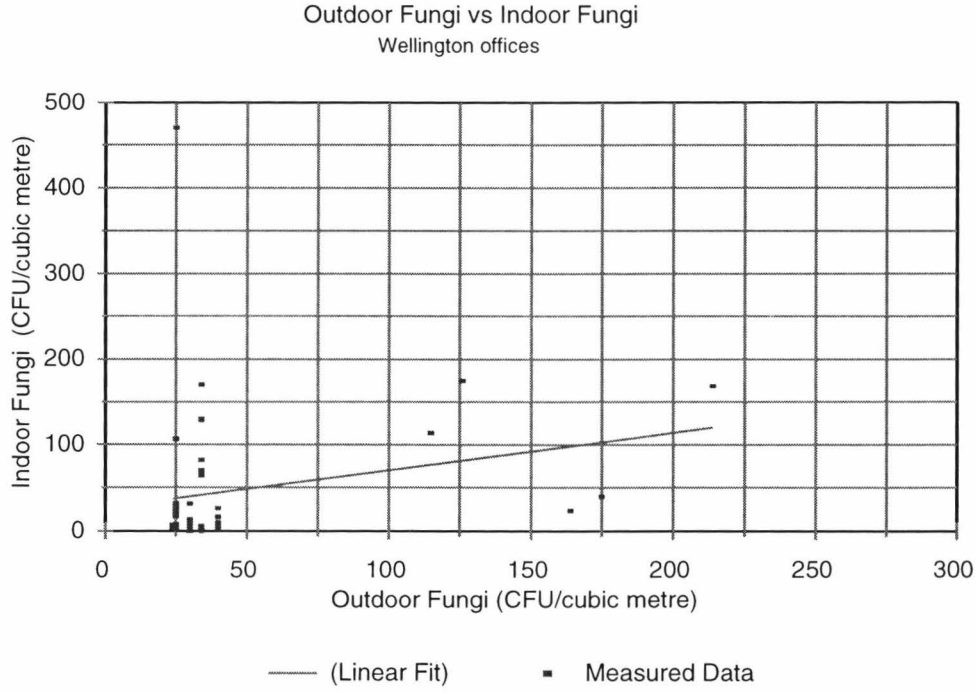

Figure 4.12: Indoor and outdoor airborne fungal levels in Wellington offices. High indoor levels coincided with relatively low outdoor levels (a number of indoor levels exceeded 50 CFU/m^3 while their outdoor levels were significantly below the 50 CFU/m^3 level).

4.3.7 ASSOCIATION BETWEEN INDOOR AIRBORNE BACTERIA AND FUNGI

Linear regression analysis of indoor bacteria and indoor fungi in Auckland offices showed significant association between the two pollutants. The R^2 value for this relation was 0.27 ▸ in the case of using both ESR and ABS in the analysis (the R^2 values were 0.11▸ and 0.51▸ in the case of using ESR data and ABS data respectively - Figure 4.13). The Pearson chi-square analysis also showed a significant dependence relationship between the two contaminants (P = 0.016 in the case of using ESR and ABS data while P values were 0.036 and 0.55 for the ESR data and ABS data respectively - see Appendix 4). In Wellington offices, on the other hand, regression analysis of indoor bacteria and indoor fungi in Wellington offices indicated no association between the two pollutants (R^2= 0.003 ♦ - see Figure 4.14). The two-way table analysis also indicated that indoor airborne bacteria and fungi were independent. (P= 0.818 - see Appendix 4).

This would suggest that in Auckland offices with high bacterial levels were more likely to have higher levels of indoor fungi too. In other words, indoor factors which encouraged indoor bacteria species to flourish might be the same factors encouraging fungal growth. In Wellington offices, on the other hand, this was not the case. An Australian study produced a similar result [5]. It has found no association between indoor bacterial levels and any mould levels (this study was based on 40 residential naturally ventilated buildings in Victoria, Australia).

Strong association was found between outdoor bacterial and fungal concentrations in Auckland. The R^2 value for this relation was 0.25 ▸ while the Pearson chi-square test probability was 0.006 (Appendix 4). Outdoor bacteria and outdoor fungi in Wellington, on the other hand, appeared to have no correlation. The R^2 value was 0.0002♦. The Pearson chi-square analysis produced a similar result (P=0.095 - see Appendix 4). It should be noted that the 46 offices surveyed in Wellington were located in only 11 buildings. This means that because there were only 11 outdoor records to be analysed, the validity of the above conclusion is limited. The differences in statistical analysis outcomes comparing outdoor airborne bacterial and fungal concentrations in Auckland

and Wellington could be explained by the fact that outdoor climatic conditions in Auckland City are more suitable for fungal growth than those of Wellington. However, it should be noted that Wellington City is more windy than Auckland [4] and outdoor bacterial levels in general tend to increase with high wind velocity [6] (see Appendix 7).

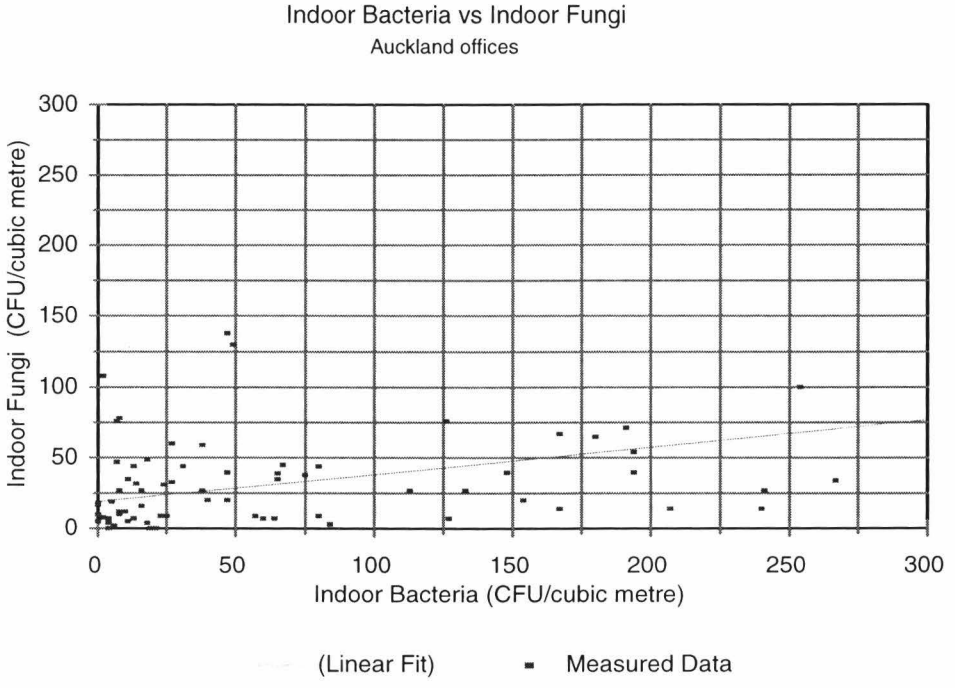

Figure 4.13: Indoor airborne bacterial and fungal levels in Auckland offices. Most indoor bacterial levels above 100CFU/m^3 were ABS. Using ESR or ABS data separately has provided an accurate indication of the relationship between the two pollutants in the office environment.

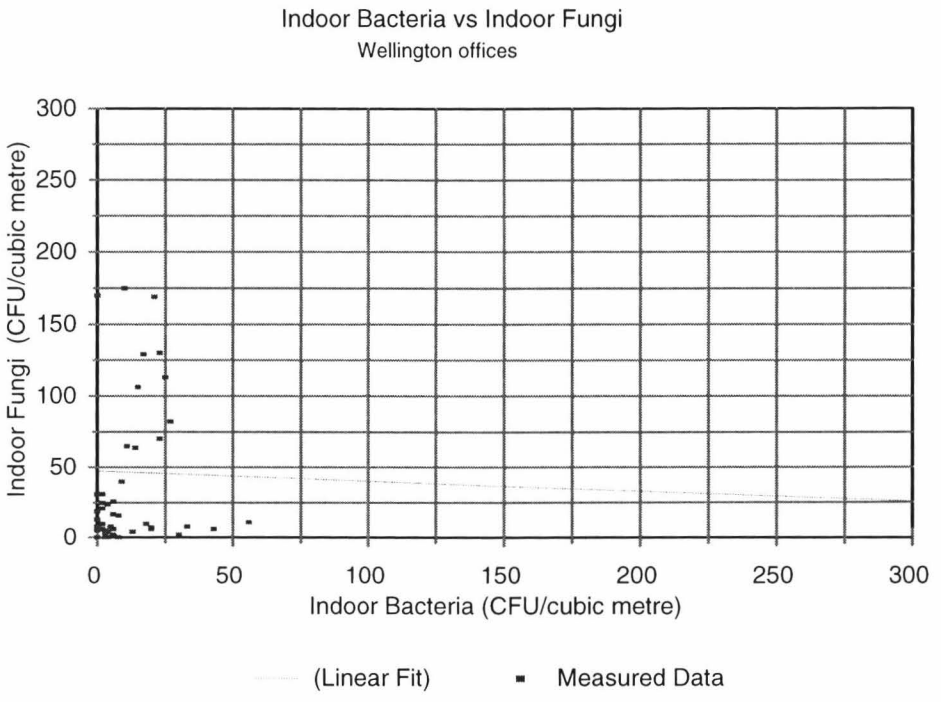

Figure 4.14: Indoor airborne bacterial and fungal levels in Wellington offices. No significant association was found as no clear pattern in this distribution can be observed.

4.4 INDOOR/OUTDOOR AIRBORNE BACTERIAL AND FUNGAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES (DESCRIPTIVE ANALYSIS)

The indoor/outdoor bacterial and fungal ratios in Auckland and Wellington offices are listed in Table 4.2.

4.4.1 INDOOR/OUTDOOR BACTERIAL AND FUNGAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES

Indoor/outdoor airborne bacterial ratios in general were slightly higher in Wellington offices. The mean value for Auckland offices was significantly below that of Wellington offices. The median value in Auckland was also lower than that of Wellington. In 41% of the offices in Auckland, the indoor/outdoor bacterial ratio was above 1, whereas this percentage was 44% in Wellington.

Indoor/outdoor airborne fungal ratios in Wellington offices were significantly higher than those of Auckland. The mean value in Auckland offices was one-third lower than that of Wellington offices. The indoor/outdoor airborne fungal ratios were above 2 in 15% of the offices surveyed in Wellington whereas in Auckland, none of the offices exceeded that level. Indoor/outdoor airborne fungal ratios in Auckland were below 1 in 94% of the offices surveyed, whereas this percentage in Wellington was 74%.

TABLE 4.2: INDOOR/OUTDOOR AIRBORNE BACTERIAL AND FUNGAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES.

	Airborne Bacteria Indoor/outdoor Ratio	**Airborne Fungi Indoor/outdoor Ratio**
Auckland offices		
Mean	**1.46**	**0.20**
Median	**0.84**	**0.08**
Range	**0 - 9.50**	**0 - 1.84**
Count	**48**	**53**
Wellington offices		
Mean	**2.75**	**1.26**
Median	**1.33**	**0.32**
Range	**0 - 18.00**	**0 - 18.80**
Count	**31**	**46**

4.5 TESTING FOR DIFFERENCES BETWEEN AIRBORNE BACTERIAL AND FUNGAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES (STATISTICAL ANALYSIS)

The Mann-Whitney test[31] tests for differences between two independent groups and attempts to establish whether two samples come from identically distributed populations. In this test, a value of $\mathbf{P < 0.05}$ would imply a significant difference, indicating that the two samples tested had not come from the same populations .

In this section, the Mann-Whitney test is used to determine whether there were any significant differences between indoor/outdoor bacterial and fungal ratios in Auckland and Wellington offices. The aim of these analyses was to compare Auckland and Wellington offices in terms of their major sources of indoor airborne bacteria and to extrapolate any significant differences between the efficiency of the filtering devices of the HVAC systems in preventing outdoor contaminations from penetrating into the office environment in Auckland and Wellington offices (in the case of analysing indoor/outdoor fungal ratios).

4.5.1 DIFFERENCES BETWEEN INDOOR/OUTDOOR BACTERIAL AND FUNGAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES

In the case of indoor /outdoor bacterial ratios, the Mann-Whitney probability value (P) was 0.329 which suggests no significant differences between these ratios in Auckland and Wellington (Appendix 4).

In the case of indoor/outdoor fungal ratios, however, the Mann-Whitney probability value (P) for Auckland and Wellington showed that there were significant differences between the populations of fungal ratios in both groups of offices. The (P) value for this relation was 0.00 (Appendix 4).

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31 The Mann-Whitney test is the nonparametric equivalent of the two-sample student t test.

An American study on some 116 residences [7] showed that indoor /outdoor airborne fungal ratios were less than 1 in the majority of houses surveyed. The study indicated that infiltration was the source of indoor airborne fungi and accounted for 60% of indoor mould. This finding seems to be confirmed in the case of Auckland offices. In Wellington offices, on the other hand, it appears that internal sources[32] were the major source of indoor airborne fungi.

The indoor/outdoor bacterial and fungal ratios have been plotted against indoor levels in Figures 4.15 and 4.16 in order to provide a clear picture of how indoor levels related to indoor/outdoor ratios.

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32 As Nathanson reported [8], such internal sources might include mouldy and wet materials, water damage, stagnant water in the HVAC system ....etc.

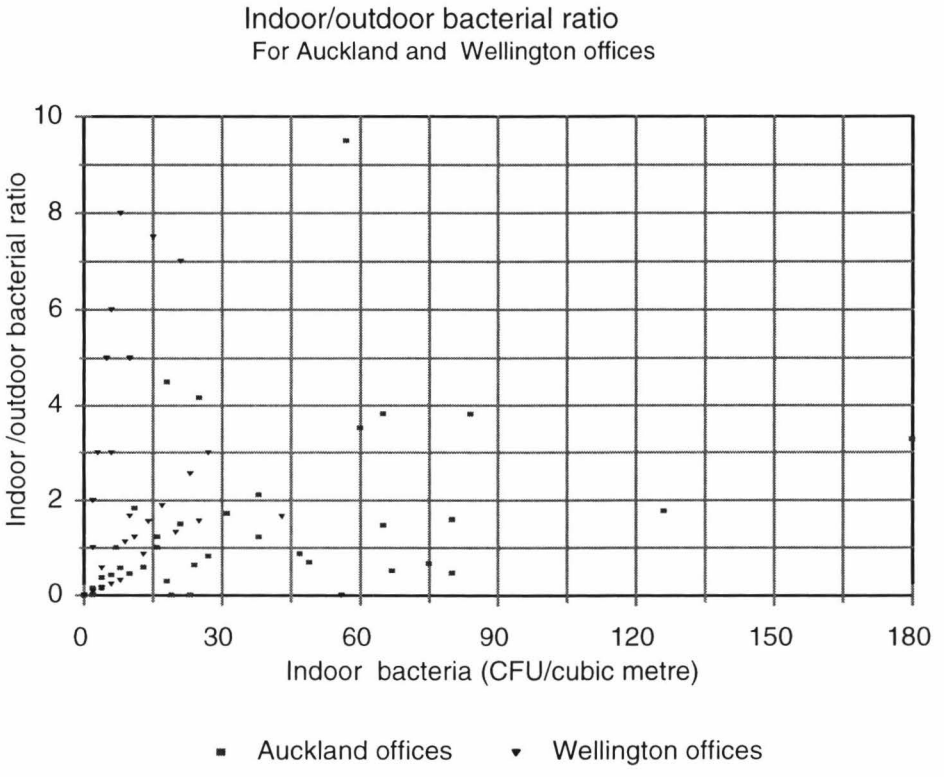

Figure 4.15: Indoor/outdoor bacterial ratios in Auckland and Wellington offices. No significant differences between Auckland and Wellington ratios can be observed.

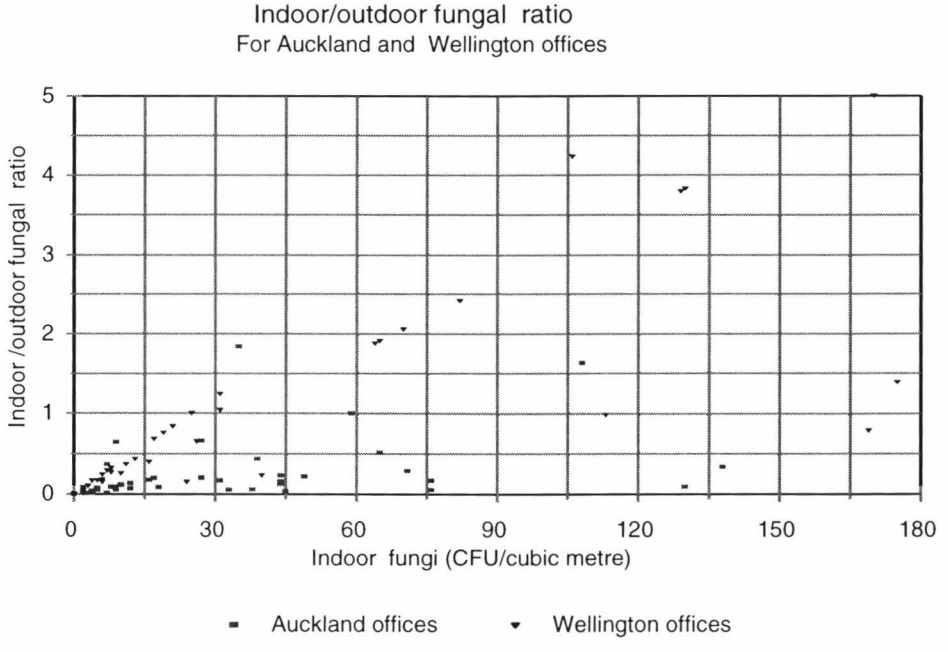

Figure 4.16: Indoor/outdoor fungal ratios in Auckland and Wellington offices. Most fungal ratios above 1 occurred in Wellington offices. These ratios coincided with indoor levels higher than 30 CFU/m^3.

4.6 DISCUSSION

Statistical analyses suggested that indoor airborne bacterial levels in Auckland and Wellington offices were not significantly associated with indoor air temperature. This conclusion has been reached after conducting additional statistical analyses using the ESR and ABS data separately (see the Recapitulation section).

Indoor bacterial levels in general were higher than outdoor levels in both Auckland and Wellington offices. Indoor bacterial levels in Wellington offices were significantly lower than those of Auckland. The median indoor bacteria value in Auckland was 53 CFU/m^3, whereas in Wellington, the median value was just 7 CFU/m^3. Several overseas studies found that indoor bacterial levels are strongly associated with increased human activity [9,10,11]. One possible explanation could be the occupancy rate in Auckland offices may be significantly higher[33] than Wellington offices.

Airborne fungal levels in Auckland and Wellington offices did not appear to be associated with indoor relative humidity. This might be explained by the fact that indoor relative humidity levels in both Auckland and Wellington offices were below the range (70-90% relative humidity) which supports fungal growth [13,14]. However, longer term measurements (eg; over one/two weeks) of indoor air temperature, humidity and indoor airborne bacteria and fungi are needed to provide a clear indication of the effects of indoor air temperature and relative humidity fluctuations on indoor airborne bacterial and fungal concentrations in the office environment.

Another interesting finding was that, where in Auckland indoor fungal levels were significantly related to (though much reduced from) outdoor levels, the same was not true in Wellington. In Wellington, outdoor fungal levels were not correlated to and were furthermore materially lower than indoor levels- the opposite finding to that of Auckland

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33 As WHO reports, the major source of indoor airborne bacteria is the occupants and their activities [12].

and one which indicates an indoor source for Wellington fungal levels.

Successful operation of air handling unit filters might explain the reduction of indoor fungal levels in the Auckland office environment. However, it would also appear that the Auckland office environment and HVAC systems do not generate airborne fungi in significant levels themselves. On the other hand, lack of proper hygiene programmes and/or maintenance of HVAC systems may be some of the likely causes of high indoor airborne fungal concentrations in Wellington offices.

4.7 RECAPITULATION

Indoor and outdoor bacterial levels of Auckland offices were five times higher than those of Wellington offices. Indoor fungal levels in Auckland offices, on the other hand, were slightly below those of Wellington offices despite the fact that outdoor fungal levels were four to five times higher in Auckland offices.

Statistical analyses of indoor bacteria and fungi suggested no significant association between indoor airborne bacteria and indoor air temperature in Auckland and Wellington offices. Indoor relative humidity appeared also to have no effects on indoor airborne bacteria and fungi in the office environment. As mentioned previously in Chapter 1, indoor measurements were carried out for only a short period of time. Therefore, more data is needed in order to determine the impact of indoor air temperature and humidity fluctuations on indoor bacterial and fungal levels in the office environment (see the Limitations section of Chapter 1).

Outdoor bacterial levels appeared to have a strong impact on indoor levels in Auckland offices[34]. Indoor fungal levels also appeared to be affected by outdoor levels in Auckland offices.

Indoor/outdoor fungal ratios showed that outdoor air infiltration was the major source of indoor airborne fungi in Auckland offices. In Wellington offices, on the other hand, internal sources appeared to be the major contributors of indoor airborne fungi.

A summary of statistical analysis of various factors affecting indoor bacterial and fungal levels in Auckland and Wellington offices is presented in Table 4.3.

In the next chapter, indoor air profiles of Auckland and Wellington offices during

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34 In 71% of Auckland offices, higher outdoor bacterial levels coincided with higher indoor levels.

summer and winter will be studied and discussed. The aim of this is to provide a clearer understanding of the impact of seasonal variations on indoor airborne bacteria and fungi in fully sealed mechanically ventilated offices.

TABLE 4.3: SUMMARY OF STATISTICAL ANALYSES OF INDOOR MICROCLIMATIC PARAMETERS, OUTDOOR AND INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN AUCKLAND AND WELLINGTON

	LINEAR REGRESSION (R^2)		PEARSON CHI-SQUARE TEST (P)	
	AUCKLAND	WELLINGTON	AUCKLAND	WELLINGTON
TEMPERATURE vs INDOOR BACTERIA	0.16*▸ 0.04** ♦ 0.09# ♦	0.03**♦	0.01* 1.00** 0.03#	0.61**
HUMIDITY vs INDOOR BACTERIA	0.05* ♦ 0.00** ♦ 0.13# ▸	0.00**♦	0.19* 0.65** 0.28#	0.35**
TEMPERATURE vs INDOOR FUNGI	0.07 ▪♦	0.02**♦	0.56 ▪	0.80**
HUMIDITY vs INDOOR FUNGI	0.00 ▪♦	0.00**♦	0.22 ▪	0.82**
OUTDOOR BACTERIA vs INDOOR BACTERIA	0.39** ▸	0.08**♦	0.00**	0.08**
OUTDOOR FUNGI vs INDOOR FUNGI	0.28** ▸	0.01**♦	0.00**	0.16**

Significant association (Pearson chi-square < 0.05).

Insignificant association (0.05< Pearson chi-square< 0.1).

Further analyses have been performed, without the use of ABS data, as the validity of the initial analysis (through the combined use of ESR and ABS data) was inconclusive.

▸ Significant linear association (X Coef./ Std Err of Coef. > 2)

♦ Insignificant linear association (X Coef./ Std Err of Coef. < 2)

* Results is affected by the combined use of ESR and ABS data (see chapter 3 and Appendix 1).

** Only ESR data have been used. # Only ABS data have been used.

▪ Both ABS and ESR data have been used (results is not affected, see Appendix1).

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CHAPTER 5

SEASONAL VARIATIONS OF AIRBORNE BACTERIAL AND FUNGAL CONCENTRATIONS IN AUCKLAND AND WELLINGTON OFFICES

- DESCRIPTIVE ANALYSIS
- STATISTICAL ANALYSIS

CHAPTER 5

SEASONAL VARIATIONS OF AIRBORNE BACTERIAL AND FUNGAL CONCENTRATIONS IN AUCKLAND AND WELLINGTON OFFICES

"Some of the most commonly brought-in outside air pollutants are smog; elevated mould spore or pollen levels, due to seasonal growth; legionella, other bacteria or biocides from adjacent cooling towers; bacteria, yeasts or algae from standing water or decaying vegetation near outside air intakes" [1].

5.1 INTRODUCTION

Outdoor climatic variations directly affect the use of ventilation and air conditioning systems in buildings. This may in turn affect the growth of microbiological contaminants on building materials and in HVAC systems where such contaminants may become airborne and spread into the indoor environment. An Italian study showed that differences between summer and winter bacterial concentrations were not statistically significant [2]. A Finnish study, on the other hand, reported significant variations in indoor airborne fungal levels between summer and winter in office buildings[35] [3]. An American study [4] reported also differences (though not significant) between fungal ratios in summer and winter in 36 non-complaint office buildings.

Therefore, an attempt has been made in this Chapter to determine whether seasonal variations of airborne bacterial and fungal levels occur in New Zealand fully sealed mechanically ventilated offices .

Statistical analyses[36] have been carried out to determine the impact of indoor

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35 Outdoor seasonal variations were even more significant than indoor variations.

36 Linear regression analysis and Fisher's exact test.

microclimatic parameters as well as outdoor bacterial and fungal levels on indoor levels in 119 offices in Auckland and Wellington during summer and winter months[37]. The objectives of these analyses were:

1. To identify the indoor airborne bacterial and fungal concentrations in New Zealand offices during heating and cooling seasons.

2. To investigate whether there was any association between outdoor airborne bacterial and fungal levels, indoor microclimatic parameters and indoor airborne bacterial and fungal levels during the summer and winter months in Auckland and Wellington offices.

The indoor/outdoor fungal ratios will also be observed and analysed to determine whether the performance of HVAC systems is affected by seasonal variations.

37

Only in 119 of the 235 offices studied had records kept of the season in which the measurements were carried out. It should be noted that these were all measured by ESR as ABS did not record such data (see Chapter 1).

5.2 INDOOR AIR PROFILE IN AUCKLAND AND WELLINGTON OFFICES SURVEYED IN SUMMER AND WINTER (DESCRIPTIVE ANALYSIS)

In Auckland offices, indoor air temperatures were slightly higher in summer. In Wellington offices, on the other hand, indoor air temperature were higher in offices surveyed in winter. Indoor relative humidity levels were slightly higher in both Auckland and Wellington offices surveyed in summer.

Indoor bacterial concentrations in both summer and winter were generally higher in Auckland than in Wellington offices. In the summer months, they were above 50 CFU/m^3 in 31% of Auckland offices, but only 5% of Wellington offices. On the other hand, they were below 10 CFU/m^3 in 24% of the offices surveyed in Auckland as compared to 31% of Wellington offices. In wintertime, indoor bacterial levels were above 50 CFU/m^3 in 19% of Auckland offices but just 3% of Wellington offices. Indoor bacterial levels were below 10 CFU/m^3 in 42% and 74% of Auckland and Wellington offices respectively. This demonstrates the significance of the variations in indoor airborne bacterial levels between Auckland and Wellington offices surveyed in summer and winter.

In regard to fungal concentrations, the situation was somewhat different. In summertime, 27% of Auckland offices were above 50 CFU/m^3 and 20% were below 10 CFU/m^3, while in Wellington the corresponding figures were 52% and 47%. In wintertime, on the other hand, indoor fungal levels were above 50 CFU/m^3 in 4% and 7%, and below 10 CFU/m^3 in 57% and 40% of Auckland and Wellington offices respectively.

The mean, median and range of microclimatic parameters, carbon dioxide levels and indoor and outdoor bacterial and fungal levels in Auckland and Wellington offices surveyed in summer and winter are listed in Tables 5.1 and 5.2.

TABLE 5.1: THE MEAN, MEDIAN AND RANGE OF MICROCLIMATIC PARAMETERS, CARBON DIOXIDE LEVELS AND OUTDOOR AND INDOOR AIRBORNE BACTERIAL AND FUNGAL CONCENTRATIONS IN AUCKLAND OFFICES SURVEYED IN SUMMER AND WINTER.

	Indoor air temperature ^{o}c	Indoor humidity %	Outdoor bacteria CFU/m^3	Indoor bacteria CFU/m^3	Outdoor fungi CFU/m^3	Indoor fungi CFU/m^3	Carbon dioxide ppm
Auckland offices (surveyed in summer)							
Mean	22	45	49	45	313	42	587
Median	21.8	45	27	27	176	39	559
Range	20-24	34-60	4-292	0-191	42-1382	0-138	458-854
Count	23	23	34	29	34	29	35
Auckland offices (surveyed in winter)							
Mean	21.4	45	10	20	77	16	558
Median	21.6	45	14	11	84	9	542
Range	19-24	32-59	0-22	0-84	14-183	0-108	412-814
Count	31	31	19	21	19	21	32

TABLE 5.2: THE MEAN, MEDIAN AND RANGE OF MICROCLIMATIC PARAMETERS, CARBON DIOXIDE LEVELS AND OUTDOOR AND INDOOR AIRBORNE BACTERIAL AND FUNGAL CONCENTRATIONS IN WELLINGTON OFFICES SURVEYED IN SUMMER AND WINTER.

	Indoor temperature ° C	Indoor humidity %	Outdoor bacteria CFU/m³	Indoor bacteria CFU/m³	Outdoor fungi CFU/m³	Indoor fungi CFU/m³	Carbon dioxide ppm
Wellington offices (surveyed in summer)							
Mean	22.3	43	16	39	52	66	512
Median	22.4	41	15	15	34	64	514
Range	20.8-24.2	28-57	3-26	0-450[38]	24-214	0-175	442-616
Count	15	15	18	18	18	18	14
Wellington offices (surveyed in winter)							
Mean	22.6	37	1	9	40	33	531
Median	23.1	37	2	4	30	11	471
Range	20-23.9	27-53	0-8	0-56	25-175	0-470	367-851
Count	21	21	27	27	27	27	15

38 As mentioned previously in Chapters 3 and 4, the 450 CFU/m³ is a very high value (considering the rest of indoor airborne bacterial levels of Wellington offices surveyed in summer). The second highest bacterial level recorded in a Wellington office was just 43 CFU/m³ (see Appendix 2 of the separate report). Therefore, the indoor airborne bacterial range of **0-43 CFU/m³** might reflect more accurate range. This is also the case in the 0-470 CFU/m³ range of indoor airborne fungi in Wellington offices surveyed in winter. The second highest level in a Wellington office was just 106 CFU/m³. Therefore, the indoor airborne fungal range of **0-106 CFU/m³** might also reflect more accurate range.

5.3 ASSOCIATION BETWEEN INDOOR MICROCLIMATIC PARAMETERS AND INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN OFFICES SURVEYED IN SUMMER AND WINTER (STATISTICAL ANALYSIS)

Linear regression analysis and the two-way table analysis (Fisher's exact test) have been used to determine to what extent indoor microclimatic parameters in summer and winter as well as outdoor seasonal variations in airborne bacterial and fungal levels affect indoor airborne bacterial and fungal levels in Auckland and Wellington offices. Fisher's exact test (a statistical tool used in investigating for an association between two variables) has been used here instead of the Pearson chi-square test. This is because the number of offices surveyed in summer and winter were not enough to consider the Pearson chi-square probability value valid (a warning has been observed in the output of these analyses which applied only for the Pearson chi-square values - see Appendix 5 of the separate volume). Furthermore, the Fisher's exact probability test appeared only in the 2x2 table analysis whereas the Pearson Chi-Square probability test is more applicable to 2x3 and 3x3 table analysis (Appendix 5). The probability (P) value of Fisher's test is considered significant if **$P < 0.05$**.

5.3.1 ASSOCIATION BETWEEN INDOOR AIR TEMPERATURE AND INDOOR AIRBORNE BACTERIA IN SUMMER AND WINTER.

Linear regression analysis showed no association between indoor air temperature and indoor bacterial levels in Auckland offices surveyed in summer and winter ($R^2 = 0.13$♦ and 0.01♦ in summer and winter respectively - see Figure 5.1). This conclusion was consistent with the Fisher's exact test ($P = 0.301$ and 1.00 in summer and winter respectively - see Appendix 5).

Similarly, no association was found between indoor bacterial levels and indoor air temperature in Wellington offices surveyed in summer and winter (Figure 5.2). The R^2 values of the linear regression analysis were 0.09 ♦ and 0.14 ♦ in summer and winter respectively. The Fisher's exact test verified this conclusion ($P = 0.358$ in summer

offices and 0.596 in winter offices).

