ENABLING CONTINUOUS COMMISSIONING THROUGH BUILDING MANAGEMENT SYSTEMS

BY

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A thesis

submitted to the Victoria University of Wellington

in fulfilment of the requirements for the degree of

Masters of Building Science

October 2018

Victoria University of Wellington

ABSTRACT

The use and application of energy efficient technologies within new and existing buildings is a growing global trend. However, if they aren't being commissioned, controlled and operated in an efficient way, are they really making a valid impact on the energy efficiency of our buildings?

Building Management Systems (BMS) are installed within large scale non-residential buildings to control and govern the operation of Heating Ventilation and Air-Conditioning systems (HVAC). BMS monitor and process large amounts of data during their day-to-day operation, while the potential usefulness of BMS to implement energy optimising strategies is typically left un-utilised. There is a growing need to reduce building energy demand. Continuous Commissioning (CCx) may offer the potential to achieve this reduction through the ongoing or periodical assessment of building HVAC operation. As CCx is a cyclic process, and because BMS already monitor and process data in their day-to-day operations, they offer a potential, low overhead means of running CCx processes in buildings. This thesis reports a research project which explores this opportunity to assess and improve building operating efficiency by identifying what data and functional capabilities are required of a BMS to facilitate Continuous Commissioning.

A systematic assessment of existing research and standards has highlighted a gap in industry knowledge on the specification of data required to implement CCx assessments to HVAC. There was also no definition of what BMS capabilities were important to the Continuous Commissioning process. These research gaps inspired five secondary research questions around which a mixed-method survey was developed and implemented to bridge the gap between BMS and CCx.

The research methodology integrated a standard questionnaire and the Delphi method to explore user perceptions and develop a consensus of BMS requirements. Three survey rounds were distributed to New Zealand based industry experts. Each round informed the following round, with an element of feedback provided through the compilation of the previous round's responses. This process enabled the industry experts to agree or disagree with the proposed consensus or provide an alternative insight to the questions asked.

The results of the surveys were compiled to establish a definition of the top five CCx assessments applied to typical HVAC systems, data point trending requirements and BMS functions important to facilitating Continuous Commissioning. These findings were used to create a guideline for specifying BMS to facilitate Continuous Commissioning and create a soft landing for assessing HVAC during the operation phase of a building's life. The outcome of this research bridges the gap between the specification of Building Management Systems and the requirements of the Continuous Commissioning process.

ACKNOWLEDGEMENTS

I would like to thank my research supervisor Dr. Michael Donn for his time and experience and additional support and guidance provided by Nigel Isaacs.

Thank you to Shaan Cory for being my Building Science mentor at work and throughout the development and completion of this thesis.

Thank you to all the participants who took part in this research, your contribution of knowledge and experience is invaluable.

Thank you to the Building Research Levy (BRANZ), and Victoria University of Wellington for providing financial assistance for this research.

Shout out to the Building Science Masters class of 2018. You guys made working at university fun and so much easier. Thank you to Beth Noble especially, for helping and supporting me with the completion of this thesis. Nick Forbes you are a legend.

Thank you to my Mum, Dad, Sister Emma and closest friends for your unconditional support throughout this long journey. I couldn't have done it without you.

Finally, thank you to my football family for sticking by me throughout the highs and lows, I couldn't be more grateful to have such amazing people in my life. You all mean the world to me. Oscar, Pirate, Jo, Michelle, Naomi, Sophie and Toni.

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LIST OF ACRONYMS AND ABBREVIATIONS

Relevant Organisations	
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BEES	Building Energy End-use Study
BRANZ	Building Research Association of New Zealand
CIBSE	Charted Institute of Building Services Engineers
EECA	Energy Efficiency and Conservation Authority of New Zealand
EMANZ	Energy Management Association of New Zealand
FMANZ	Facilities Management Association of New Zealand
NREL	National Renewable Energy Laboratory
PNNL	Pacific North-West National Laboratory
TAMU	Texas A&M University
Energy and Heating, Ventilation and Air-Conditioning Equipment	
HVAC	Heating, Ventilation, and Air Conditioning
AHU	Air Handling Unit
BMS	Building Management System
CO2	Carbon Dioxide
VAV	Variable Air Volume
CAV	Constant Air Volume
FCU	Fan Coil Unit
VSD	Variable Speed Drive
Energy Efficiency Improvement Processes	
FDD	Fault Detection and Diagnostics
CCx	Continuous Commissioning
RCx	Recommissioning

1 INTRODUCTION

The use and application of energy efficient technologies is a growing global trend. They are implemented to reduce the use of energy, not only to reduce Greenhouse Gas (GHG) emissions but to improve individual business profitability through reduced building operating costs. However, if these technologies are not correctly installed, commissioned and controlled in an efficient way, are they really making a valid impact on the energy efficiency of our buildings? This thesis acknowledges the importance of Building Management Systems (BMS) in monitoring and operating Heating, Ventilation and Air-Conditioning (HVAC) within commercial buildings. However, the literature review for this thesis has found the potential usefulness of BMS to implement energy optimising strategies is typically under-utilised. Continuous Commissioning (CCx) is a cyclic process used to identify faults and opportunities for implementing improved control strategies by assessing HVAC data trends. As BMS already monitor and process data in their day-to-day operations, they offer a potential, low overhead means of implementing CCx in existing buildings. The question is:

What is required of a Building Management System to facilitate Continuous Commissioning?

Buildings account for over 20% of global energy consumption, making them a significant contributor to greenhouse gas emissions (U.S. Energy Information Administration, 2016) (EIA). The EIA identifies the non-residential building sector to be “the fastest growing energy demand sector” with an average growth of 1.6% per year. In New Zealand, existing non-residential buildings consume approximately 16% of New Zealand’s total electricity consumption, 38% of which is attributed to Heating Ventilation and Air Conditioning (HVAC) (Amitrano et al., 2014). As more than 85% of the current building stock will still be in operation in the year 2050 (The Chartered Institute of Building, 2013), we must consider how to improve their operating energy performance to reduce energy consumption and therefore reduce our greenhouse gas emissions.

It is typically assumed existing buildings have been commissioned on completion and continue to operate optimally. Fullbrook and Arnold (2007) investigated a best practice approach to building completion commissioning in New Zealand. The investigation was based on stakeholder perceptions. The primary issue reported was that commissioning is “often required to be compressed, and as a result is not done adequately”. Poor commissioning leads to poor building functionality, occupant dissatisfaction and lowered productivity due to a lack of measured performance (Grigg and Graves, 2004). If systems are not adequately reviewed or monitored to measure performance following a building’s practical completion, they are likely to be operating inefficiently causing unnecessary energy consumption and escalated operating costs.

Building energy efficiency performance can be measured as the achievement of occupant satisfaction, while performing as efficiently as possible. It is estimated that the cost of a building's design and construction accounts for 25% of the lifecycle cost, while the remaining 75% is attributed to building operation (Moore, 2014). While it is important to ensure new buildings are *designed* to perform in an energy efficient manner, there is often a large performance gap between anticipated energy performance and how they actually perform in operation (Menezes, 2012).

BMS are standard practice within large non-residential buildings (Lewry, 2014). Their primary purpose is to meet the specified indoor air quality and thermal comfort needs of building occupants, while the potential usefulness of BMS to improve energy efficient operation is typically left under-utilised. By ensuring HVAC systems operate as efficiently as possible, reduction in both energy consumption and operational costs can be achieved.

Continuous Commissioning is a process that looks to resolve the energy performance gap through the continuous monitoring of building HVAC performance, integrating fault detection and diagnostics (FDD)[1], energy efficiency and occupant satisfaction. Continuous Commissioning requires HVAC operating trends to identify faults and opportunities for improved control strategies. BMS monitor and process data in their day-to-day operations, offering a potential, low overhead means of implementing CCx in existing buildings.

This thesis explores the opportunity and barriers to assessing and improving building operation efficiency by utilising BMS through Continuous Commissioning (CCx). In particular, it looks to obtain feedback from experienced practitioners on the role and requirements of BMS to facilitate the CCx process.

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[1] FDD is a data analysis technique which applies rule-based assessments to detect and diagnose HVAC operating faults and inefficiencies PINHO, A. 2015. Analytics of building management systems for improved energy & plant performance. *CIBSE Technical Symposium 2015.*

1.1 THE ENERGY PERFORMANCE GAP

"Buildings do not perform as well as anticipated at design stage".

— Anna Menezes, CIBSE Energy Performance Group, 2012

PROBE studies (Post Occupancy Review of Buildings and their Engineering) provide evidence that buildings typically consume between two to five times more energy than predicted (Menezes, 2012). They are not operating as efficiently as they should be or could be. This is the building energy performance gap. Continuous Commissioning and BMS data could offer a potential solution for overcoming the energy performance gap.

The Carbon Trust, a global leader in carbon reduction strategies, used the data from several PROBE studies to identify key contributors to the energy performance gap (The Carbon Trust, 2011). Some of the key contributors identified by the Carbon Trust as causing buildings to consume up to five times more energy than anticipated during their operating phase:

- Complex building controls and HVAC systems.
- Discrepancies between HVAC system design specifications and as-built.
- Inadequate commissioning.
- Insufficient means of measuring and managing the performance of building systems in operation.
- Designers and contractors are not involved post building completion.
- The building is not operated properly by facility management teams.

The key causes of the discrepancy between predicted and actual energy consumption listed above can be summarised as poor handover between building completion and operation. This leads to inefficient building operation, excess energy consumption, escalated operating costs and unnecessary carbon emissions. Bunn et al. (2014) recognised the need to improve building handover from design to operation, leading to the development of the "Soft Landings Framework" (SLF), as a way to reduce the energy performance gap. The SLF aims to incorporate post-occupancy building stakeholders such as facility managers and building energy managers into building design and construction phases, to ensure their requirements will be met upon building completion (Bunn et al., 2014). Continuous Commissioning, while not a specific component of the SLF, would benefit from the same principles as the SLF. For example, during the building design and construction phases, to ensure the required data is available and accessible on building completion.

1.2 A POTENTIAL SOLUTION: CONTINUOUS COMMISSIONING

"An ongoing process to resolve operating problems, improve comfort, and optimize energy use for existing commercial and institutional buildings and central plant facilities."

— David Claridge, *(Texas A&M University Energy Systems Laboratory, 2018)*

Continuous Commissioning (CCx) is a building operation philosophy implemented to monitor and optimise building performance, specifically HVAC operation, with the aim of achieving continuous energy savings and occupant satisfaction during the operating phase of a building (Portland Energy Conservation, 2003). The Continuous Commissioning philosophy was first implemented in 1994 by Liu and Claridge (Liu et al., 2002). In the United States, Texas A&M University (TAMU) have established a specific form of this philosophy as a process, trademarked as Continuous Commissioning® (CC®)[2]. For simplicity this research thesis uses the term "Continuous Commissioning" (CCx), however, is not governed by the specific approach trademarked by TAMU.

For the purpose of this research CCx involves an ongoing or periodical application of parameter-based assessments to HVAC data trends[3] to detect faults and inefficiencies from which suitable optimisation strategies can be implemented. Under this definition, the term CCx may also be known as building tuning, system optimisation, monitoring and targeting, measurement and verification and FDD.

Continuous Commissioning aims to maintain the efficient performance of HVAC and energy savings achieved by re-commissioning through ongoing or high frequency assessments, as demonstrated in Figure 1.

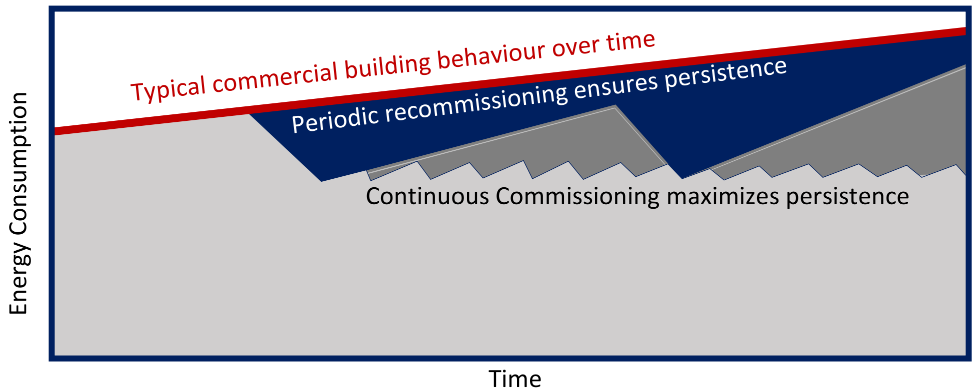

Figure 1: Energy savings from Continuous Commissioning (Energy Systems Laboratory, 2018)

[2] Continuous Commissioning® and CC® are registered trademarks of Texas A&M University's Energy Systems Laboratory.
[3] Data recorded at specified time intervals and stored for a period of time.