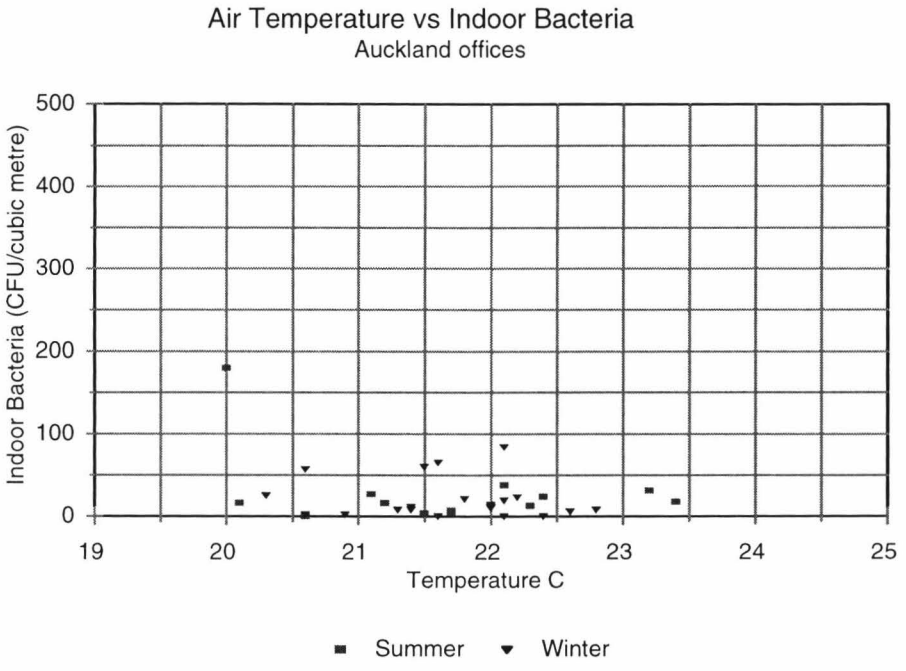

Figure 5.1: Indoor air temperature and indoor airborne bacterial levels in Auckland offices surveyed in summer and winter

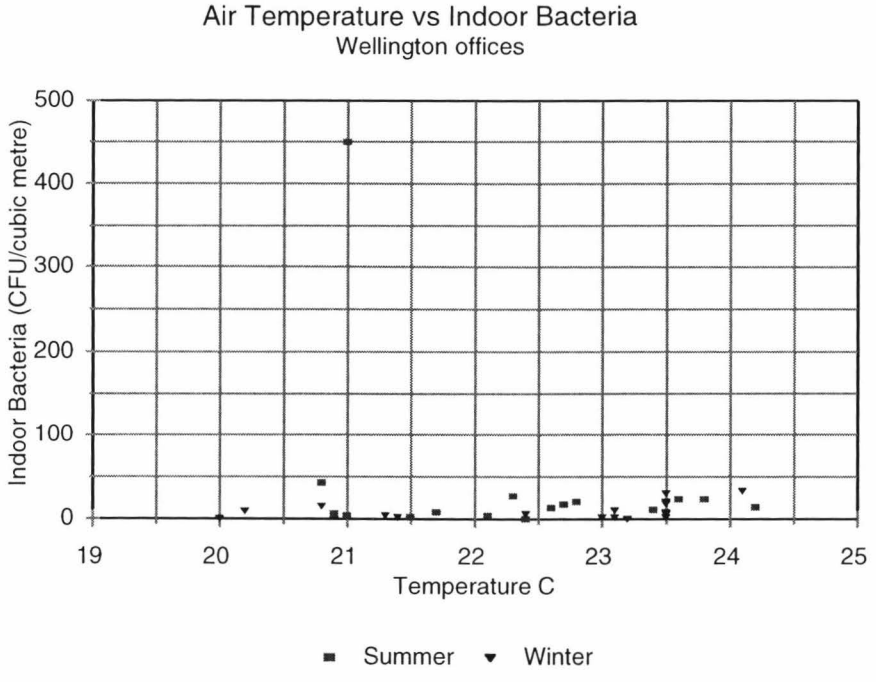

Figure 5.2: Indoor air temperature and indoor airborne bacterial levels in Wellington offices surveyed in summer and winter

5.3.2 ASSOCIATION BETWEEN INDOOR RELATIVE HUMIDITY AND INDOOR AIRBORNE BACTERIAL LEVELS IN SUMMER AND WINTER

No association was found between indoor bacteria and relative humidity in Auckland offices surveyed in summer and winter. Linear regression analysis showed no association between the two variables (R^2 = 0.02♦ and 0.01♦ in summer and winter respectively). Fisher's exact probability values resulting from two-way table analysis were also found to be statistically insignificant (P = 0.592 and 0.183 in offices surveyed in summer and winter respectively - Figure 5.3).

The results for Wellington offices were similar. No linear association was found between indoor bacteria and relative humidity in offices surveyed during summer and winter. The R^2 values were 0.01 ♦ and 0.03 ♦ in offices surveyed in summer and winter respectively. The Fisher's exact test produced similar results (P = 0.299 and 1.00 in offices surveyed in summer and winter respectively - see Appendix 5). Figure 5.4 shows indoor relative humidity and indoor airborne bacterial levels in Wellington offices in both seasons.

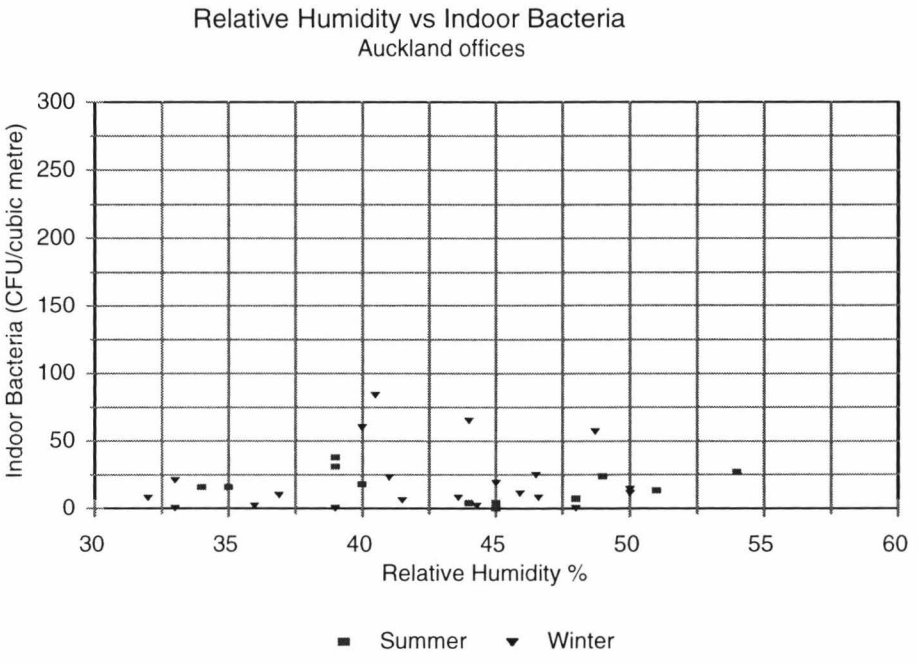

Figure 5.3: Indoor relative humidity and indoor airborne bacterial levels in Auckland offices surveyed in summer and winter

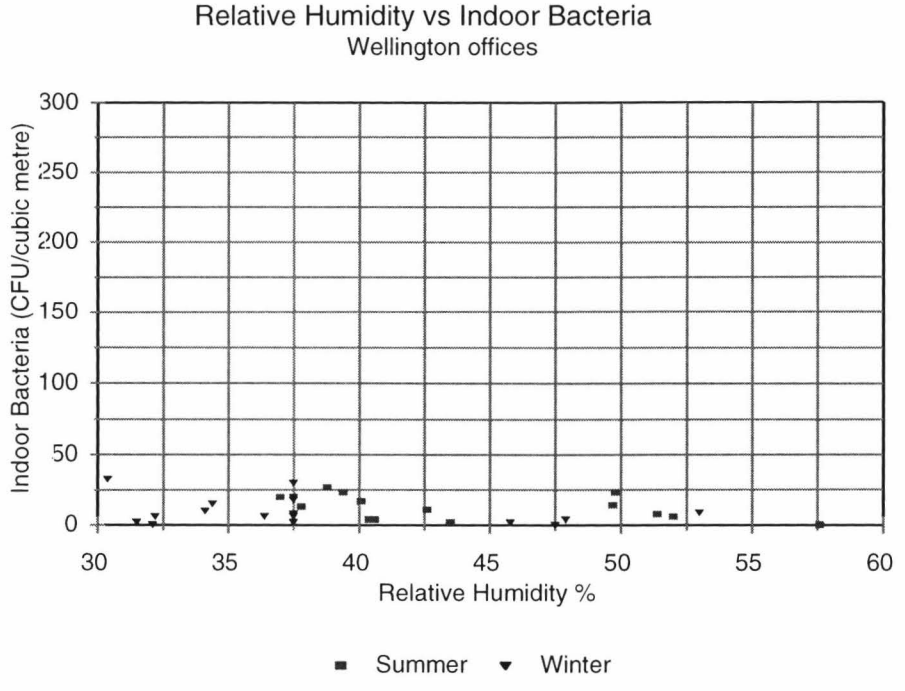

Figure 5.4: Indoor relative humidity and indoor airborne bacterial levels in Wellington offices surveyed in summer and winter

5.3.3 ASSOCIATION BETWEEN INDOOR AIR TEMPERATURE AND INDOOR FUNGAL LEVELS IN SUMMER AND WINTER MONTHS

In Auckland, no association between indoor fungi and indoor air temperature was found in offices surveyed both in summer and winter months (Figure 5.5). The R^2 values were 0.01 ♦ and 0.03 ♦ in summer and winter respectively. The Fisher's exact test produced similar results (P = 0.29 and 0.65 during summer and winter respectively-see Appendix 5).

In Wellington, on the other hand, the statistical evidence showed strong association between indoor fungi and indoor air temperature in offices surveyed during summertime. Linear regression analysis for these offices produced a strong positive linear association (R^2 =0.30 ▸). The Fisher's exact test produced comparable results[39] (P=0.088). In offices surveyed during wintertime, however, no association was found between indoor fungi and indoor air temperature (R^2 =0.00 ♦). The Fisher's exact probability value (P) was 0.342 (see Appendix 5 - Figure 5.6). This could mean that the operation of the HVAC systems particularly in summertime (as expressed in air temperature levels) in Wellington offices might be one of the factors encouraging fungal growth in the indoor environment.

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39 Although P > 0.05 (0.088), it can be considered as a positive association between temperature and indoor airborne fungi (though not a significant one).

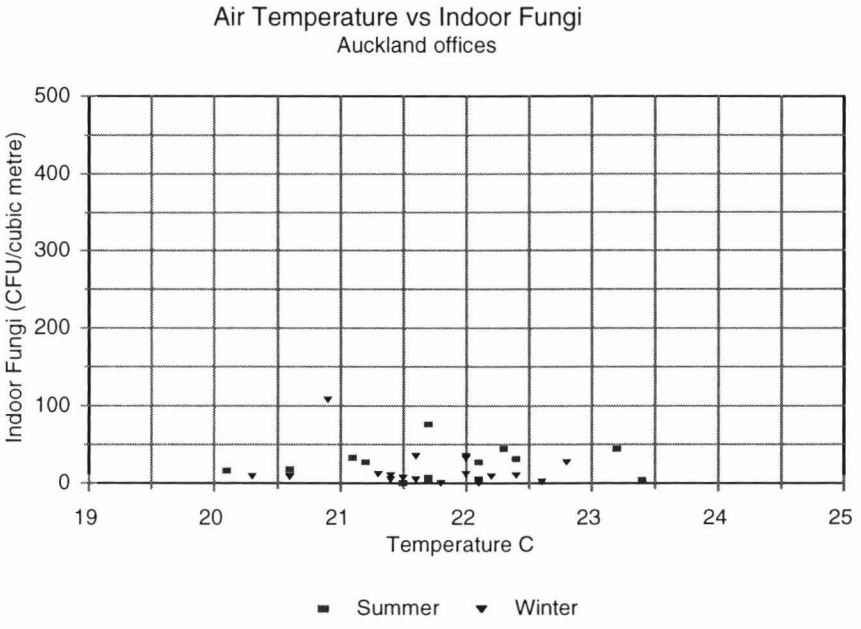

Figure 5.5: Indoor air temperature and indoor airborne fungal levels in Auckland offices surveyed in summer and winter

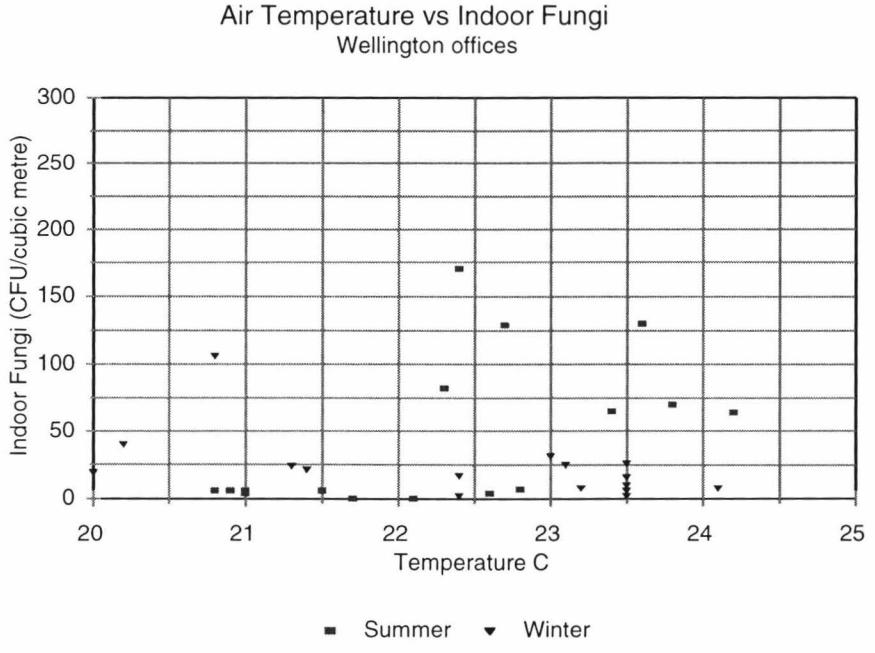

Figure 5.6: Indoor air temperature and indoor airborne fungal levels in Wellington offices surveyed in summer and winter. Data distribution in the case of offices surveyed in summer shows a clear association between the two variables.

5.3.4 ASSOCIATION BETWEEN INDOOR RELATIVE HUMIDITY AND INDOOR FUNGAL LEVELS IN SUMMER AND WINTER

In Auckland, no association was found between indoor airborne fungi and indoor relative humidity in offices surveyed in both summer and winter. The linear regression (R^2) values for offices surveyed in summer and winter were 0.07 ♦ and 0.00 ♦ respectively. The Fisher exact probability (P) values were 1.00 and 0.638 in offices surveyed in summer and winter respectively (Figure 5.7).

Likewise, in Wellington, no association was found in offices surveyed in summer and winter between indoor relative humidity and indoor airborne fungi. The R^2 values were 0.17 ♦ and 0.01 ♦ in offices surveyed in summer and winter respectively - Figure 5.8). The Fisher's exact test also showed no indication of such association between indoor fungi and humidity (P = 0.596 and 1.00 in summer and winter respectively - see Appendix 5).

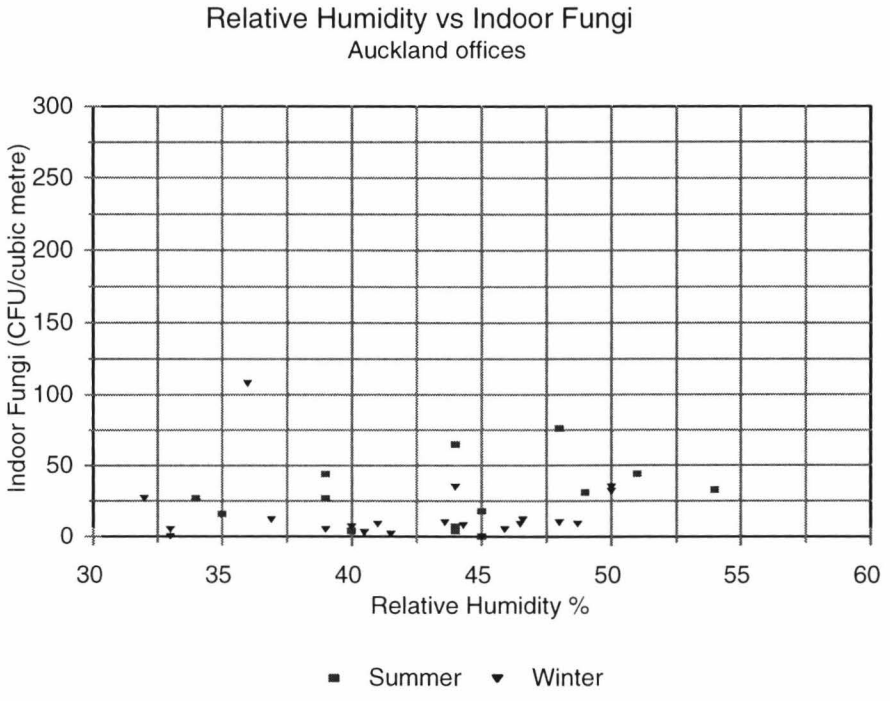

Figure 5.7: Indoor relative humidity and indoor airborne fungal levels in Auckland offices surveyed in summer and winter

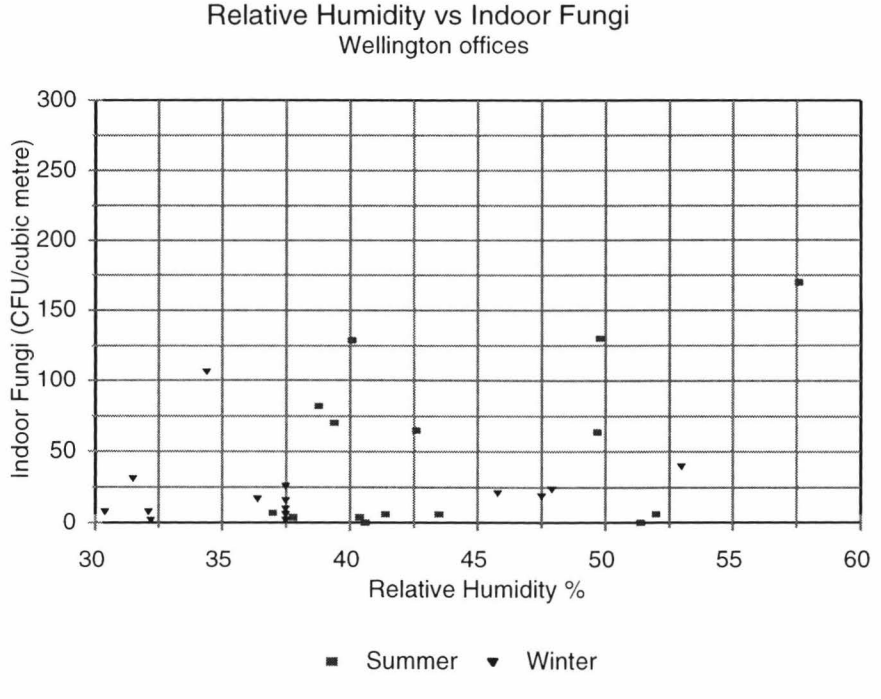

Figure 5.8: Indoor relative humidity and indoor airborne fungal levels in Wellington offices surveyed in summer and winter

5.4 ASSOCIATION BETWEEN INDOOR AND OUTDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN SUMMER AND WINTER (STATISTICAL ANALYSIS)

Gammage et al. [5] pointed out that the majority of biological pollutants found indoors come from the outdoor environment during the growing season. Therefore, statistical analyses[40] have been carried out to determine to what extent seasonal variations in outdoor bacterial and fungal levels affect indoor levels in fully sealed mechanically ventilated offices in Auckland and Wellington.

5.4.1 ASSOCIATION BETWEEN INDOOR AND OUTDOOR AIRBORNE BACTERIAL LEVELS IN SUMMER AND WINTER

Linear regression analysis was carried out to test for association between outdoor and indoor bacterial levels in offices surveyed in summer and winter. Linear association was found between outdoor and indoor airborne bacterial levels in Auckland offices surveyed during summertime (R^2 = 0.18 ▸). The two-way table analysis (Fisher's exact test) showed strong association between outdoor and indoor levels (P=0.002 - see Appendix 5). This indicates that outdoor sources are a major contributor to indoor airborne bacteria in Auckland offices during summer. In offices surveyed during wintertime, however, no linear association was found between outdoor and indoor levels (R^2 = 0.15 ♦). Fisher's exact probability was also statistically insignificant (P= 0.37 - see Figure 5.9).

No association was found between indoor and outdoor bacterial levels in Wellington offices surveyed during either summertime or wintertime (Figure 5.10). Linear regression analysis and the two-way table analysis gave statistically negligible results (R^2 = 0.04 ♦ and P = 0.37 in offices surveyed in summer, R^2 = 0.00 ♦ and P = 0.707 in offices surveyed in winter).

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40 Linear and non-linear analyses.

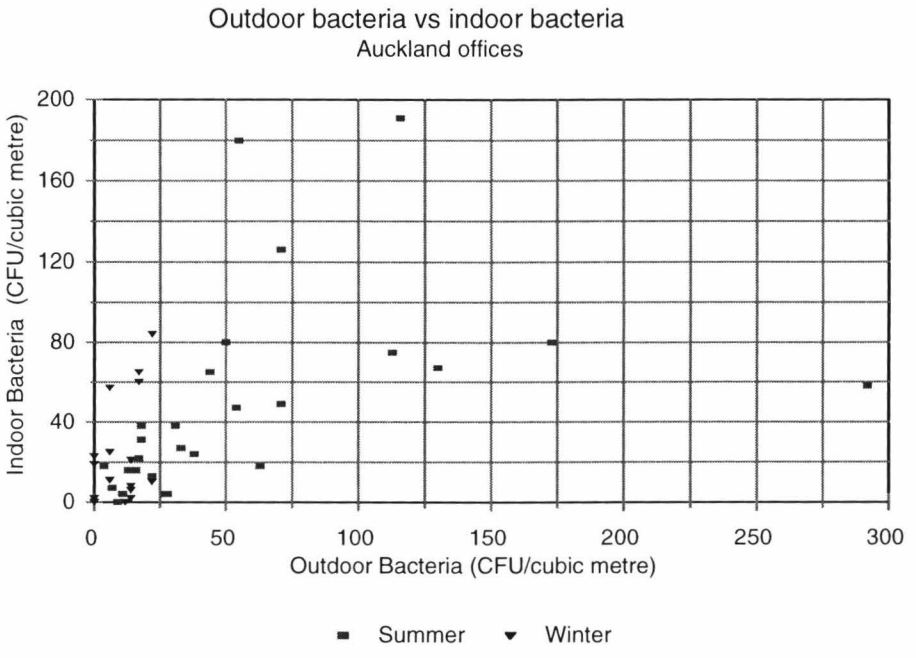

Figure 5.9: Indoor and outdoor airborne bacterial levels in Auckland offices surveyed in summer and winter. Data distribution of offices surveyed in summer shows clear linear association between the two variables.

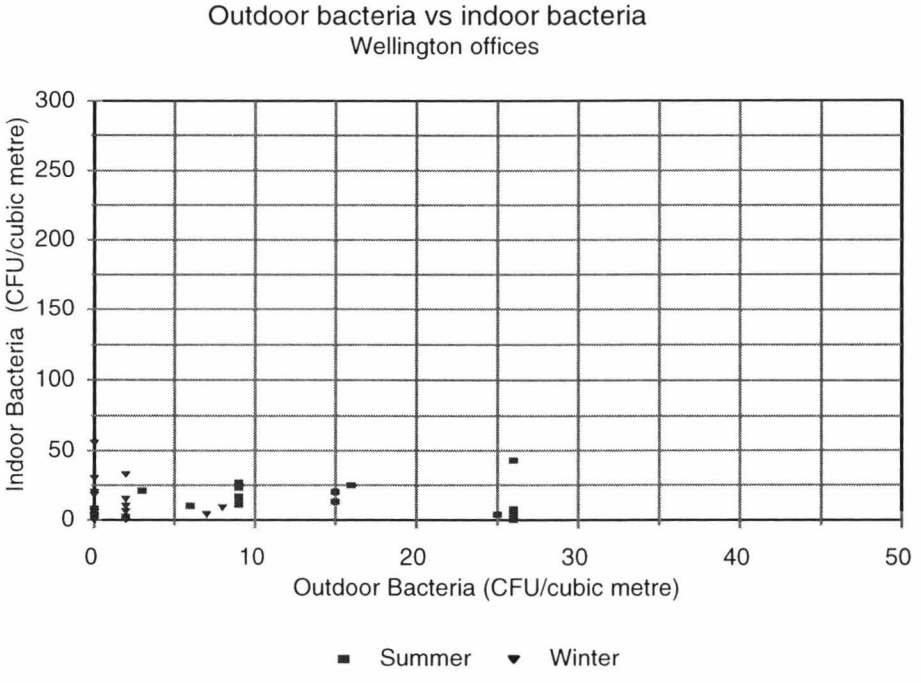

Figure 5.10: Indoor and outdoor airborne bacterial levels in Wellington offices surveyed in summer and winter.

5.4.2 ASSOCIATION BETWEEN INDOOR AND OUTDOOR AIRBORNE FUNGAL LEVELS IN SUMMER AND WINTER

Overall indoor and outdoor fungal levels in Auckland appeared to be more associated in summertime than in wintertime. Linear regression analysis showed that indoor fungal levels were likely to be higher in summer at the same time as outdoor levels increased ($R^2 = 0.27$▸ and 0.01♦ in offices surveyed in summer and winter respectively). Fisher's exact test, on the other hand, showed no association between outdoor and indoor levels[41] (P = 0.218 and 1.00 in offices surveyed in summer and winter respectively). Figure 5.11 shows that the association between indoor and outdoor levels in offices surveyed in summer is a linear one. Therefore, the R^2 value would be a reliable measure in this case.

In Wellington, on the other hand, there was statistical evidence to support an association between indoor and outdoor fungal levels in summertime. The linear regression (R^2) value for summer was 0.38 ▸ and Fisher's exact probability value (P)was also significant (P=0.03). In 52% of the offices surveyed in summer, outdoor levels were significantly higher than indoor levels. This would suggest that indoor and outdoor sources were equally important contributors to indoor airborne fungi in summer. In Auckland, on the other hand, in most of the offices (96%) surveyed in summer, outdoor levels were significantly higher than those indoors.

In the Wellington offices surveyed during wintertime, no association was found between indoor and outdoor fungal levels. Both (R^2) and (P) values were statistically insignificant (0.02 ♦ and 1.00 respectively). Figure 5.12 shows outdoor and indoor fungal levels in Wellington offices in summer and winter.

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41 Figure 35 shows that the relationship between indoor and oudoor fungal levels is a linear one. Therefore, the linear regression analysis can be considered a reliable measure in this case.

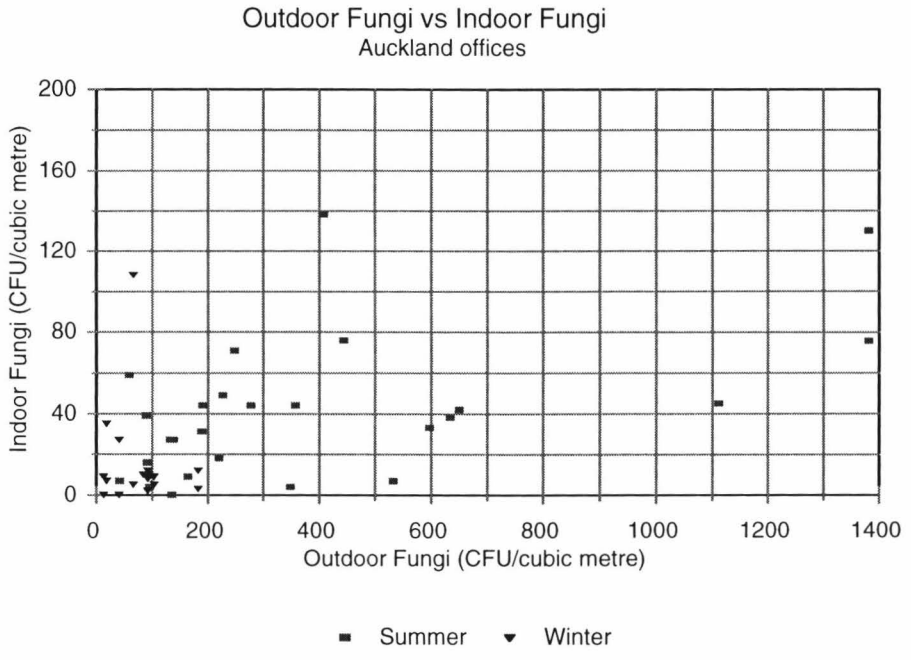

Figure 5.11: Outdoor and indoor airborne fungal levels in Auckland offices surveyed in summer and winter. Indoor airborne fungal levels seemed to increase in summer as outdoor levels reach its peak.

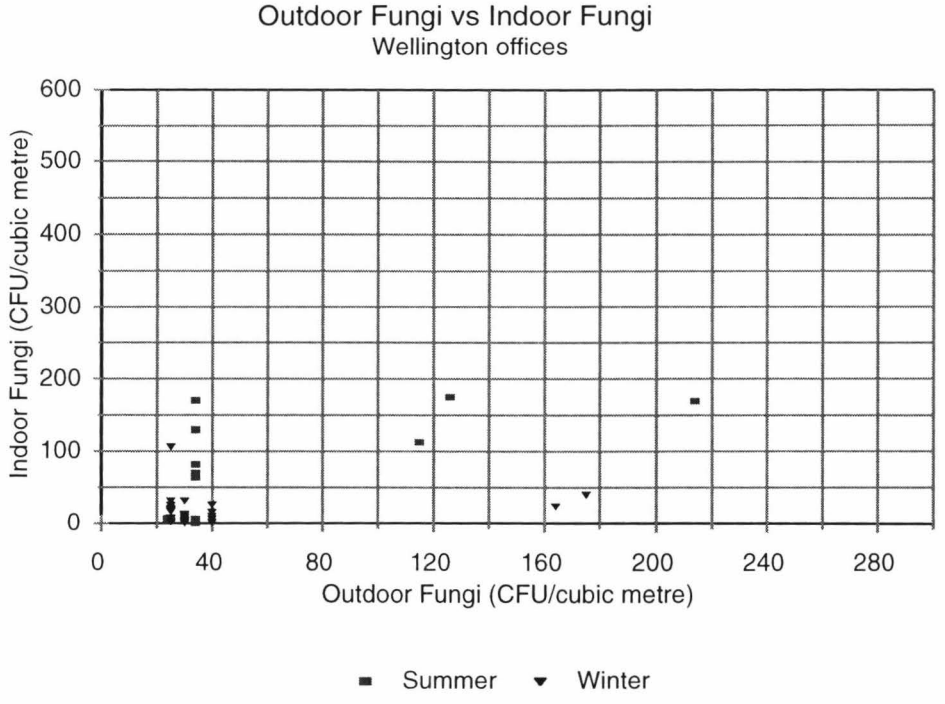

Figure 5.12: Indoor and outdoor airborne fungal levels in Wellington offices surveyed in summer and winter.

5.5 TESTING FOR SEASONAL (SUMMER/WINTER) DIFFERENCES BETWEEN INDOOR AND OUTDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS (DESCRIPTIVE AND STATISTICAL ANALYSIS)

Statistical analysis was carried out to determine whether there was a significant differences in airborne bacterial and fungal concentrations between summer and winter months in the offices surveyed. This would indicate whether and to what extent seasonal variations affect the level of indoor and outdoor airborne bacteria and fungi.

The Mann-Whitney test[42] is a statistical tool used for examining differences across two independent groups and to establish whether the two groups come from identically distributed populations. The Mann-Whitney test has been used here to determine whether there are any seasonal differences between summer and winter in airborne bacterial and fungal levels in Auckland and Wellington offices. The Mann-Whitney test defines a difference as significant if the probability value $\mathbf{P < 0.05}$.

5.5.1 SEASONAL (SUMMER/WINTER) COMPARISON OF INDOOR AND OUTDOOR AIRBORNE BACTERIAL LEVELS IN AUCKLAND OFFICES

The Mann-Whitney test showed that outdoor bacterial concentrations in Auckland were significantly different from summer to winter (P= 0.00). This indicates that seasonal variations affect outdoor bacterial concentrations in a significant way (Appendix 5). Outdoor bacterial concentrations were higher than indoor levels in 55% of all offices surveyed in summer whereas this percentage was just 26% in wintertime.

Indoor bacterial concentrations also appeared to differ significantly from summer to winter in Auckland offices (P=0.025), with summer concentrations significantly

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42 The Mann-Whitney test is the nonparametric equivalent of the two-sample student t test.

exceeding those of winter (Appendix 5).

5.5.2 SEASONAL (SUMMER/WINTER) COMPARISON OF INDOOR AND OUTDOOR AIRBORNE FUNGAL LEVELS IN AUCKLAND OFFICES

Analysis of outdoor fungal levels in summer and winter in Auckland showed that there were significant differences between those surveyed in summer and those surveyed in winter (P=0.00). In 26% of all offices surveyed during summer months, the outdoor fungal levels were above 500 CFU/m^3, whereas none of the winter cases were above the 500 CFU/m^3 level (Appendix 5). This would indicate that seasonal variations have a strong impact on the level of outdoor airborne fungi.

Indoor fungal levels also appeared to be affected by seasonal differences. The Mann-Whitney probability for summer and winter was 0.001. Indoor fungal levels were significantly higher in offices surveyed in summer than those surveyed in winter (appendix 5).

5.5.3 SEASONAL (SUMMER/WINTER) COMPARISON OF INDOOR AND OUTDOOR AIRBORNE BACTERIAL LEVELS IN WELLINGTON OFFICES

The Mann-Whitney probability test showed significant seasonal differences in outdoor bacterial levels of Wellington offices surveyed in summer and winter (P=0.00) (Appendix 5). The number of buildings surveyed was seven and four in summer and winter respectively.

Indoor bacterial levels also appeared to be affected by seasonal variations in Wellington offices (P= 0.008). Indoor bacterial levels were below 10 CFU/m^3 in 74% of offices surveyed in winter, but only 31% of offices surveyed in summer.

5.5.4 SEASONAL (SUMMER/WINTER) COMPARISON OF INDOOR AND OUTDOOR AIRBORNE FUNGAL LEVELS IN WELLINGTON OFFICES

The Mann-Whitney probability test indicated that outdoor fungal levels in Wellington were not affected by seasonal variations (P= 0.182). In 11 Wellington buildings containing a total of 46 offices, surveyed in winter and summer months, no significant differences were observed in outdoor fungal levels (Appendix 5). Indoor fungal levels in offices surveyed in summer and winter showed also no significant differences between the two samples (P = 0.269).

Table 5.3 summarizes the significance of summer and winter seasonal variations of bacterial and fungal levels in Auckland and Wellington offices.

TABLE 5.3: THE SIGNIFICANCE OF SUMMER AND WINTER SEASONAL VARIATIONS OF AIRBORNE BACTERIAL AND FUNGAL LEVELS IN AUCKLAND AND WELLINGTON OFFICES

	Mann-Whitney probability value	
	Auckland	Wellington
Indoor bacteria	0.025	0.008
Outdoor bacteria	0.000	0.000
Indoor fungi	0.001	0.269
Outdoor fungi	0.000	0.182

Significant differences (P< 0.05)

5.6 INDOOR/OUTDOOR AIRBORNE BACTERIAL AND FUNGAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES IN SUMMER AND WINTER (DESCRIPTIVE ANALYSIS)

Indoor/outdoor bacterial ratios in Auckland offices were below those of Wellington offices (the mean ratio was 0.88 and 2.4 in Auckland and Wellington respectively). This indicates that the majority of airborne bacteria in Wellington offices arose from internal sources (eg; high occupancy rates). In Auckland offices, internal sources appeared to be less significant. Figures 5.13 and 5.14 show indoor/outdoor bacterial ratios in Auckland and Wellington offices surveyed in summer and winter.

Indoor/outdoor fungal ratios were also lower in Auckland offices, with a mean value of 1.33 in Wellington offices but only 0.18 in Auckland offices. This means that Auckland offices had some success in preventing the relatively high outdoor fungal levels from penetrating the office environment[43]. The indoor/outdoor fungal ratios in Wellington offices, on the other hand, indicated that indoor fungal levels were more likely to be generated from internal sources. Figures 5.15 and 5.16 show indoor/outdoor fungal ratios in Auckland and Wellington offices surveyed in summer and winter. The mean, median and range values of indoor/outdoor ratios of airborne bacteria and fungi in summer and winter are presented in Table 5.4.

Wellington's high indoor /outdoor fungal ratios were an indication that proper hygiene

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43 Proper maintenance of the air handling units (i.e. upgrading the filter efficiency) would decrease fungal contamination from outdoor sources especially in summer months when outdoor levels reach their peak.

maintenance programs as well as 'clean' indoor environments[44] might be lacking in Wellington offices. A study carried out in a number of residential buildings in Taiwan [6] found indoor /outdoor ratios ranging from 0.35 to 2, which suggested that both internal and external sources were contributing to indoor airborne fungal levels. Another survey conducted on 116 residential units in the U.S. found that the indoor/outdoor fungal ratios of two-thirds of the units were below 1, suggesting that infiltration was the major source of indoor fungi [7]. As we have seen, in Auckland, infiltration was more likely to be the major source of indoor fungi in summer and winter. In Wellington, on the other hand, there was strong statistical evidence to suggest that internal sources were the major source of indoor airborne fungi in summer (see Table 5.4).

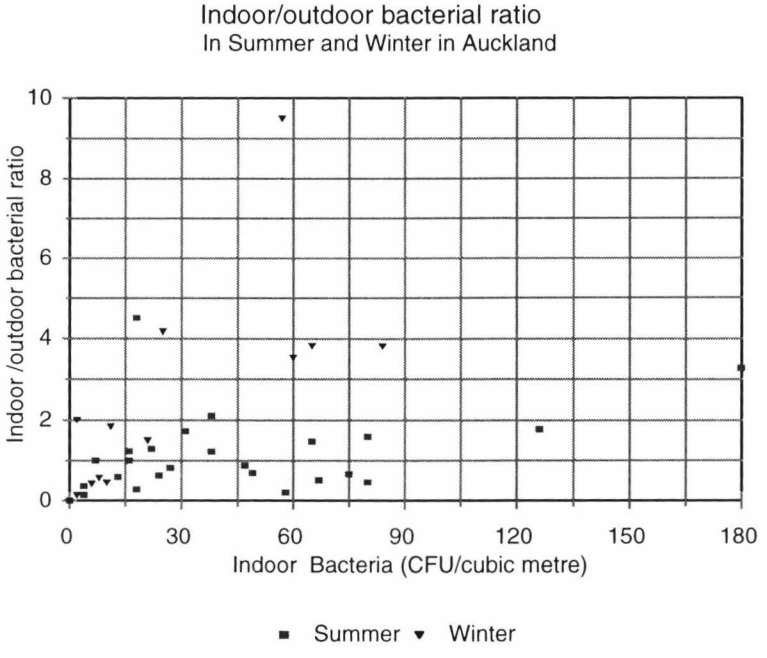

Figure 5.13: Indoor/outdoor bacterial ratios in Auckland offices surveyed in summer and winter

44 A clean indoor environment means a hygienic and well maintained environment which prevents any possible fungal growth factors (eg. mouldy and wet ceiling tiles, water leaks, stagnant water in the HVAC system) from existing indoors.

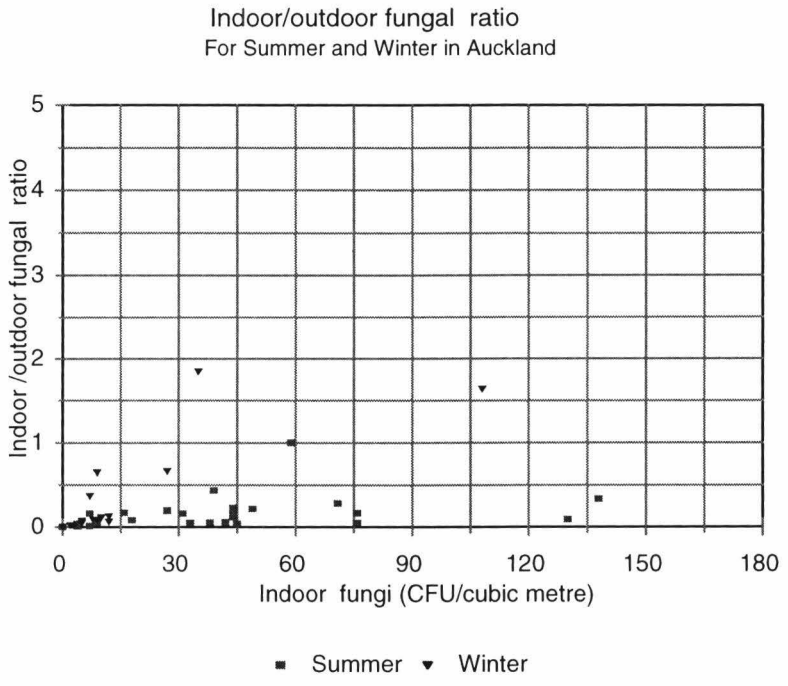

Figure 5.14: Indoor /outdoor fungal ratios in Auckland offices surveyed in summer and winter. Most indoor levels higher than 50 CFU/m3 were of offices surveyed in summer (with fungal ratios below 1). This means that high indoor levels were due to elevated outdoor levels.

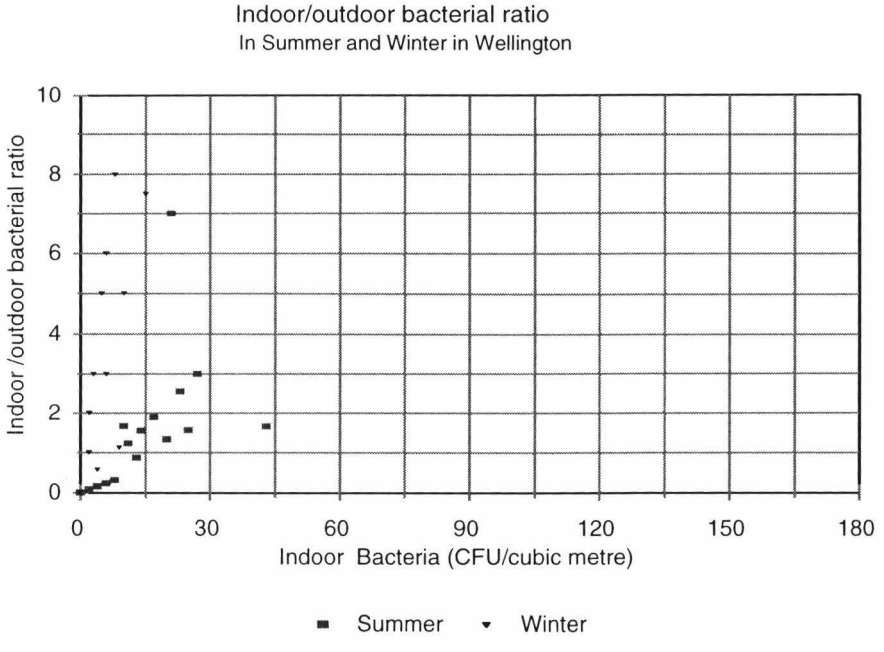

Figure 5.15: Indoor /outdoor bacterial ratios in Wellington offices surveyed in summer and winter

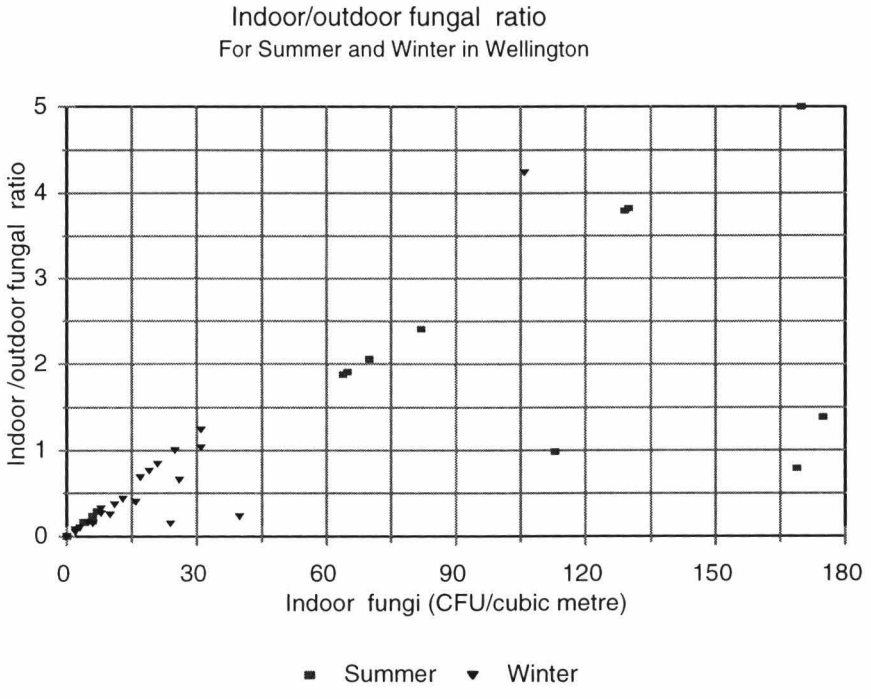

Figure 5.16: Indoor /outdoor fungal ratios in Wellington offices surveyed in summer and winter. Most indoor/outdoor fungal ratios above 1 were of offices surveyed in summer (with indoor levels above 50 CFU/m^3). This means that internal fungal sources were the main cause of high indoor levels in these offices surveyed summer.

TABLE 5.4: INDOOR / OUTDOOR AIRBORNE BACTERIAL AND FUNGAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES SURVEYED IN SUMMER AND WINTER

	Bacterial Indoor/outdoor Ratio	Fungal Indoor/outdoor Ratio	Bacterial Indoor/outdoor Ratio	Fungal Indoor/outdoor Ratio
	SUMMER		WINTER	
AUCKLAND OFFICES				
Mean	0.88	0.14	2.20	0.31
Median	0.64	0.07	1.03	0.08
Range	0-4.50	0-1.00	0-9.5	0-1.84
Count	27	27	19	19
WELLINGTON OFFICES				
Mean	2.4	1.33	3.30	1.21
Median	1.55	0.78	1.06	0.32
Range	0-18.00	0-5.00	0-16.50	0-18.80
Count	19	19	27	27

5.7 THE SIGNIFICANCE OF SEASONAL VARIATIONS IN INDOOR /OUTDOOR AIRBORNE BACTERIAL AND FUNGAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES (STATISTICAL ANALYSIS)

The Mann-Whitney test was used in this section to examine the significance of seasonal differences between indoor/outdoor airborne bacterial and fungal ratios in Auckland and Wellington offices surveyed in summer and winter. The results for each separate city are presented in Table 5.5. A city to city comparisons of indoor/outdoor bacterial and fungal ratios for each season was also carried out in an attempt to identify whether the differences between the two sets of ratios were significant. These results are summarised in Table 5.6.

AUCKLAND OFFICES

The statistical analyses of indoor/outdoor microbial ratios in summer and winter found no seasonal (summer/winter) differences between indoor/outdoor airborne bacteria and fungal ratios in Auckland offices (P= 0.422 and 0.815 for bacteria and fungi respectively). This means that this study found no significant seasonal changes in the relationship between indoor microbial levels and outdoor levels in Auckland offices.

WELLINGTON OFFICES

The Mann-Whitney probability values for bacterial and fungal ratios in Wellington offices were 0.478 and 0.176 respectively. This also indicates no significant seasonal varaiations in the indoor/outdoor microbial level relationship.

TABLE 5.5: THE SIGNIFICANCE OF SEASONAL VARIATIONS IN INDOOR/OUTDOOR MICROBIAL RATIOS IN AUCKLAND AND WELLINGTON OFFICES (SUMMER VS WINTER)

	INDOOR/OUTDOOR BACTERIAL RATIO	**INDOOR/OUTDOOR FUNGAL RATIO**
	(SEASONAL DIFFERENCES)	
AUCKLAND OFFICES	**P = 0.422**	**P = 0.815**
WELLINGTON OFFICES	**P = 0.478**	**P = 0.176**

Significant differences (P< 0.05)

AUCKLAND AND WELLINGTON OFFICES IN SUMMER (BACTERIAL RATIOS)

In comparing indoor/outdoor bacterial ratios in Auckland and Wellington offices in summer, no significant differences between the two sets of ratios were found (P= 0.237). This might suggest that indoor sources were the major contributors of indoor airborne bacteria in both Auckland and Wellington offices.

AUCKLAND AND WELLINGTON OFFICES IN WINTER (BACTERIAL RATIOS)

In winter, indoor sources are likely to be the major contributors of indoor bacteria. The Mann-Whitney probability value for indoor/outdoor bacterial ratios across the two cities in winter was 0.353. Indoor sources, however, seem to be more important in winter than in summer in both Auckland and Wellington. This might be due to the high percentage of air recirculated in winter for energy conservation purposes.

AUCKLAND AND WELLINGTON OFFICES IN SUMMER (FUNGAL RATIOS)

As far as indoor/outdoor fungal ratios in summer were concerned, the ratios for Auckland and Wellington offices were significantly different (P=0.001). This indicates that in summertime, external sources were the major contributors to indoor airborne fungi in Auckland, while indoor sources were the major contributors to indoor fungi in Wellington (see Table 5.4).

AUCKLAND AND WELLINGTON OFFICES IN WINTER (FUNGAL RATIOS)

Indoor/outdoor fungal ratios for Auckland and Wellington offices in winter were also significantly different (P=0.009). Again this indicates that indoor sources were more important contributors for indoor fungi in Wellington in winter. However, indoor sources in Wellington offices surveyed during summertime seem to be more important than indoor sources in offices surveyed during wintertime (the median values for fungal ratios in Wellington offices were 0.78 and 0.32 in summer and winter respectively- see

Table 5.4).

TABLE 5.6: THE SIGNIFICANCE OF SEASONAL VARIATIONS IN INDOOR/OUTDOOR BACTERIAL AND FUNGAL RATIOS BETWEEN AUCKLAND AND WELLINGTON OFFICES (AUCKLAND VS WELLINGTON)

	INDOOR/OUTDOOR BACTERIAL RATIO	**INDOOR/OUTDOOR FUNGAL RATIO**
AUCKLAND AND WELLINGTON OFFICES (SUMMER)	**P = 0.237**	**P = 0.001**
AUCKLAND AND WELLINGTON OFFICES (WINTER)	**P = 0.353**	**P = 0.009**

Significant differences (P< 0.05)

5.8 DISCUSSION

In general, indoor airborne bacterial concentrations were significantly higher in offices surveyed in summer months. This could be due to the fact that in summer more fresh air is likely to be brought inside, when outdoor bacterial levels are at their peak. Consequently, more outdoor airborne bacterial penetrate the indoor environment[45]. An Australian study conducted in an office building in Perth found that of nine occasions when indoor bacterial levels were at their peak, seven occured in midsummer [8].

Indoor airborne bacterial levels were slightly higher than outdoor levels in winter in both Auckland and Wellington offices. This could be due to the fact that less fresh air is brought inside (for energy conservation purposes) and consequently airborne bacteria generated from internal sources start to build up. Other studies carried out in China and the U.S. have found that indoor bacterial levels were twice as high in summer as in winter and are almost always higher than outdoor levels in both seasons [9,10].

Carbon dioxide levels in Auckland offices in both seasons were higher than those of Wellington offices[46]. This could mean that the number of people per square metre in Auckland offices is, in general, higher than in Wellington offices and/or the percentage of fresh air to recirculated air and the ventilation rate, in general, is less in Auckland offices than in Wellington [11].

Indoor fungal concentrations were generally below outdoor levels in winter in both Auckland and Wellington offices. In summer, on the other hand, indoor fungal levels

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45 This could also explain the strong association found between indoor and outdoor bacterial levels in offices surveyed in summer.

46 Mean and median values were 587 and 559 ppm in Auckland offices during summer whereas in Wellington the mean and median were 512 and 514 ppm respectively. The winter values were 558 and 542 ppm in Auckland offices and 531 and 471 ppm in Wellington offices.

were higher than outdoor levels only in Wellington offices[47]. This implies that indoor fungal levels in Wellington were generated from internal sources. This also could be due to the extremely low outdoor fungal levels in Wellington which occur because outdoor climatic conditions are not encouraging to fungal growth even during summertime (see Appendix 7).

The association found between indoor air temperature [48] and indoor airborne fungi in Wellington offices during summertime could explain why indoor airborne fungi was found to be generated mainly from internal sources (see 4.6 Discussion). A Japanese study [12] found that fungal growth of a common indoor species[49] is faster under a constant temperature of 25 °C than with temperature variation of 20~30°C or 15~35°C[50]. This means that a constant indoor air temperature is more suitable for fungal growth than a fluctuating air temperature. Therefore, more data regarding temperature and humidity fluctuations (and perhaps data regarding the ventilation rate) on a daily and monthly basis are needed to provide clear understanding for the strong correlation between indoor air temperature and indoor airborne fungal concentrations which existed only in Wellington offices during summertime.

Seasonal variations were found to be one of the major factors affecting outdoor and indoor bacterial and fungal levels in Auckland offices and indoor and outdoor bacterial levels in Wellington offices. Indoor and outdoor fungal levels in Wellington offices, on the other hand, were not affected by seasonal variations. This could be explained by the

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47 The mean indoor fungal level in Wellington during summer was 66 CFU/m^3.

48 The median indoor air temperature in Wellington offices was 0.6 °C higher than the median value in Auckland offices during summer months (22.4 °C for Wellington and 21.8 °C for Auckland) .

49 *Cladosporium cladosporioides*.

50 Indoor humidity level during that time was at a constant level of 90%.

indoor sources were the major contributors of indoor fungal levels in Wellington, while outdoor climatic conditions in both summer and winter (unlike Auckland) were not supportive of fungal growth (Appendix 7). This finding could be useful in determining appropriate changes to indoor air measurement strategies. Indoor air measurements for airborne fungal concentrations, for instance, might not be required in wintertime (unless there are visual signs of moulds on interior surfaces or symptoms reported by office workers which might suggest the existence of elevated airborne fungal levels - see Chapter 2) as indoor airborne bacterial and fungal concentrations were at low levels in wintertime and therefore unlikely to pose any serious indoor problem[51].

External sources seemed to be the major contributors of indoor airborne fungi in Auckland offices throughout the year, whereas indoor sources appeared to be the major source of indoor fungi in Wellington offices in both seasons. A Finnish study carried out on a residential building during the heating seasons in subarctic regions [13] found that indoor/outdoor fungal ratios were higher than 1 in both a "problem house" and a "reference house"[52][53]. Thus high indoor/outdoor fungal ratio does not necessarily indicate serious indoor fungal contamination sources.

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51 In the next Chapter, indoor airborne bacterial and fungal concentrations in offices with and without reported complaints will be investigated in order to establish whether the airborne bacterial and fungal levels were genuinely related to the complaint reported in some offices.

52 The mean indoor/outdoor fungal ratio values were 1.55 and 1.04 in "problem and "reference" houses respectively.

53 It should be noted that outdoor fungal levels in a subarctic region during the heating season would be at their minimum levels as snow covers the ground.

5.9 RECAPITULATION

The main objective of this chapter was to determine whether seasonal variations in airborne bacterial and fungal concentrations occur in indoor air. The statistical analyses suggested that there are significant seasonal variations in indoor bacterial and fungal concentrations in Auckland offices and significant seasonal variations in indoor bacterial concentrations in Wellington offices. No significant seasonal variations were observed in indoor fungal concentrations in Wellington offices.

In general, indoor bacterial levels in summer were three times higher than those in winter while indoor fungal levels were twice as high as those in winter. Indoor bacterial concentrations were higher than outdoor while outdoor fungal levels were higher than indoor (except in Wellington offices during summertime).

Significant association has been found between indoor air temperature and indoor airborne fungi in Wellington offices during summer months. In Auckland offices, association has been found between indoor and outdoor airborne bacteria also during summer months. A summary of the linear regression analysis and Fisher's exact test for Auckland and Wellington offices in both seasons are presented in Tables 5.7 and 5.8.

Outdoor fungal levels were higher than indoor levels in Auckland in both seasons and in Wellington only in winter. Indoor fungal levels in Wellington offices in summer, however, were significantly higher than outdoor levels, which suggested the presence of internal fungal sources in Wellington offices during summertime[54].

Statistical analysis suggested that indoor/outdoor fungal ratios in summer in Auckland and Wellington offices were significantly different (P=0.001). During winter these differences were also significant (P=0.009). This could be due to the fact that indoor

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54 This can be explained by the fact that indoor air temperature and indoor airborne fungi were correlated in Wellington offices surveyed in summer.

fungal levels in Auckland offices were below those of Wellington offices even though outdoor fungal levels of Auckland offices were always significantly higher than those of Wellington offices in both seasons. This might indicate that Auckland offices in general were successful in preventing outdoor fungal pollutants from penetrating the indoor environment while indoor fungi in Wellington offices were generated by indoor sources.

In the next Chapter, indoor airborne bacterial and fungal concentrations in offices with and without reported complaints will be investigated in order to establish whether the airborne bacterial and fungal levels were associated with the complaint reported in some offices.

TABLE 5.7: SUMMARY OF LINEAR REGRESSION ANALYSIS BETWEEN INDOOR MICROCLIMATIC PARAMETERS, OUTDOOR AIRBORNE BACTERIA AND FUNGI, AND INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS, IN AUCKLAND AND WELLINGTON OFFICES SURVEYED IN SUMMER AND WINTER (ALL RESULTS WERE BASED ON ESR DATA).

	LINEAR REGRESSION (R^2) SUMMER		**LINEAR REGRESSION (R^2) WINTER**	
	AUCKLAND	WELLINGTON	AUCKLAND	WELLINGTON
TEMPERATURE vs INDOOR BACTERIA	**0.13** ♦	**0.09** ♦	**0.01** ♦	**0.14** ♦
HUMIDITY vs INDOOR BACTERIA	**0.02** ♦	**0.01** ♦	**0.01** ♦	**0.03** ♦
TEMPERATURE vs INDOOR FUNGI	**0.01** ♦	**0.30** ▸	**0.03** ♦	**0.00** ♦
HUMIDITY vs INDOOR FUNGI	**0.07** ♦	**0.17** ♦	**0.00** ♦	**0.01** ♦
OUTDOOR BACTERIA vs INDOOR BACTERIA	**0.18** ▸	**0.04** ♦	**0.15** ♦	**0.00** ♦
OUTDOOR FUNGI vs INDOOR FUNGI	**0.27** ▸	**0.38** ▸	**0.01** ♦	**0.02** ♦

▸ Significant linear association (X Coef./ Std Err of Coef. > 2)

♦ Insignificant linear association (X Coef./ Std Err of Coef. < 2)

TABLE 5.8: SUMMARY OF NON-LINEAR REGRESSION ANALYSES (FISHER'S EXACT TEST) BETWEEN INDOOR MICROCLIMATIC PARAMETERS, OUTDOOR AIRBORNE BACTERIA AND FUNGI, AND INDOOR AIRBORNE BACTERIA AND FUNGI, IN AUCKLAND AND WELLINGTON OFFICES (ALL RESULTS WERE BASED ON ESR DATA).

	FISHER EXACT PROBABILITY (P) SUMMER		**FISHER EXACT PROBABILITY (P) WINTER**	
	AUCKLAND	WELLINGTON	AUCKLAND	WELLINGTON
TEMPERATURE vs INDOOR BACTERIA	**0.30**	**0.35**	**1.00**	**0.59**
HUMIDITY vs INDOOR BACTERIA	**0.59**	**0.29**	**0.18**	**1.00**
TEMPERATURE vs INDOOR FUNGI	**0.29**	**0.08**	**0.65**	**0.34**
HUMIDITY vs INDOOR FUNGI	**1.00**	**0.59**	**0.63**	**1.00**
OUTDOOR BACTERIA vs INDOOR BACTERIA	**0.00**	**0.37**	**0.37**	**0.70**
OUTDOOR FUNGI vs INDOOR FUNGI	**0.21**	**0.03**	**1.00**	**1.00**

Significant association ($P < 0.05$).

Insignificant association ($0.05 < P < 0.1$).

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CHAPTER 6

INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN COMPLAINT AND NON-COMPLAINT OFFICES

- DESCRIPTIVE ANALYSIS
- STATISTICAL ANALYSIS

CHAPTER 6
INDOOR BACTERIAL AND FUNGAL CONCENTRATIONS IN COMPLAINT AND NON-COMPLAINT OFFICES

> *"The World Health Organization defined sick building syndrome on the basis of a group of frequently reported symptoms or complaints including (1) sensory irritation in eyes, nose, and throat;(2) neurotoxic or general health problems; (3) skin irritation; (4) nonspecific hypersensitivity reactions; and (5) odour and taste sensations."* [1].

6.1 INTRODUCTION

Some people may be more susceptible to bacterial and fungal exposure than others. The degree of reaction to airborne bacteria and fungi is highly dependent on the age, sex and medical conditions of individuals. Sisk [2] reported that symptoms appear to be influenced by a large number of variables including age, gender and job description. Therefore, the symptoms reported by the occupants of New Zealand complaint offices surveyed were investigated to determine whether these complaints were associated with indoor air quality[55].

Data in 119 offices in Auckland and Wellington were analysed[56]. The aim of these analyses was to examine the differences in indoor and outdoor parameters between complaint and non-complaint offices.

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55 The ESR data have no records regarding the number of occupants reporting complaints in the surveyed offices. The symptoms reported also were based on vague reports. Therefore, important data such as the percentage of occupants experiencing symptoms (which might be caused by indoor pollutants and/or indoor microclimatic factors in the office environment) were not available.

56 The number of offices measured in response to a complaint situation was 58 and the number of offices measured as part of an annual routine check of indoor air quality was 61. The rest of the 235 offices studied had no records regarding the reasons for carrying out indoor air measurements.

Nine of these parameters[57] will be discussed and statistically analysed. These parameters are:

1. Indoor air temperature
2. Indoor relative humidity
3. Indoor airborne bacteria
4. Indoor airborne fungi
5. Outdoor airborne bacteria
6. Outdoor airborne fungi
7. Indoor/outdoor bacterial ratios
8. Indoor/outdoor fungal ratios
9. Carbon dioxide level

The ESR data were divided into two sets[58]. The first set contained 58 offices with reported complaints. These complaints included eye irritation, skin irritation and "flu like" symptoms. The second set contained 61 offices measured as part of routine annual inspection for indoor air quality. It should be noted that Auckland and Wellington offices were not analysed separately as the number of measurements available for complaint offices in Auckland was limited (see Table 6.1) and this in turn may affect the validity of the analyses.

The statistical analyses will not determine the causes of complaints in offices. Rather, they will show what was the indoor environment profile at the time of measurement in both complaint and non-complaint offices and the 'likely' causes of complaint (from the statistical analyses point of view). Godish [1] reported that the symptoms (according to a working group of the Commission of the European Communities) are likely to be caused by multiple factors. As a consequence, no single parameter can be said to be responsible. Therefore, to identify the causes of complaint each building or office should be investigated individually and measurements should be taken for a significant period of time.

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57 As these 9 parameters were the only measurements carried out by ESR.

58 Only ESR data have been used in this chapter because ABS data has no records regarding the reason for carrying out the indoor air measurements.

6.2 INDOOR MICROCLIMATIC PARAMETERS IN COMPLAINT AND NON-COMPLAINT OFFICES (DESCRIPTIVE ANALYSIS)

Significant differences were found between microclimatic parameters in complaint and non-complaint offices. The mean and median values of indoor air temperature in complaint offices (22.3°C and 22.5°C respectively) were almost 1°C higher than those of non-complaint offices (21.5°C and 21.6°C respectively). In 40% of complaint offices, the indoor air temperature was above 23°C, whereas only 5% of non-complaint exceeded this level (Figure 6.1).

The mean and median values of indoor relative humidity in offices with complaints (42% and 40% respectively) were only slightly below those of non-complaint offices (43% and 44% respectively - see Figure 6.2).

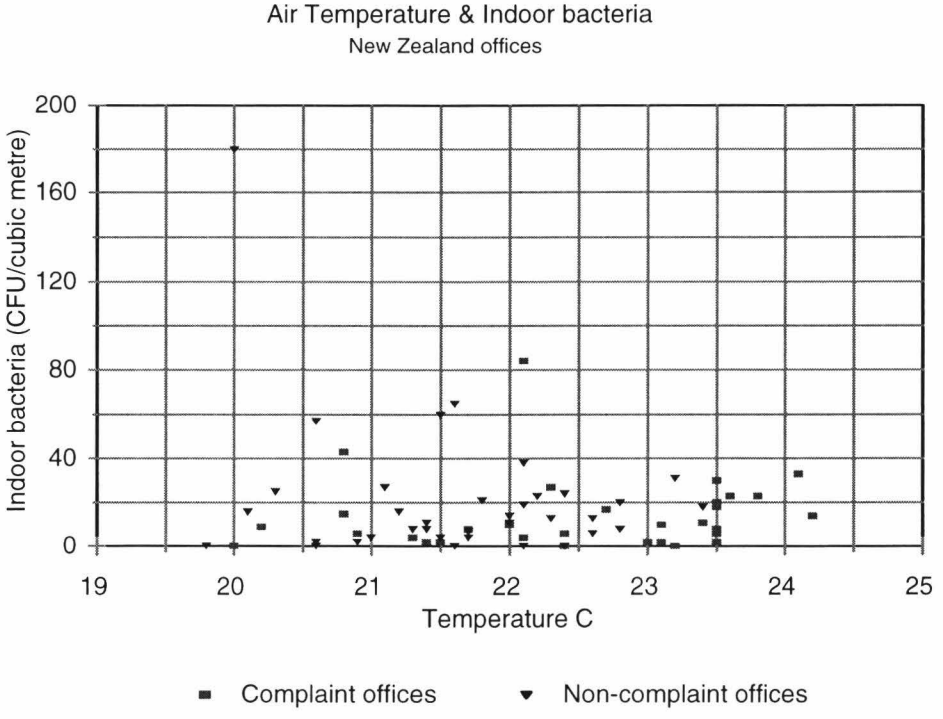

Figure 6.1: Indoor air temperature in complaint and non-complaint offices. Clear differences in indoor air temperature levels can be seen between complaint and non-complaint offices (records higher than 23°C were mostly of complaint offices).

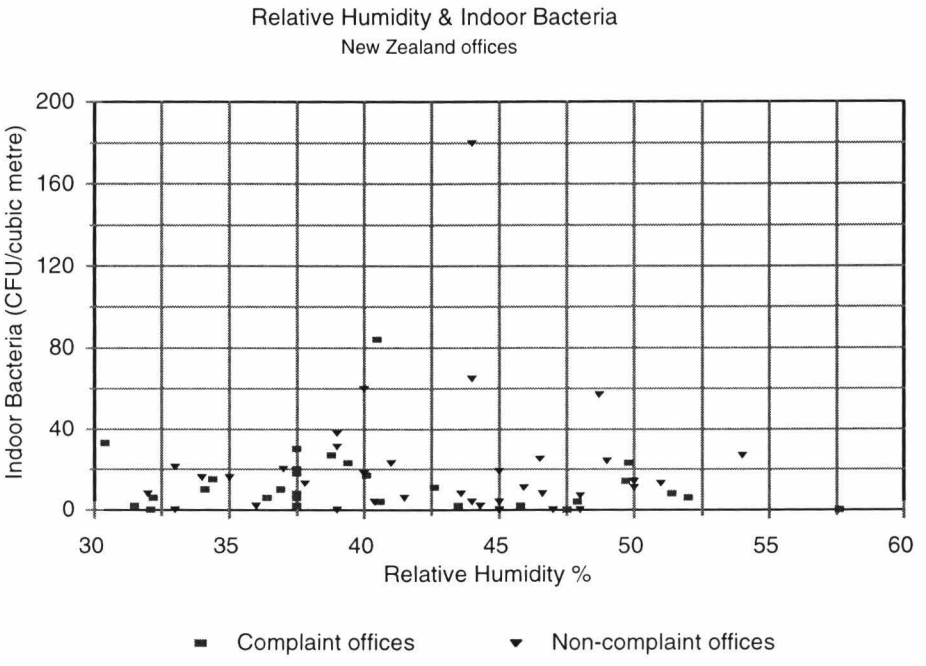

Figure 6.2: Indoor relative humidity in complaint and non-complaint offices

6.3 INDOOR AND OUTDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN COMPLAINT AND NON-COMPLAINT OFFICES (DESCRIPTIVE ANALYSIS)

Indoor airborne bacterial concentrations in complaint offices were lower than those of non-complaint offices. In 2% of the complaint offices surveyed, indoor bacterial levels were higher than 50 CFU/m^3, whereas 22% of the non-complaint offices had indoor bacterial levels above 50 CFU/m^3. Indoor bacterial levels were below the 10 CFU/m^3 level in 51% of the complaint offices whereas this percentage was 39% in offices with no complaints. Indoor bacterial levels in complaint and non-complaint offices are shown in Figure 6.3.