A 2004 US study carried out a cost benefit analysis of 150 existing buildings to find an average of 15% of annual energy savings could be achieved through an effective re-commissioning procedure (Mills et al., 2004). This figure is comparable to the claim by the World Business Council for Sustainable Development (WBCSD) that up to 15% energy savings can be achieved by assessing the feedback performance of HVAC equipment within BMS. In New Zealand, the Building Energy End-Use Study (BEES) concluded a similar proportion of energy savings could be achieved through increased monitoring, management and maintenance of HVAC in New Zealand's non-residential building stock (Amitrano et al., 2014).

From the literature in this field, (Liu et al., 2002; Katipamula and Brambley, 2008; McManus, 2009), it is possible to break Continuous Commissioning into six defined stages of a cyclic process, stage six being followed by a repetition of stage one and so on (Table 1). Continuous Commissioning requires trend data in order for assessments to be carried out and energy saving strategies to be implemented. Building Management Systems are potentially an important tool in this process as they have the ability to monitor and record the HVAC data required for CCx.

***Table 1: Typical Continuous Commissioning Process*[4]**

Continuous Commissioning Stage		Description
1	**Monitor HVAC Operation**	Ensure the required data is monitored and stored.
2	**Extract Data**	Extract the data from the BMS.
3	**Process Data**	Process the data into a usable form to apply CCx Assessments.
4	**Analyse and Report**	Assess the data against control strategies or CCx Assessments.
5	**Implement Control Strategies**	Implement performance improvements through control parameters.
6	**Measure and Verify**	Measured and verify the improvement strategies through the assessment of energy consumption and new HVAC operating trends.

[4] A typical Continuous Commissioning process was defined based on the similarities of multiple resources which reported on ongoing commissioning methods aiming to improve the operating energy performance of buildings (Liu et al., 2002; Katipamula and Brambley, 2008; McManus, 2009).

1.3 THE BRAIN OF BUILDINGS: BUILDING MANAGEMENT SYSTEMS

"Cost effective savings are often possible by making better use of existing plant and equipment."

- **(Energy Efficiency and Conservation Authority, 2017)**

In addition to the 15% energy savings estimate, the WBCSD stated that they did not have sufficient evidence that building decision-makers are implementing BMS effectively, suggesting there is a BMS performance gap (World Business Council for Sustainable Development, 2009). Weinschenk reiterates this issue, stating there is a large gap in research between what experts claim in regards to the effectiveness of BMS and what is actually happening in practice in regards to energy management (Weinschenk, 2015). This BMS performance gap suggests there are barriers to the effective implementation and use of BMS in the achievement of energy savings.

For the purpose of this research the term BMS is used to encompass all building energy, control and monitoring systems, such as Building Automation Systems (BAS), Building Energy Management Systems (BEMS) and Building Automation and Control Systems (BACS). A range of literature recognises the interchangeability of the terms, including energy management researchers G. Levermore (1992), A. Lewry (2014), and building control manufacturers KMC Controls (2012).

Computerised Building Management Systems (BMS) are standard practice within large non-residential buildings (Lewry, 2014). BMS were first implemented in the early 1970s (Fawkes, 2001) as an improved management strategy for the increasing complexity of building services and to meet the need to control them (Sinopoli, 2012). In 1992, Levermore stated the development of BMS was enabled by computing revolution, progressively making BMS more accessible through improved efficiency, reduced equipment size and cost. This continues to be true today. As the development of BMS continues to progress, BMS could offer an opportunity for effectively providing data to the Continuous Commissioning process.

HVAC data is processed on a day to day basis by a BMS to determine the achievement of indoor environmental comfort, based on environmental sensor feedback. Trending and storing the data that a BMS collects can be used to assess the performance of HVAC operation against operating parameters and control strategies to identify the potential for energy savings. BMS are an existing source of data therefore they offer a low capital cost opportunity to identify potential areas for energy and cost savings.

Makarechi and Kangari compare the importance of a BMS in a large non-residential building to the brain in a living organism, highlighting their common ability to control, record and store data within a central network (Makarechi and Kangari, 2011). The components of a BMS can be categorised within a three-tier structure. The first tier consists of physical equipment such as heating and cooling plant, system actuators and environmental sensors, much like organs in the body. The second tier is the infrastructure network including communication protocols and wiring networks (KMC Controls, 2012). This is comparable to an organism's nervous system. The final tier is the software interface level, enabling the input of control strategies and operating parameters much like a conscious brain. The software interface provides facility managers and contractors with the ability to make operating changes, check space temperatures and identify faults in equipment operation through the monitoring and trending of HVAC operation.

1.4 RESEARCH OVERVIEW

What is required of a BMS to facilitate Continuous Commissioning?

In order to understand the actual potential of Building Management Systems (BMS) to contribute to Continuous Commissioning (CCx), this thesis looked to draw from the experience of CCx professionals. The goal was to draw on their understanding of HVAC systems, and current BMS capabilities to form a picture of the type of data that could and should be collected by BMS to facilitate CCx. It also sought to understand what functionality might be required of BMS in order to present the data needed in a form suitable for CCx. As a result, the research aim became more focused:

This thesis aims to specify the data and functional capabilities required of a BMS to facilitate Continuous Commissioning.

1.4.1 SCOPE OF RESEARCH

This thesis focuses on the opportunity to improve the energy performance of non-residential buildings containing Building Management Systems, through the application of Continuous Commissioning, assessing the operation of HVAC systems. It is likely the results of this research will be of relevance to larger non-residential buildings as the extent and complexity of HVAC in larger buildings requires a central control system (BMS).

The research is implemented in New Zealand, most applicable to buildings larger than 3500m^2. The BEES (2014) study revealed that these buildings represent approximately 40% of the total floor are in New Zealand. Because these are larger buildings, they are typically constructed using centralised HVAC systems and BMS that are manufactured for an international market. The implications of carrying out the research in New Zealand in regards to the international applicability of the research conclusions, are dealt with in section 3.5.1.

This research does not go into detail about how Continuous Commissioning is carried out, but the way in which BMS facilitate this process through the data and functional capabilities they could provide. The data and functional capabilities are explored at a high level such as defining what would ideally be provided by BMS, not how they are specifically coded or programmed within BMS.

Research has identified a significant gap in knowledge. They have highlighted BMS have the potential to provide the information that CCx practitioners need to achieve up to 15% savings in annual energy use in non-residential buildings (World Business Council for Sustainable Development, 2009). They have also noted that these types of buildings represent a large fraction of global energy use (EIA, 2016). What they have not identified is how well the data gathering and analysis capabilities of current BMS systems match the needs of CCx. This thesis aims to fill this gap by asking CCx practitioners to assess current BMS and their future capabilities. From the outset, it was hoped that from this research it would be feasible to construct a specification for future BMS outlining the data collection and functional capabilities required of a BMS to facilitate Continuous Commissioning.

2 SYSTEMATIC LITERATURE REVIEW

A systematic literature review was carried out to ensure the process of collecting, assessing and quality assuring the investigated literature, was credible and repeatable for use in future research (Boland et al., 2014). This chapter is split into two key sections, the first section summarises the systematic process and the second section reports on the key findings from literature. For the purpose of this thesis the term literature includes peer reviewed publications, such as theses, journal articles and conference papers, and industry publications such as standards, reports, specifications and guidelines.

The primary aim of the systematic literature review was to identify any existing research or industry literature on the role and requirements of BMS within the Continuous Commissioning process. By situating the initial research question within existing literature "*What is required of a BMS to facilitate Continuous Commissioning";* secondary research questions and objectives could then be developed. The systematic literature review presents *current* theory with an industry context required to design a primary research methodology of greatest relevance to international and national industry practice.

2.1 SYSTEMATIC LITERATURE REVIEW PROCESS

The systematic review process applied to this study was adapted from Boland et al.'s book 'Doing a Systematic Review' (Figure 2). A rigorous searching and screening protocol was developed to find literature relevant to the research question through online databases (section 2.1.3). The literature was then assessed in more detail, ranked by relevance and assessed for credibility through a quality assessment procedure. The details of each stage of the process are provided in the subsections to follow.

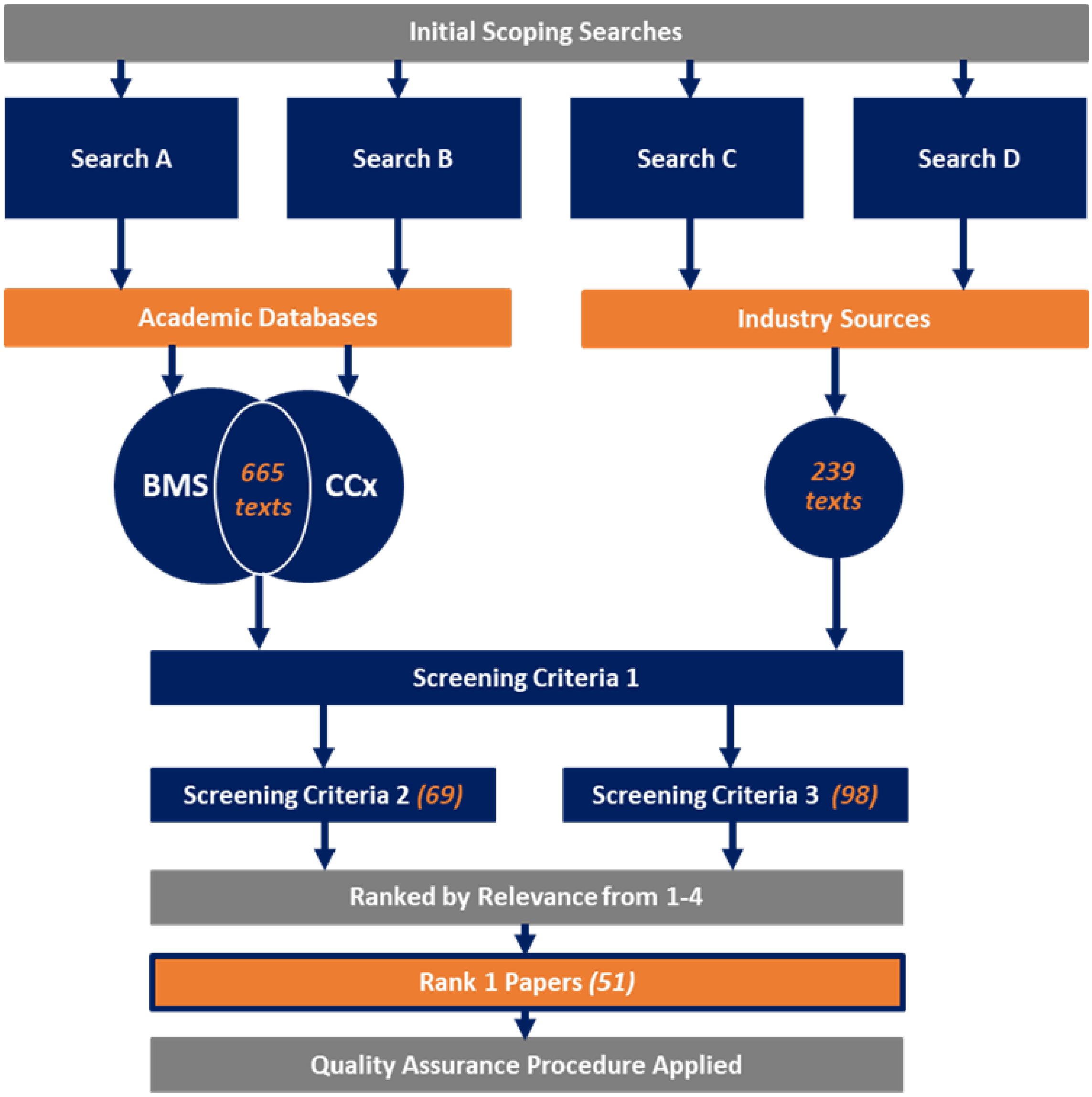

Figure 2: Systematic Literature Searching and Screening Process (adapted from (Boland et al., 2014))

2.1.1 INITIAL SCOPING SEARCHES

Initial scoping searches were used to identify what specific inclusion and exclusion parameters were required for the refined search protocol. Two key phrases, "Building Management System" and "Continuous Commissioning", based off the initial research question, were used as search terms for the initial scoping search. Through the scoping searches, it was quickly identified that all variations of the term BMS such as "Building Automation System", would be required to ensure all research carried out on building monitoring and control systems were included in the resulting literature despite a variation in terminology. Variations of the Continuous Commissioning process such as "recommissioning" or "retro-commissioning" were also required, as while these processes may not be ongoing or periodical, the concept of achieving occupant satisfaction and improving energy efficiency remain the same.

The scoping search phrases were combined with the Boolean connector "AND" as presented in Table 2's keyword inclusions. This search was initially applied to two large online academic databases (Science Direct and Scopus) to gauge the type of literature and the number of responses resulting from the two search phrases. The number of texts resulting from the search terms found in either the title, abstract or keywords was limited, while the search terms found in any field were numerous. It should be noted that approximately half of all resulting texts found in any field were published within the past five years, reflecting the novelty of research in this area. The number and variation of literature results returned by the scoping search terms found in any field made it clear the search protocol needed to be more specific based on inclusion and exclusion parameters.

No publication date restriction was applied to the initial scoping searches, however limiting the publication timeframe in the search protocol to the past ten years was considered as a way to narrow the number of resulting texts. The relevance of research prior to the past ten years was also expected to be limited due to the technological progression of BMS (Donnelly, 2012). Therefore, the search protocol was restricted to a publication period of 2007-2018. However, any research referenced within the resulting publications prior to this time period and considered relevant and applicable to the research question as deemed by the researcher, were also included for assessment. Table 2 summarises the findings of the initial scoping searches and describes the reasoning for inclusion and exclusion parameters to be developed for the final search protocol.

Table 2: Search Protocol Development Summary

Parameter	Initial Scoping Search	Search Protocol Inclusion/Exclusion	Reasoning for Inclusion
Publication Date	No date restriction; Past five years observation	Limited to the past 12 years (2007-2018)	The majority of resulting research was identified within the past twelve years and any research prior to this was considered outdated, unless specifically referred to by texts resulting from the search protocol and deemed relevant to the research question.
Search Term Fields	Title, Abstract, Keywords;	Any Field	Literature resulting from search terms to found only the Title, Abstract or Keywords was limited, by searching any field, search results increased and the detection of non-relevant texts were excluded through the screening criteria later applied.
Keyword Inclusions and Exclusions	(“Building Management System” OR "Building automation system" OR "building control system" OR "energy management system") AND ("commissioning" OR "recommissioning" OR "re-commissioning" OR "retro-commissioning" OR "Continuous Commissioning") No keyword exclusions.	‘Building’ AND ‘HVAC’ AND ‘Energy’ AND ‘Data’ AND (“Building Management System” OR "Building automation system" OR "building control system" OR "energy management system") AND NOT House AND NOT Home ‘Building’ AND ‘HVAC’ AND ‘Data’ AND ‘Energy’ AND ("commissioning" OR "recommissioning" OR "re-commissioning" OR "retro-commissioning" OR "Continuous Commissioning") AND (‘Procedure’ OR ‘process’) AND NOT House AND NOT Home	More specific search terms were required to focus the resulting texts on commissioning processes which aim to reduce energy consumption through the use of HVAC operating data. As the search protocol became longer and more complex some website had the limitation of a number of Boolean search terms, therefore it was decided the BMS and CCx searches would be carried out individually as presented. Any duplicates of texts identified across both searches could then be identified as containing both. The scope of this research looks at the application and use of BMS within non-residential buildings.
Search Engines	Academic Databases	Academic databases and industry websites (refer to section 2.1.3)	The range of search engines was expanded to include relevant industry websites to optimise the inclusion of industry specific research and reports.

2.1.2 REFINED SEARCH PROTOCOL

The inclusion of industry websites as literature search engines required a manual adaption of the two search protocol phrases presented in Table 2, due to the limitations of typical website search bars unable to interpret Boolean connectors. Due to the limitation of industry websites combined with the limited number of Boolean connectors allowed on some academic databases, four search phrases were established as presented in Table 3.

Search A and Search B were applied to a range of multi-disciplinary academic databases (presented in Table 4). Where duplicates were found across searches A and B, the publications could be identified as containing relevant information on BMS in association with CCx processes. Search C and Search D were applied individually within industry websites, depending on the limitations of the search engines. Once the resulting texts from each search phrase were collected, additional screening criteria were then applied, following the process shown in Figure 2.

Table 3: Final Literature Search Protocols

Search Phrase	Search Engine Application	Search Type	Search Protocol
Search A	Research Databases, Google Scholar	Automatic	‘Building’ AND ‘HVAC’ AND ‘Energy’ AND ‘Data’ AND (“Building Management System” OR "Building automation system" OR "building control system" OR "energy management system") NOT house NOT home
Search B	Research Databases, Google Scholar	Automatic	‘Building’ AND ‘HVAC’ AND ‘Data’ AND ‘Energy’ AND ("commissioning" OR "recommissioning" OR "re-commissioning" OR "retro-commissioning" OR "Continuous Commissioning") AND (‘Procedure’ OR ‘process’) NOT house NOT home
Search C	Industry Websites: where Boolean Connectors could be used	Automatic	(“Building Management System” OR "Building automation system" OR "building control system" OR "energy management system") AND data AND ("commissioning" OR "recommissioning" OR "re-commissioning" OR "retro-commissioning" *OR "Continuous Commissioning")*
Search D	Industry Websites: Online Magazines, Conference Topics	Manual Screening of Titles and Abstracts	“Building Management System” (including variations) OR “Data” NOT “Data Centres” OR “Commissioning” (including variations)

2.1.3 DATABASES AND SEARCH ENGINES

The academic databases and industry websites used to find literature are presented in Table 4. For a detailed summary on the number of texts obtained from each source, refer to Appendix 10.1.1. An academic librarian was consulted to ensure there were no other academic databases which were likely to provide relevant papers in addition to the databases presented in Table 4. The librarian was satisfied that the databases and industry sources would encompass the most relevant and trustable citations for the research topic. The suggestion was made to consider engineering specific databases, however following an investigation of these, papers contained within these databases typically did not cover building related topics. The selection of academic databases presented in Table 4 are multidisciplinary, eliminating the need to utilise more databases.

New Zealand specific industry websites were included as part of the systematic literature review as it was anticipated that the research method to be carried out would be geographically restricted to New Zealand, due to the limited timeframe of Master's thesis research.

Table 4: Academic Databases and Industry Search Engines

Search Databases	
Academic Databases	Google Scholar
	ProQuest Dissertations and Theses Global
	ProQuest Science Journals
	SAGE Journals
	Science Direct
	Scopus
	Taylor and Francis Online
International Industry Websites	American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
	Chartered Institution of Building Services Engineers (CIBSE), UK
	Building Research Establishment (BRE), UK
	Facilities.Net
	American Council for an Energy-Efficient Economy (ACEEE)
New Zealand Websites	Building Research Association of New Zealand (BRANZ)
	Energy Management Association of New Zealand (EMANZ)
	Facilities Management Association of New Zealand (FMANZ)
	Energy Efficiency and Conservation Authority (EECA)

2.1.4 TITLE AND ABSTRACT SCREENING CRITERIA

Once literature had been obtained from the search engines and the duplicates across searches A and B were identified, the resulting texts underwent further screening criteria to apply additional inclusion and exclusion criteria to titles and abstracts (Table 5). Screening criteria one was applied to all resulting publications to exclude texts where the title contained keywords with limited relevance to the research question. Screening criteria two was then applied to the remaining academic papers to ensure the abstracts contained relevant keywords to further exclude papers which lacked specific relevance to the research topic.

An alternative screening criterion (screening criteria 3), was applied to industry website results as the literature resulting from these sources typically did not have an abstract, therefore the title, full text or summary descriptions were searched for the inclusions of all keywords.

Table 5: Title and Abstract Screening Criteria

Screening Stage	Application	Screening Type	Screening Criteria
Screening Criteria 1	All search results	Title Exclusions	“Lighting”, “Solar”, “Simulation”, “Renewable”, “Ocean Engineering”, “Pumps”, “Geothermal”, “Hotels”, “Hospitals”, “Data Centres”, “Energy Storage”, “Thermal Storage”, “Model”, “Virtual”, “Plumbing”, “Fire Systems”, “Refrigerant”
Screening Criteria 2	Academic Database Search Results	Abstract Inclusions	ANY Keywords to be included in Abstract: “Building” OR “HVAC” OR “Facility” ALL Keywords to be included in Abstract: “Data” AND “System” AND “Commission”
Screening Criteria 3	Industry Website Search Results	Any Field Inclusions	ALL Keywords to be included in any field: “Data” AND “System” AND “Commission”

2.1.5 RELEVANCE RANKING AND QUALITY ASSURANCE

While the search protocol was designed to identify the most relevant publications relating to the initial research question, the searching and screening criteria cannot assess the context of which the inclusion and exclusion terms are situated. Relevance ranking scores were applied to each publication remaining following the application of screening criteria (168). The four levels of relevance rankings presented in Table 6 were adapted from Bond and Acheson’s guide to writing a literature review (Bond and Acheson, 2017). The researcher determined 51 publications to have a relevance rank of one.

Table 6: Literature Relevance Rank Index

Rank	Description
1	Paper holds information directly relevant to the topic about the use of building data for commissioning processes.
2	Paper holds relevant information which supports the need for commissioning or improved energy performance. Suitable as background material.
3	Paper holds limited relevance to the research question, such as only offering peripheral information.
4	Paper holds no relevance to the research question despite promising title or abstract.

During the ranking of relevance of papers, each text could be categorised as a type of document, containing specific themes relating to the research question. The key themes included the role of BMS within the CCx process, the need for quality data and the limitations of BMS within the CCx process. In order to best report these themes across the CCx process, the assessment of literature is broken down into the stages of the CCx process, followed by an assessment of relevant guidelines and specifications (section 2.2).

Each publication with a rank of one was assessed for credibility against weighted quality characteristics. The quality characteristics can be categorised into four quality assurance checks; Author bias, funding bias, whether evidence is provided and the level of peer review.

The quality assurance procedure was not about excluding papers, but to acknowledge their credibility regarding their level of peer review and potential bias. For example, if the author or publishing organisation had the potential to benefit from the presented results, the publication is seen as less credible than a journal paper which has undergone an academic peer-review. Refer to Appendix 10.1.2 for the quality assurance scoring matrix.

2.1.6 LIMITATIONS OF THE SYSTEMATIC SEARCH PROCEDURE

While it is inevitable to not find every relevant publication relating to the research question, the systematic search procedure aims to reduce the likelihood of relevant literature being missed by documenting the systematic process to allow search changes to be made easily. In cases where the full texts of relevant resources were inaccessible, particularly some standards, where appropriate, descriptions of these texts have been used to assign relevance, however the assessment of such texts is limited.

A single researcher carried out the systematic review as effectively as possible. In future, to add additional rigour to this systematic process, multiple researchers could follow the same systematic procedure and assessment of texts in order to minimise any potential bias unintentionally applied by a single researcher.

2.2 ASSESSMENT OF LITERATURE

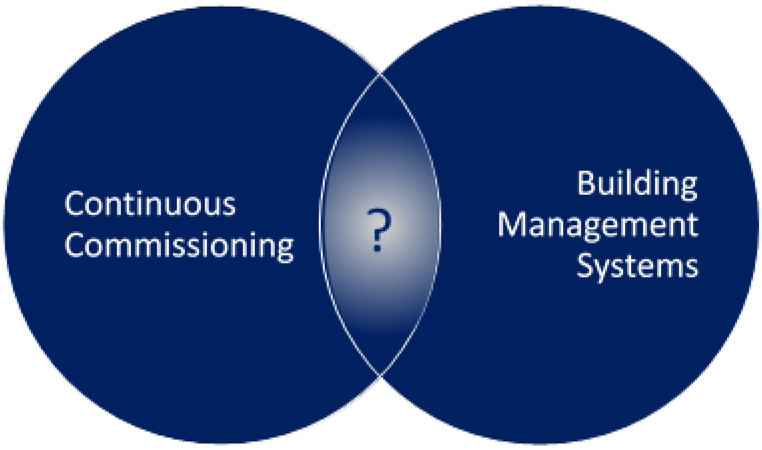

Figure 3: Exploring the research gap within literature:

What is required of a BMS to facilitate Continuous Commissioning?