Indoor airborne fungal levels, on the other hand, were higher in complaint offices. Levels were above 50 CFU/m^3 in 32% of complaint offices but just 12% of non-complaint offices. In 29% of offices with complaints, indoor fungal levels did not exceed the 10 CFU/m^3 level, whereas 45% of non-compliant offices did not exceed this level. Figure 6.4 shows that 6 complaint offices had high levels of airborne fungi (over 60 CFU/m^3) while the outdoor levels of these offices were below 50 CFU/m^3. This means that the indoor airborne levels in these offices were generated from internal sources.

Outdoor airborne bacterial and fungal levels of complaint offices were lower than those of non-complaint offices. None of the complaint offices had outdoor bacterial levels higher than 50 CFU/m^3, (as compared to 20% of non-complaint offices). Furthermore, outdoor fungal levels were higher than 50 CFU/$m^{3)}$ in 17% and 67% of complaint and non-complaint offices respectively.

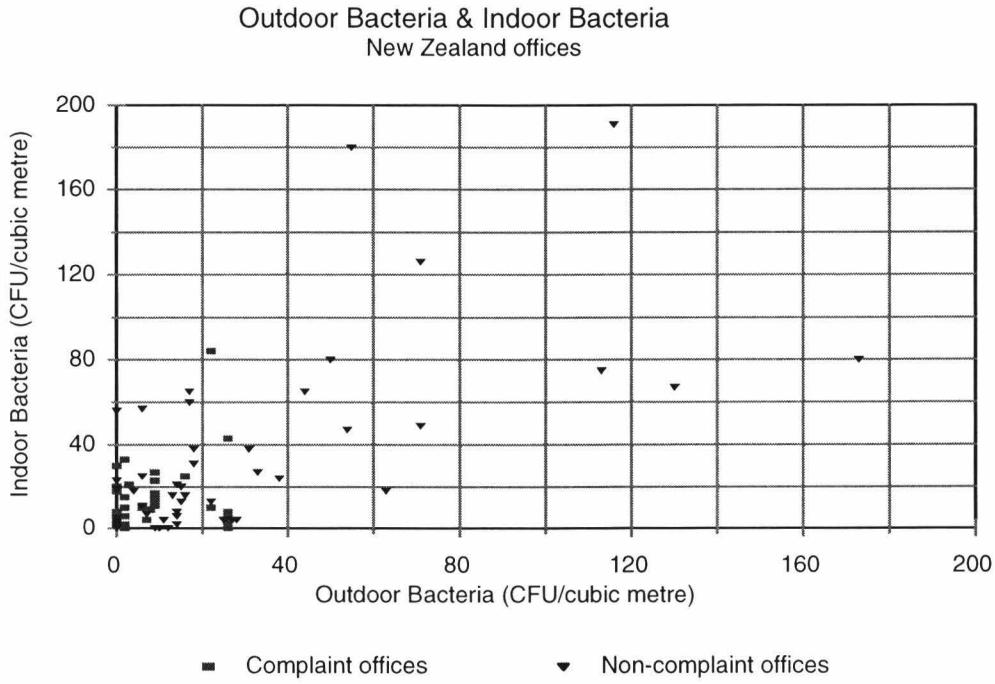

Figure 6.3: Indoor and outdoor airborne bacterial levels in complaint and non-complaint offices.

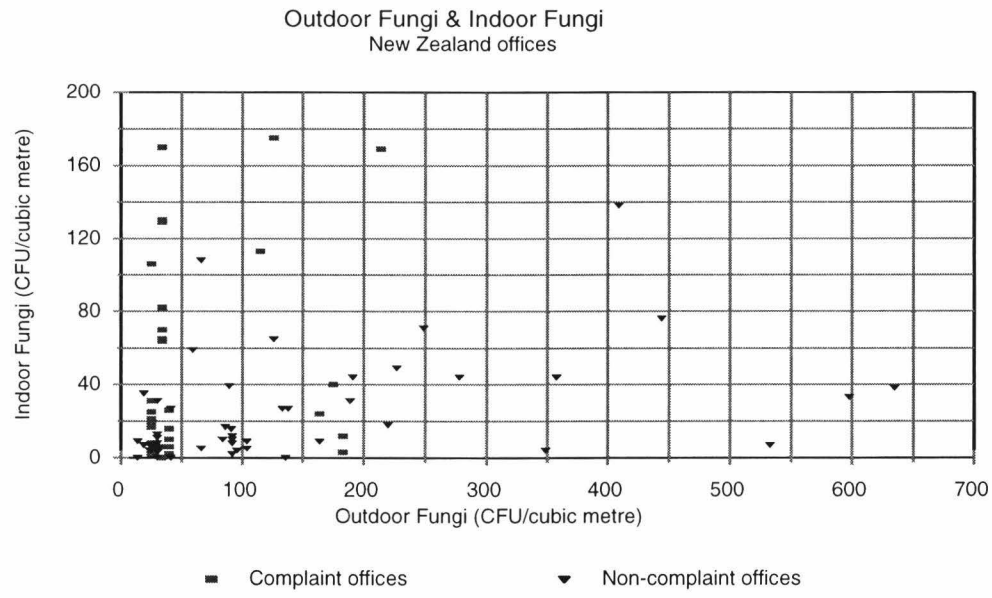

Figure 6.4: Indoor and outdoor airborne fungal levels in complaint and non-complaint offices. No significant differences can be observed in indoor airborne fungal levels between complaint and non-complaint offices (it should be noted that high airborne levels in many non-complaint offices were mainly due to elevated outdoor levels).

6.4 INDOOR CARBON DIOXIDE LEVELS IN COMPLAINT AND NON-COMPLAINT OFFICES (DESCRIPTIVE ANALYSIS)

No significant differences were found between carbon dioxide levels in complaint and non-complaint offices. Carbon dioxide levels were above 800 ppm in 6% and 2% of the complaint and non-complaint offices respectively. Carbon dioxide levels in complaint and non-complaint offices are shown in Figure 6.5.

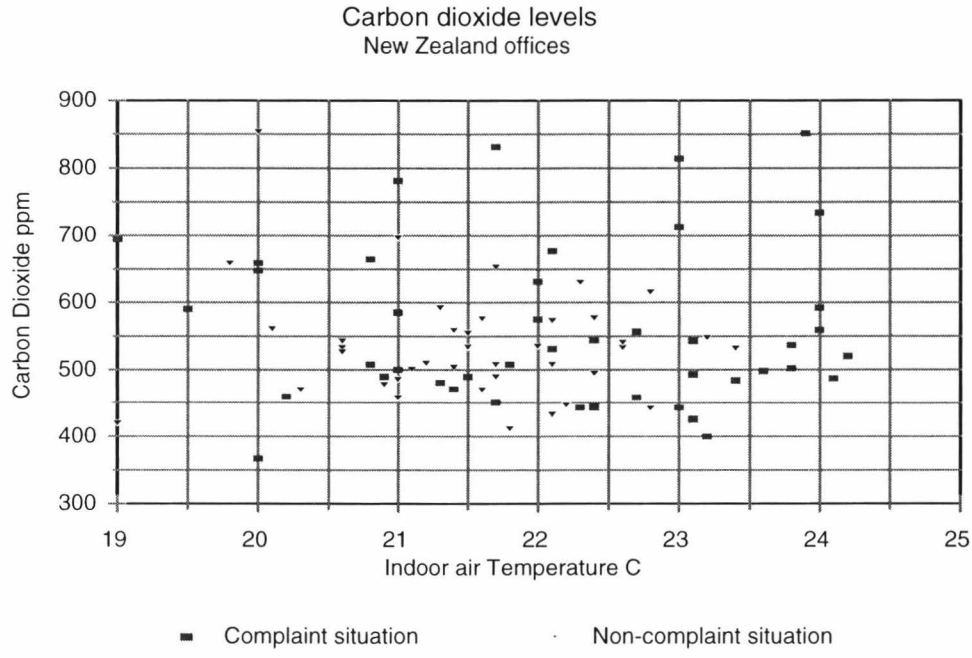

Figure 6.5: Carbon dioxide levels in complaint and non-complaint offices. No clear differences can be seen in carbon dioxide levels between complaint and non-complaint offices.

6.5 INDOOR/OUTDOOR BACTERIAL AND FUNGAL RATIOS IN COMPLAINT AND NON-COMPLAINT OFFICES (DESCRIPTIVE ANALYSIS)

Differences were found between the indoor/outdoor bacterial ratios of complaint and non-complaint offices. These ratios were above 1 in 48% of the complaint offices surveyed, but in only 32% of non-complaint offices[59]. Indoor/outdoor bacterial ratios in both complaint and non-complaint offices are presented in Figure 6.6.

Indoor/outdoor fungal ratios in complaint and non-complaint offices appeared to be significantly different. In 34% of the complaint offices, the indoor/outdoor ratio exceeded 1, whereas in non-complaint offices this percentage was just 7%. Indoor/outdoor fungal ratios in complaint and non-complaint offices are presented in Figure 6.7.

59 The indoor/outdoor bacterial ratios in some offices were 0.00 as the indoor bacterial levels were 0 CFU/m^3.

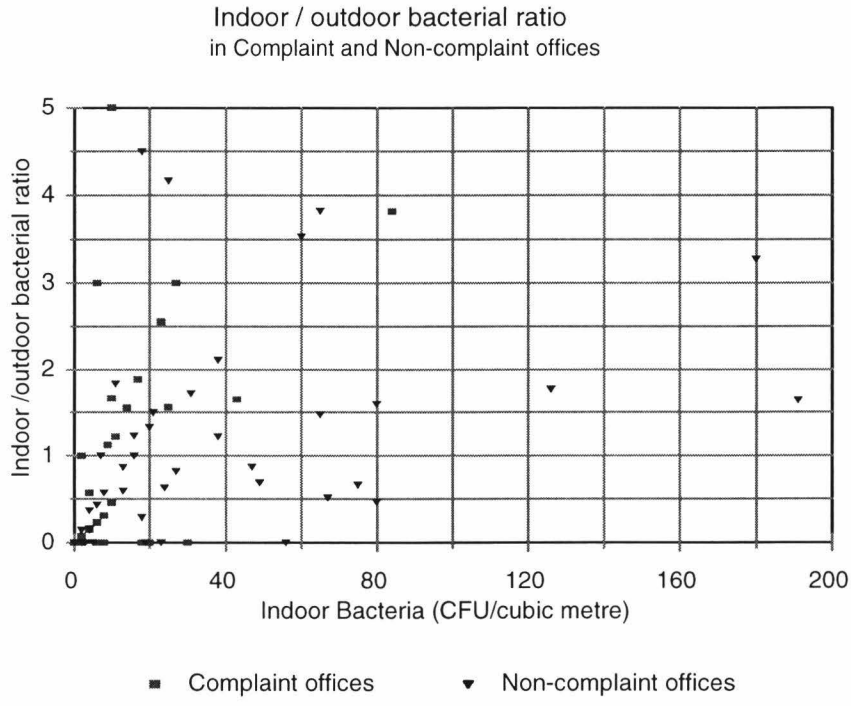

Figure 6.6: Indoor /outdoor bacterial ratios in complaint and non-complaint offices. No clear differences can be observed in indoor/outdoor bacterial ratios between complaint and non-complaint offices.

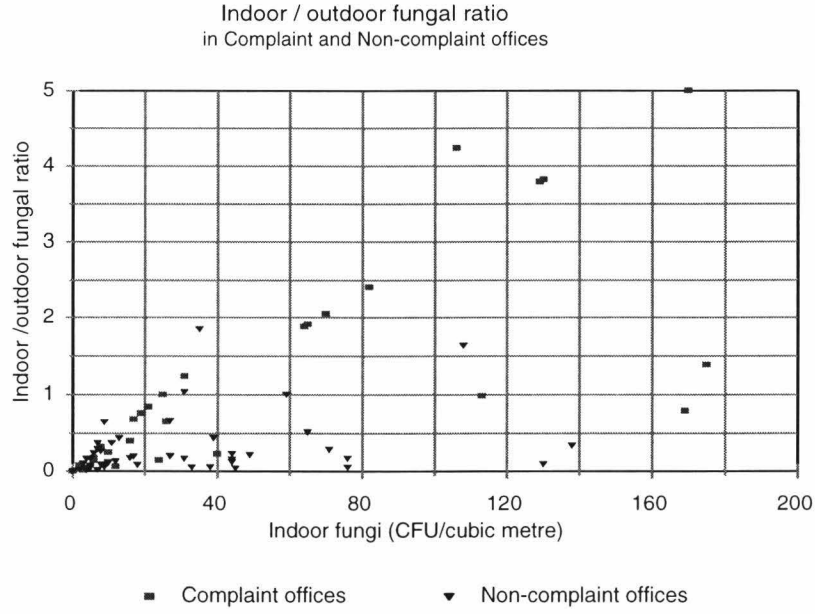

Figure 6.7: Indoor /outdoor fungal ratios in complaint and non-complaint offices. Most indoor/outdoor fungal ratios above 1 were of offices measured in response to complaint situation.

A study carried out by the American Conference of Governmental Industrial Hygienists (ACGIH) suggested that if the airborne fungal level in an office exceeds the outdoor level by 33% or if indoor airborne bacterial levels are higher than 50 CFU/m^3, then that office is suspected of being contaminated with excessive bioaerosols (cited in Holt [3]). Just half (54%) of all complaint offices surveyed exceeded the 33% indoor/outdoor fungal ratio suggested by ACGIH, but only 3% of these had indoor bacterial levels which exceeded the 50 CFU/m^3 level. In non-complaint offices, on the other hand, while only 19% of the offices exceeded the indoor/outdoor fungal ratio guideline, 23% exceeded the 50 CFU/m^3 bacterial level.

The mean and median values of non-complaint offices were also well below the 33% criterion[60]. The mean and median values of indoor bacteria in non-complaint offices were well below[61] the 50 CFU/m^3 suggested by the ACGIH. Interestingly, the corresponding values for indoor bacterial levels in complaint offices were even less[62].

The mean, median and range values for indoor air temperature, indoor relative humidity, indoor and outdoor bacterial and fungal levels and carbon dioxide levels in complaint and non-complaint offices are presented in Table 6.1. The mean, median and range of indoor/outdoor bacterial and fungal ratios in complaint and non-complaint offices in New Zealand are shown in Table 6.2.

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60 The mean and median values for indoor/outdoor fungal ratio in non-complaint offices were 0.25 and 0.15 respectively (see Table 6.2).

61 The mean and median values for non-complaint offices were 36 CFU/m^3 and 15 CFU/m^3 respectively (see Table 6.2).

62 The mean and median values for indoor bacterial levels were 13 CFU/m^3 and 9 CFU/m^3 respectively (see Table 6.1).

TABLE 6.1: THE MEAN, MEDIAN AND RANGE OF MICROCLIMATIC PARAMETERS, OUTDOOR AND INDOOR AIRBORNE BACTERIAL AND FUNGAL CONCENTRATIONS AND CARBON DIOXIDE LEVELS IN NEW ZEALAND COMPLAINT AND NON-COMPLAINT OFFICES

	Indoor temperature oC	Indoor humidity %	Outdoor bacteria CFU/m^3	Indoor bacteria CFU/m^3	Outdoor fungi CFU/m^3	Indoor fungi CFU/m^3	carbon dioxide ppm
New Zealand offices (complaint)							
Mean	22.3	42	10	13	56	57	557
Median	22.5	40	9	9	34	21	525
Range	19-24.2	27-60	0-26	0-84	25-214	0-470[63]	367-851
Count	52	52	41	37	41	37	46
New Zealand offices (non-complaint)							
Mean	21.5	43	31	36	206	26	561
Median	21.6	44	14	15	92	11	545
Range	19-23.4	32-59	0-292	0-450	14-1382	0-138	412-854
Count	40	40	58	58	58	58	52

63 As mentioned previously, the 470 CFU/m^3 is a very high value (considering the rest of airborne fungal levels in complaint offices). The second highest fungal level recorded under this category was just 175 CFU/m^3 (see Appendix 2 of the separate report). Therefore, the range of **0-175 CFU/m^3** might reflect more accurate airborne fungal range in complaint offices. This is also the case in the 0-450 CFU/m^3 range of indoor airborne bacteria in non-complaint offices. The second highest airborne bacterial level in a non-complaint office was just 191 CFU/m^3. Therefore, the indoor airborne bacterial range of **0-191 CFU/m^3** might also reflect more accurate range of airborne bacteria in non-complaint offices.

TABLE 6.2: INDOOR/OUTDOOR BACTERIAL AND FUNGAL RATIOS IN COMPLAINT AND NON-COMPLAINT OFFICES

	INDOOR/OUTDOOR RATIO (BACTERIA)	INDOOR/OUTDOOR RATIO (FUNGI)
NEW ZEALAND OFFICES (complaint)		
MEAN	**4.38**	**1.57**
MEDIAN	**1.67**	**0.65**
RANGE	**0-30.00**	**0-18.80**
NUMBER OF OFFICES	**35**	**35**
NEW ZEALAND OFFICES (non-complaint)		
MEAN	**3.39**	**0.25**
MEDIAN	**0.94**	**0.15**
RANGE	**0-56.00**	**0-1.84**
NUMBER OF OFFICES	**56**	**56**

6.6 THE SIGNIFICANCE OF PARAMETER DIFFERENCES BETWEEN COMPLAINT AND NON-COMPLAINT OFFICES (STATISTICAL ANALYSIS)

The Mann-Whitney[64] test is a statistical tool used to examine differences across two independent groups and to establish whether these groups come from identically distributed populations. If the probability value $P < 0.05$, this implies a significant differences and indicates that the two groups tested do not come from the same populations.

The Mann-Whitney test was performed here on a number of indoor and outdoor parameters in complaint and non-complaint offices. The aim of these analyses was to observe any significant differences between these parameters and determine the 'likely' causes of complaint (from a statistical analyses point of view). The parameters examined were:

1- Indoor air temperature
2- Indoor relative humidity
3- Indoor bacterial levels
4- Outdoor bacterial levels
5- Indoor fungal levels
6- Outdoor fungal levels
7- Indoor/outdoor bacterial ratio
8- Indoor/outdoor fungal ratio
9- Indoor carbon dioxide levels

The differences in indoor air temperature between complaint and non-complaint offices were statistically significant (P=0.001). Indoor relative humidity levels, on the other hand, appeared to be similar in complaint and non-complaint offices (P=0.383).

No significant differences were found between indoor airborne bacterial levels in

64 The Mann-Whitney test is the nonparametric equivalent of the two-sample student t test.

complaint and non-complaint offices[65] (P=0.186). The mean levels in complaint and non-complaint offices were 13 CFU/m^3 and 36 CFU/m^3 respectively. A similar study carried out in four schools in Finland [4] found that the average indoor bacterial levels in "problem schools" were significantly below the bacterial level in "a reference school".

Indoor airborne fungal levels also appeared to be similar in complaint and non-complaint offices (P=0.105). The Finnish study also found no significant differences between the indoor airborne fungal concentrations in the two "problem schools" and the "reference school". The mean indoor fungal concentrations in these schools were 53 CFU/m^3 and 59 CFU/m^3 for the two problem schools and 53 CFU/m^3 for the reference school. Here too, the mean indoor fungal concentrations in complaint and non-complaint offices (57 CFU/m^3 and 26 CFU/m^3 respectively) were near those of the Finnish schools surveyed.

Indoor carbon dioxide levels were found to be similar in complaint and non-complaint offices (P=0.459). Carbon dioxide levels in general were below 850 ppm in both complaint and non-complaint offices. This would suggest that inadequate fresh air ventilation is unlikely to be one of the causes of complaints. Several studies have found the percentage of fresh air supply to be negatively correlated with the level of indoor carbon dioxide [5,6].

Outdoor bacterial levels were significantly higher in non-complaint offices (P=0.053). This means that indoor/outdoor bacterial ratios were affected (to a certain degree) by these significant differences. Outdoor fungal levels were also significantly higher in non-complaint offices (P=0.003) making indoor/outdoor fungal ratios of these offices significantly lower than those of complaint offices. This also means that indoor fungal levels in non-complaint offices were not affected by the relatively high outdoor fungal concentrations.

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65 The mean indoor airborne bacterial levels were slightly higher in non-complaint offices.

The differences between indoor/outdoor bacterial ratios in complaint and non-complaint offices were not statistically significant (P=0.071). Indoor/outdoor fungal ratios, on the other hand, were significantly higher in complaint offices (P<0.001). This could mean that one of the causes of complaint is the 'unhealthy' indoor environment which promotes fungal growth and consequently (given suitable indoor air temperature and humidity) encourages fungal spores to become airborne.

Table 6.3 summarises the Mann-Whitney probability values for the nine parameters examined. The statistical outputs of these analyses are presented in Appendix 6.

TABLE 6.3: SUMMARY OF MANN-WHITNEY PROBABILITY VALUES FOR INDOOR MICROCLIMATIC PARAMETERS, INDOOR AND OUTDOOR BACTERIA AND FUNGI, CARBON DIOXIDE AND INDOOR/OUTDOOR BACTERIAL AND FUNGAL RATIOS IN COMPLAINT AND NON-COMPLAINT OFFICES.

	NUMBER OF OFFICES SURVEYED		MANN-WHITNEY PRO. VALUE
	COMPLAINT	N.COMPLAINT	
INDOOR AIR TEMPERATURE	52	40	0.001
INDOOR RELATIVE HUMIDITY	52	40	0.383
INDOOR AIRBORNE BACTERIA	37	58	0.186
INDOOR AIRBORNE FUNGI	37	58	0.105
INDOOR CARBON DIOXIDE	46	52	0.459
OUTDOOR AIRBORNE BACTERIA	41	58	0.053
OUTDOOR AIRBORNE FUNGI	41	58	0.003
IN/OUT BACTERIA RATIO	35	56	0.071
IN/OUT FUNGAL RATIO	35	56	0.000

Significant differences (P< 0.05)

6.7 DISCUSSION

The mean and median indoor air temperature in complaint offices were almost 1°C higher than those of non-complaint offices. Statistical analysis showed that indoor air temperature levels in the offices with complaints were significantly different from those of the offices with no complaints (P = 0.001 - see Table 6.3). This would suggest that indoor air temperature could be one of the likely causes for complaint in offices. Indoor relative humidity levels in both complaint and non-complaint offices, on the other hand, were not statistically different. The Mann-Whitney test suggested that indoor relative humidity is unlikely to have been a cause for complaint (P = 0.383).

A Danish study [7] showed that a significant percentage of employees complaining over various indoor climatic factors (14% of the employees had complaints about low temperature, 15% about changes in temperature, 14% about draughts and 33% about dry air). A Norwegian study indicated that 35-40% of employee complaints were indoor climate related [8]. This supports the contention that the complaints in New Zealand offices could at least partly be related to indoor climatic factors.

Mean and median indoor airborne bacterial levels in complaint offices were below those of non-complaint offices. Mean and median indoor airborne fungal levels in complaint offices were slightly higher than those in non-complaint offices (no significant differences were found between indoor fungal levels in complaint and non-complaint offices - P= 0.105). This means that airborne bacteria and fungi, from the statistical analyses point of view, were unlikely to be one of the causes of complaints in the New Zealand offices surveyed. **Therefore, there is a need to examine whether there is a necessity to look at indoor airborne bacterial and fungal measurements as a priority when conducting indoor air quality investigations in response to complaint situations in an office environment.**

Carbon Dioxide also appeared to be unassociated with any complaint reported (P = 0.459). The carbon dioxide levels were in most cases significantly lower than the

ASHRAE standard of 1000 ppm[66] [9].

Outdoor bacterial and fungal levels of complaint offices were lower than those of non-complaint offices. This could be due to the fact that the number of Auckland offices represented in the complaint category was just 12 compared with 48 offices in the non-complaint category. As outdoor microbial concentrations in Auckland offices were significantly higher than those of Wellington offices (see Chapter 4 and Appendix 7), this had the effect of skewing the results.

Indoor/outdoor bacterial ratios in complaint offices were higher than those of non-complaint offices. However, the differences in bacterial ratios between complaint and non-complaint offices were not statistically significant (P = 0.071). Indoor/outdoor fungal ratios in complaint and non-complaint offices, on the other hand, were significantly different (P = 0.000). This could be due to the fact that outdoor fungal levels in complaint offices were significantly lower than those of non-complaint offices and consequently the indoor/outdoor fungal ratio would be significantly higher in complaint offices. However, this also may indicate that the office environment was the main source of indoor fungal contaminations[67].

Two main conclusions can be drawn from these analyses. The first is that high indoor air temperature levels could be one of the likely causes of complaint. The second conclusion is that the indoor environment in complaint offices may have been encouraging fungal growth and consequently becoming a source of airborne fungi[68].

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66 The mean values for carbon dioxide levels were 557 ppm and 561 ppm for complaint and non-complaint offices respectively.

67 This is clearly illustrated by the fact that the mean fungal ratio in complaint offices was 1.57 whereas the mean fungal ratio for non-complaint offices was just 0.25.

68 Even though the airborne fungal levels were not significantly different from those of non-complaint offices.

6.8 RECAPITULATION

Statistical analysis showed that indoor air temperature levels in complaint offices were significantly different from those found in non-complaint offices (P=0.001). The mean indoor air temperature in complaint offices was almost 1°C higher than the mean air temperature in non-complaint offices. Carbon dioxide levels in complaint offices were similar to those found in non-complaint offices (P=0.459).

No statistical evidence has been found to link indoor bacterial and fungal levels to the complaints reported in the 58 offices surveyed. The Mann-Whitney probability values were 0.186 and 0.105 for indoor airborne bacteria and fungi respectively.

Outdoor bacterial levels of complaint offices were slightly lower than those of non-complaint offices. The mean outdoor bacterial levels of complaint and non-complaint offices were 10 CFU/m^3 and 31 CFU/m^3 respectively. Outdoor fungal levels in complaint offices, on the other hand, were significantly lower than those of non-complaint offices. The mean outdoor fungal level of complaint and non-complaint offices were 56 CFU/m^3 and 206 CFU/m^3 respectively.

Indoor/outdoor bacterial ratios in complaint offices were not significantly different from those of non-complaint offices. Indoor/outdoor fungal ratios, on the other hand, were significantly higher in complaint offices (P=0.000). This means that the maintenance of a clean indoor environment[69] and the filtering devices, which play a vital role in preventing elevated outdoor fungal levels from penetrating the office environment could be key factors making the difference between the indoor environment in complaint and

69 Clean indoor environment means a hygienic and well maintained environment which prevents any possible fungal growth factors (eg. mouldy and wet ceiling tiles, water leak, stagnant water in the HVAC system ...etc) from existing indoors.

non-complaint offices[70].

The likely factors which might be considered as causes for complaints are presented in Table 6.4.

TABLE 6.4: INDOOR AIRBORNE BACTERIAL AND FUNGAL SOURCES IN THE NEW ZEALAND OFFICE ENVIRONMENT AND THEIR LIKELY SIGNIFICANCE

PROBLEM TYPE	DEGREE OF SIGNIFICANCE
CONTAMINATION FROM INDOOR SOURCES	**LIKELY** (as indoor/outdoor fungal ratios show that the indoor environment in complaint offices could be one of the potential sources for indoor airborne fungi).
CONTAMINATION FROM OUTDOOR SOURCES	**LIKELY** (as significant association has been found between outdoor and indoor airborne fungi in Auckland and Wellington offices surveyed in summer - see chapter 5).
INDOOR MICROCLIMATIC FACTORS	**LIKELY** (as indoor air temperature levels were significantly higher in complaint offices and a significant association has been found between indoor air temperature and indoor airborne fungal levels in Wellington offices surveyed in summer - see Chapter 5).
INADEQUATE VENTILATION	**UNLIKELY** (no significant differences have been found in carbon dioxide levels between complaint and non-complaint offices).

In the next Chapter, indoor airborne bacterial and fungal levels in New Zealand offices will be compared with those found in similar indoor environment overseas in order to determine how 'good' New Zealand offices are compared to their overseas counterparts.

70

The mean outdoor and indoor fungal levels in complaint offices were **56** CFU/m^3 and **57** CFU/m^3 respectively. The mean outdoor and indoor fungal levels in non-complaint offices were **206** CFU/m^3 and **26** CFU/m^3 respectively.

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CHAPTER 7

COMPARISON BETWEEN INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN NEW ZEALAND OFFICES AND THOSE FOUND IN SIMILAR OVERSEAS ENVIRONMENTS

- LITERATURE SURVEY
- COMPARATIVE ANALYSIS

CHAPTER 7

COMPARISON BETWEEN INDOOR AIRBORNE BACTERIAL AND FUNGAL LEVELS IN NEW ZEALAND OFFICES AND THOSE FOUND IN SIMILAR OVERSEAS ENVIRONMENTS

"From the indoor air quality point of view, it is important to know the normal behaviour of pollutants to be able to detect harmful levels or otherwise to characterize and detect an unusual exposure situation. The possible value of airborne bacteria as an indicator of indoor air quality should be evaluated. Therefore, information is needed about the normal sources, the range of the typical concentrations, and the main factors that affect their levels. Such information on airborne bacteria has been practically nonexistent". [1]

7.1 INTRODUCTION

In this chapter, airborne bacterial and fungal levels in New Zealand offices will be compared with those found in a number of offices overseas. It should be noted, however, that using different measurement techniques for collecting and analysing airborne bacteria and fungi can affect their absolute counts. The sampling duration may also affect the bacterial and fungal counts significantly. This means that numerical comparisons between indoor airborne bacterial and fungal levels in New Zealand offices and their overseas counterparts are not always conclusive (see Section 1.4 Limitations). Therefore, an attempt to develop a new evaluation tool will be made to overcome the difficulties which might be associated with the comparisons between indoor airborne fungal data obtained by different measurement techniques.

Indoor airborne bacterial and fungal levels in New Zealand offices will also be evaluated against three overseas bacterial and fungal guidelines. These guidelines are: (i) the European guidelines for indoor airborne bacteria and fungi developed by the Commission of the European Communities [2]; (ii) the American guidelines for indoor airborne bacteria and fungi in the office environment developed by the American Conference of Governmental Industrial Hygienists (ACGIH) [3]; (iii) the Canadian guidelines for indoor airborne fungi in office buildings developed by the Canadian Federal - Provincial

Advisory Committee on Environmental and Occupational Health [4].

These three guidelines will be discussed and evaluated as a first step towards developing airborne bacterial and fungal standard for the New Zealand office environment. The advantages and disadvantages associated with the use of each of these guidelines will also be highlighted .

7.2 INDOOR BACTERIAL AND FUNGAL LEVELS FOUND IN OFFICE ENVIRONMENTS OVERSEAS (LITERATURE SURVEY)

Indoor airborne bacterial and fungal levels in New Zealand offices were within those found in similar indoor environments overseas. Table 7.1 summarises the mean and range values of airborne bacterial and fungal levels presented in a number of overseas studies of fully sealed mechanically ventilated offices. These studies show that:

1. The mean indoor airborne bacterial level in these offices was 160 CFU/m^3 (400 offices) with a range of 0-1922 CFU/m^3 (447 offices were surveyed).

2. The mean indoor airborne fungal level in these offices was 67 CFU/m^3 (65 offices) with an average range of 1-686 CFU/m^3 (109 offices).

It should be noted, however, that sampling methods used in some of these studies were different from those used in measuring bacterial and fungal counts in New Zealand offices. This will affect the bacterial and fungal absolute counts significantly (see the 1.4 limitations Section). Furthermore, the sampling time used in all the overseas studies was significantly shorter than the sampling duration of the measurements carried out by the Institute of Environmental Science and Research (ESR) for the recovery of viable airborne microbial cells[71]. Therefore, caution should be used in comparing bacterial and fungal counts in New Zealand to those of overseas offices.

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71 The sampling time taken for recovering airborne microbial cells in most of overseas studies was between (1-15 minutes) whereas ESR sampling time was approximately 8 hours.

TABLE 7.1: INDOOR BACTERIAL AND FUNGAL LEVELS IN FULLY SEALED MECHANICALLY VENTILATED OFFICES IN NEW ZEALAND AND OVERSEAS.

	INDOOR AIRBORNE BACTERIA (CFU/m^3)	**INDOOR AIRBORNE FUNGI (CFU/m^3)**
NEW ZEALAND OFFICES (Chapter 3)	MEAN: 68 RANGE: 0-621 NUMBER OF OFFICES: 138	MEAN: 38 RANGE: 0-470 NUMBER OF OFFICES: 121
AMERICAN OFFICES [3,5]	MEAN: 124 RANGE: 12-1201 NUMBER OF OFFICES: 326	NOT AVAILABLE
	MEAN: 65 RANGE: 0-274 NUMBER OF OFFICES: 36	MEAN: 159 RANGE: 1-686 NUMBER OF OFFICES: 36
AUSTRALIAN OFFICES [6]	MEAN: 277 RANGE: 0-1922 NUMBER OF OFFICES: 1	NOT AVAILABLE
FRENCH OFFICES [7]	MEAN: NOT AVAILABLE RANGE: 0-300 NUMBER OF OFFICES: 3	NOT AVAILABLE
ITALIAN OFFICES [8]	MEAN: 143 RANGE: 6-611 NUMBER OF OFFICES: 25	MEAN: 15 RANGE: 6-94 NUMBER OF OFFICES: 17
SINGAPORIAN OFFICES [9]	MEAN: NOT AVAILABLE RANGE: 19-465 NUMBER OF OFFICES: 44	MEAN: NOT AVAILABLE RANGE: 5-93 NUMBER OF OFFICES: 44
SWEDISH OFFICES [10]	MEAN: 190 RANG: 40-480 NUMBER OF OFFICES: 12	MEAN: 28 RANGE: 1-140 NUMBER OF OFFICES: 12
ALL OVERSEAS OFFICES	MEAN: 160 (No. :400) RANGE: 0-1922 NUMBER OF OFFICES: 447	MEAN: 67 (No. :65) RANGE: 1-686 NUMBER OF OFFICES: 109

Furthermore, in New Zealand offices, the sampling technique used by ESR differs from that used by Advanced Building Services (ABS) for measuring indoor airborne bacteria in fully sealed offices. This can be seen by the significant shift between the plotted ESR and ABS measurements[72] (see Appendix 1). The mean indoor airborne bacterial level measured by ABS was five times higher than the mean indoor airborne bacterial level measured by ESR. Several studies have shown that the sampling techniques and duration of the measurements have a significant impact on the bacterial and fungal counts [11,12]. However, any evaluation of the measurement techniques used by ESR and ABS would be out of the scope of this thesis.

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The Mann-Whitney test showed that ESR data were significantly different from those of ABS (in the case of indoor airborne bacteria - P = 0.00). Whereas no significant differences have been found in indoor airborne fungi between ABS and ESR measurements (P = 0.272 - see Chapter 1 and Appendix 1).

7.3 INDOOR AIRBORNE BACTERIAL AND FUNGAL GUIDELINES IN EUROPE AND NORTH AMERICA (COMPARATIVE ANALYSIS)

During the last decade, several attempts have been made to develop guidelines for indoor airborne bacteria and fungi in the office environment. Three of these attempts[73] will be discussed and evaluated against the indoor bacterial and fungal levels in New Zealand offices. The first set of guidelines was developed by the Science, Research and Development Institute of the Commission of the European Communities as an evaluation tool only[74] [2]. These guidelines were based on the results of several studies on indoor airborne bacteria and fungi in offices throughout the European Community. They define five indoor bacterial and fungal concentration categories ranging from "very low" to "very high". The European guidelines categories for indoor airborne bacteria and fungi in nonindustrial indoor environments are presented in Table 7.2.

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73 These guidelines have been chosen to represent two of the main regions of the developed world (Europe and North America).

74 This means that these guidelines were not based on health risk factors.

TABLE 7.2: THE EUROPEAN GUIDELINES FOR INDOOR AIRBORNE BACTERIA AND FUNGI IN THE OFFICE ENVIRONMENT

CATEGORY	INDOOR BACTERIA[75] (CFU/m^3)	INDOOR FUNGI[76] (CFU/m^3)
VERY LOW	<50	<25
LOW	<100	<100
INTERMEDIATE	<500	<500
HIGH	<2000	<2000
VERY HIGH	>2000	>2000

The second set of guidelines was developed by the American Conference of Governmental Industrial Hygienists (ACGIH) [3]. These guidelines were based on an indoor/outdoor fungal ratio of 0.33 as the upper threshold for indoor airborne fungi and 50 CFU/m^3 as the upper threshold for indoor airborne bacteria[77].

The third set of guidelines was developed by the Canadian Federal-Provincial Advisory Committee on Environmental and Occupational Health and published by Health Canada [4]. These guidelines identified a number of fungal species such as *Aspergillus* which should not be present in the indoor office environment. They also recommended a number of threshold values for indoor airborne fungi based on the types of fungal species present in the indoor environment[78].

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75 The Commission of the European Communities report [2] indicated that these categories were based on the Andersen six-stage sampling method with sampling time 10-15 minutes at 20-25°C for 3-5 days.

76 The Commission of the European Communities report [2] indicated that these categories were based on the Andersen one and six-stage sampling method.

77 The ACGIH [3] reported that these guidelines were based on the two-stage Andersen sampling method.

78 The Canadian Committee on Environmental and Occupational Health report [4] indicated that these guidelines were based on Reuter centrifugal samples with a 4-minute sampling time.

The upper indoor fungal threshold values of the Canadian guidelines are as follows:

1- More than 50 CFU/m^3 of a single species (other than Cladosporium or Alternaria) may be reason for concern. Further investigation is necessary.

2- More than 150 CFU/m^3 is acceptable if there is a mixture of species reflective of the outdoor air spores. Higher counts suggest dirty or low efficiency air filters or other problems.

3- Up to 500 CFU/m^3 is acceptable in summer if the species present are primarily Cladosporium or other tree and leaf fungi. Values higher than this may indicate failure of the filter or contamination in the building.

In the next few sections, indoor bacterial and fungal levels in the New Zealand office environment will be analysing in the light of the European, U.S. and the Canadian airborne bacterial and fungal guidelines. The bacterial and fungal levels will be evaluated in terms of : (i) Auckland and Wellington offices; (ii) offices measured in summer and winter; (iii) complaint and non-complaint offices. These analyses will be useful in evaluating the indoor airborne bacterial and fungal levels under these six different categories.

7.3.1 THE EUROPEAN GUIDELINES AS A TOOL FOR ASSESSING INDOOR BACTERIAL AND FUNGAL LEVELS IN THE NEW ZEALAND OFFICE ENVIRONMENT.

Indoor airborne bacterial levels in New Zealand offices have been plotted on the European guidelines charts. The bacterial levels have been examined from three different angles. Figures 7.1 and 7.2 show airborne bacterial and fungal levels in Auckland and Wellington offices, Figures 7.3 and 7.4 show the distribution of bacterial and fungal levels in offices measured during summer and winter and Figures 7.5 and 7.6 show these levels in complaint and non-complaint offices.

By the standard of the European guidelines, airborne bacterial levels in most New Zealand offices were either 'low' or 'very low'. Only three New Zealand offices, two of them were in Auckland, were measured at levels which exceeded the 'low' category.

The evaluation of indoor airborne fungal levels in New Zealand offices from the European guidelines point of view shows that New Zealand fungal levels were also lower than those found in European offices. Only seven offices[79] fall into the intermediate category while the rest fall into either the "low" or "very low" categories.

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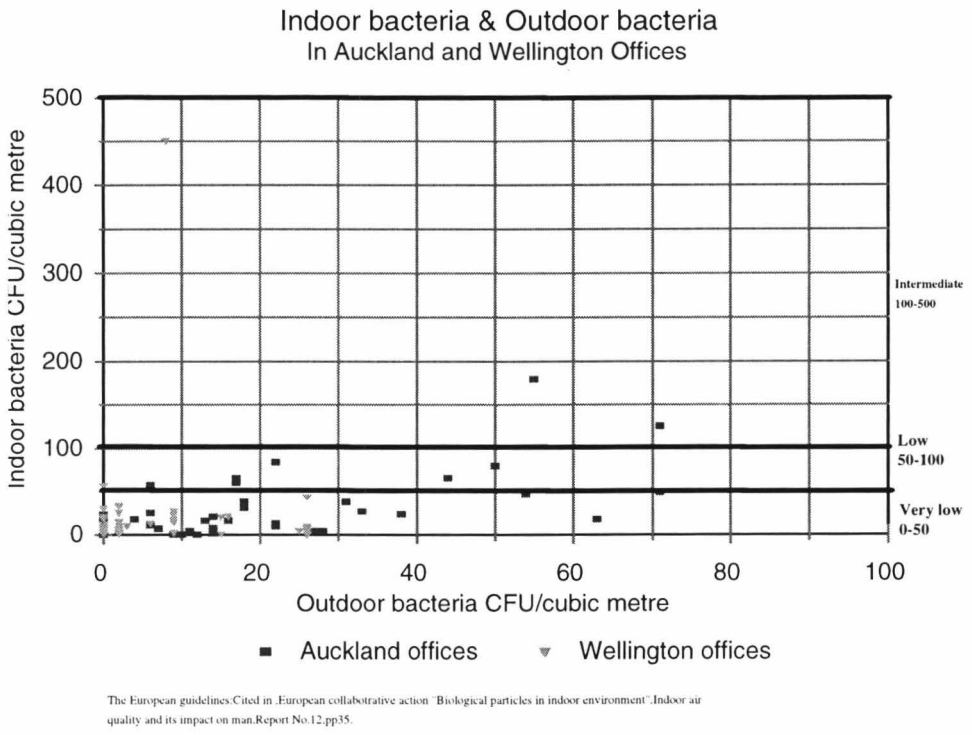
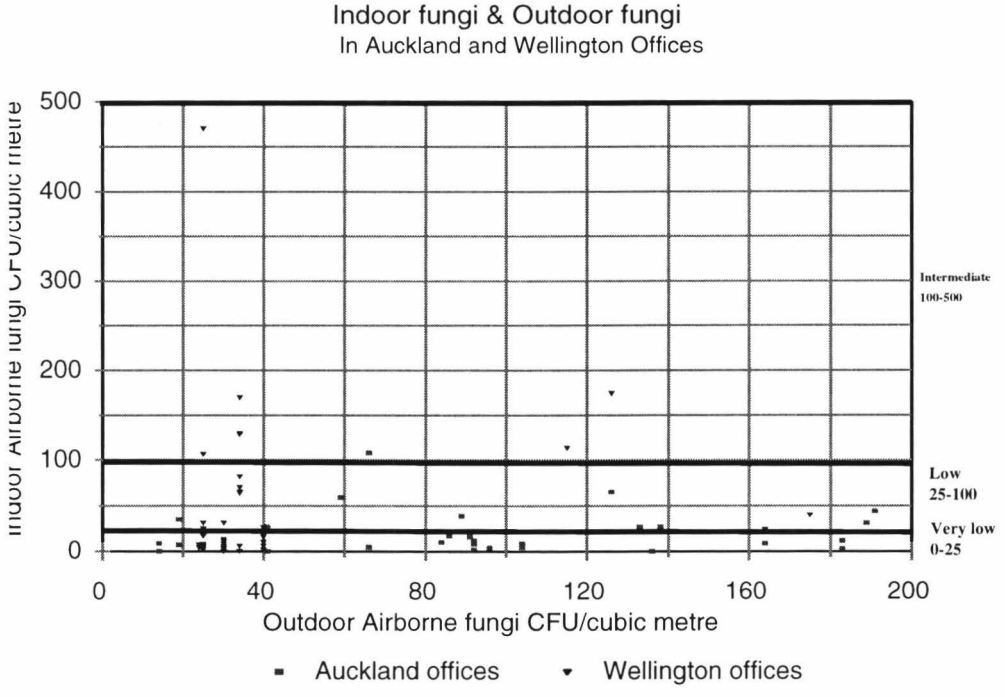
79 Most of these seven offices were in Wellington (four of them were measured during summer time). Four of these offices reported complaints.



The European guidelines:Cited in ,European collabotrative action "Biological particles in indoor environment",Indoor air quality and its impact on man,Report No.12,pp35.

Figure 7.1: The European guidelines evaluation of bacterial levels in Auckland and Wellington offices. Most indoor airborne levels which fall in the low and intermediate categories were Auckland offices records.



The European guidelines:Cited in ,European collabotrative action "Biological particles in indoor environment",Indoor air quality and its impact on man,Report No.12,pp35.

Figure 7.2: The European guidelines evaluation of fungal levels in Auckland and Wellington offices. Most airborne levels which fall in the intermediate category were Wellington offices records.

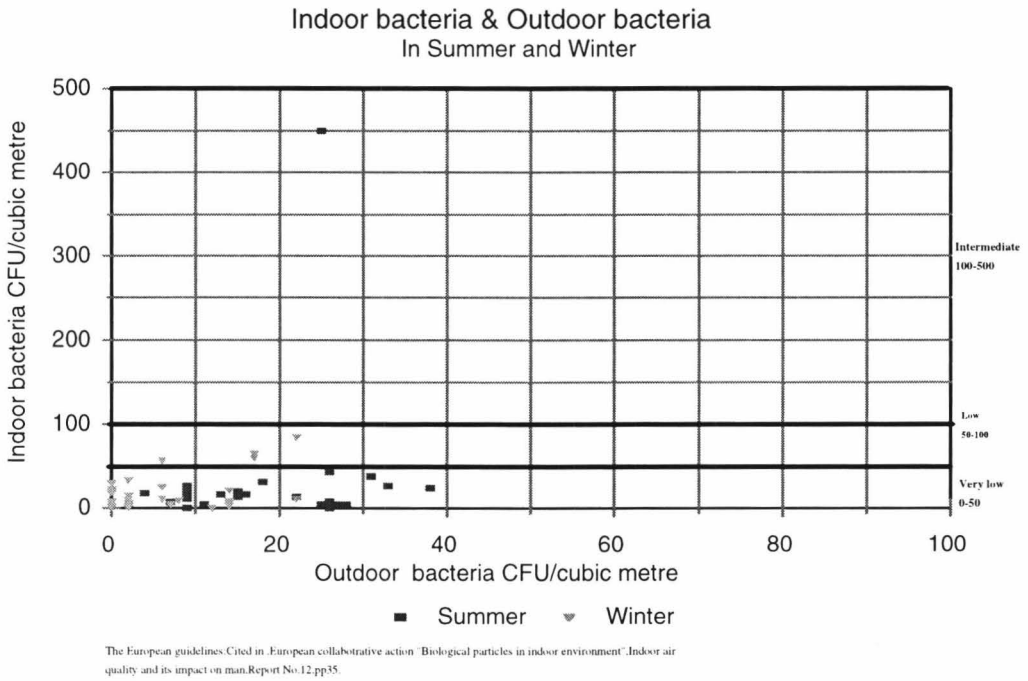


Figure 7.3: The European guidelines evaluation of bacterial levels in New Zealand offices surveyed in summer and winter

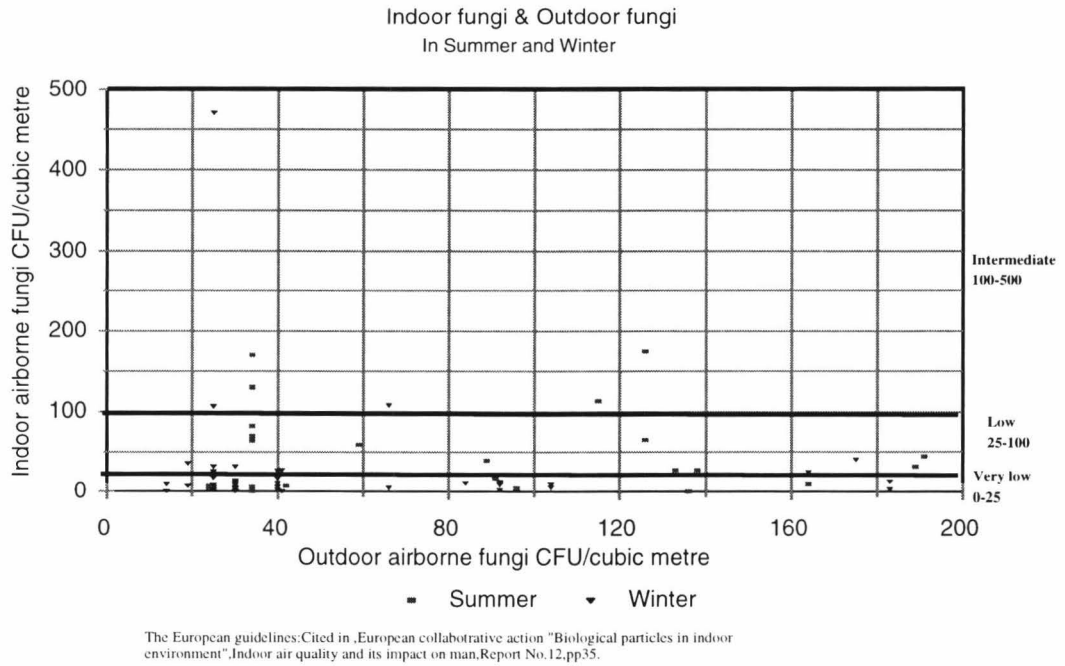


Figure 7.4: The European guidelines evaluation of fungal levels in New Zealand offices surveyed in summer and winter.

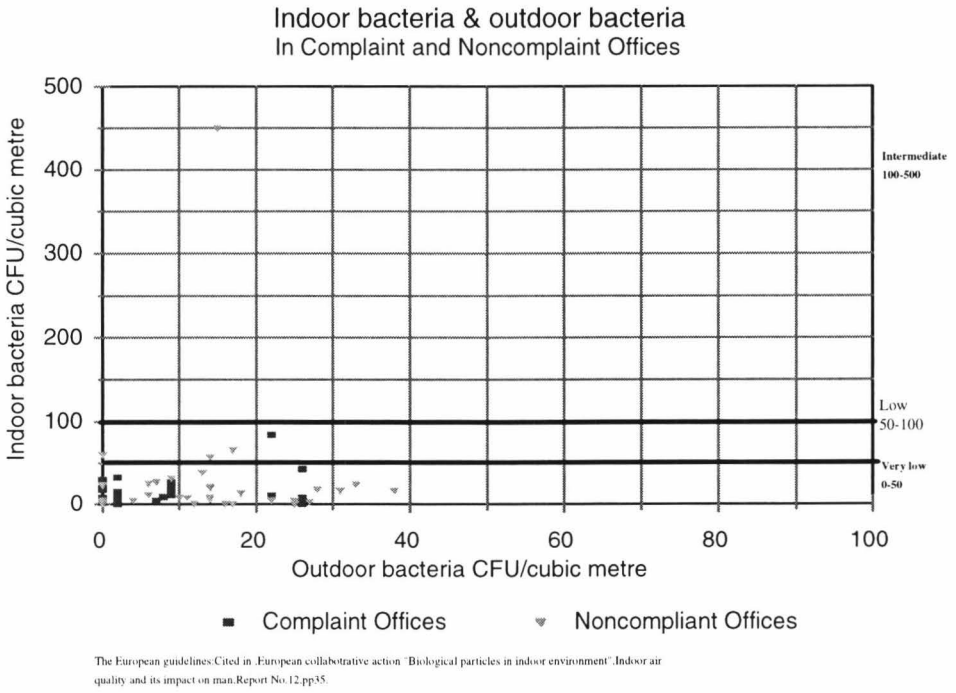


Figure 7.5: The European guidelines evaluation of bacterial levels in New Zealand complaint and non-complaint offices

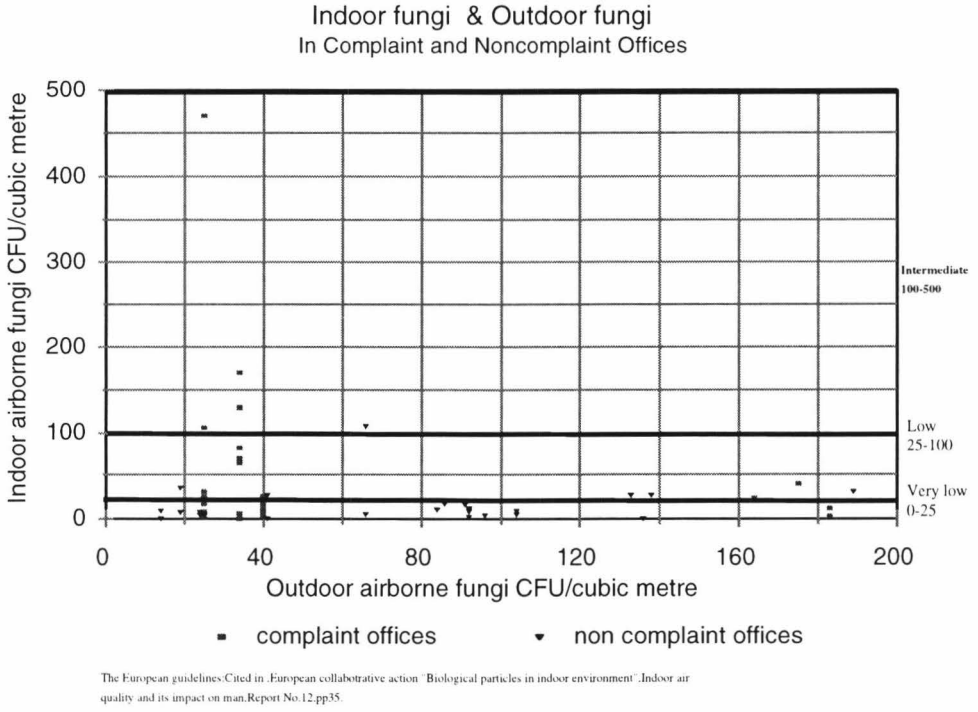


Figure 7.6: The European guidelines evaluation of fungal levels in New Zealand complaint and non-complaint offices. All indoor airborne levels which fall in the intermediate category were due to excessive indoor fungal contamination.

7.3.2 THE U.S. GUIDELINES AS A TOOL FOR ASSESSING THE INDOOR BACTERIAL AND FUNGAL LEVELS IN THE NEW ZEALAND OFFICE ENVIRONMENT

Indoor airborne indoor bacterial levels have been plotted against indoor/outdoor fungal ratios on the U.S. guidelines charts. The bacterial levels and the fungal ratio have been examined in Auckland and Wellington offices (Figure 7.7), in offices surveyed during summer and winter (Figure 7.8), and in complaint and non-complaint offices (Figure 7.9).

Only four New Zealand offices exceeded both the 50 CFU/m^3 bacterial level and the 0.33 fungal ratio threshold of the U.S. guidelines. Three of these offices were in Auckland [80]. However, 28 offices exceeded the 0.33 fungal ratio threshold. *Aspergillius* and *Penicillium* might be two of the major fungal species identified in these offices as these species are likely to flourish indoors (as fungal ratios above 0.33 is considered by the U.S. guidelines as internal fungal problem - see Chapter 2). Most of these offices were in Wellington (70%) and were surveyed in winter and considered problem offices (68%).

From the bacterial guidelines point of view, around 13 offices exceeded the 50 CFU/m3 (most of these offices have been measured by ABS). Around 90% of the 13 offices were in Auckland.

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80 Limited data were available on the season in which these offices were surveyed and whether the indoor measurements were carried out in response to complaints.

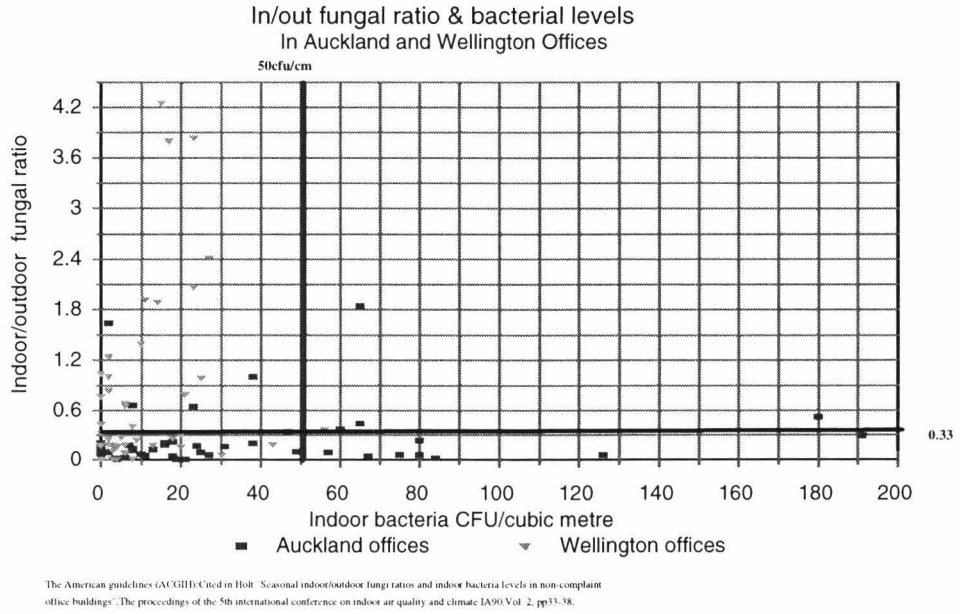


Figure 7.7: The U.S. guidelines evaluation of bacterial and fungal levels in Auckland and Wellington offices. Most indoor/outdoor fungal ratios above 0.33 were recorded in Wellington offices while most of indoor bacterial levels above the 50 CFU/m^3 level were recorded in Auckland offices.

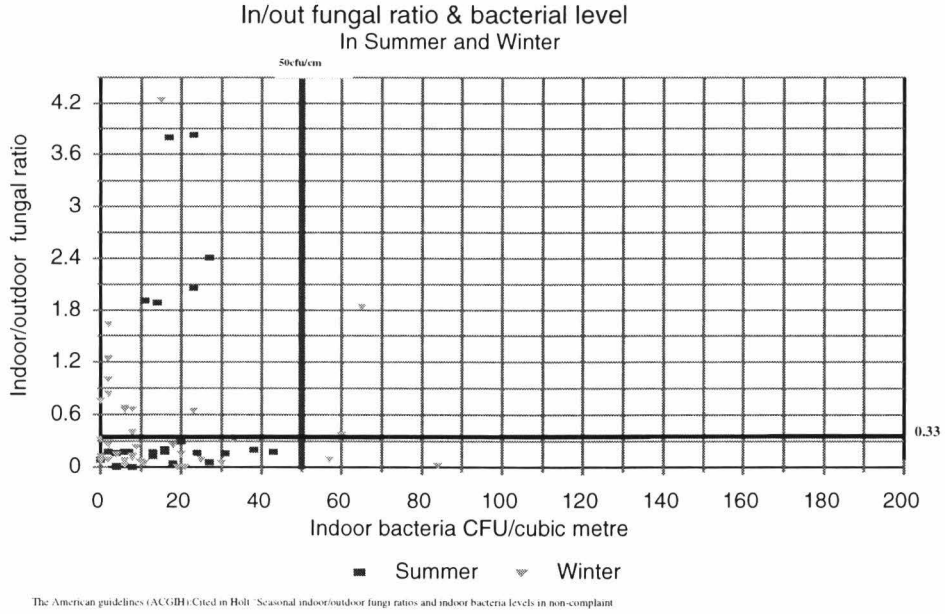
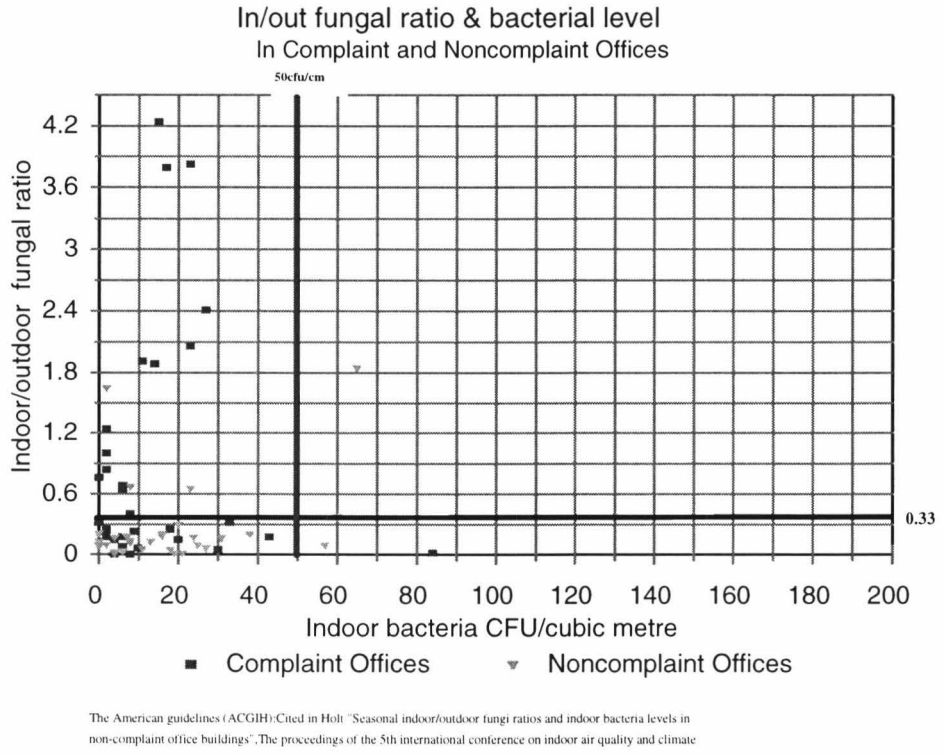


Figure 7.8: The U.S. guidelines evaluation of bacterial and fungal levels in New Zealand offices surveyed in summer and winter



The American guidelines (ACGIH):Cited in Holt "Seasonal indoor/outdoor fungi ratios and indoor bacteria levels in non-complaint office buildings",The proceedings of the 5th international conference on indoor air quality and climate

Figure 7.9: The U.S. guidelines evaluation of bacterial and fungal levels in New Zealand complaint and non-complaint offices. Most indoor/outdoor fungal ratios above 0.33 were recorded in complaint offices.

7.3.3 THE CANADIAN GUIDELINES AS A TOOL FOR ASSESSING THE INDOOR BACTERIAL AND FUNGAL LEVELS IN THE NEW ZEALAND OFFICE ENVIRONMENT

Airborne fungal levels were plotted on the Canadian guidelines chart. Figure 7.10 shows the airborne fungal levels distribution in Auckland and Wellington offices. Figure 7.11 shows airborne fungal levels in offices surveyed during summer and winter. Figure 7.12 shows airborne fungal levels in complaint and non-complaint offices.

The Canadian 50 CFU/m^3 threshold was exceeded by 18% of the New Zealand offices surveyed[81]. Only three offices (all in Wellington) exceeded the 150 CFU/m^3 threshold (two of these offices were surveyed during summer[82]), and no offices exceeded the 500 CFU/m^3 threshold. However, the Canadian guidelines cannot be applied in full because of lack of data regarding the type of fungal species identified in most of the offices surveyed[83].

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81 Of these offices, 80% were surveyed in summertime and 20% were surveyed in wintertime and approximately 80% of these offices reported complaints.

82 No data were available on whether the primary fungal species identified in these offices was *Cladosporium*.

83 Only 33 offices in Auckland have records regarding the type of fungal species identified indoors (see Chapter 2).

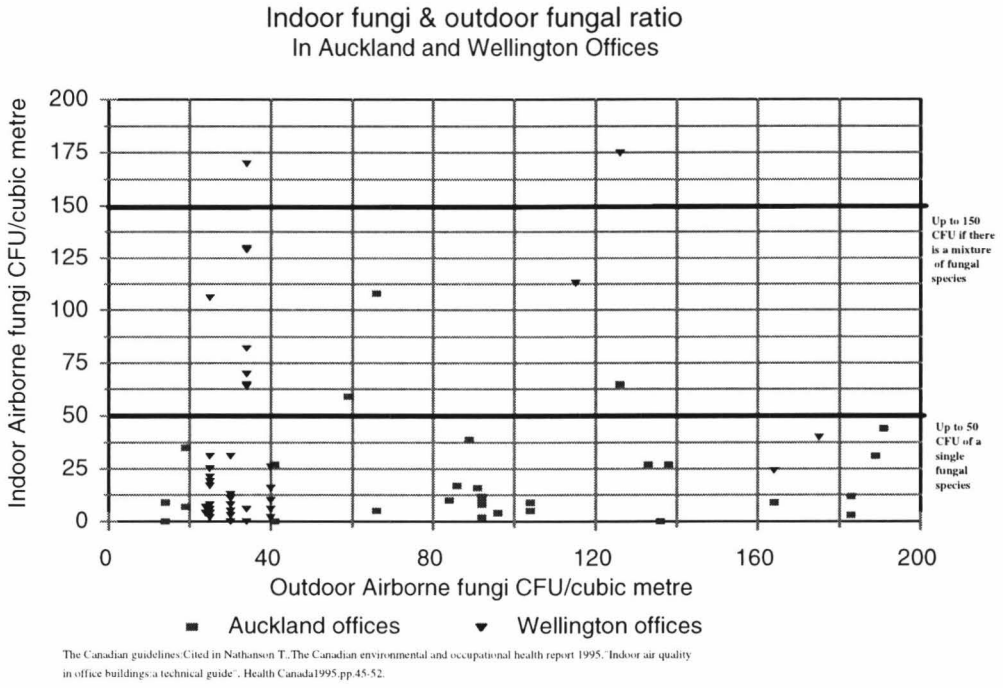

Figure 7.10: The Canadian guidelines evaluation of fungal levels in Auckland and Wellington offices. Most indoor levels exceeded the 50 CFU/m^3 threshold were recorded in Wellington offices.

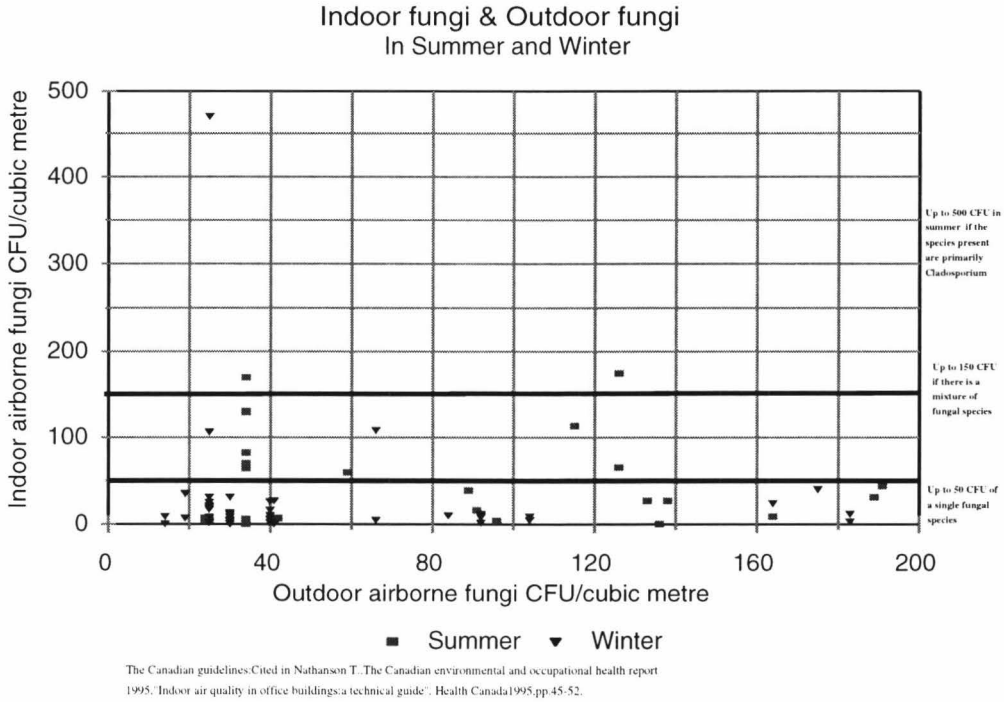

Figure 7.11: The Canadian guidelines evaluation of fungal levels in New Zealand offices surveyed in summer and winter. Most indoor levels exceeded the 50 CFU/m^3 threshold were recorded in offices surveyed in summer.