The aim of the literature review was to establish whether any publications report on the relationship between Continuous Commissioning (CCx) and Building Management Systems (BMS), more specifically the role and requirements of BMS within the CCx process. The benefits of Continuous Commissioning have been widely investigated (McManus, 2009; Keuhn and Mardikar, 2013; Thomson and Roose, 2017; Hart, 2012), as well as the hurdles encountered through its implementation (Lee et al., 2007; Salsbury, 2005; Hung, 2010). It is also frequently noted that the success of Continuous Commissioning is dependent on the quality of data available (Cheng, 2016; Visier and Buswell, 2010; Choiniere, 2008). While many citations report on the importance of quality data and identify BMS as the source of this data, few citations directly report on the specific requirements of BMS within the CCx process.

This assessment of literature explores how BMS are used within CCx processes and some of the barriers BMS present, in order to highlight what capabilities of BMS might be important to facilitating this process. While few papers report directly on the initial research question, the content of relevant papers identified from the systematic procedure could be categorised to report the role of BMS at each stage of a typical CCx process and any hurdles relating to BMS encountered through the implementation of CCx. This chapter concludes with an assessment of BMS requirements for CCx within existing standards, guidelines and specifications to optimise the applicability of the research to industry.

2.2.1 BMS AND BARRIERS WITHIN THE CONTINUOUS COMMISSIONING PROCESS

There is no prescribed Continuous Commissioning process, however, six definitive stages (Figure 4) can be established based on the similarities of CCx process steps recognised within literature (Liu et al., 2002; Katipamula and Brambley, 2008; McManus, 2009; Garr et al., 2012). CCx involves the monitoring, extraction, processing and analysis of building operation data, to apply energy optimising strategies which are measured to verify improvements in building energy performance.

While there are clear similarities across CCx processes, Friedman and Piette (2001) report there is little overlap in the current tools used to implement CCx assessments. Keuhn and Mardikar (2013) state CCx processes typically involve the use of an external tool, ranging from spreadsheets to bespoke software which assess trend data for inefficient operation. CCx tools typically account for the processing of raw data trends and the application of CCx assessments which assess data against an optimal sequence of operation (Keuhn and Mardikar, 2013).

Each stage of the CCx process presented in Figure 4 are discussed in the sub-sections to follow, reporting on the role of BMS and hurdles encountered at each stage, as reported by literature. The question was posed: *at what stages of the Continuous Commissioning process are BMS most important and are BMS meeting the needs of continuous commissioners?*

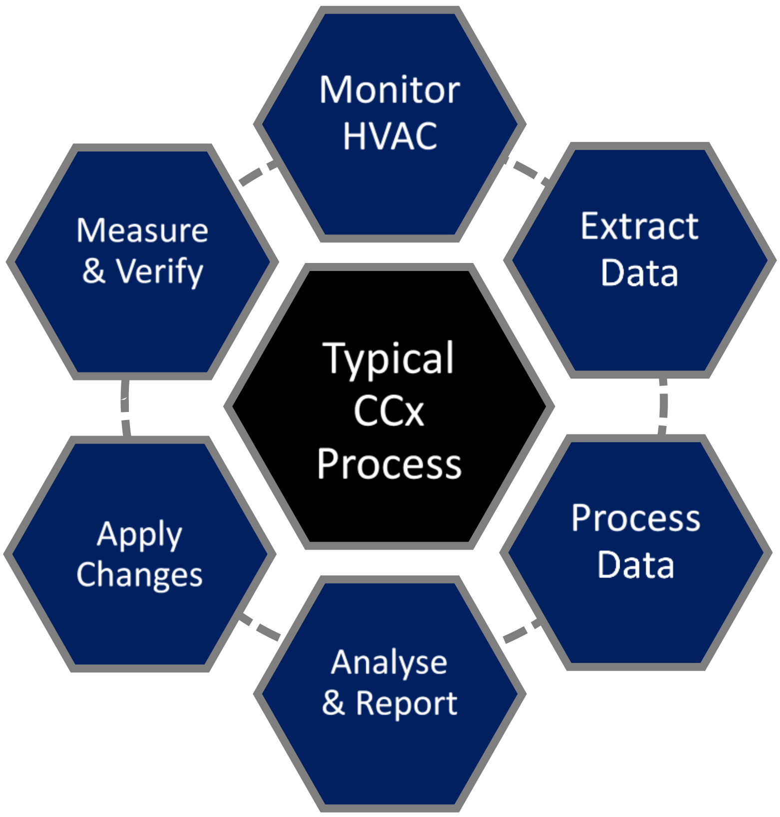

Figure 4: Typical Continuous Commissioning Process Stages

2.2.1.1 Monitoring HVAC Operation

The CCx process begins with the monitoring and trending (recording and storage) of Heating, Ventilation and Air-conditioning (HVAC) operation data and indoor environmental performance data (Ahmad et al., 2016). The CCx process relies on real data to assess building operating performance. HVAC operation data might include equipment status (on/off), operating speeds (%) and valve positions (%), while indoor environmental data typically includes space temperature (°C), relative humidity (%) and air quality (CO_2) (Liu et al., 2013). BMS monitor and process data on a day to day basis, making it the primary source of the data needed for CCx, however BMS are not typically set up to record and store data for the future use to assess building operating performance (Hart, 2012). As a result of this, the initial implementation of a Continuous Commissioning process or tool is often the most time, effort and cost intensive stage of CCx (Hart, 2012).

During the initial implementation of CCx, continuous commissioners require an understanding of the HVAC systems being monitored and controlled by the BMS to appropriately select and implement CCx assessments. Djuric et al. acknowledge the lack of consistency across building and HVAC system documentation, resulting in misconceptions of the data potentially available or trend-able within a BMS. This is noted as a discouraging factor to the implementation of CCx due to the initial investment of time and money required to set up CCx (Djuric et al., 2012).

A reoccurring finding within literature is the lack of consideration of post-occupancy building performance analyses during the design and construction phases (Bunn et al., 2014; Djuric et al., 2012; Lietz, 2007). This is a likely cause of the large upfront investment of time and money in setting up CCx. Lietz (2007) reports on the lessons learnt from ten sustainable buildings. One of the greatest lessons learnt was that the performance of a building and the ability to assess post-occupancy performance relies on design decisions and system specifications employed throughout a new building's development and construction. Lietz (2007) specifically refers to operation and maintenance (O&M) manuals being overlooked, as well as user-friendly BMS being lost in cost cutting processes. Each of these items contribute to the need for retrospective tools and documentation in order to assess post-occupancy building performance. Lietz (2007) states, these reviews can only be based on the data available, "which sometimes is too little".

In 2010, a study was carried out in Hong Kong on barriers to the application of FDD to HVAC. Researcher Lee Hung identified two of the key technical barriers to be missing data points and insufficient data storage. These barriers were reflected in the assessment of a chiller system, of which not all assessments could be applied due to the unavailability of data in the BMS (Hung, 2010). A general assumption is made that if a building has a BMS, CCx can be carried out, however such as this example conveys is not necessarily the case.

Multiple papers report the limited reliability of BMS due inconsistent control logic, sensor calibration and hardware faults (Cutler et al., 2016; Hung, 2010; Ahmad et al., 2016). Limited reliability of BMS may result in limited access to data and limited credibility of the diagnostics applied to the data. As Jimmieson (2016) states “garbage in, garbage out”.

Keuhn and Mardikar (2013) and Heller and Baylon (2008) also report accessing the required data to implement CCx assessments as the greatest hurdle within the CCx process. Keuhn and Mardikar (2013) state a lack of integration of all systems and data points within the BMS, leading to the addition of temporary data loggers to obtain the data needed to assess HVAC. While this provided a temporary solution, it was noted that permanent data loggers were required for implementing CCx long term (Keuhn and Mardikar, 2013). Heller and Baylon (2008) stated the limited capability of the BMS to record and store data lead to increased time and cost at the initial implementation stage of CCx. This raises the question: *what data should be trended by BMS to facilitate CCx?*

Based on this analysis, the two greatest hurdles encountered during the initial set up phase of CCx, specifically data monitoring, is the lack of documentation available on HVAC systems and the BMS not being reliable to provide the data needed for assessment. Literature highlighted the importance of access to HVAC system documentation for such as operation and maintenance manuals for setting up CCx (Lietz, 2007; Bunn et al., 2014; Djuric et al., 2012). However, there is limited to no reporting of this information being accessible within BMS, despite BMS being the central system for HVAC control and monitoring. This is suggestive of a way in which BMS could help to facilitate the CCx process by providing a centralised point for building operation documentation.

2.2.1.2 DATA EXTRACTION, DATA PROCESSING AND ANALYSIS AND REPORTING

The second, third and fourth steps in the CCx process: data extraction, data processing and analysis and reporting are easiest discussed together, as they are the provision of usable data trends from a BMS to a CCx tool where the data is typically assessed. As previously identified by Keuhn and Mardikar (2013), CCx processes typically involve the use of an external tool, ranging from spreadsheets to bespoke software which apply CCx assessments to trend data (Keuhn and Mardikar, 2013). Therefore, BMS data trends typically need to be extracted from the BMS in order to be assessed against optimal sequences of operation within CCx tools. In order for this data to be useful, it needs to be provided by the BMS in a suitable form.

Brambley and Katipamula (2009) present a case for the application of monitoring, analysis and diagnostic tools for monitoring-based commissioning. They highlight a key limitation of BMS, or Energy Management and Control Systems (EMCS), regarding the provision of data during the data extraction phase:

> *"Although most EMCS can trend and export data to files, the formats of trend logs vary from one EMCS to another. There is no standard for such output, and each EMCS vendor exports the data in a different format."*
>
> *- (Brambley and Katipamula, 2009)*

Brambley and Katipamula's research (2009) is suggestive that the inconsistency of data formats provided by BMS limits the ability to standardise and automate a CCx tool due to the need to process the data trends into a usable form. Cutler et al. (2016) look to overcome hurdles of the CCx process through the development of an automated data assessment tool. However, the specific data transfer between BMS and tool remains as a bespoke process due to the variances across BMS (Cutler et al., 2016). Friedman and Piette (2001) identified the need for further research into understanding the capabilities and limitations of BMS in providing the data required for CCx tools. The use of bespoke tools likely makes the specification of data crucial to the success of the CCx process. While initially thought, automated CCx tools would be more equipped to resolve and adapt to data inconsistencies, the literature suggests the same limitations of BMS are encountered by both manual and automated CCx processes (Friedman and Piette, 2001).

This raises the question: *are characteristics of CCx, such as level of automation influenced by the capabilities of a buildings BMS?* The limitation of BMS data exports is a commonly encountered hurdle during the implementation of CCx processes and tools (Choiniere, 2008; Cutler et al., 2016; Lee et al., 2007). This raises the question: *what data extraction capabilities of BMS are important to facilitating the CCx process?*

The fourth stage of the CCx process is the analysis and reporting stage. This is the stage at which CCx assessments are applied to data trends to assess areas for improved energy efficiency. CCx assessments may include the assessment of equipment operation data against occupancy schedules or indoor environmental performance indicators, such as temperature and air quality.

Garr et al. (2012), identify a lack of procedure for the analysis and interpretation of building energy and operation performance data. Many papers report on a bespoke CCx tool which have been developed to apply CCx assessments to building operation data trends, however the specific assessments applied are not transparent (Choiniere, 2008; Cutler et al., 2016; Lee et al., 2007). This raises the question: *What Continuous Commissioning assessments are typically applied to improve the energy efficiency of HVAC systems?*

Shalabi (2016) presents Building Information Modelling (BIM) as a potential tool for post occupancy building assessments. BIM models are continually developed throughout the design and construction phases of a building, as a centralised information database for design decisions. The paper suggest BIM is a solution for providing a centralised data repository and information database for facilities management, energy monitoring and potentially CCx (Al Shalabi, 2016). The specific data and information to be stored in a BIM model to facilitate post-occupancy performance reviews is not specified. *This raises the question what specific data is required to implement Continuous Commissioning?*

The Soft Landings Framework (SLF), states:

> "The frequency (of data logging) will depend on extent of sub-metering and provision of energy data gathering, monitoring and analysis software running on the Building Management System."
>
> *- (Bunn et al., 2014)*

It is understandable the data logging capabilities for a building are dependent on BMS software, however, if requirements of BMS capabilities were prescribed to ensure the minimum requirements for assessing post occupancy building performance were specified up front, some of the hurdles encountered throughout CCx implementation would be overcome. There are likely minimum requirements of data needed to assess environmental and energy performance, therefore data trending should not be dependent on software capabilities of BMS. Software capabilities of BMS should be designed to meet these requirements, not the other way around.

2.2.1.3 IMPLEMENTATION OF CONTROL IMPROVEMENTS

The fifth stage of the CCx process is the implementation of the improvement strategies identified through the analysis and reporting stage. As BMS are the central control system, improvement strategies identified through CCx assessments are typically implemented within the BMS.

Penney and Grosso identify the importance of BMS usability, for operation and maintenance personnel to be able to effectively implement efficiency improvement strategies (Penney and Grosso, 2014). In 1996, Lowry carried out an assessment of user-perceptions on Building Energy Management Systems, of which the usability of BMS scored relatively low (Lowry, 1996). While this study was carried out in 1996, some of the issues reported by more recent literature suggests the usability of BMS is still an issue, particularly for CCx. This is suggestive BMS are not necessarily designed or implemented for those who could or should use them.

Makarechi and Kangari carried out a study to identify the significant parameters defining building automation function and performance. Their study has proved that the scope and function of a BMS has changed over time and proved to be dependent on specific parameters (2011). The study involved an expert panel of 29 BMS experts including Building Commissioners, Network Engineers, Facility Managers and System Manufacturers. The resultant parameters include the categories; simplicity of learning and operating, integration with components, user needs, cost and availability of maintenance. These parameters are respectively ordered by experts based on the importance of the parameter. Makarechi and Kangari compared the frequency of citation of these parameters by experts to the frequency of citation within BMS literature, shown in Table 7. The comparison identifies a significant variance in frequency of citation for the simplicity parameter highlighted by Table 7. This conveys a gap in knowledge between what BMS experts identify as a crucial parameter and the available research which investigates this issue.

Table 7: BMS Performance Parameters (Makarechi and Kangari, 2011)

Performance Parameter	Expert Survey Ranking	Literature Search
Cost	M	M
User-Needs	H	M
Simplicity	H	L
Integration	H	H
Availability	L	L
Key: L= Low citation (1-9%) M= Medium citation (10-19%) H= High citation (20-31%)		

This finding reiterates the limited exploration of BMS usability (user-needs and simplicity), despite being considered important by experts. If some of the usability limitations of BMS were overcome, the implementation of control strategies could become an easier process. This raises the question: *what non-control capabilities of BMS are important to facilitating Continuous Commissioning and are BMS providing these capabilities at a satisfactory level?*

2.2.1.4 MEASUREMENT AND VERIFICATION

The sixth stage of Continuous Commissioning is the measurement and verification of energy savings achieved from the implementation of improved control strategies.

NABERSNZ, a post-occupancy energy efficiency rating is considered to be gaining momentum in New Zealand as the demand for energy efficient buildings increases. However, a lack of energy sub-metering within buildings is considered a large hurdle to the achievement of a NABERSNZ ratings, such as the base building and tenancy ratings (McGrath, 2015). Energy sub-metering also enables the effective measurement and verification of improvement strategies and energy savings in the CCx process, however, energy is typically metered via a designated system, not specifically within a

BMS (Donnelly, 2012). This raises the question: *would it be beneficial to the CCx process to access energy data within BMS, where all other data is monitored and typically stored?*

2.2.2 WHAT DO CONTINUOUS COMMISSIONING GUIDELINES SAY ABOUT BMS?

This section assesses international Continuous Commissioning and energy efficiency guidelines, identified through the systematic literature search, to understand the extent of which BMS requirements are reported for these processes. Each guideline has been analysed against the following criteria and is presented in Table 8.

Purpose: What is the purpose of the guideline?

BMS and Data Requirements: To what extent are BMS discussed and does the guideline identify the requirements of BMS to effectively implement CCx or energy efficient strategies? Does the guideline identify what data is needed to carry out certain energy efficiency assessments?

Table 8: BMS Content within Continuous Commissioning and Energy Efficiency Guidelines

ASHRAE/IES Standard 90.1-2014: Energy Standard for Buildings Except Low-Rise Residential Buildings	
Purpose	**"**To establish the minimum energy efficiency requirements of buildings other than low-rise residential buildings for: a. design, construction, and a plan for operation and maintenance; and b. utilization of on-site, renewable energy resources." (ASHRAE, 2014a)
BMS and Data Requirements	BMS or 'Direct Digital Control' (DDC) as used in this standard, are identified as the means to **monitor and control** HVAC equipment. By this standard, BMS in new buildings are required to **trend data**, **automatically detect operation of equipment outside control parameters** and generate an **indicator** of this occurrence. BMS are also required to be **"capable of trending and graphically displaying input and output points" (ASHRAE, 2014a)**.
ASHRAE RP-1455-2014: Advanced Control Sequences for HVAC Systems *Note: Superseded by ASHRAE Guideline 36-2018 High-Performance Sequences of Operation for HVAC*	
Purpose	"The purpose of this guideline is to provide uniform sequences of operation for heating, ventilating, and air-conditioning (HVAC) systems that are intended to maximize HVAC system energy efficiency and performance, provide control stability, and **allow for real-time fault detection and diagnostics."** (ASHRAE, 2014b)
BMS and Data Requirements	This standard presents a list of system data points to be hardwired, controlled and monitored by BMS. While it is not specifically suggested these data points be trended, this standard gives an indication of the types of data points which might be associated with specific HVAC systems.

FEMP Continuous Commissioning Guidebook	
Purpose	"This guidebook presents a comprehensive ongoing process to resolve operating problems, improve comfort, optimise energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities." (Liu et al., 2002)
BMS and Data Requirements	BMS is identified as a tool to implement control strategies and in some cases calculate data points. The type and condition of the BMS is signalled as directly affecting the cost of Continuous Commissioning. It advises that the more meters installed as part of a BMS, the lower the cost.
CIBSE Guide F: Energy Efficiency in Buildings 2012	
Purpose	"This guide shows how to improve energy performance, reduce running costs and minimise the environmental impact of buildings by: designing energy efficient new buildings and **refurbishment of existing buildings** managing and operating buildings in an energy efficient way upgrading buildings to improve ongoing energy efficiency **enabling engineers to overcome barriers to energy efficiency** in discussions with clients and other members of the design and construction team demonstrating the value of energy efficiency to clients, developers and tenants." (CIBSE, 2012)
BMS and Data Requirements	▪ This guideline acknowledges that BMS are not being used to their full potential. While they are considered most successful in their role as plant control systems, non-control capabilities such as energy metering and monitoring and targeting, are considered under-utilised. ▪ Performance monitoring capabilities of BMS are identified as assisting maintenance and monitoring. They quantify energy consumption and savings. BMS retrofits with improved control strategies can improve energy efficiency and comfort, but trained staff are typically required to operate BMS. Regular reviews of BMS are needed to identify poor design, operation and maintenance. Information overload identified as a potential issue arising from complex BMS. For example, excessive alarms and monitoring can become pointless to actioning information. It suggests energy metering integrated into BMS can significantly improve overall management and performance of buildings. ▪ The importance of choosing the right BMS vendor is highlighted, along with the need to give a clear brief and a full functional specification. ▪ "A clear, informative and usable graphical user interface is essential to provide a better understanding and use of a BEMS and hence, energy savings. Dynamic displays provide useful aids to fault diagnosis, as well as a visual indication of plant status and relationships between points." ▪ While this guide is suggestive data should be monitored and automatically trended, reference is only made to whole building energy and energy sub-metering only. Despite the data focus of this guide being energy consumption, specific details around data trending frequency and specific building services to be sub-metered is not provided.

2.2.3 WHAT DO BMS SPECIFICATIONS SAY ABOUT CONTINUOUS COMMISSIONING?

This section, much like the previous section, assesses international Building Management System standards and specifications, to understand the extent of which BMS are specified for Continuous Commissioning or similar operational assessment of energy efficiency. For consistency, the term CCx encompasses all post-occupancy operational assessments for energy efficiency. Each standard has been analysed against the following criteria and is presented in Table 9.

Purpose: What is the purpose of the standard?

BMS and Data Requirements Relating to CCx: To what extent are the requirements of BMS specified for Continuous Commissioning? Does the guideline identify what data should be trended within BMS to facilitate Continuous Commissioning?

Table 9: BMS Requirements for Continuous Commissioning within Standards and Specifications

CIBSE Guide H: Building Control Systems 2009	
Purpose	"To provide the building services engineer with a sufficient understanding of modern control systems and relevant information technology to ensure that the best form of control system for the building is specified and that proper provision is made for its installation, commissioning, operation and maintenance." (CIBSE, 2009)
BMS and Data Requirements Relating to CCx:	▪ In this guide BMS are recognised as tools of growing importance in measuring and monitoring energy performance. Modern BMS technology enables systems to be interrogated, monitored and controlled via common IT and web browser applications to produce reports, energy monitoring and targeting and maintenance schedules. However, while commissioning and building fine tuning are recognised as important, there is limited guidance on how to implement these processes. ▪ This guide specifically identifies suitable control and alarm system strategies to be implemented within a BMS, but does not report on how they can be assessed. A BMS points list is identified as being required, but not covered in detail. ▪ Monitoring of specific equipment is limited to run time and fault status. ▪ "Energy monitoring, fault reports and maintenance scheduling" focuses on facilities management only, and is not related to energy efficiency. ▪ No specific data information is provided beyond suggestive energy submetering applied to a central plant.
ASHRAE Guideline 13-2014: Specifying Building Automation Systems	
Purpose	▪ "The purpose of this guideline is to provide recommendations for developing specifications for building automation systems in heating, ventilating, and air-conditioning (HVAC) control applications, as well as recommendations for specifying the integration of other building systems into a building automation system (BAS)." ▪ "This guideline represents a standardization of approach to the design, documentation, and specification of DDC system BAS for HVAC control and energy management applications" (ASHRAE, 2015)

BMS and Data Requirements Relating to CCx	This guideline contains detail on data trending, sampling and storing and BMS capabilities which many other standards and guidelines do not cover. However, this detail is hard to find within the document as it is not specifically identified as an aid for monitoring and measuring performance and carrying out optimisation assessments such as CCx. Annex D – presents 3 levels of performance monitoring for BMS and their requirements: ▪ L1: BMS must support trending, must be able to graph at least one trend against time. ▪ L2: L1 requirements + some data analysis capability (not specified), ability to graph X-Y plots or data export capability ▪ L3: L1&L2 Requirements + Ability to identify and predict equipment faults or provide analysis of data relating to operating issues, ▪ Reference Annex D – table D2 in guideline for more detail. There is some level of detail relating to performance monitoring capabilities of BMS and specific points for trending, however it does not identify and make a connection to the specific energy efficiency assessments to be carried out.
EN15232: Energy Performance of Buildings: Impact of Building Automation, Controls and Building Management (2017)	
Purpose	This European standard specifies: ▪ A structured list of control, building automation and technical building management functions which have an impact on the energy performance of buildings ▪ A method to define minimum requirements regarding control, building automation and technical building management functions to be implemented in buildings of different complexity Provides detailed methods to assess the impact of control functions on a given building, when calculating energy ratings and performance indicators. (European Standard, 2017)
BMS and Data Requirements Relating to CCx:	This guideline specifies types of BMS control functions such as: night cooling, supply temperature control. It associates these functions to an efficiency class from D to A. A being high energy performance, D being a non-energy efficient BMS. It identifies some control/measurement accuracies but does not specify data trending requirements for the control strategies of specific HVAC systems.
ISO 16484-3: Building Automation and Control Systems (BACS) Part 3: Functions	
Purpose	This description is specific to part 3 of the wider ISO standard 16484: "Part 3 of the standard specifies the requirements for the overall functionality and engineering services to achieve building automation and control systems. It defines terms, which shall be used for specifications and it gives guidelines for the functional documentation of project/application specific systems. It provides a sample template for documentation of plant/application specific functions, called BACS points list in annex A." (International Organisation for Standardisation, 2005)
BMS and Data Requirements Relating to CCx:	This standard identified some BMS control strategies which can reduce energy consumption if implemented correctly and identified management functions of BMS such as recording, archiving and statistical analysis of data, important to evaluating energy use and operational costs. However, while statistical data display formats are noted, no relation is made to facilitating CCx or energy efficiency.

By assessing the content of CCx and energy efficiency guidelines against the criteria of containing references to BMS, the gaps in requirements of BMS and data trending could be recognised. The key finding of assessing standards and guidelines highlighted that, like literature, BMS are important tools to providing the data needed to improve the energy performance of HVAC and buildings.

However, the process of setting up a BMS to ensure it provides the required data and has the functions needed to implement the six stages of CCx is a step missed by many CCx guidelines. For example the FEMP CCx guidebook claims the success of CCx is dependent on the type and condition of the facility's BMS, however does not specify the functions and performance requirements of a BMS for this process (Liu et al., 2002). Likewise, BMS specifications and standards typically do not identify how a BMS should be set up for ongoing monitoring to facilitate the assessment of HVAC performance during operation beyond maintenance alarming.