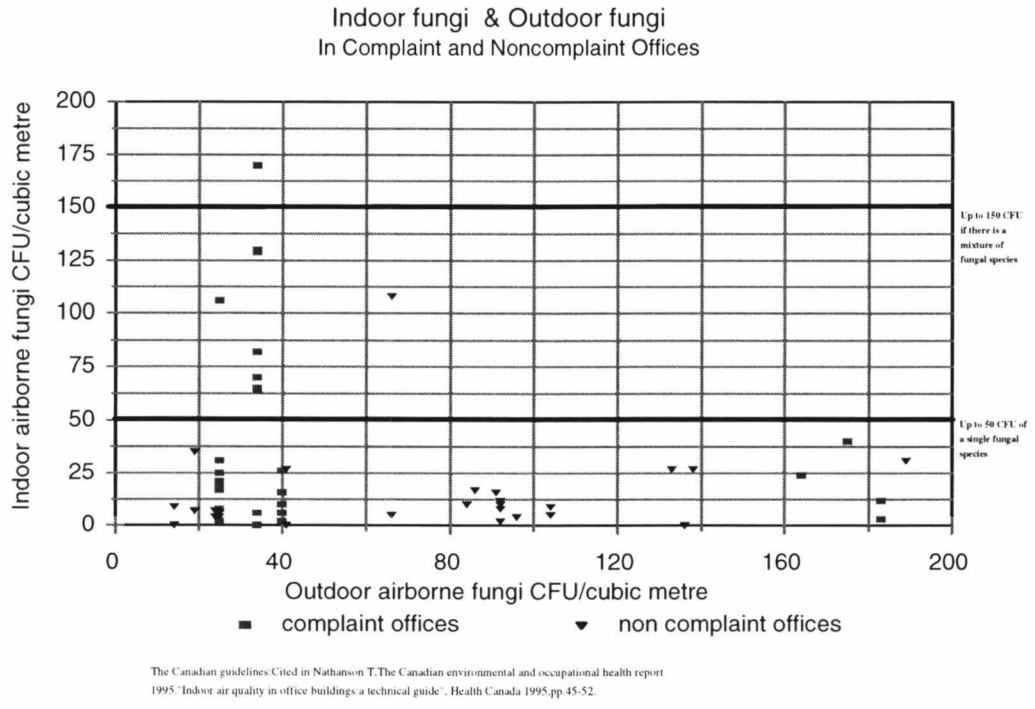

Figure 7.12: The Canadian guidelines evaluation of fungal levels in New Zealand complaint and non-complaint offices. Most indoor levels exceeded the 50 CFU/m^3 threshold were recorded in complaint offices .

7.4 STEPS TOWARDS DEVELOPING GUIDELINES FOR AIRBORNE BACTERIA AND FUNGI IN THE NEW ZEALAND OFFICE ENVIRONMENT

The European, Canadian and U.S. guidelines are significant steps towards developing standard guidelines for bacterial and fungal contamination in the office environment. There are advantages and disadvantages associated with these guidelines. The advantages are:

1. Regarding the U.S. guidelines, the adoption of an indoor/outdoor fungal ratios rather than using the actual indoor fungal count avoids the problems associated with the use of airborne fungal level as a threshold[84].

2. Regarding the Canadian guidelines, the recognition of the importance of the fungal type found in the indoor environment emphasizes the need for knowledge about the potential health risks associated with specific fungal species.

3. In all three guidelines, the identification of the measurement techniques on which the guidelines were based is important as the bacterial and fungal counts are highly dependent on the sampling technique used.

Disadvantages of two of the guidelines should also be noted:

1. In the case of the U.S. guidelines, the 0.33 fungal ratio and the 50 CFU/m^3 bacterial threshold have not been related to the type of bacterial and fungal species involved.

2. The Canadian guidelines have not taken into account the outdoor fungal levels as a possible major source of indoor airborne fungi.

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84 The use of a fungal ratio as an indicator of airborne fungal contamination rather than the fungal absolute counts which might not be legitimate indicator especially when comparing data obtained using different measurement techniques.

It seemed that an evaluation tool was needed which was able to identify the existence of a fungal problem in an office environment and to determine the likely sources of this problem regardless of the measurement technique used in collecting and analysing the fungal samples (Figure 7.13). To this end, the U.S. indoor/outdoor fungal ratio guideline developed by the ACGIH was used in conjunction with the Canadian indoor fungal guidelines proposed by Health Canada. The resulting tool could be used to determine how successful the ventilation system is in preventing outdoor air pollutants from penetrating into the office environment.

Thus, an indoor/outdoor fungal ratio above 0.5 could be considered as either external fungal sources problem (where fungal ratio< 0.5) or as a filter problem (where 0.5 < fungal ratio < 1) or as an internal fungal sources problem (where fungal ratio >1). In this case, the likely fungal species to be identified are *Aspergillius* and *Penicillium* whereas in the case of fungal ratio < 0.5, *Cladosporium* would be the likely fungal species to be identified (as this particular species is more likely to flourish outdoors - see Chapter 2). In keeping with the Canadian guidelines, the 50 CFU/ m^3 level is considered as a reference only of how significant the airborne fungal level is in the office environment.

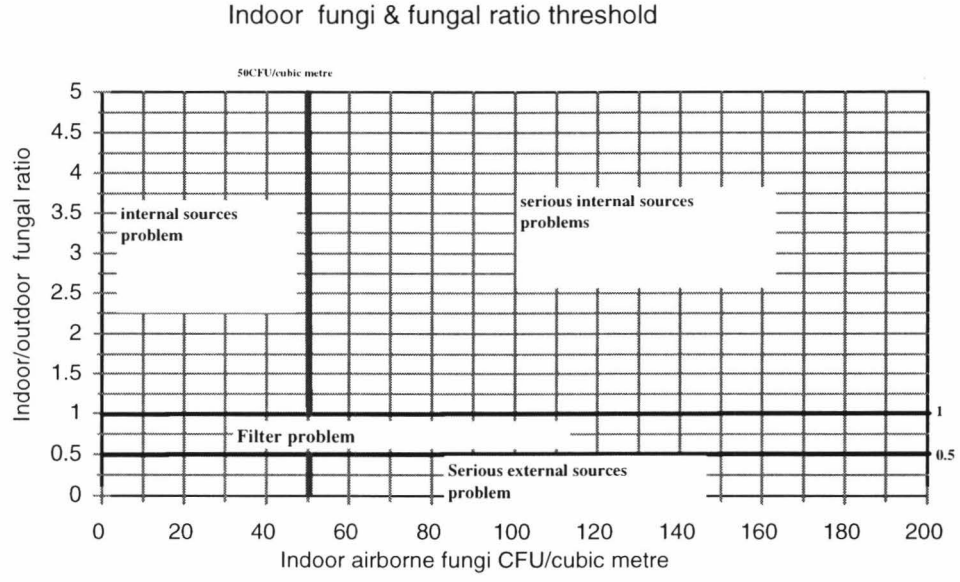

Figure 7.13: The evaluation tool proposed for indoor airborne fungi in the office environment.

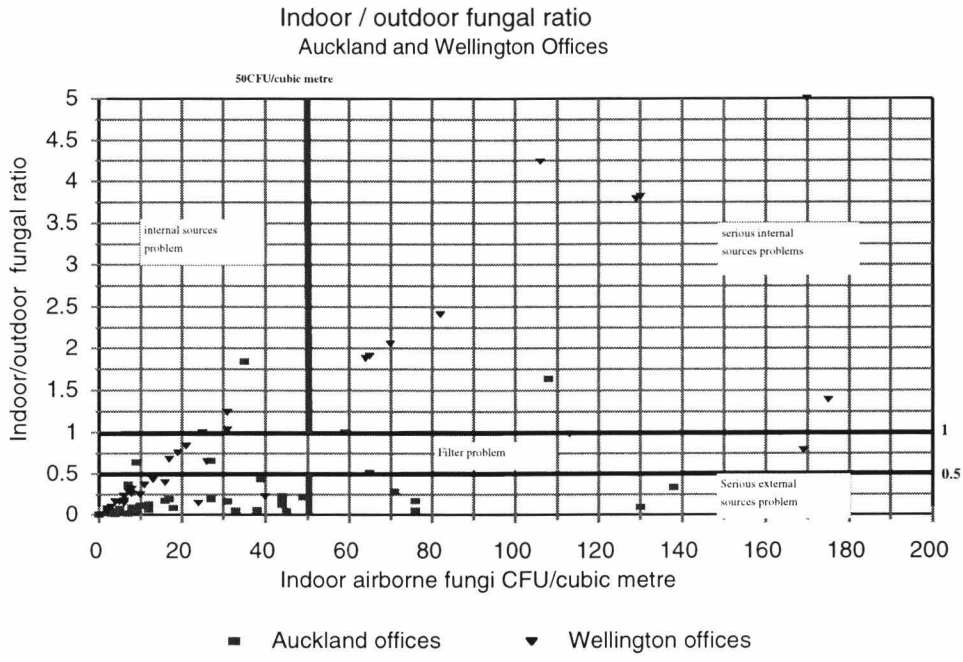

Figure 7.14: Indoor fungal evaluation of Auckland and Wellington offices. Most measurements which exceeded both thresholds (the fungal ratio of 0.5 and the indoor fungal level of 50 CFU/m^3) were recorded in Wellington offices.

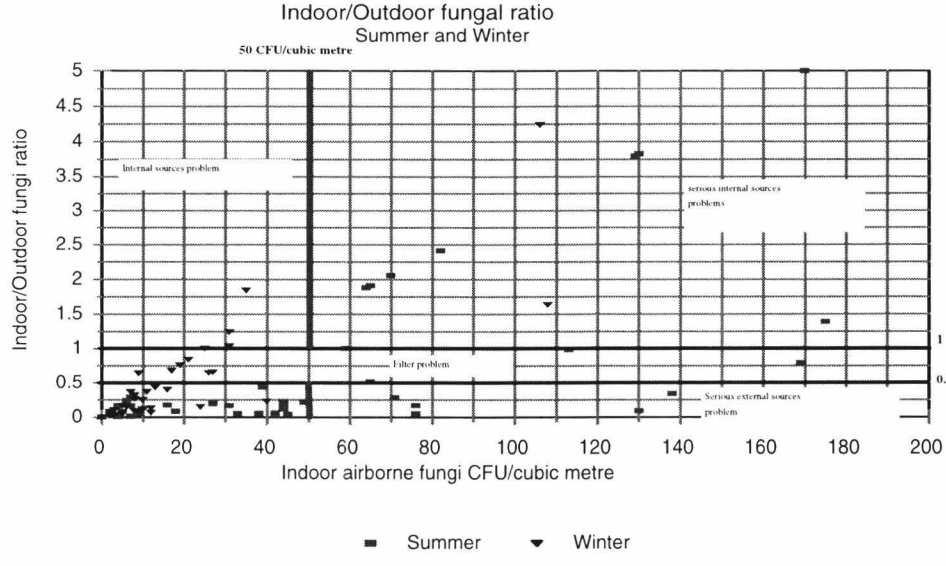

Figure 7.15: Indoor fungal evaluation of offices surveyed in summer and winter. Most measurements which exceeded both thresholds (the fungal ratio of 0.5 and the indoor fungal level of 50 CFU/m^3) were recorded in offices surveyed during summer.

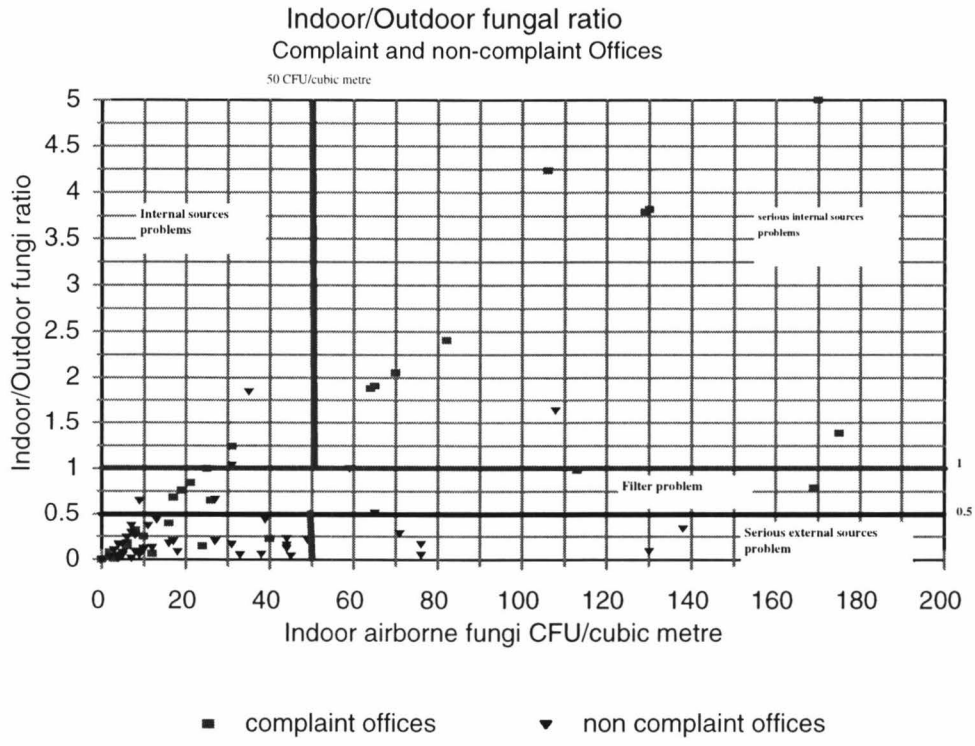

Figure 7.16: Indoor fungal evaluation of complaint and non-complaint offices. Most measurements which exceeded both thresholds (the fungal ratio of 0.5 and the indoor fungal level of 50 CFU/m^3) were recorded in complaint offices.

This evaluation tool has been applied to Auckland and Wellington offices, offices surveyed in summer and winter and offices with and without complaints (Figures 7.14,7.15 and 7.16). Twenty of the New Zealand offices studied exceeded the 50 CFU/m^3 airborne fungi level (12 were complaint offices), and 25 offices exceeded the 0.5 fungal ratio (18 were complaint offices). Fifteen offices exceeded both thresholds, of which 12 were complaint offices. The number of New Zealand offices exceeding the proposed thresholds are presented in Table 7.3.

A classification of New Zealand offices in terms of possible causes of complaints (indoor air temperature and indoor/outdoor fungal ratio-see Chapter 6) is presented in Appendix 7.

TABLE 7.3: THE NUMBER OF NEW ZEALAND OFFICES EXCEEDING ONE OR BOTH THRESHOLDS PROPOSED

FUNGAL THRESHOLDS	NUMBER OF OFFICES	WITH COMPLAINTS	WITHOUT COMPLAINTS
ABOVE 50 CFU/m^3 LEVEL	20 (22%)	12 (34%)	8 (14%)
ABOVE 0.5 RATIO	25 (27%)	18 (51%)	7 (12%)
ABOVE BOTH 50 CFU/m^3 AND 0.5 RATIO	15 (16%)	12 (34%)	3 (5%)
BELOW BOTH THRESHOLDS	58 (63%)	17 (48%)	41 (73%)
THE TOTAL NUMBER OF OFFICES	91	35	56

As mentioned in Chapter 6, indoor air temperature and indoor/outdoor fungal ratios were significantly higher in complaint offices. By plotting the measured data (Figure 7.17) of complaint and non-complaint offices on the horizontal axis (which represents indoor air temperature[85]) and on the vertical axis (which represents the indoor/outdoor fungal ratios threshold proposed), the majority of the complaints offices records will fall above either

85

An indoor air temperature level (line) has been drawn to divide the measured data vertically according to complaint and non-complaint categories. The indoor air temperature level of 23°C appeared to divide the majority of complaint offices (below the indoor/outdoor fungal ration of 1) from the majority of non-complaint offices.

indoor air temperature level of 23°C or indoor/outdoor fungal ratio of 0.5 or both.

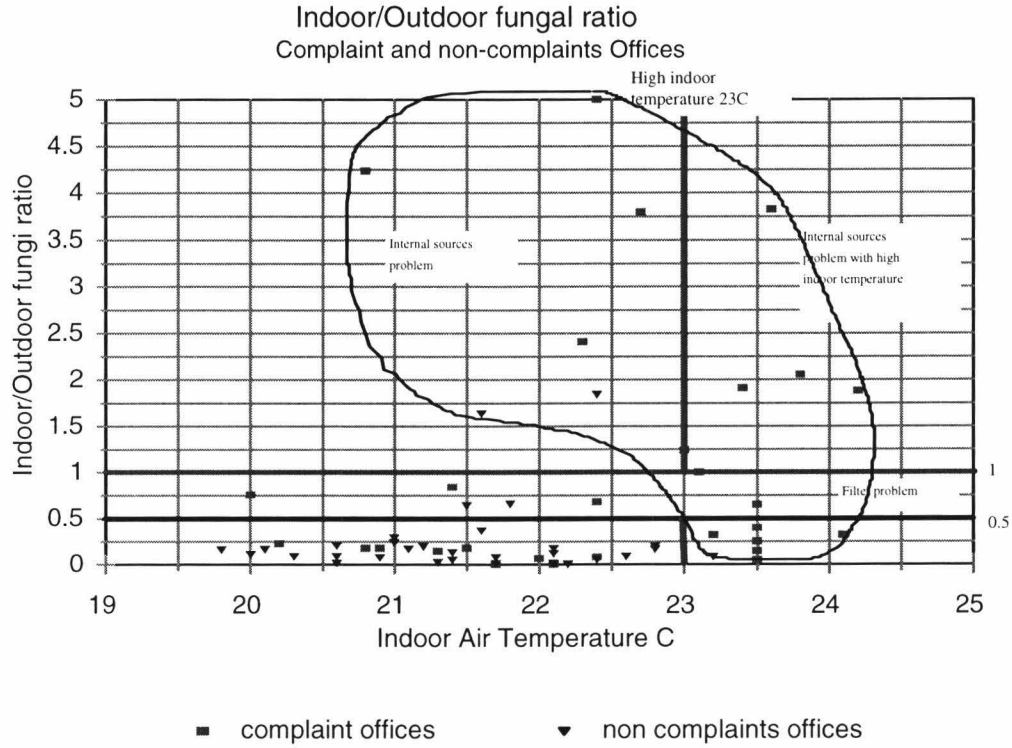

Figure 7.17: Indoor air temperature and indoor/outdoor fungal ratio as possible causes for complaints (see Chapter 6). Most records above either the indoor air temperature of 23°C or the fungal ratio of 0.5 or both were of complaint offices.

7.5 DISCUSSION

Indoor bacteria and fungal levels in New Zealand offices appeared in this study to be similar to those found in comparable overseas office. However, the differing measurement techniques and sampling times used has affected the validity of the comparisons [13]. Therefore, this issue could not be addressed adequately (see Section 1.4 Limitations).

Bacterial and fungal levels in most of New Zealand offices surveyed were within the three guidelines reviewed. Applying the European guidelines has shown that most of the offices surveyed fall within the "low" or the "very low" categories. Applying the Canadian guidelines has shown that only 4% of New Zealand offices exceeded the 150 CFU/m^3 threshold and 16% exceeded the 50 CFU/m^3 threshold. Most of these offices were in Wellington (they represent 40 % of the measured Wellington offices and just 11% of the Auckland offices).

Applying the U.S. guidelines, on the other hand, showed that a significant number of offices exceeded one or both thresholds. 32% of all Auckland offices and 4% of all Wellington offices exceeded the bacterial threshold of 50 CFU/m^3. 21% of all Auckland offices and 50% of all Wellington offices exceeded the fungal ratio threshold of 0.33. Furthermore, 6% of all New Zealand offices surveyed have exceeded both thresholds. Half of all New Zealand offices surveyed may exceeded at least one of the two thresholds proposed by the ACGIH.

Developing airborne bacterial and fungal standards for the New Zealand office environment is highly dependent on the standardization of the sampling techniques used for measuring these indoor pollutants. Furthermore, as mentioned previously in Chapter 1, the airborne bacterial and fungal samples were collected by ESR for approximately 8 hours. Stanevich [11] indicated that the mean CFU/m^3 decreased as sampling time increased. This means that airborne bacterial and fungal concentrations measured by ESR might be heavily reduced by the sampling procedure used. Therefore, the sampling

time is also an important factor which affect the airborne bacterial and fungal absolute counts significantly. Moreover, bacterial and fungal measurements in New Zealand offices were based on a 'snapshot' (taken on one day) rather than on observation of bacterial and fungal levels over a longer period of time (such as throughout a week, season or year).

There is also a need to address the issue of bacterial and fungal species found in the office environment as the integration of numerical guidelines with the type of bacterial and fungal species is of great importance. The existence of certain fungal species (such as *Aspergillius*) at certain level, for instance, is not acceptable as this species is an indicator of elevated indoor fungal problems (see Chapter 2).

7.6 RECAPITULATION

Indoor airborne bacterial levels in New Zealand offices were within the range of those found overseas. The mean airborne bacterial level of the 138 New Zealand offices surveyed was well below that of 400 overseas offices. Indoor airborne fungal levels in New Zealand offices were also within the levels of those found in similar overseas environment. However, the average range of indoor airborne fungi in the 121 New Zealand offices was almost twice as high as that of the 109 overseas offices observed in the literature.

The European, American and Canadian guidelines for indoor airborne bacteria and fungi in the office environment have several advantages and disadvantages. The advantages are : (i) the use of fungal ratio by the ACGIH as a way of avoiding the difficulty of comparing airborne fungal counts which have been collected using different measuring techniques or sampling times; (ii) the identification of specific fungal species in the Canadian guidelines is also advantageous and represents an important step towards the recognition of health hazards associated with these species in the indoor environment. The disadvantages associated with these guidelines are: (i) the failure by the American guidelines to identify the type of bacterial species on which the 50 CFU/m^3 threshold is based ; (ii) the failure by the Canadian guidelines to recognize outdoor fungal levels as an important source for indoor airborne fungi.

An evaluation tool, therefore, has been developed based on the fact that the use of different procedures in measuring airborne bacteria and fungi will affect the airborne bacterial and fungal absolute counts significantly (see Chapters 1, 3, 4 and Appendix 1). This tool has been developed through the integration of indoor/outdoor fungal ratio (as a way for avoiding the use of fungal level-CFU/m^3-as a threshold) and the fungal level (as a reference only to the degree of severity of airborne fungal level). This tool can be used to identify whether there is a fungal problem in an office environment and the likely cause of this problem.

The evaluation tool is a chart divided into five sections. On the vertical axis, there are three sections divided according to the fungal ratio. A fungal ratio above 1 is considered an internal sources problem. A fungal ratio between 0.5 and 1 is considered to be a filter problem. Below 0.5 is considered an acceptable ratio. On the horizontal axis, there are two sections divided according to the actual fungal count (CFU/m^3). Fungal levels above 50 CFU/m^3 are considered a reason for concern, but fungal levels below this threshold are considered acceptable if the fungal ratio is below 0.5.

In the next and final Chapter, the main conclusions and recommendations will be highlighted and discussed in detail.

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CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

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> *"In summary, a single cause for SBS is unlikely. Rather, many hypotheses (sources/causes) must be considered in determining the cause of complaint in any particular building, including ventilation rates, ventilation system maintenance and type, off gassing of building furnishings, and evolution of a multitude of irritants from occupant activities, microbial contamination, etc."* [1]

8.1 CONCLUSIONS

As mentioned previously in Chapter 1, the aim of this thesis was to identify the type and investigate the levels of indoor airborne bacteria and fungi in the New Zealand office environment and to determine the impact of some indoor and outdoor parameters on those levels. Regarding the type of airborne bacteria and fungi, *Flavobacterium* and *Pseudomonas* were the most common bacterial species identified. *Penicillium*, *Cladosporium* and *Aspergillius* were the most common fungal species isolated from the office environment. The review of the literature in Chapter 2 showed that high indoor level of *Penicillium* and *Aspergillius* is an indicator of internal mould problems whereas *Cladosporium* is an outdoor species. Therefore the presence of high indoor levels of this species is an indicator of outdoor sources problem which suggests a poor filter performance in fully sealed offices.

The first objective was to investigate the indoor airborne bacterial and fungal levels in Auckland and Wellington offices and to compare the air quality of in offices in these cities. Indoor airborne bacteria and fungi in Auckland offices surveyed were twice as high as those of Wellington offices. Indoor airborne fungal levels, on the other hand, in Wellington offices were twice as high as those of Auckland offices despite the fact that outdoor fungal levels in Auckland were four times higher than those of Wellington (Chapters 3 and 4). This means that outdoor air infiltration was the major source of indoor airborne fungi in Auckland offices whereas in Wellington offices, internal sources

were the major contributors of indoor airborne fungi.

The statistical analyses of Chapters 3 and 4 of this thesis revealed that the combined use of both ESR and ABS data in a number of statistical analyses has made the interpretations of the statistical analyses results complicated. These analyses showed that there were significant differences in airborne bacterial absolute counts between ESR and ABS measurements. This means that the use of different measurement techniques influenced, to a great extent, the airborne bacterial absolute counts and consequently the results of these statistical analyses (Chapter 1 and Appendix 1). Therefore, to avoid such problems, it is recommended that airborne bacterial and fungal data collected using different measurement techniques should not be combined in any analysis in future studies unless there is strong statistical evidence to suggest that the measurement techniques used have not affected the airborne bacterial and fungal absolute counts significantly (a statistical procedure used to detect such problems is presented in Appendix 1).

The second objective was to determine whether seasonal variations of airborne bacterial and fungal levels occur in fully sealed mechanically ventilated offices in New Zealand. Statistical analyses showed that there were significant seasonal variations (summer vs winter) in airborne bacterial and fungal concentrations in Auckland offices but in only airborne bacterial concentrations in Wellington offices (indoor airborne bacterial and fungal concentrations in offices surveyed in wintertime were significantly lower than those of offices surveyed in summertime - see Chapter 5). This finding could prove useful in helping determine appropriate changes to indoor air measurements strategies. Indoor air measurements for airborne bacterial and fungal concentrations, for instance, might not be required especially in wintertime (unless there are visual signs of moulds on interior surfaces) as indoor airborne bacterial and fungal concentrations were found to be at low levels and therefore unlikely to pose any serious indoor problem especially in winter.

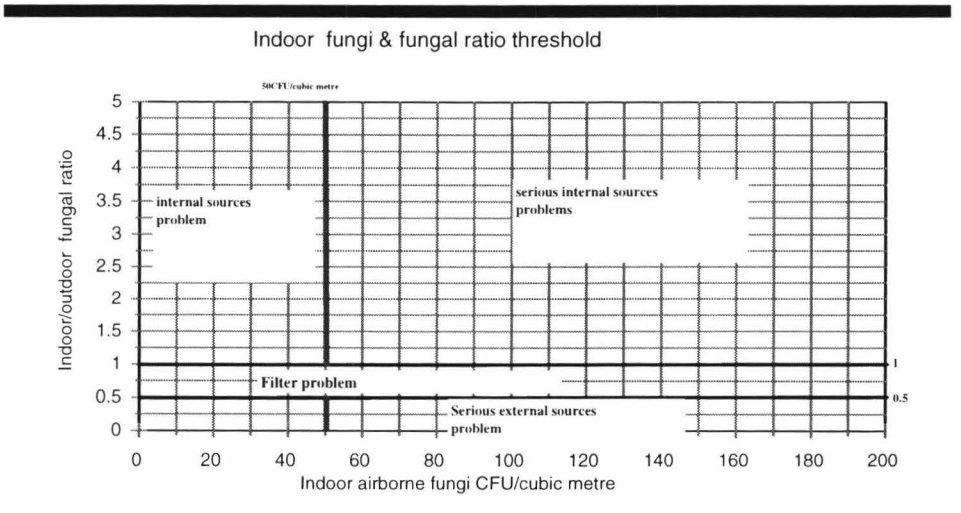
Statistical analyses showed that outdoor bacterial and fungal levels had significant impact on the indoor levels in Auckland offices especially in summer. Indoor airborne fungal levels in Wellington offices, on the other hand, appeared to be generated from internal sources. In the Wellington offices surveyed in summer, there was strong statistical evidence to suggest that indoor airborne fungal levels were associated with indoor air temperature (Chapter 5). This could explain why indoor sources were the major contributors of indoor fungi in Wellington offices in general. Outdoor air infiltration, on the other hand, was the major source for indoor airborne fungi in Auckland offices.

The third objective was to examine the differences in indoor airborne bacterial and fungal levels between complaint and non-complaint offices in order to determine whether the complaints reported were associated with those levels. Statistical analyses carried out in Chapter 6 showed no significant differences in indoor airborne bacterial and fungal levels between complaint and non-complaint offices surveyed. This means that the complaints reported in some of the offices surveyed were not associated with indoor airborne bacterial and fungal levels. Therefore, there is a need to examine whether it is necessary to look at indoor airborne bacterial and fungal measurements as a priority when conducting indoor air quality investigations in response to complaint situations in an office environment (Chapter 6).

However, statistical analyses in Chapter 6 showed that indoor air temperature levels in complaint offices were significantly higher than those of non-complaint offices. This means that indoor air temperature levels might be one of the causes of the complaints reported. Indoor/outdoor fungal ratios in complaint offices were also significantly higher than those of non-complaint offices. This suggests that the indoor environment of complaint offices had the potential (eg; through lack of HVAC maintenance, water damage, mouldy and wet materials, condensation in drain pans...etc.) to be one of the major sources of airborne fungi (Chapter 6).

The fourth and final objective was to gain an indication of how indoor air quality in New Zealand offices (in terms of airborne bacterial and fungal levels) compares to that of overseas offices. This issue has not been addressed conclusively in this thesis. This is due to the fact that the measurement techniques used by ESR and ABS in measuring the levels of airborne bacteria and fungi were different from those used overseas. This in turn can affect the airborne bacteria and fungal absolute counts. Therefore, any attempt to make comparisons between airborne bacterial and fungal levels found in New Zealand offices and those of similar overseas environments should be done with caution (Chapter 7).

Thus, an evaluation tool has been developed to overcome the difficulties associated with comparisons between indoor airborne fungal levels obtained by the use of different measurement techniques. This evaluation tool has been developed through the integration of indoor/outdoor fungal ratios (as a way for avoiding the use of the fungal level - CFU/m^3- as a threshold) and the fungal level (as a reference only to the degree of severity of airborne fungal level in the office environment). This tool can be used to establish whether elevated fungal problems exist in an office environment and the likely causes of these problems (see Chapter 7).



The evaluation tool proposed

8.2 RECOMMENDATIONS

Although this thesis provides the first published information on indoor airborne bacteria and fungi in fully sealed mechanically ventilated offices in New Zealand, further studies are needed to determine the long term impact of microclimatic parameters (air temperature, relative humidity, ventilation rates ...etc.) and outdoor bacterial and fungal levels on the indoor levels. These studies should be based on data collected using a standard sampling technique and duration for a significant period of time (throughout a week, a month, a season).

This study provides answers to the questions which it set out to answer but it also raised new issues. These issues are as follows:

1. The reasons behind the strong association found between airborne fungal levels and indoor air temperature (see Chapter 5) which existed only in Wellington offices surveyed in summer, for instance, need to be explained.

2. The significant differences found in indoor/outdoor fungal ratios between Auckland and Wellington offices (particularly in offices surveyed in summer - see Chapters 4 and 5) need to be investigated.

3. Further studies are needed to examine the HVAC systems types in relation to airborne fungal concentrations in both Auckland and Wellington office environments. Several overseas studies showed that air-conditioning systems are potential sources of fungal colonization and proliferation [2,3,4,5]. These studies showed that some parts of HVAC systems (eg; air filters, fibreglass air ducts, air inlets and outlets, cooling coils) may become excessively contaminated with microbial pollutants as these parts are normally wet for a long period of time, hence may support fungal growth. This might be the case in a significant number of Wellington offices which had elevated levels of airborne fungi due to internal contamination (see Chapters 4 and 7) whereas the HVAC systems in most

of Auckland offices had succeeded to a great extent in preventing elevated outdoor airborne fungal levels from penetrating the office environment.

Finally, the standardization of airborne bacterial and fungal measurement procedures is an essential step towards developing reliable and universal guidelines for airborne bacteria and fungi in the office environment.

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APPENDIXES

APPENDIX 1

A- SOME EXAMPLES OF VENTILATION AND AIR -CONDITIONING SYSTEMS

B- THE DIFFERENCES IN INDOOR BACTERIAL LEVELS BETWEEN ESR AND ABS MEASUREMENTS

C- THE DIFFERENCES IN INDOOR FUNGAL LEVELS BETWEEN ESR AND ABS MEASUREMENTS

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THE COMMON FUNGAL SPECIES IDENTIFIED IN VARIOUS INDOOR ENVIRONMENTS OVERSEAS

APPENDIX 3

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION AND PEARSON CHI-SQUARE TEST OUTPUTS OF CHAPTER 3

A- LINEAR REGRESSION OUTPUTS

B- PEARSON CHI-SQUARE TEST

APPENDIX 4

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION, PEARSON CHI-SQUARE TEST AND MANN-WHITNEY TEST OF CHAPTER 4

A- LINEAR REGRESSION OUTPUTS

B- PEARSON CHI-SQUARE OUTPUTS

C- MANN-WHITNEY TEST OUTPUTS

APPENDIX 5

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION, FISHER EXACT TEST AND MANN-WHITNEY TEST OUTPUTS OF CHAPTER 5

A- LINEAR REGRESSION OUTPUTS

B- FISHER EXACT TEST OUTPUTS

C- MANN-WHITNEY TEST OUTPUTS

APPENDIX 6

SUMMARY OF STATISTICAL OUTPUTS OF MANN-WHITNEY TEST OF CHAPTER 6

A- MANN-WHITNEY TEST OUTPUTS

APPENDIX 7

A- CARBON DIOXIDE LEVELS IN AUCKLAND OFFICES SURVEYED BY ESR AND ABS

B- CARBON DIOXIDE LEVELS IN AUCKLAND AND WELLINGTON OFFICES

C- COMPARISON BETWEEN OUTDOOR CLIMATIC CONDITIONS SUITABLE FOR FUNGAL GROWTH IN AUCKLAND AND WELLINGTON

D- INDOOR AIR TEMPERATURE AND INDOOR/OUTDOOR FUNGAL RATIO (AS POSSIBLE CAUSES FOR COMPLAINT-SEE CHAPTER 6) IN AUCKLAND AND WELLINGTON OFFICES AND IN OFFICES SURVEYED IN SUMMER AND WINTER

APPENDIX 1

A- SOME EXAMPLES OF VENTILATION AND AIR-CONDITIONING SYSTEMS

B- THE DIFFERENCES IN INDOOR AIRBORNE BACTERIAL LEVELS BETWEEN ESR AND ABS MEASUREMENTS.