Limited requirements of BMS are specified by these standards and guidelines to a level which enables the upfront specification of BMS requirements for facilitating Continuous Commissioning.

3 RESEARCH STRATEGY

This chapter describes the research framework for investigating the role of Building Management Systems (BMS) and their requirements in the Continuous Commissioning (CCx) process. This chapter focuses on the selection of appropriate research methods to answer secondary research questions identified throughout the assessment of literature. The next chapter (chapter 4) outlines the details of the application of the selected research methods.

3.1 THE NEED FOR A SPECIFICATION

The assessment of existing literature, standards and guidelines (section 2.2), made it clear BMS are crucial to all variations of CCx. However, there is a limited cross over between what is required of a BMS to facilitate Continuous Commissioning and the way in which BMS are specified.

The ability of a BMS to monitor, trend and store HVAC operation and indoor air quality (IAQ) data, enables the CCx process to be implemented to improve the operating efficiency of HVAC and the overall energy performance of a building. To achieve improved efficiency, the CCx process involves the assessment of the data, provided by the BMS, against operating parameters or FDD rules of which for the purpose of this report will be referred to as CCx assessments.

Despite the undeniable importance of BMS in providing the data required to carry out CCx on building HVAC, there is currently a lack of specification of how BMS should be set up to facilitate CCx. Many research publications recognised the importance of BMS, however, many papers also identified some of the key issues encountered through implementing CCx occurred during the initial set up phase, in association with the non-control capabilities of BMS and obtaining the required data trends (Hart, 2012; Hung, 2010; Heller and Baylon, 2008).

The data requirements for CCx reported by some research papers and industry guidelines are limited to specific applications, such as assessing a single HVAC system type or control strategy (Zmeureanu and Vandenbroucke, 2015; Heller and Baylon, 2008; Cheng, 2016; Chen, 2015; Liu et al., 2013). Other research papers present a wider view on the implementation of Continuous Commissioning or a specific CCx tool, but fail to provide detail on how data is obtained from a BMS and specific characteristics of the data required, such as trending intervals, period of storage and file format. CCx guidelines convey the assumption that any BMS can immediately provide the information needed to carry out CCx (section 2.2.2), while BMS specifications contain limited information on setting up BMS in a way to facilitate the assessment of HVAC equipment efficiency during operation (section 2.2.3).

It is hypothesised that many BMS are not currently set up in a way that enables Continuous Commissioning. If BMS were specified with minimum data trending requirements and capabilities important to facilitating Continuous Commissioning, they could be more useful and usable for this process. By overcoming some of the key hurdles encountered through the initial set up of Continuous Commissioning, the uptake of Continuous Commissioning would be more approachable and easier to implement to meet the growing demand for energy efficient buildings and tenancies (McGrath, 2015).

The aim of this thesis is to bridge the gap between the specification of BMS and the Continuous Commissioning process, by developing:

A comprehensive guideline outlining the data trending and functional requirements of a BMS to facilitate Continuous Commissioning.

In order to achieve this aim, the following primary research question must be answered:

What data and functional capabilities are required of a Building Management System to facilitate the Continuous Commissioning of typical HVAC systems?

A guideline outlining how to specify BMS data trending requirements and capabilities required to facilitate CCx is anticipated to provide building operation stakeholders with a document enabling them to identify whether their existing BMS is able to facilitate CCx based on suggested requirements. Alternatively, if a BMS is upgraded or implemented into a new building, a guideline would present the types of data trends needed to be able to assess certain types of HVAC systems in future and the functions which would facilitate the implementation of CCx to assess the operational performance of equipment. By pinpointing the limitations of BMS functions to facilitating CCx and the data required to carry out specific CCx assessments the overall research aim could be achieved.

3.2 WHAT DATA WAS TO BE COLLECTED AND WHY?

In order to answer the primary research question, secondary research questions (SRQs) were defined based on the questions raised throughout the assessment of literature and existing standards. The secondary research questions were set to create a research framework of achievable stepping stones to achieve the overall aim of the research. Table 10 presents the secondary research questions which became the foundation for selecting and designing a suitable research methodology.

Table 10: Secondary Research Questions

Secondary Research Questions (SRQ)		What further research was needed?
SRQ 1	At what stages of the Continuous Commissioning process are BMS most important and are BMS meeting the needs of continuous commissioners?	The importance of BMS is claimed by many citations, however it has never been measured based on continuous commissioner experience throughout the CCx process.
SRQ 2	What common Continuous Commissioning assessments are applied to improve the energy efficiency of typical HVAC systems?	Common CCx assessments needed to be defined in association with typical HVAC systems within large non-residential buildings to be able to define the data required for trending.
SRQ 3	What data points and trending frequency is required to carry out Continuous Commissioning assessments?	The most common CCx assessments applied to HVAC systems could be used to define the data points required to carry out the assessments. The granularity of data is important to CCx, however there is no clear definition of the minimum and ideal trending frequency and storage period.
SRQ 4	What non-control capabilities of BMS are important to facilitating Continuous Commissioning and are BMS providing these capabilities at a satisfactory level?	CCx processes rely on BMS to provide usable data and make control improvements, but the requirement of non-control features of BMS such as data extraction capabilities, visualisations and usability are not clearly defined, nor is whether BMS provide these capabilities to a satisfactory level.

In order to define the data points required to be trended and stored within BMS we first needed to know what Continuous Commissioning assessments are commonly used. To ensure the research is applicable to the greatest range of buildings, the CCx assessments needed to be associated to typical HVAC systems found within large non-residential buildings. Once defined, the CCx assessments could then be used to indicate what data would be required to carry them out. As highlighted in literature, CCx processes rely on the accessibility of data, therefore non-control capabilities of BMS needed to be explored to be able to report on what BMS capabilities are important to Continuous Commissioning and whether BMS are providing necessary functions effectively.

3.3 SELECTING A RESEARCH METHOD

Many of the assessed research papers applied a case study methodology to report on the improved operation of HVAC and whole building energy performance following the implementation of a Continuous Commissioning procedure or tool (Keuhn and Mardikar, 2013), (Cutler et al., 2016), (Cmar et al., 2008), (Hart, 2012). While the case study methodology was appropriate for these studies, it was not considered suitable to answer the research questions posed in this thesis. Case study buildings and their BMS were used by these researchers as they tested the implementation of a specific CCx process or tool. No BMS case studies could be used to assess whether BMS currently provide the BMS data and functions required for CCx as there is a lack of consensus from literature of what these might be. The research reported by this thesis takes a step back from the application of a specific CCx procedure and looks at defining the data and functional requirements of a BMS to facilitate CCx.

The further research needed to answer the secondary research questions presented in Table 10 made it clear the answers would primarily be obtained from surveying industry. The research method to be implemented needed to be based on the expertise of people within the building industry, with experience in Continuous Commissioning. As people would be the source of the information to be obtained, a range of survey research methods were assessed against the criteria of what method would be best able to provide a representative sample of opinions and knowledge of expertise in the field of Continuous Commissioning in New Zealand.

With the research method situated in New Zealand, New Zealand industry professionals were to be the target participants of this research. As Jimmieson (2016) noted there was a small CCx market in New Zealand, therefore, it was anticipated a broader definition of Continuous Commissioning experience may be required, encompassing building control and HVAC operation professionals who implemented energy efficient strategies. The target participants of this study and the New Zealand context is presented in more detail in section 3.5.

Four potential survey methods were assessed for their suitability to answer the secondary research questions. Table 11 presents the advantages and limitations of the four potential methods; standard questionnaire, Delphi method, interviews and focus groups.

Table 11: Advantages and Limitations of Potential Research Methods

Survey Method	Method Description	Advantages	Limitations
Standard Questionnaire (Denscombe, 2014)	Questionnaires typically consist of one round of written questions, designed to collect information from research participants to subsequently be used for data analysis.	**Scalable:** Not restricted by researcher location, increasing the potential number of participants. **Anonymity across Participants:** Participants are not known by other participants. **Practical**: Participants have time and location flexibility for completion. **Quantification**: Closed ended questions can be quantified easily.	**Risk of misinterpretation of questions:** Participants may interpret questions in different ways, impacting the credibility of responses. **Produces a lot of data:** Due to the scalability of questionnaires, the quantity of data can become hard to manage.
Delphi Method (Skulmoski et al., 2007; Okoli and Pawlowski, 2004; Hsu and Sandford, 2007)	The Delphi Process is an iterative survey process collecting the opinions of a group of experts, anonymous to each other, with the aim of forming a consensus of opinions.	**Consensus can be formed:** Used to establish a consensus through multiple rounds of refined questions and responses **Does not require a large number of participants:** The Delphi method doesn't rely on statistical power due to the involvement of experts. **Anonymity across Participants:** Participants are not known by other participants. **Practical**: Participants have time and location flexibility for completion.	**Low response rate and time consuming:** Unlike a standard questionnaire, the Delphi method consists of multiple rounds requiring more time dedication from participants, reducing response rates. **Equivalent knowledge and experience:** Participant knowledge and experience may vary, impacting the ability to form a consensus. **Conforming:** Participants may feel they have to adapt their opinions based on the feedback provided from the previous round.
One-to-One Interviews (Denscombe, 2014)	One-to-One interviews are typically structured or semi-structured with open ended questions. Often involves the researcher taking notes and potentially an audio recording of the interview.	**Controlled Responses:** The researcher can ensure questions are answered to a satisfactory level of detail. **Non-bias responses:** Participant opinions are not impacted by others	**Geographical limitations:** Participants typically limited by the location of the interviews. **Verbal content:** content analysis typically required in addition to note taking during interview, due to open ended questions, typically time consuming. **Interviewer effect:** Possibility to deter from structured interview questions.
Focus Groups (Wilkinson, 2004; Breen, 2007; Morgan, 1997; Onwuegbuzie et al., 2009)	Focus groups are a qualitative data collection method which involves an informal gathering of a small group of peoples to discuss issues or new ideas on a particular topic. Typically involves audio recordings and note taking by the researcher.	**Does not require a large number of participants:** Typically, 15-20 participants are involved in a focus group discussion. **Aims to achieve a form of agreement among participants:** Attitudes and opinions are socially formed, aiming to achieve some level of agreement.	**No anonymity across participants** **An Influencer**: one person may take control which can influence the decisions of others. **Geographical limitations:** Participants typically limited by the location of the focus group meeting. **Difficult to derive results:** A qualitative and thematic analysis of transcripts and recordings is needed may lead to open interpretation.

3.4 A MIXED METHOD APPROACH

The Delphi survey method was the most suitable research method for forming a credible guideline on the data and BMS requirements for facilitating Continuous Commissioning. The Delphi method typically consists of multiple survey rounds aiming to establish an agreement among experts (Cuhls, 2005).

A standard questionnaire would have provided limited credibility for defining a guideline or specification for BMS as standard questionnaires are conducted as a single round of questions. This would not provide the opportunity for rigorous consensus to be formed, such as the Delphi method offers (Okoli and Pawlowski, 2004).

However, the complexity of the information to be obtained, that is, the need for an agreement of BMS data requirements (SRQ 2 and SRQ 3) and an understanding of the experiences of industry professionals with BMS throughout the CCx process (SRQ 1 and SRQ 4), lead to the development of a mixed method survey. One which would combine the ability to form a consensus of industry professionals (Delphi) and question user perceptions (standard questionnaire).

The Delphi method was selected to answer SRQ 2 and SRQ 3 in Table 10 by forming consensus through multiple survey rounds, while a standard questionnaire could be used to answer items SRQ 1 and SRQ 4 through a single round of questions. An online survey made it feasible to obtain a representative sample of participants for both the standard questionnaire and Delphi methods. The number of participants needed to provide a representative sample of continuous commissioners is presented in section 3.5.

An online questionnaire was considered as a potentially suitable survey distribution method to be implemented to conduct the mixed-methodology. Having an online survey, it became possible to extend the questionnaires by a small amount to ensure both the Delphi method and more conventional survey questions could be asked.

By distributing the survey online, the scalability and convenience of participant completion could be optimised and enabled participant responses to be easily collected, assessed and quantified (Denscombe, 2014). The ease of result quantification was anticipated to give a clear indication of the level of agreement or disagreement of the representative group of participants.

3.4.1 THE DELPHI METHOD

The Delphi method was established by The Research and Development Corporation (RAND) in the 1950s (Cuhls, 2005). The Delphi method is defined as "a technique used for the elicitation of opinions with the object of obtaining a group response of a panel of experts" (Brown, 1968). Principally, Delphi is a survey method used to form a consensus on a topic based on the response of experts in that field. Each round of survey questions informs the following round, with an element of feedback provided through the compilation of the previous round's responses (Figure 5). This enables participants to agree, disagree or provide alternative insight to the questions asked and the proposed consensus (Cuhls, 2005).

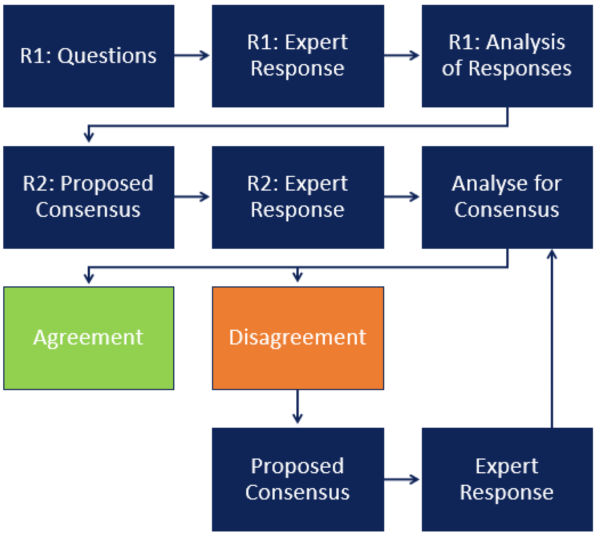

Figure 5: Typical Delphi Survey Process (Author's diagram)

The Delphi method consists of at least two rounds of questions and aims to identify "what could/should be" signifying its value for innovative developments relevant to the progression of an industry (Miller, 2006). This aspect of the Delphi survey is valuable for identifying both the minimum requirements for Continuous Commissioning currently used in practice and the ideal information and capabilities which could be provided by BMS.

The Delphi survey method targets a highly knowledgeable and experienced panel of experts, for this research, in the field of building operation and control. The multi-round Delphi process enables participants to agree, disagree or revise their own and peer responses in each round, in order to arrive at a consensual resolution (Miller, 2006). According to Okoli and Pawlowski (2004), Delphi methods typically need 10-18 participants, as it does not depend on statistical power, but arriving at a consensus among experts. The Delphi method aims to optimise the applicability of the research to industry, due to the definition of a consensus rather than a majority response which does not determine the level of agreement made by all participants.

Diamond et al. carried out a systematic assessment of 100 Delphi methods carried out within literature to explore the varying definition of consensus (Diamond et al., 2013). Key methodological considerations are proposed by Diamond et al. (2013) to be used to most effectively report the criteria to which the Delphi method is to be implemented. Table 12 presents the criteria defined by Diamond et al. and how each criterion is addressed within this research.

Table 12: Key Methodologic Criteria to Report for Delphi Studies

Methodologic Criteria (Diamond et al., 2013)	How the criteria have been addressed?
Does the Delphi study aim to address consensus?	The aim of this Delphi Study was to form a consensus on Continuous Commissioning assessments applied to improve the energy efficiency of typical HVAC systems and form a consensus on the data and trending frequency required within BMS to carry out these assessments.
How will participants be selected or excluded?	Participants were recruited based on meeting industry accreditation criteria defined in section 4.1 Participant Recruitment.
How will the consensus be defined?	The definition of consensus used in this thesis is addressed in section 4.3.5 Two different definitions of consensus have been used to account for variations in the way questions were asked to form consensus.
What criteria will be used to determine to stop the Delphi process or will the Delphi be run for a specific number of rounds only?	Due to the limited time and resources available to implement the Delphi survey process and the amount of information to get out of it, the entire survey process was limited to three rounds, whether a consensus for all data and BMS requirements could be formed or not.

3.4.1.1 DEFINING CONSENSUS

Gracht (2012) and Diamond et al. (2013) summarise the issues surrounding the most difficult aspect of Delphi surveys: defining consensus. The approaches of defining consensus range across a spectrum. Table 13 presents the top five most commonly implemented definitions of consensus within Delphi Studies (Diamond et al., 2013). The detailed approach to consensus defined in this thesis is addressed in section 4.3.5.

Table 13: Exploring Definitions of Consensus (Diamond et al., 2013)

Definition of Consensus	Example
Percentage agreement	>80% with same rating
Proportion within a range	90% scoring 7+ on a 9-point scale
Decrease in Variance	Interquartile range less than three on a nine-point scale
Central Tendency	Median ranking
Statistical Measures of Agreement	Kappa statistic, Crohnbach's alpha, Kendall's co-efficient of concordance (W)

3.4.1.2 OVERCOMING LIMITATIONS OF THE DELPHI METHOD

While the Delphi method offers the benefit of forming a consensus over typical, single-round questionnaires, there are still limitations to the method which required consideration. Hsu and Sandford report on some of the key limitations of the Delphi method (Hsu and Sandford, 2007). Delphi limitations are presented in Table 14 with an explanation of how each limitation has been mitigated within this research.

Table 14: Overcoming Limitations of the Delphi Method (Hsu and Sandford, 2007)

Common Limitations of the Delphi Method	How they were overcome
Low response rate and time consuming	Participants were contacted directly in advance of receiving the survey to seek their interest and willingness to participate. During recruitment, participants were advised of the likelihood of three survey rounds being required to form a consensus of opinions, each anticipated to take no more than 15 minutes to complete. Deadline dates for each survey round were provided on distribution of each survey. A reminder email for participants to complete their online questionnaire was provided the day before each survey deadline. Where required, the deadline of each survey round was adapted to give participants the greatest opportunity to complete the surveys.
Ensuring equivalent knowledge and experience	Background questions needed to be asked to document the years of participant experience. While this does not create equality of knowledge and experience, it provides transparency by quantifying experience, to be considered when assessing consensus.
Conforming	Providing participants with an opportunity to disagree and comment on a proposed consensus minimises the chance of participants feeling obliged to conform to the proposed consensus.

3.4.2 STANDARD QUESTIONNAIRE METHODS

The purpose of including standard survey questions was to obtain more generalised information on the survey participants such as their experience in the field of building operation and control, and more specifically Continuous Commissioning.

BMS research Gordon Lowry (1996), carried out a survey on user perceptions of Building and Energy Management System functions. The survey was implemented in 1996, potentially limiting the potential relevance of the results to BMS today, however, the questionnaire employed by Lowry was considered suitable for assessing the importance and satisfaction of BMS capabilities within the CCx process (Lowry, 1996). Lowry's (1996) questionnaire was an adaption of Levermore's (1993) questionnaire method which assesses building occupants' perceptions of their built environment. It consists of a seven-point Likert scale for both importance and satisfaction in order to derive an overall "Likeness score" (Levermore, 1993). A Likert scale is defined as an attempt to assign a quantitative value to an attitude or opinion (Javaras, 2004), i.e. the perceived level of importance and satisfaction. Likert scales are ordinal, meaning the exact difference between scale intervals is undefined, but presented in order (Franceschini et al., 2004). By using importance and satisfaction scales in this research, the importance and satisfaction of BMS and the functions they provide could be assessed in relation to Continuous Commissioning. The detailed application of importance and satisfaction scales in this research is reported in section 4.2.2.

3.4.2.1 OVERCOMING LIMITATIONS OF STANDARD QUESTIONNAIRES

The two greatest limitations of standard questionnaires are the risk of question misinterpretation and too much data. Participants may interpret questions in different ways, impacting the credibility of responses (Denscombe, 2014). To mitigate this limitation of surveys, a pilot study was carried out to ensure clarity across questions beyond the researcher. Due to the scalability of questionnaires, the quantity of data can become hard to manage. Implementing importance and satisfaction scales into the survey method for a range of BMS capabilities ensured that every response can be assessed in the same way, for example, the median response, in contrast to the questions being multi-choice. The repetition of multiple importance and satisfaction scales also meant the participant could answer each question knowing the layout was the same in the same way, making it simple for participants.

3.5 TARGET PARTICIPANTS, SAMPLE SIZE AND THE NEW ZEALAND CONTEXT

The target participants for this study were building control and HVAC operation professionals with experience in Continuous Commissioning. Continuous Commissioning experience was defined as including industry professionals with experience in fault detection and diagnostics, Continuous Commissioning, building tuning, monitoring and targeting and measurement and verification. Participants were recruited based on meeting industry accreditation criteria defined in section 4.1. There were inevitably going to be variations across experts regarding the use of Continuous Commissioning methods and processes, this is not considered to impact the data required from a BMS.

The qualitative and consensual nature of this research did not rely on the statistical power of significant response rates. Due to the targeted participation of experts in the field of Continuous Commissioning as defined above, the number of participants required to obtain a comprehensive range of CCx requirements and form a reliable consensus is reduced compared to a survey targeting the general population (Okoli and Pawlowski, 2004).

The qualitative and consensual nature of this research does not rely on the statistical power of significant response rates (Nielsen, 2012). On average, the number of participants required for a Delphi method 10-20 experts (Okoli and Pawlowski, 2004). Recruiting more participants than required for the Delphi method enabled the standard questionnaire to run in parallel. While it made the Delphi process more time consuming, the increased number of participants enabled a more representative group of industry professionals to run a general survey in parallel. This may have increased the complexity of the Delphi process, however can also be considered to be more representative of a range of CCx experts. Refer to section 0 regarding the number of participants during each survey round.

This research was conducted under the rules and guidelines of the Victoria University of Wellington Ethics Committee (Victoria University of Wellington, 2018). The Human Ethics Policy can be read at: http://www.victoria.ac.nz/documents/policy/research-policy/human-ethics-policy.pdf

3.5.1 NEW ZEALAND CONTEXT

The research method was designed and implemented within the New Zealand building industry.

Continuous Commissioning is not considered standard practice in any country and New Zealand is no exception. It was stated within one piece of New Zealand literature that the Continuous Commissioning market was particularly small in New Zealand compared to the global CCx market (Jimmieson, 2016). The New Zealand building stock contains HVAC and BMS from suppliers which can be found internationally, and there is no universal CCx tool applied anywhere (Friedman and Piette, 2001). Therefore, there seemed no reason to believe the intention, use of BMS and process stages of Continuous Commissioning in New Zealand would vary from the global CCx market. With a consideration of climate, the findings from this research are considered internationally applicable.

New Zealand's mild climate and dominant demand for building space cooling has an influence on the HVAC systems and control strategies considered typical in New Zealand (Gates, 2013). Therefore, it was anticipated some of the common control strategies or Continuous Commissioning assessments considered appropriate for the New Zealand climate, might not have been as applicable for cooler climates. Beyond the variation of some CCx assessments considered common in New Zealand, it was likely the data trending requirements of HVAC systems wouldn't change, but potentially the parameters against which the data would be assessed. The specific definition of parameters and schedules of Continuous Commissioning assessments is beyond the scope of this research.

3.6 ONLINE SURVEY USABILITY

An informal pilot of the initial survey round was carried out to check the usability and interpretation of the survey questions. The two participants of the pilot study were not considered "experts" in the field of Continuous Commissioning however they had some knowledge on building control and HVAC. The participants of the pilot study were not included as participants for the official survey rounds, but they ensured the survey language and usability was suitable for industry professionals within the same field. A survey needs to be coherent and concise (Denscombe, 2014). Comments were made by the pilot study participants, focusing on reducing potential confusion of participants and increasing simplicity of completion. The general lessons learned from this pilot study that were used in the refinement and delivery of the actual survey rounds are as follows:

- Use simple English and provide notes and examples. The participant must be able to understand the question and context in order to minimise incorrect question interpretations.
- Break up some questions throughout the survey by putting them on separate pages. This will help to prevent previous questions informing future answers.
- Limit the ability for participants to read the answers before the question – as this may lead to incorrect interpretations/inaccurate responses.
- Incorporate a consistent scale system, e.g. if one seven-point scale is used, make all seven-point scales for consistency.
- Inclusions and exclusions of the survey needed to be clearly defined to ensure participants provide answers consistent to the questions and scope provided.

4 DETAILED RESEARCH METHODOLOGY

The previous chapter outlined the research objectives and assessed the suitability of a range of research methods to collect data to answer the research questions and achieve the overall research aim. This chapter reports on the application of the mixed-methodology, providing detail on the survey structure, development of survey questions and processing of responses.

In order to develop a clear consensus, gain the opinions of participants on BMS in the CCx process and to deal with the quantity of information to be collected, more than two rounds were needed. More than three rounds would have created a long and complex process. Therefore, the research method consisted of three survey rounds, designed around the information needed to answer the secondary research questions Table 15. The decision to limit the survey to three rounds resulted in a likely outcome that a genuine consensus could not be developed on all items of interest (Skulmoski et al., 2007).