C- THE DIFFERENCES IN INDOOR AIRBORNE FUNGAL LEVELS BETWEEN ESR AND ABS MEASUREMENTS.

APPENDIX 1

A- SOME EXAMPLES OF VENTILATION AND AIR-CONDITIONING SYSTEMS

The function of an air-conditioning system is to provide and maintain an artificial environment within a building enclosure, for comfort and welfare of the occupants. Full year-round air-conditioning provides simultaneous control of air temperature, relative humidity, ventilation and air cleanliness. An airconditioning system ventilates, normally heating and humidifying in winter, and cooling and dehumidifying in summer. They may be classified according to the types of heating and cooling media employed to provide the final heating and cooling effect within the space. Four examples of air conditioning systems are classified as follows:

1- conventional systems

These comprises a central air handling plant with distribution duct work connected to the various spaces served (Figure A1.1).

2. Terminal reheat system

This comprises a terminal reheat unit with a heating coil. Reheat is added as required by the room unit, as recirculated room air is induced across the heating coil. A typical system layout is shown in Figure A1.2.

3. Multi-zone system

This system employs one or more central air handling units. The heating and cooling coils located in parallel, downstream of the supply fan (Figure:A1.3).

4. Dual duct system

This is all-air system which conditions air in a central plant and distributes it at high velocity to the conditioned spaces through two parallel ducts (Figure:A1.4).

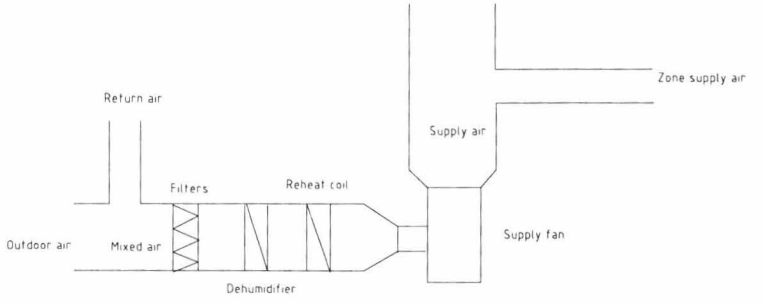

Figure A1.1: Conventional system (Variable volume constant temperature system)

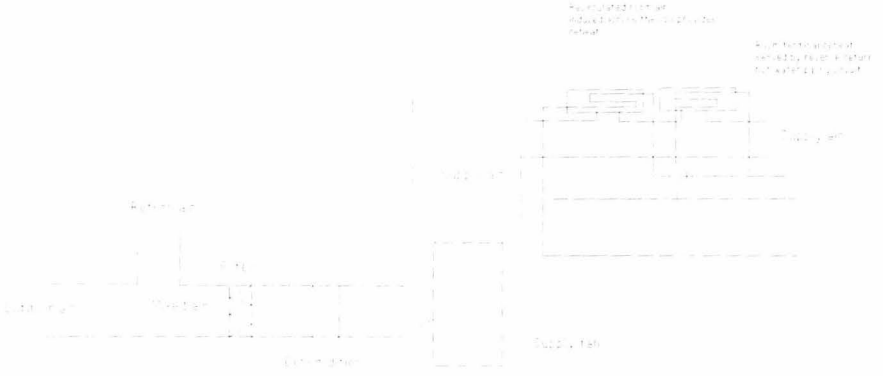

Figure A1.2: Terminal reheat system

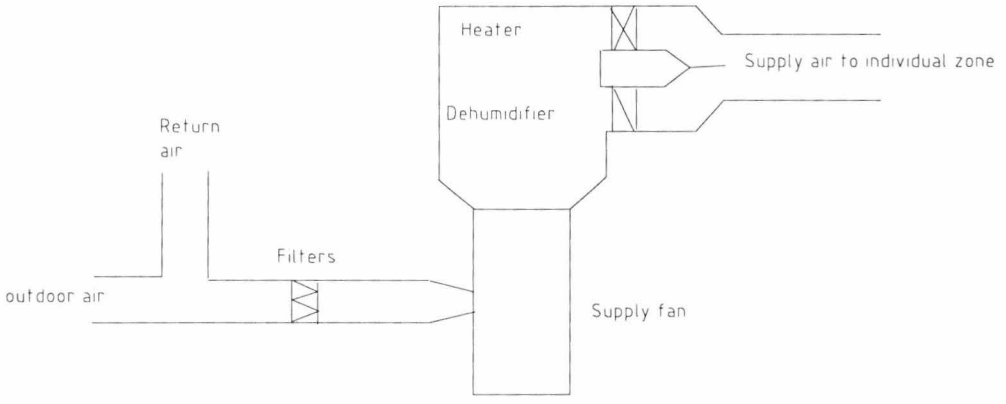

Figure A1.3: Multizone system

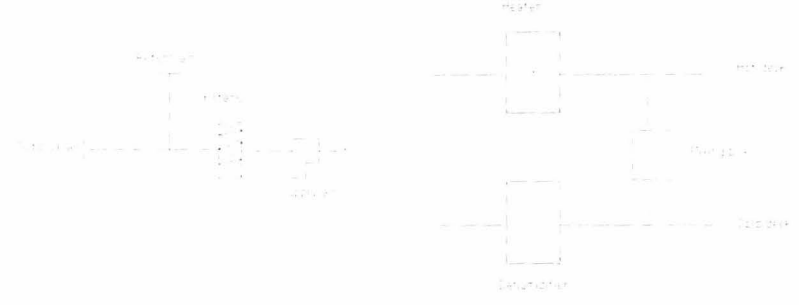

Figure A1.4: Dual duct system

B- THE DIFFERENCES IN INDOOR AIRBORNE BACTERIAL LEVELS BETWEEN ESR AND ABS MEASUREMENTS.

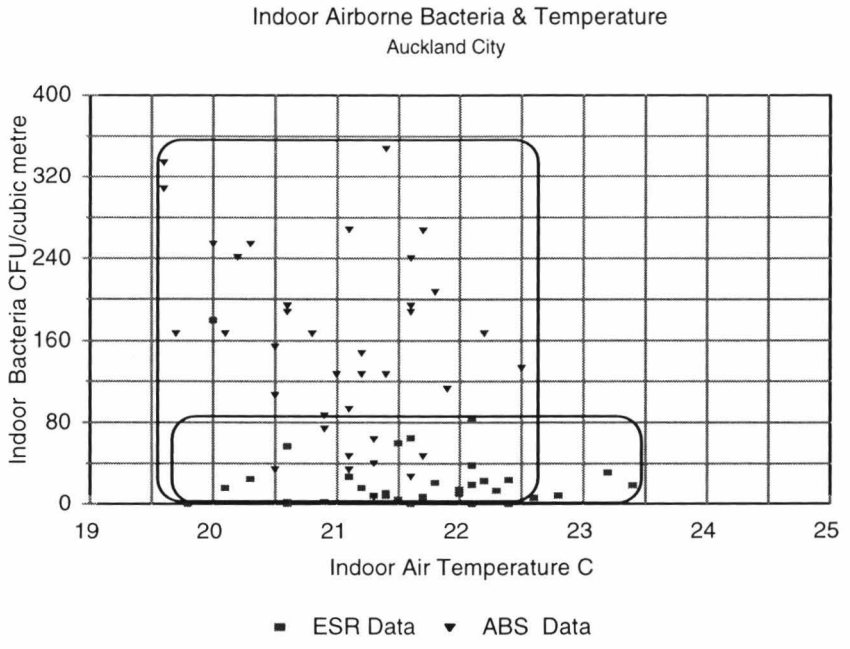

Figure A1.5: Indoor airborne bacterial counts of ESR and ABS. Almost all indoor airborne bacterial levels exceeded the 80 CFU/m^3 level were ABS measurements.

Mann-Whitney test output

A-1 Indoor airborne bacterial counts differences between ESR and ABS data.

	Group	Count	Rank Sum
ESR	1.0	36	745.000
ABS	2.0	39	2105.000

Mann-Whitney U test statistics 79.000

Probability = 0.000 (ESR and ABS are not coming from the same population).

This means that the sampling technique used by ABS to measure airborne bacterial concentrations was different from that used by ESR. This in turn has affect the sampling results significantly.

C- THE DIFFERENCES IN INDOOR AIRBORNE FUNGAL LEVELS BETWEEN ESR AND ABS MEASUREMENTS.

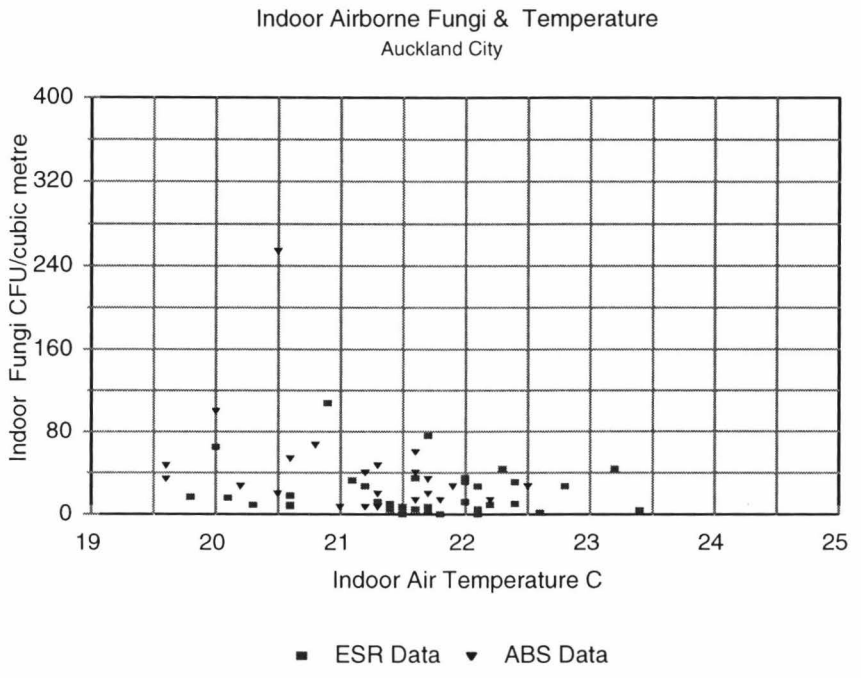

Figure A1.6: Indoor airborne fungal counts of ESR and ABS. No significant differences can be observed in airborne fungal levels between ESR and ABS measurements.

Mann-Whitney test output

A-1 Indoor airborne fungal counts differences between ESR and ABS data.

	Group	Count	Rank Sum
ESR	1.0	49	1763.500
ABS	2.0	26	1086.500

Mann-Whitney U test statistics 538.500

Probability = 0.272 (ESR and ABS data are coming form the same population).

This means that the sampling techniques used by ESR and ABS have not affected the results significantly

APPENDIX 2

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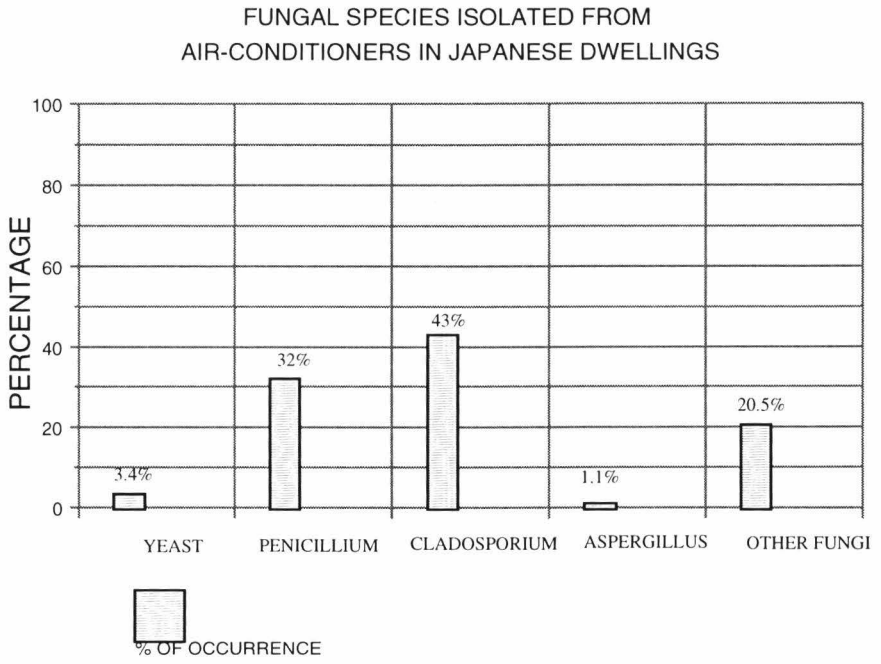
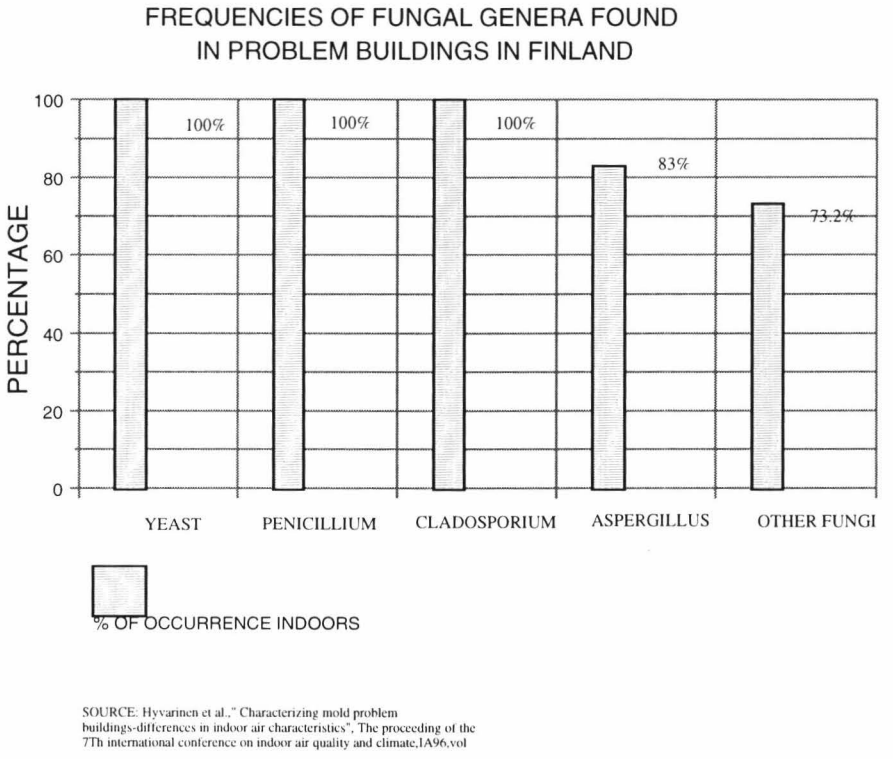
THE COMMON FUNGAL SPECIES IDENTIFIED IN VARIOUS INDOOR ENVIRONMENTS OVERSEAS.



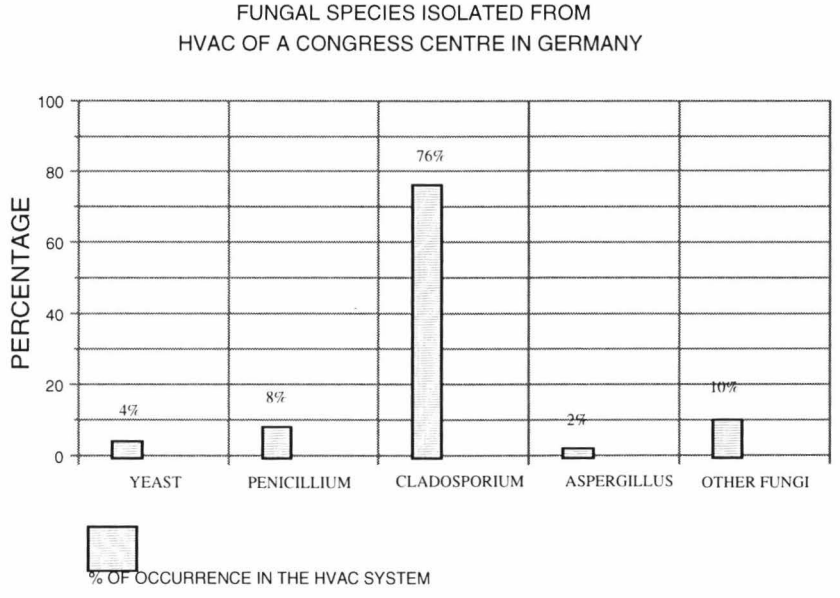
SOURCE: Iida Y et al.," Characterization of fungi in air-conditioners in dwellings", The proceeding of the 7Th international conference on indoor air quality and climate,IA96,vol 3,pp.221-226.

Figure A2.1: The frequencies of different fungal species isolated from air-conditioners in Japanese dwellings



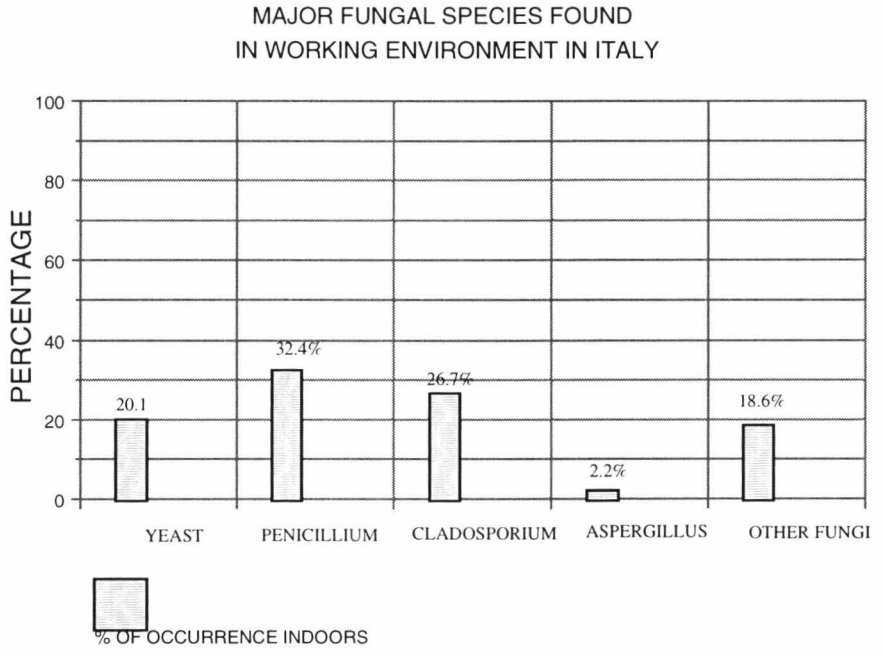
SOURCE: Hyvarinen et al.," Characterizing mold problem buildings-differences in indoor air characteristics", The proceeding of the 7Th international conference on indoor air quality and climate,1A96,vol

Figure A2.2: The frequencies of different fungal species isolated from problem buildings in Finland.



SOURCE: Neumeister H. et al.," Investigation on allergic potential induced by fungi on air filters of HVAC systems". The proceeding of the 7Th international conference on indoor air quality and climate.IA96.vol 3.pp.125-130.

Figure A2.3 :The frequencies of different fungal species isolated from HVAC of a congress centre in Germany.



SOURCE: Cosentino S et al.,"Occurrence of airborne fungal spores in industrial working environment", The proceeding of the 5th international conference on indoor air quality and climate,IA90,vol 2,pp. 115-119

Figure A2.4: The frequencies of different fungal species isolated from a working environment in Italy.

APPENDIX 3

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION AND PEARSON CHI-SQUARE OF CHAPTER 3 ANALYSES.

APPENDIX 3

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION AND PEARSON CHI-SQUARE OF CHAPTER 3 ANALYSES.

(The actual statistical outputs are presented in a separate report)

A- LINEAR REGRESSION ANALYSES

A-1 Temperature Vs indoor bacteria (ESR+ABS data)

Regression output:

R Squared	**0.17**	No. of observations	107
X Coefficient (s)	-41.9	Std Err of Coef.	8.667

A-1 Temperature Vs indoor bacteria (only ESR data)

Regression output:

R Squared	**0.033**	No. of observations	68
X Coefficient (s)	-9.96	Std Err of Coef.	6.50

A-2 Temperature Vs indoor fungi

R Squared	**0.003**	No. of observations	93
X Coefficient (s)	3.03	Std Err of Coef.	5.77

A-3 Humidity Vs indoor bacteria (ESR+ABS data)

R Squared	**0.063**	No. of observations	107
X Coefficient (s)	4.27	Std Err of Coef.	1.57

A-3 Humidity Vs indoor bacteria (ESR data only)

R Squared	**0.00**	No. of observations	68
X Coefficient (s)	0.047	Std Err of Coef.	1.05

A-4 Humidity Vs indoor fungi

R Squared	**3E-05**	No. of observations	93
X Coefficient (s)	0.049	Std Err of Coef.	0.94

A-5 Indoor bacteria Vs outdoor bacteria

R Squared	**0.16**	No. of observations	91
X Coefficient (s)	0.77	Std Err of Coef.	0.182

A-6 Indoor fungi and outdoor fungi

R Squared	**0.013**	No. of observations	91
X Coefficient (s)	0.02	Std Err of Coef.	0.02

A-7 Indoor bacteria Vs indoor fungi

R Squared	**0.033**	No. of observations	118
X Coefficient (s)	0.11	Std Err of Coef.	0.05

A-8 Outdoor bacteria and outdoor fungi

R Squared	**0.32**	No. of observations	91
X Coefficient (s)	0.06	Std Err of Coef.	0.01

B- PEARSON CHI-SQUARE OUTPUTS

B-1 Temperature Vs indoor bacteria (ESR+ ABS data)

	Low indoor temperature	High indoor temperature	Total
Medium indoor bacteria	6	21	27
Low indoor bacteria	10	40	50
High indoor bacteria	17	13	30
Total	33	74	107

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	13.076	2	**0.001**

B-1 Temperature Vs indoor bacteria (ESR data)

	High indoor temperature	Low indoor temperature	Total
High indoor bacteria	26	7	33
Low indoor bacteria	27	8	35
Total	53	15	68

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	0.027	1	**0.870**

B-2 Humidity Vs indoor bacteria (ESR+ABS data)

	Low indoor humidity	High indoor humidity	Total
Medium indoor bacteria	30	13	43
Low indoor bacteria	12	16	28
High indoor bacteria	26	10	36
Total	68	39	107

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	7.06	2	**0.029**

B-2 Humidity Vs indoor bacteria (ESR data)

	High indoor humidity	Low indoor humidity	Total
Medium indoor bacteria	8	18	26
High indoor bacteria	1	6	7
Low indoor bacteria	13	22	35
Total	22	46	68

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	1.441	2	**0.487**

B-3 Temperature Vs indoor fungi

	Low indoor temperature	High indoor temperature	Total
High indoor fungi	25	8	33
Low indoor fungi	45	15	60
Total	70	23	93

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	0.007	1	**0.935**

B-4 Humidity Vs indoor fungi

	High indoor humidity	Low indoor humidity	Total
Low indoor fungi	26	11	37
High indoor fungi	13	3	16
Medium indoor fungi	31	9	40
Total	70	23	93

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	0.911	2	**0.634**

B-5 Indoor bacteria Vs outdoor bacteria

	Medium outdoor bacteria	High outdoor bacteria	Low outdoor bacteria	Total
Medium indoor bacteria	21	16	10	47
high indoor bacteria	14	8	22	44
Total	35	24	32	91

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	8.477	2	**0.014**

B-6 Indoor fungi Vs outdoor fungi

	High outdoor fungi	Low outdoor fungi	Total
Low indoor fungi	8	33	41
High indoor fungi	9	11	20
Medium indoor fungi	14	16	30
Total	31	60	91

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	7.052	2	**0.029**

B-7 Indoor bacteria Vs indoor fungi

	Low indoor fungi	High indoor fungi	Total
Medium indoor bacteria	21	31	52
Low indoor bacteria	24	20	44
High indoor bacteria	6	16	22
Total	51	67	118

Test Statistics	Value	DF	Prob.
Pearson Chi-square test	4.75	2	**0.093**

APPENDIX 4

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION ANALYSES, PEARSON CHI-SQUARE AND MANN WHITNEY OF CHAPTER 4

APPENDIX 4

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION ANALYSES, PEARSON CHI- SQUARE AND MANN WHITNEY TEST OF CHAPTER 4.

(The actual statistical outputs are presented in a separate report)

A- LINEAR REGRESSION OUTPUTS

A-1 Temperature Vs Indoor bacteria

- Auckland (ESR+ABS data)

R Squared	**0.16**	No. of Observations	73
X Coefficient (s)	-55.47	Std Err of Coef.	14.38

- Auckland (ESR data)

R Squared	**0.04**	No. of Observations	36
X Coefficient (s)	-8.5	Std Err of Coef.	6.56

- Auckland (ABS data)

R Squared	**0.09**	No. of Observations	39
X Coefficient (s)	-51.3	Std Err of Coef.	25.91

- Wellington

R Squared	**0.03**	No. of Observations	34
X Coefficient (s)	-11.74	Std Err of Coef.	11.23

A-2 Temperature Vs Indoor fungi

- Auckland

R Squared	**0.07**	No. of Observations	59
X Coefficient (s)	-12.40	Std Err of Coef.	5.62

- Wellington

R Squared	**0.02**	No. of Observations	34
X Coefficient (s)	10.67	Std Err of Coef.	12.87

A-3 Humidity Vs Indoor bacteria

- Auckland (ESR + ABS data)

R Squared	**0.054**	No. of Observations	73
X Coefficient (s)	5.19	Std Err of Coef.	2.52

- Auckland (ESR data)

R Squared	**0.00**	No. of Observations	36
X Coefficient (s)	0.19	Std Err of Coef.	1.02

- Auckland (ABS data)

R Squared	**0.13**	No. of Observations	39
X Coefficient (s)	15.62	Std Err of Coef.	6.4

- Wellington

R Squared	**0.0002**	No. of Observations	34
X Coefficient (s)	-0.14	Std Err of Coef.	1.80

A-4 Humidity Vs Indoor fungi

- Auckland

R Squared	**0.005**	No. of Observations	59
X Coefficient (s)	0.48	Std Err of Coef.	0.89

- Wellington

R Squared	**0.003**	No. of Observations	34
X Coefficient (s)	0.64	Std Err of Coef.	2.05

A-5 Indoor bacteria Vs outdoor bacteria

- Auckland

R Squared	**0.39**	No. of Observations	46
X Coefficient (s)	0.72	Std Err of Coef.	0.13

- Wellington

R Squared	**0.08**	No. of Observations	46
X Coefficient (s)	1.97	Std Err of Coef.	1.00

A-6 Outdoor fungi Vs indoor fungi

- Auckland

R Squared	**0.27**	No. of Observations	45
X Coefficient (s)	0.05	Std Err of Coef.	0.01

- Wellington

R Squared	**0.015**	No. of Observations	46
X Coefficient (s)	-0.33	Std Err of Coef.	0.40

A-7 Indoor fungi Vs indoor bacteria

- Auckland (ESR+ABS)

R Squared	**0.26**	No. of Observations	75
X Coefficient (s)	0.19	Std Err of Coef.	0.03

- Auckland (ESR data)

R Squared	**0.11**	No. of Observations	49
X Coefficient (s)	0.26	Std Err of Coef.	0.10

- Auckland (ABS data)

R Squared	**0.51**	No. of Observations	26
X Coefficient (s)	0.26	Std Err of Coef.	0.05

- Wellington

R Squared	**0.003**	No. of Observations	43
X Coefficient (s)	-0.07	Std Err of Coef.	0.18

A-8 Outdoor bacteria and outdoor fungi

- Auckland

R Squared	**0.25**	No. of Observations	45
X Coefficient (s)	0.059	Std Err of Coef.	0.015

- Wellington

R Squared	**0.000**	No. of Observations	46
X Coefficient (s)	-0.00	Std Err of Coef.	0.03

B- PEARSON CHI-SQUARE TEST OUTPUTS

B-1 Indoor air temperature Vs indoor bacteria

- Auckland (ESR+ABS data)

	Low indoor temperature	High indoor Temperature	Total
Medium indoor bacteria	5	16	21
Low indoor bacteria	5	18	23
High indoor bacteria	16	13	29
Total	26	47	73

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**8.045**	**2**	**0.018**

- Auckland (ESR data)

	High indoor temperature	Low indoor Temperature	Total
High indoor bacteria	7	5	12
Low indoor bacteria	14	10	24
Total	21	15	36

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**0.000**	**1**	**1.000**

- Auckland (ABS data only)

	High indoor temperature	Low indoor Temperature	Total
High indoor bacteria	8	13	21
Low indoor bacteria	13	5	18
Total	21	18	39

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**4.542**	**1**	**0.033**

- Wellington

	Low indoor temperature	High indoor Temperature	Total
Low indoor bacteria	13	9	22
High indoor bacteria	6	6	12
Total	19	15	34

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**0.260**	**1**	**0.610**

B-2 Indoor relative humidity Vs indoor bacteria

- Auckland (ESR + ABS data)

	High indoor humidity	Low indoor humidity	Total
Medium indoor bacteria	18	16	34
High indoor bacteria	11	11	22
Low indoor bacteria	13	4	17
Total	42	31	73

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**3.3**	**2**	**0.192**

- Auckland (only ESR data)

	High humidity	Low Humidity	Total
High indoor bacteria	11	9	20
Low indoor bacteria	10	6	16
Total	21	15	36

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**0.206**	**1**	**0.650**

- Auckland (only ABS data)

	High humidity	Low Humidity	Total
High indoor bacteria	13	8	21
Low indoor bacteria	14	4	18
Total	27	12	39

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**1.146**	**1**	**0.284**

- Wellington

	Low humidity	High Humidity	Total
High indoor bacteria	11	4	15
Low indoor bacteria	11	8	19
Total	22	12	34

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**0.875**	**1**	**0.350**

B-3 Indoor air temperature Vs indoor fungi

- Auckland

	Low indoor temperature	High indoor Temperature	Total
Low indoor fungi	14	7	21
High indoor fungi	28	10	38
Total	42	17	59

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**0.325**	**1**	**0.569**

- Wellington

	Low indoor temperature	High indoor Temperature	Total
High indoor fungi	12	6	18
Low indoor fungi	10	6	16
Total	22	12	34

Test Statistics	Value	DF	Prob
Pearson Chi-square	**0.064**	**1**	**0.800**

B-4 Indoor relative humidity Vs indoor fungi

- Auckland

	Low indoor temperature	High indoor Temperature	Total
Low indoor fungi	13	8	21
High indoor fungi	12	2	14
Medium indoor fungi	19	5	24
Total	44	15	59

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**2.961**	**2**	**0.228**

- Wellington

	Low indoor temperature	High indoor Temperature	Total
High indoor fungi	13	5	18
Low indoor fungi	11	5	16
Total	24	10	34

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**0.049**	**1**	**0.824**

B-5 Indoor bacteria Vs outdoor bacteria

- Auckland

	Low outdoor bacteria	High outdoor bacteria	Total
High indoor bacteria	8	15	23
Low indoor bacteria	18	5	23
Total	26	20	46

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**8.84**	**1**	**0.003**

- Wellington

	Medium Outdoor bacteria	High outdoor bacteria	Low outdoor bacteria	Total
Low indoor bacteria	6	4	9	19
High indoor bacteria	7	14	6	27
Total	13	18	15	46

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**4.99**	**2**	**0.082**

B-6 Indoor fungi Vs Outdoor fungi

- Auckland

	High outdoor fungi	Low outdoor fungi	Total
Low indoor fungi	8	11	19
High indoor fungi	11	2	13
Medium indoor fungi	7	6	13
Total	26	19	45

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**102.79**	**6**	**0.000**

- Wellington

	High outdoor fungi	Low outdoor fungi	Total
Medium indoor fungi	7	8	15
Low indoor fungi	9	13	22
High indoor fungi	7	2	9
Total	23	23	46

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**3.57**	**2**	**0.168**

B-7 Indoor bacteria Vs indoor fungi

- Auckland (ESR+ABS data)

	low indoor fungi	High indoor fungi	Total
Medium indoor bacteria	16	19	35
Low indoor bacteria	14	5	19
High indoor bacteria	6	15	21
Total	36	39	75

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**8.27**	**2**	**0.016**

- Auckland (ESR data)

	High indoor bacteria	Low indoor bacteria	Total
High indoor fungi	7	7	14
Low indoor fungi	7	28	35
Total	14	35	49

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**4.410**	**1**	**0.036**

- Auckland (ABS data)

	High indoor bacteria	Low indoor bacteria	Total
High indoor fungi	9	9	18
Low indoor fungi	3	5	8
Total	12	14	26

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**0.348**	**1**	**0.555**

- Wellington

	High indoor fungi	Low indoor fungi	Total
Low indoor bacteria	13	12	25
High indoor bacteria	10	8	18
Total	23	20	43

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**0.053**	**1**	**0.818**

B-8 Outdoor bacteria Vs outdoor fungi

- Auckland

	low outdoor bacteria	High outdoor bacteria	Medium outdoor bacteria	Total
High outdoor fungi	5	13	8	26
Low outdoor fungi	7	1	11	19
Total	12	14	19	45

Test Statistics	Value	DF	Prob.
Pearson Chi-square	**10.252**	**2**	**0.006**

- Wellington

	Medium outdoor bacteria	High outdoor bacteria	Low outdoor bacteria	Total
Low outdoor fungi	5	0	6	11
High outdoor fungi	18	8	9	35
Total	23	8	15	46

Test Statistics	Value	DF	Prob
Pearson Chi-square	**4.708**	**2**	**0.095**

C- MANN-WHITNEY TEST OUTPUTS

C-1 Indoor/outdoor bacterial ratios in Auckland and Wellington offices

Group	Count		Rank Sum
Auckland	45		2191.5
Wellington	46		1994.5
Mann-Whitney U test statistic		=	1156.5
Probability is		**0.329**	

C-2 Indoor/outdoor fungal ratios in Auckland and Wellington offices

Group	Count		Rank Sum
Auckland	45		1571.5
Wellington	46		2614.5
Mann-Whitney U test statistic		=	536.5
Probability is		**0.000**	

APPENDIX 5

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION, FISHER'S EXACT TEST AND MANN-WHITNEY TESTS OF CHAPTER 5 ANALYSES.

APPENDIX 5

SUMMARY OF STATISTICAL OUTPUTS OF LINEAR REGRESSION, FISHER EXACT TEST AND MANN-WHITNEY TESTS OF CHAPTER 5 ANALYSES.

(The actual statistical outputs are presented in a separate report)

A- LINEAR REGRESSION OUTPUTS

A-1 Temperature Vs Indoor bacteria

- Auckland Summer

R Squared	**0.13**	No. of Observations	14
X Coefficient (s)	-16.24	Std Err of Coef.	12.01

- Auckland Winter

R Squared	**0.01**	No. of Observations	21
X Coefficient (s)	-4.60	Std Err of Coef.	8.30

- Wellington Summer

R Squared	**0.09**	No. of Observations	16
X Coefficient (s)	-30.53	Std Err of Coef.	25.51

- Wellington Winter

R Squared	**0.14**	No. of Observations	18
X Coefficient (s)	2.99	Std Err of Coef.	1.80

A-2 Temperature Vs Indoor fungi

- Auckland Summer

R Squared	**0.015**	No. of Observations	13
X Coefficient (s)	2.86	Std Err of Coef.	6.77

- Auckland Winter

R Squared	**0.03**	No. of Observations	21
X Coefficient (s)	-6.26	Std Err of Coef.	7.99

- Wellington Summer

R Squared	**0.29**	No. of Observations	16
X Coefficient (s)	28.22	Std Err of Coef.	11.52

- Wellington Winter

R Squared	**0.009**	No. of Observations	18
X Coefficient (s)	-0.71	Std Err of Coef.	21.43

A-3 Humidity Vs Indoor bacteria

- Auckland Summer

R Squared	**0.02**	No. of Observations	13
X Coefficient (s)	-0.29	Std Err of Coef.	0.58

- Auckland Winter

R Squared	**0.01**	No. of Observations	21
X Coefficient (s)	0.48	Std Err of Coef.	0.99

- Wellington Summer

R Squared	**0.01**	No. of Observations	16
X Coefficient (s)	-1.94	Std Err of Coef.	4.00

- Wellington Winter

R Squared	**0.03**	No. of Observations	18
X Coefficient (s)	-0.27	Std Err of Coef.	0.35

A-4 Humidity Vs Indoor fungi

- Auckland Summer

R Squared	**0.07**	No. of Observations	14
X Coefficient (s)	1.07	Std Err of Coef.	1.08

- Auckland Winter

R Squared	**0.008**	No. of Observations	21
X Coefficient (s)	-0.39	Std Err of Coef.	0.96

- Wellington Summer

R Squared	**0.17**	No. of Observations	16
X Coefficient (s)	3.25	Std Err of Coef.	1.88

- Wellington Winter

R Squared	**0.012**	No. of Observations	18
X Coefficient (s)	-1.78	Std Err of Coef.	3.97

A-5 Indoor bacteria Vs Outdoor bacteria

- Auckland Summer

R Squared	**0.18**	No. of Observations	27
X Coefficient (s)	0.34	Std Err of Coef.	0.14

- Auckland Winter

R Squared	**0.15**	No. of Observations	19
X Coefficient (s)	1.31	Std Err of Coef.	0.75

- Wellington Summer

R Squared	**0.03**	No. of Observations	19
X Coefficient (s)	2.33	Std Err of Coef.	2.78

- Wellington Winter

R Squared	**0.008**	No. of Observations	27
X Coefficient (s)	-0.58	Std Err of Coef.	1.26

A-6 Indoor fungi Vs Outdoor fungi

- Auckland Summer

R Squared	**0.27**	No. of Observations	26
X Coefficient (s)	0.04	Std Err of Coef.	0.016

- Auckland Winter

R Squared	**0.016**	No. of Observations	19
X Coefficient (s)	-0.06	Std Err of Coef.	0.11

- Wellington Summer

R Squared	**0.37**	No. of Observations	19
X Coefficient (s)	0.83	Std Err of Coef.	0.25

- Wellington Winter

R Squared	**0.029**	No. of Observations	26
X Coefficient (s)	0.09	Std Err of Coef.	0.11

A-7 Indoor bacteria Vs indoor fungi

- Auckland Summer

R Squared	**0.12**	No. of Observations	29
X Coefficient (s)	0.24	Std Err of Coef.	0.12

- Auckland Winter

R Squared	**0.05**	No. of Observations	21
X Coefficient (s)	-13.38	Std Err of Coef.	8.45

- Wellington Summer

R Squared	**0.04**	No. of Observations	19
X Coefficient (s)	-0.30	Std Err of Coef.	0.36

- Wellington Winter

R Squared	**0.00**	No. of Observation	27
X Coefficient (s)	0.00	Std Err of Coef.	0.02

A-8 Outdoor bacteria Vs outdoor fungi

- Auckland Summer

R Squared	**0.162**	No. of Observation	34
X Coefficient (s)	2.48	Std Err of Coef.	1.00

- Auckland Winter

R Squared	**0.19**	No. of Observation	19
X Coefficient (s)	2.86	Std Err of Coef.	1.40

- Wellington Summer

R Squared	**0.22**	No. of Observation	19
X Coefficient (s)	-0.08	Std Err of Coef.	0.03

- Wellington Winter

R Squared	**0.66**	No. of Observation	27
X Coefficient (s)	0.04	Std Err of Coef.	0.00

B- FISHER EXACT TEST OUTPUTS

B-1 Indoor bacteria Vs temperature

- Auckland Summer

	Low indoor temperature	High indoor temperature	Total
High indoor bacteria	4	4	8
Low indoor bacteria	5	1	6
Total	9	5	14

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.6	1	0.198
Fisher Exact test			**0.301**

- Auckland Winter

	Low indoor temperature	High indoor temperature	Total
High indoor bacteria	6	5	11
Low indoor bacteria	5	5	10
Total	11	10	21

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.043	1	0.835
Fisher Exact test			**1.000**

- Wellington summer

	Low indoor temperature	High indoor temperature	Total
High indoor bacteria	5	4	9
Low indoor bacteria	2	5	7
Total	7	9	16

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.16	1	0.280
Fisher Exact test			**0.358**

- Wellington Winter

	Low indoor temperature	High indoor temperature	Total
High indoor bacteria	6	7	13
Low indoor bacteria	1	4	5
Total	7	11	18

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.03	1	0.308
Fisher Exact test			**0.596**

B-2 Indoor fungi Vs temperature

- Auckland Summer

	Low indoor temperature	High indoor temperature	Total
High indoor fungi	6	2	8
Low indoor fungi	2	3	5
Total	9	5	13

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.5	1	0.207
Fisher Exact test			**0.293**

- Auckland Winter

	Low indoor temperature	High indoor temperature	Total
High indoor fungi	8	6	14
Low indoor fungi	3	4	7
Total	11	10	21

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.382	1	0.537
Fisher Exact test			**0.659**

- Wellington Summer

	Low indoor temperature	High indoor temperature	Total
High indoor Fungi	4	5	9
Low indoor Fungi	0	7	7
Total	4	12	16

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	4.14	1	0.042
Fisher Exact test			**0.088**

- Wellington Winter

	Low indoor temperature	High indoor temperature	Total
High indoor Fungi	5	3	8
Low indoor bacteria	3	7	10
Total	8	10	18

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.901	1	0.168
Fisher Exact test			**0.342**

B-3 Indoor bacteria Vs humidity

- Auckland Summer

	Low indoor humidity	High indoor humidity	Total
High indoor bacteria	2	3	5
Low indoor bacteria	5	3	8
Total	7	6	13

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.62	1	0.429
Fisher Exact test			**0.592**

- Auckland Winter

	Low indoor humidity	High indoor humidity	Total
High indoor bacteria	9	2	11
Low indoor bacteria	5	5	10
Total	14	7	21

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	2.38	1	0.122
Fisher Exact test			**0.183**

- Wellington summer

	Low indoor humidity	High indoor humidity	Total
Low indoor bacteria	3	3	6
High indoor bacteria	8	2	10
Total	11	5	16

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.571	1	0.210
Fisher Exact test			**0.299**

- Wellington Winter

	Low indoor humidity	High indoor humidity	Total
Low indoor bacteria	8	5	13
High indoor bacteria	3	2	5
Total	11	7	18

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.004	1	0.952
Fisher Exact test			**1.000**

B-4 Indoor fungi Vs humidity

- Auckland Summer

	High indoor humidity	Low indoor humidity	Total
High indoor fungi	5	3	8
Low indoor fungi	4	2	6
Total	9	5	14

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.026	1	0.872
Fisher Exact test			**1.000**

- Auckland Winter

	High indoor humidity	Low indoor humidity	Total
Low indoor fungi	10	4	14
High indoor fungi	4	3	7
Total	14	7	21

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.429	1	0.513
Fisher Exact test			**0.638**

- Wellington Summer

	Low indoor humidity	High indoor humidity	Total
Low indoor Fungi	7	2	9
High indoor Fungi	4	3	7
Total	11	5	16

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.78	1	0.377
Fisher Exact test			**0.596**

- Wellington Winter

	High indoor humidity	Low indoor temperature	Total
High indoor Fungi	6	5	11
Low indoor bacteria	4	3	7
Total	10	8	18

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.012	1	0.914
Fisher Exact test			**1.000**

B-5 Indoor bacteria Vs outdoor bacteria

- Auckland Summer

	High outdoor bacteria	Low outdoor bacteria	Total
High indoor bacteria	12	2	14
Low indoor bacteria	3	10	13
Total	15	12	27

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	10.711	1	0.001
Fisher Exact test			**0.002**

- Auckland Winter

	Low outdoor bacteria	High outdoor bacteria	Total
High indoor bacteria	5	4	9
Low indoor bacteria	3	7	10
Total	8	11	19

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.2	1	0.260
Fisher Exact test			**0.370**

- Wellington summer

	Low outdoor bacteria	High outdoor bacteria	Total
Low indoor bacteria	6	4	10
High indoor bacteria	3	6	9
Total	9	10	19

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.351	1	0.245
Fisher Exact test			**0.370**

- Wellington Winter

	High outdoor bacteria	Low outdoor bacteria	Total
Low indoor bacteria	6	9	15
High indoor bacteria	6	6	12
Total	12	15	27

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.270	1	0.603
Fisher Exact test			**0.707**

B-6 Indoor fungi Vs Outdoor fungi

- Auckland Summer

	Low outdoor fungi	High outdoor fungi	Total
Low indoor fungi	5	3	8
High indoor fungi	6	12	18
Total	11	15	26

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.930	1	0.165
Fisher Exact test			**0.218**

- Auckland Winter

	High outdoor fungi	Low outdoor fungi	Total
Low indoor fungi	6	6	12
High indoor fungi	4	3	7
Total	10	9	19

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.090	1	0.764
Fisher Exact test			**1.00**

- Wellington summer

	High indoor fungi	Low indoor fungi	Total
High outdoor fungi	4	5	9
Low outdoor fungi	0	10	10
Total	4	15	19

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	5.63	1	0.018
Fisher Exact test			**0.033**

- Wellington Winter

	High indoor fungi	Low indoor fungi	Total
High outdoor fungi	4	9	13
Low outdoor fungi	4	9	13
Total	8	18	26

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.000	1	1.000
Fisher Exact test			**1.000**

B.7 Indoor bacteria Vs Indoor fungi

- Auckland Summer

	Low indoor bacteria	High indoor bacteria	Total
Low indoor fungi	9	2	11
High indoor fungi	5	13	18
Total	14	15	29

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	7.98	1	0.005
Fisher Exact test			**0.008**

- Auckland Winter

	High indoor bacteria	Low indoor bacteria	Total
Low indoor fungi	8	4	12
High indoor fungi	3	6	9
Total	11	10	21

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	2.29	1	0.130
Fisher Exact test			**0.198**

- Wellington summer

	Low indoor bacteria	High indoor bacteria	Total
Low indoor fungi	5	4	9
High indoor fungi	2	8	10
Total	7	12	19

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	2.574	1	0.109
Fisher Exact test			**0.170**

- Wellington Winter

	Low indoor bacteria	High indoor bacteria	Total
High indoor fungi	7	7	14
Low indoor fungi	8	5	13
Total	15	12	27

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.363	1	0.547
Fisher Exact test			**0.704**

B-8 Outdoor bacteria Vs outdoor fungi

- Auckland Summer

	High outdoor bacteria	Low outdoor bacteria	Total
High outdoor fungi	18	5	23
Low outdoor fungi	1	10	11
Total	19	15	34

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	14.44	1	0.000
Fisher Exact test			**0.000**

- Auckland Winter

	High outdoor bacteria	Low outdoor bacteria	Total
Low outdoor fungi	6	2	8
High outdoor fungi	7	4	11
Total	13	6	19

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.277	1	0.599
Fisher Exact test			**1.00**

- Wellington summer

	High outdoor bacteria	Low outdoor bacteria	Total
Low outdoor fungi	10	6	16
High outdoor fungi	1	2	3
Total	11	8	19

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	0.88	1	0.348
Fisher Exact test			**0.546**

- Wellington Winter

	High outdoor bacteria	Low outdoor bacteria	Total
High outdoor fungi	2	10	12
Low outdoor fungi	6	9	15
Total	8	19	27

Test Statistics	Value	DF	Prob.
Pearson Chi-Square	1.74	1	0.187
Fisher Exact test			**0.236**

C- SUMMARY OF MANN-WHITNEY TEST OUTPUTS

C.1 Indoor bacterial concentrations in summer and winter

-Auckland offices

Group	Count		Rank Sum
Summer	27		735
Winter	19		346
Mann-Whitney U test statistics		=	357
Probability is		**0.025**	

-Wellington offices

Group	Count		Rank Sum
Summer	19		565
Winter	27		516
Mann-Whitney U test statistics		=	357
Probability is		**0.008**	

C.2 Outdoor bacterial concentration in Summer and Winter

-Auckland offices

Group	Count		Rank Sum
Summer	27		822
Winter	19		259
Mann-Whitney U test statistics		=	444
Probability is		**0.000**	

-Wellington offices

Group	Count		Rank Sum
Summer	19		699
Winter	27		382
Mann-Whitney U test statistics		=	509
Probability is		**0.000**	

C.3 Indoor fungal concentration in Summer and Winter

-Auckland offices

Group	Count		Rank Sum
Summer	27		783
Winter	19		297
Mann-Whitney U test statistics		=	405
Probability is		**0.001**	

-Wellington offices

Group	Count		Rank Sum
Summer	19		496
Winter	27		585
Mann-Whitney U test statistics		=	306
Probability is		**0.269**	

C.4 Outdoor fungal concentrations in Summer and Winter

-Auckland offices

Group	Count		Rank Sum
Summer	27		832
Winter	19		249
Mann-Whitney U test statistics		=	454
Probability is		**0.000**	

-Wellington offices

Group	Count		Rank Sum
Summer	19		505
Winter	27		576
Mann-Whitney U test statistics		=	315
Probability is		**0.182**	

C.5 Indoor /outdoor bacterial ratio in Summer and Winter

-Auckland offices

Group	Count		Rank Sum
Summer	27		598.5
Winter	19		482
Mann-Whitney U test statistics		=	220.5
Probability is		**0.422**	

Wellington offices

Group	Count		Rank Sum
Summer	19		478
Winter	27		603
Mann-Whitney U test statistics		=	288
Probability is		**0.478**	

C.6 Indoor /outdoor fungal ratio in Summer and Winter

-Auckland offices

Group	Count		Rank Sum
Summer	27		645
Winter	19		436
Mann-Whitney U test statistics		=	267
Probability is		**0.815**	

-Wellington offices

Group	Count		Rank Sum
Summer	20		542
Winter	27		585
Mann-Whitney U test statistics		=	332
Probability is		**0.176**	

C.7 Indoor /outdoor bacterial ratio in Auckland and Wellington

-Summer

Group	Count		Rank Sum
Summer	27		581
Winter	19		499
Mann-Whitney U test statistics		=	203.5
Probability is		**0.237**	

-Winter

Group	Count		Rank Sum
Summer	19		487
Winter	27		593
Mann-Whitney U test statistics		=	297.5
Probability is		**0.353**	

C.8 Indoor/outdoor fungal ratio in Auckland and Wellington offices

-Summer

Group	Count		Rank Sum
Summer	27		493.5
Winter	19		587.5
Mann-Whitney U test statistics		=	115.5
Probability is		**0.001**	

-Winter

Group	Count		Rank Sum
Summer	19		329
Winter	27		752
Mann-Whitney U test statistics		=	139
Probability is		**0.009**	

APPENDIX 6

SUMMARY OF STATISTICAL OUTPUTS OF MANN-WHITNEY TEST OF CHAPTER 6

APPENDIX 6

A- SUMMARY OF STATISTICAL OUTPUTS OF MANN-WHITNEY TEST OF CHAPTER 6

(The actual statistical outputs are presented in a separate report)

A-1 Indoor air temperature in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	53	2914.5
Non-complaint offices	2.0	40	1456.5
Mann-Whitney U test statistics			1483.50
Probability is		**0.001**	

A-2 Indoor relative humidity in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	52	2307.5
Non-complaint offices	2.0	40	1970.5
Mann-Whitney U test statistics			929.5
Probability is		**0.383**	

A-3 Indoor airborne bacteria in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	37	1603.00
Non-complaint offices	2.0	58	2957.00
Mann-Whitney U test statistics			900
Probability is		**0.186**	

A-4 Indoor airborne fungi in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	37	1988
Non-complaint offices	2.0	58	2572
Mann-Whitney U test statistics			1285
Probability is		**0.105**	

A-5 Indoor carbon dioxide in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	46	2194.5
Non-complaint offices	2.0	53	2755.5
Mann-Whitney U test statistics			1113.5
Probability is		**0.459**	

A-6 Outdoor airborne bacteria in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	41	1779.5
Non-complaint offices	2.0	58	3170.5
Mann-Whitney U test statistics			918
Probability is		**0.053**	

A-7 Outdoor airborne fungi in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	41	1628.5
Non-complaint offices	2.0	58	3321.5
Mann-Whitney U test statistics			767.5
Probability is		**0.003**	

A-8 Indoor/outdoor bacterial ratios in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	35	1831
Non-complaint offices	2.0	56	2355
Mann-Whitney U test statistics			1201
Probability is		**0.071**	

A-9 Indoor/outdoor fungal ratios in complaint and non-complaint offices

	Group	Count	Rank Sum
Complaint offices	1.0	35	2095
Non-complaint offices	2.0	56	2091
Mann-Whitney U test statistics			1465
Probability is		**0.000**	

APPENDIX 7

A- CARBON DIOXIDE LEVELS IN AUCKLAND OFFICES SURVEYED BY ESR AND ABS

B- CARBON DIOXIDE LEVELS IN AUCKLAND AND WELLINGTON OFFICES

C- COMPARISON BETWEEN OUTDOOR CLIMATIC CONDITIONS SUITABLE FOR FUNGAL GROWTH IN AUCKLAND AND WELLINGTON

D- INDOOR AIR TEMPERATURE AND INDOOR/OUTDOOR FUNGAL RATIOS (AS POSSIBLE CAUSES FOR COMPLAINTS-SEE CHAPTER 6) IN AUCKLAND AND WELLINGTON OFFICES AND IN OFFICES SURVEYED IN SUMMER AND WINTER

APPENDIX 7

A- CARBON DIOXIDE LEVELS IN AUCKLAND OFFICES SURVEYED BY ESR AND ABS

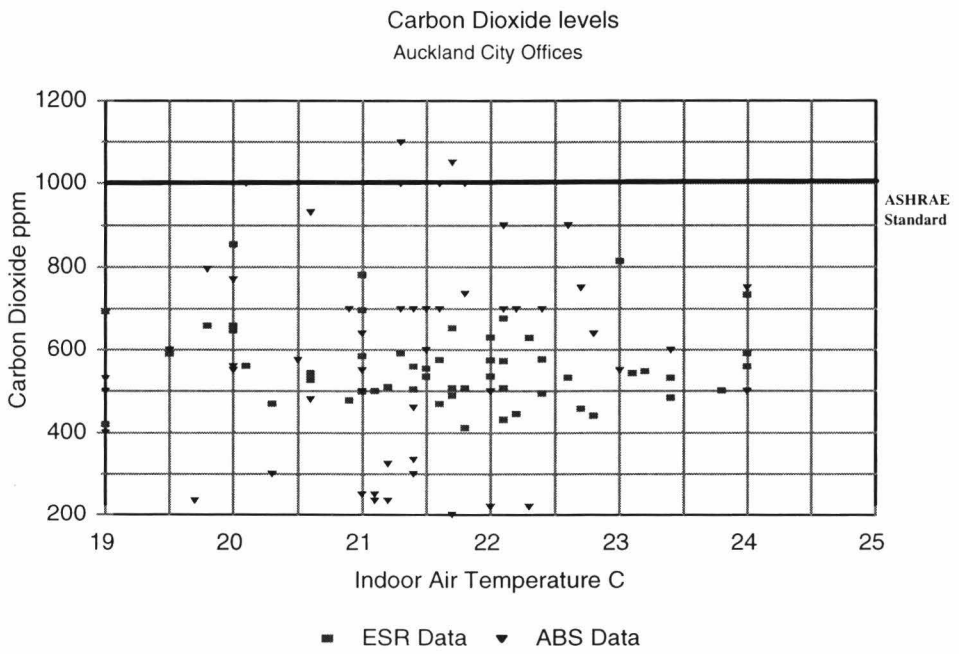


Figure A7.1: Carbon dioxide levels measured by ESR and ABS.

B- CARBON DIOXIDE LEVELS IN AUCKLAND AND WELLINGTON OFFICES

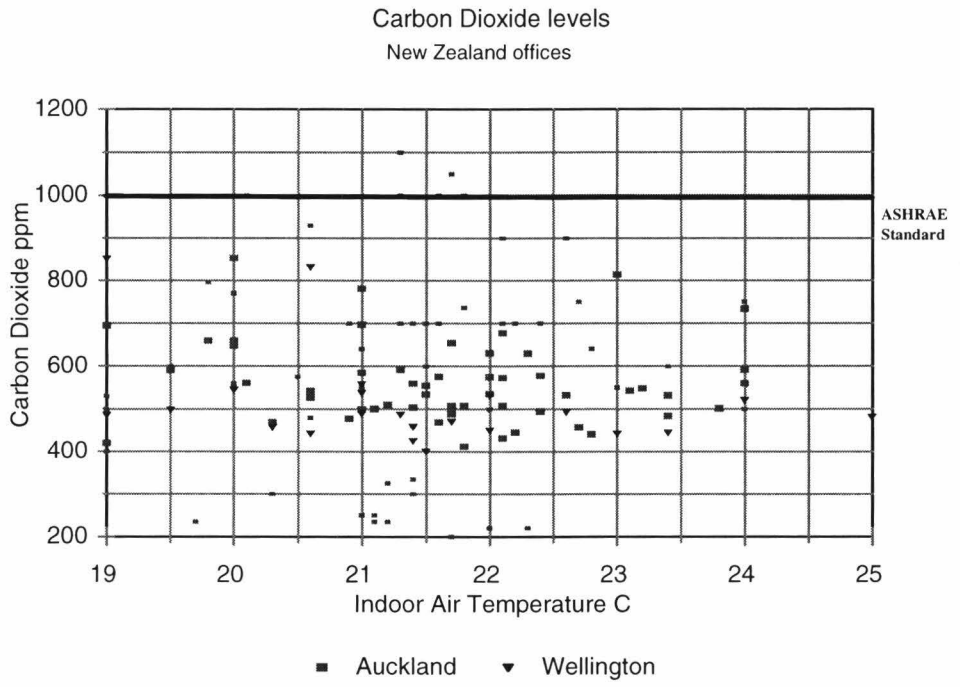


Figure A7.2: Carbon dioxide levels in Auckland and Wellington offices. No significant differences can be observed in carbon dioxide levels between Auckland and Wellington offices.

C- COMPARISON BETWEEN OUTDOOR CLIMATIC CONDITIONS SUITABLE FOR FUNGAL GROWTH [86] IN AUCKLAND AND WELLINGTON [87]

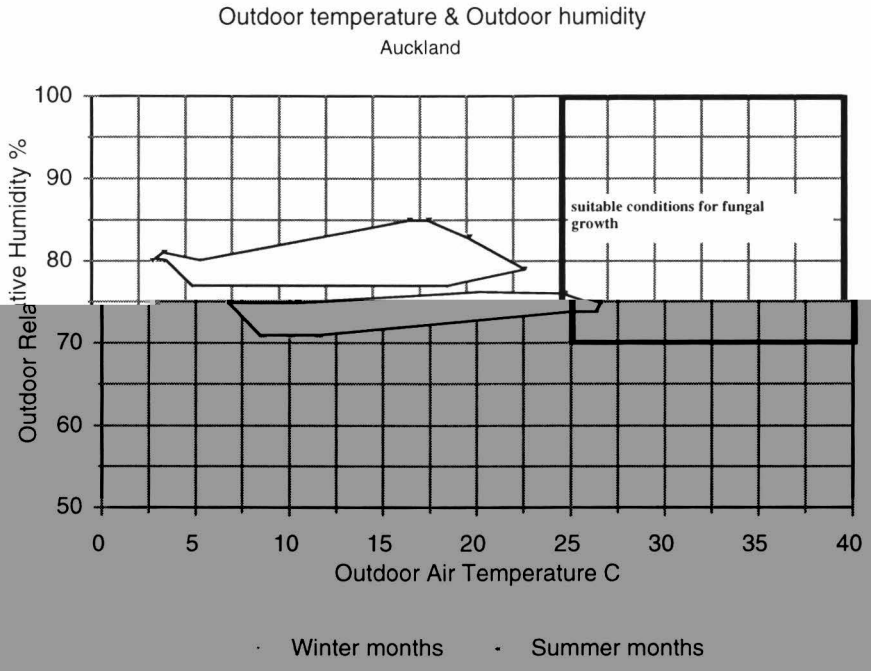


Figure A7.3: Outdoor fungal growth suitability in relation to outdoor air temperature and relative humidity in Auckland City. Limited period during summer might be suitable for fungal growth (Likely to cause elevated airborne fungal levels).

86 The conditions suitable for fungal growth according to Kalliokoski, Clarke and Skaret (references 4, 5 and 6 of Chapter 3) are air temperature above 25°C with relative humidity above 70%.

87 ESR and ABS did not measure outdoor air temperature and relative humidity. Therefore, outside climatic data was taken from the meteorological office records of the National Institute of Water and Atmospheric Research NIWA (see reference 2,3 and 4 of Chapter 4).

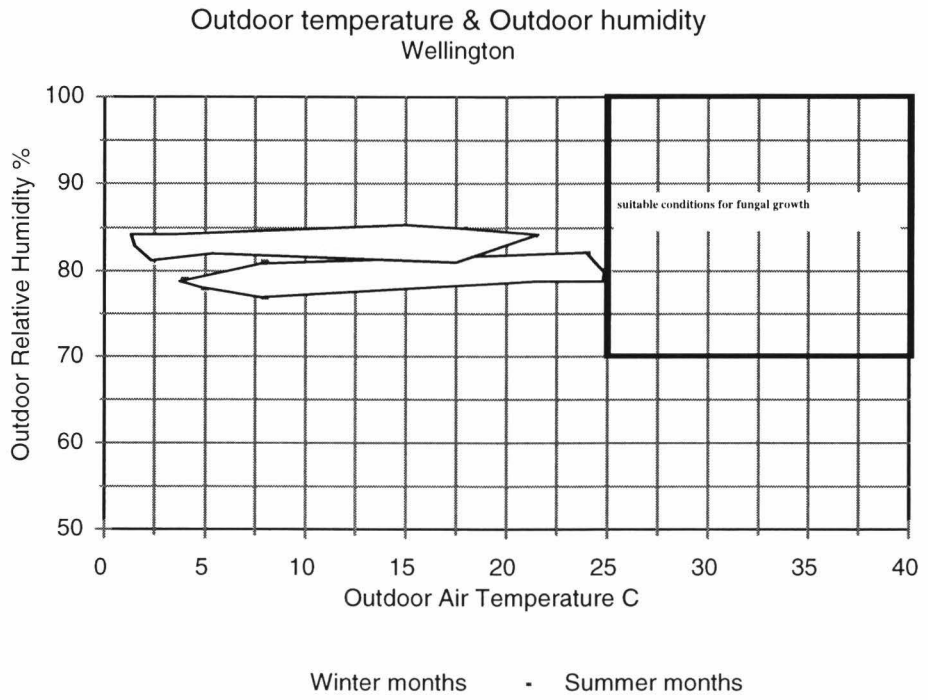


Figure A7.4: Outdoor fungal growth suitability in relation to outdoor air temperature and relative humidity in Wellington City. Summer and winter climatic conditions are unlikely to cause elevated fungal levels.

D- INDOOR AIR TEMPERATURE AND INDOOR/OUTDOOR FUNGAL RATIOS (AS POSSIBLE CAUSES FOR COMPLAINT-SEE CHAPTER 6) IN AUCKLAND AND WELLINGTON OFFICES AND IN OFFICES SURVEYED IN SUMMER AND WINTER

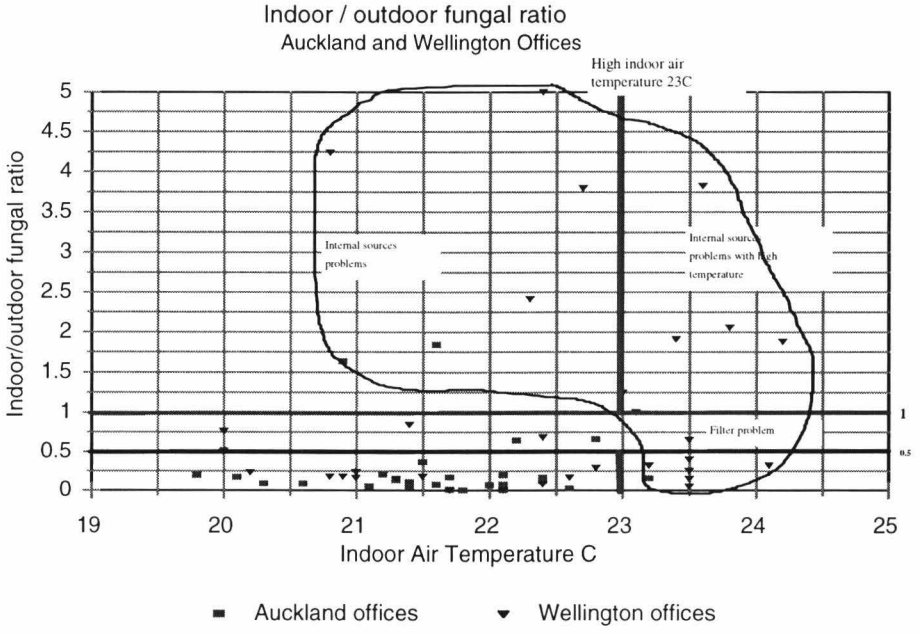


Figure A7.5: Indoor air temperature and indoor/outdoor fungal ratio as possible causes for complaints in Auckland and Wellington offices. Most records above either the indoor air temperature of 23°C or the fungal ratio of 0.5 or both were recorded in Wellington offices.

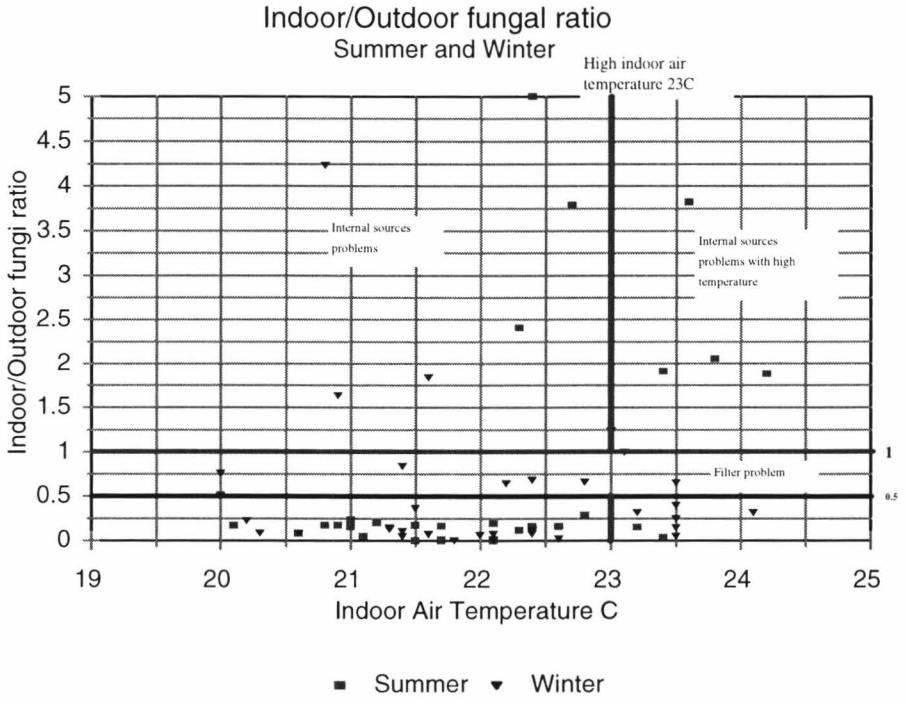


Figure A7.6: Indoor air temperature and indoor/outdoor fungal ratio as possible causes for complaints in offices surveyed in summer and winter