Table 15 summarises the secondary research questions and methods used to collect the information required to answer each question.

Table 15: Implementation of Research Methods to Answer Secondary Research Questions

Secondary Research Question (SRQ)		Applied Method
SRQ 1	At what stages of the Continuous Commissioning process are BMS most important and are BMS meeting the needs of continuous commissioners?	Standard Questionnaire (Importance and Satisfaction Scale)
SRQ 2	What common Continuous Commissioning assessments are applied to improve the energy efficiency of typical HVAC systems?	Delphi Method (Developing Consensus)
SRQ 3	What data points and trending frequency is required to carry out Continuous Commissioning assessments?	Delphi Method (Developing Consensus)
SRQ 4	What non-control capabilities of BMS are important to facilitating Continuous Commissioning and are BMS providing these capabilities at a satisfactory level?	Standard Questionnaire (Importance and Satisfaction Scale)
SRQ 5	What are the characteristics of the Continuous Commissioning processes carried out by participants?	Standard Questionnaire (Closed Questions)

The fifth secondary research question was added to identify how Continuous Commissioning was carried out by the survey participants. It was anticipated that the characteristics of the participants' Continuous Commissioning process would likely influence the requirements of BMS and therefore the reported importance of BMS at stages of Continuous Commissioning. The standard questionnaire method was used to gain a representative response of demographic, contextual and opinionated information, of which a consensus could not be formed from.

The mixed-method approach combining a standard questionnaire with the Delphi method required careful planning and consideration of survey structure with clearly defined aims for each round. The secondary research questions turned into clear aims for each survey round. The three survey rounds were structured as presented in Table 16, in order to collect the quantity of desired information as simply as possible.

Table 16: Three Round Survey Structure and Aims

Survey Round	SRQ Reference	Aim	Survey Method
Round 1 **(10.5 Appendix)**	**SRQ 5**	Identify characteristics of Continuous Commissioning Processes carried out by participants	Standard Questionnaire *(SRQ6 - Closed Questions)* *(SRQ1 - Importance and Satisfaction Scale)*
	SRQ 1	Identify the importance and satisfaction of BMS facilitating stages of the Continuous Commissioning process.	
	SRQ 2	Identify common CCx assessments applied to improve the energy efficiency of typical HVAC.	Delphi Method
Round 2 **(10.6 Appendix)**	**SRQ 2**	Form a consensus from R1: Part B	Delphi Method
	SRQ 3	Identify the minimum data points and data interval required for CCx assessments	Delphi Method
Round 3 **(10.7 Appendix)**	**SRQ 3**	Form a consensus from R2: Part B	Delphi Method
	SRQ 4	Identify the importance and satisfaction of BMS capabilities in relation to CCx.	Standard Questionnaire *(Importance and Satisfaction Scale)*

This chapter is broken into three sections: participant recruitment, the standard questionnaire and the Delphi method. Each method section reports on the development of the relevant survey questions and the analysis process applied to participant responses to these questions.

4.1 PARTICIPANT RECRUITMENT

Participants were identified through the industry directories for the organisations listed in Table 17. The selection of participants was based on their professional accreditations in the field of building services control and operation, with association to system optimisation and energy efficiency. A consideration was made to ensure there was a relatively even distribution of participants across a range of companies, as it was anticipated participants employed by one organisation would be restricted to a single CCx tool or process.

Approximately 60 professionals were identified as meeting the participant criteria. Each prospective participant was directly contacted via personalised email and provided with an information sheet about the survey procedure to be expected by the participants, if they chose to participate. The information sheet enquired on their interest, containing a description of the research project and their availability and willingness to participate in the three-round survey (Appendix 10.16). The information sheet also outlined the consideration of Human ethics, described in more detail in section 4.1.1.

Table 17: Participant Selection Criteria

Organisation	Accreditation
Energy Efficiency and Conservation Authority (EECA)	▪ EECA performance advisors for public buildings ▪ EECA Monitoring and Targeting Programme Partners ▪ EECA Systems Optimisation Programme Partners
Energy Management Association of New Zealand (EMANZ)	▪ Energy Masters Commercial Building Specialist ▪ Energy Masters Continuous Commissioning Specialist ▪ Energy Masters Commercial Building HVAC ▪ Certified Measurement & Verification Professional
New Zealand Green Building Council (NZGBC)	▪ NABERSNZ Accredited Professionals and Assessors

4.1.1 ETHICAL CONSIDERATIONS

A formal ethical consideration process was followed in compliance with Victoria University of Wellington's Human Ethics Policy. The purpose of the policy is to ensure all information collected by the researcher conforms to a high ethical standard, providing protection to both research and participants. The information sheet provided to participants assured the research was confidential and only the researcher and research supervisor would know the identity of each participant. Participants were also advised of their right to withdraw from the study at any time without providing reason. Due to the research methodology consisting of multiple survey rounds as outlined in Table 16, each round of questions underwent review and was approved by the Victoria University of Wellington Human Ethics Committee under the Application Number 0000025075.

4.1.2 SURVEY PARTICIPANTS

Thirty-three participant responses were received for round one (Table 18). All participants had a minimum of 2 years' experience in the building services or building control industry, with over 75% of all participants having more than 10 years of industry experience. All participants self-identified as having some experience in Continuous Commissioning and 27% reported having more than 10 years of CCx experience.

Table 18: Distribution of Survey Participant Occupations at each round

Survey Round	Total No. Participants	Building Services Engineer	Building Energy Specialist	HVAC Continuous Commissioner	BMS Contractor	HVAC Commissioner	Other
Round One	**33**	42.5%	33.5%	6%	6%	3%	9%
Round Two	**25**	44%	36%	8%	4%	0%	8%
Round Three	**19**	42%	37%	11%	5%	0%	5%

Thirty-three participants participated in survey round one. This was considered to be a suitable sample size of Continuous Commissioning practitioners in New Zealand, providing confidence in the representativeness of the results collected for the standard questionnaire and additional confidence in forming a consensus (Delphi method). While the number of participants had reduced substantially by round three (n=19), the representation of participant occupations remained relatively consistent, therefore no bias has been formed by the decreasing number of participants, maintaining a level of representativeness. The number of participants at each survey round is considered suitable for the Delphi method to develop consensus (refer section 3.5).

In the first survey round, participants were asked to identify their occupation based on the options presented in Table 19. Participants who acknowledged an 'other' occupation title were allocated into the provided categories as seen appropriate, included in brackets in Table 19.

Table 19: Survey Participant Occupations

Participant Occupation Title (Others included)	Description
Building Services Engineer (Other: HVAC Specialist)	Primarily mechanical engineers who design and specify building HVAC.
BMS Contractor	Suppliers and or commissioners of BMS systems and control logic.
HVAC Commissioner (Other: Commissioning Manager)	Primarily assess HVAC operation at building practical completion.
Building Energy Specialist/Manager (Other: Sustainability Leader)	Specialists in assessing a building's energy performance or managing day-to-day operations.
HVAC Continuous Commissioner, includes System Optimisation and Building Tuning Consultants	Specialists in assessing the performance of HVAC operation and advising control improvements.

4.2 STANDARD QUESTIONNAIRE DEVELOPMENT

Closed questions and Likert[5]-based importance and satisfaction questions make up the standard questionnaire method employed at the beginning of the first survey round, and at the end of the final round (Table 16). The standard questionnaire questions aimed to collect data to identify characteristics of Continuous Commissioning (CCx) processes carried out by participants and to identify the importance and typical satisfaction of BMS facilitating stages of the CCx process, through the functions they could potentially provide (SRQ 5, SRQ 1, SRQ 4).

4.2.1 CLOSED QUESTIONS

The closed research questions were developed around the information needed to understand the participants' CCx process and the tools they may use (SRQ 5). For example, participants were asked to report on how they access BMS for data, the frequency of assessment such as ongoing or periodic, and the level of automation during data export/import and analysis. Refer to Appendix 10.5 for the first-round survey questions.

4.2.2 IMPORTANCE AND SATISFACTION QUESTIONS

Importance and satisfaction (I&S) surveys were used in the first and last rounds of the survey process. In the first round, I&S surveys were developed based on the six stages of Continuous Commissioning identified by literature (section 2.2.1). Participants were asked to rate their importance and satisfaction of BMS in facilitating each stage of the Continuous Commissioning process (SRQ 1). In the third round, I&S surveys were employed to ask participants to report their perceived importance and satisfaction of specific non-control capabilities of BMS (SRQ 4). Non-control features and functions of BMS were identified and developed based on limitations of BMS throughout literature to form the I&S scales at the end of round three (Lowry, 1996; Makarechi and Kangari, 2011; International Organisation for Standardisation, 2005).

Each scale was a seven-point Likert scale. Participants were provided with the extremities of each scale; not at all important/extremely important and extremely dissatisfied/extremely satisfied. The I&S survey questions were not aiming to form a consensus, but were to be indicative of the types of BMS functions important to CCx. These results of the I&S questions are reflective of the participants involved, rather than something that can be considered as definitive requirements for all Continuous Commissioning processes.

[5] An ordinal rating system, designed to measure people's attitudes, opinions or perceptions BURNS, R. B. 2000. *Introduction to Research Methods,* London, Sage.

4.2.2.1 IMPORTANCE AND SATISFACTION SCORES: RESPONSE ANALYSIS DESIGN

The importance and satisfaction pairs reported by participants were assessed in two ways. Firstly, frequency distribution was used as a way to present a holistic view of the participants' opinions on the importance and satisfaction of BMS at stages of the CCx process and for specific BMS capabilities (Javaras, 2004). How to read the I&S distributions charts is reported in the results section 5.2.1.

As ordinal scales are based on qualitative intervals, taking the mean score reported by participants was not appropriate as the scale cannot be considered continuous (Cowell and Flachaire, 2014). Therefore, the median scores reported by participants were used to analyse the perceived importance and satisfaction of BMS capabilities, giving an indication of whether some BMS capabilities should be the focus of future BMS development to facilitate CCx.

The limitation of importance and satisfaction scales is the use of ordinal scales, as the exact difference between scale intervals is undefined. To help overcome this limitation the interpretation applied to I&S scores is presented in Table 20. The specific results from the I&S survey questions are reported in section 5.2.

Table 20: Interpretation of Levels of Importance and Satisfaction

<table>
<tr><th colspan="2">Level of Importance</th><th>Interpretation</th><th colspan="2">Level of Satisfaction</th><th>Interpretation</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Not at all important</td><td rowspan="2">Is not at all important</td><td>N/A</td><td>Not Typically Available</td><td>If a BMS is not typically provided by BMS</td></tr>
<tr><td>1</td><td>Extremely Dissatisfied</td><td>Does not meet any requirements</td></tr>
<tr><td>2</td><td>Very Unimportant</td><td rowspan="2">Some level of Unimportance to facilitating CCx</td><td>2</td><td>Very Dissatisfied</td><td rowspan="2">Some level of dissatisfaction:
Does not quite meet minimum requirements</td></tr>
<tr><td>3</td><td>Unimportant</td><td>3</td><td>Dissatisfied</td></tr>
<tr><td>4</td><td>Neither Important nor Unimportant</td><td>Undecided</td><td>4</td><td>Neither Satisfied nor dissatisfied</td><td>Undecided</td></tr>
<tr><td>5</td><td>Important</td><td rowspan="2">Some Level of Importance to facilitating CCx</td><td>5</td><td>Satisfied</td><td rowspan="2">Some level of satisfaction: Meets minimum requirements</td></tr>
<tr><td>6</td><td>Very Important</td><td>6</td><td>Very Satisfied</td></tr>
<tr><td>7</td><td>Extremely Important</td><td>Essential to facilitating CCx</td><td>7</td><td>Extremely Satisfied</td><td>Exceeds requirements</td></tr>
</table>

One variation to the satisfaction scale of specific BMS capabilities was the addition of an option for participants to recognise whether a capability was not typically available based on the BMS' used by participants. This is because the seven-point scale did not account for whether the function was typically available and if a participant is extremely dissatisfied with a function, this is different to it not actually being available.

4.3 DELPHI METHOD SURVEY DEVELOPMENT

Questions employed to develop a consensus among participants which are attributed to the Delphi method, formed the core of the three round survey process.

The Delphi aspect of the surveys aimed to develop consensus on the common CCx assessments applied to typical HVAC (SRQ 2) and the data requirements for the CCx assessments (SRQ 3). Each round of questions informed the following round, with an element of feedback provided through the compilation of the previous round's responses. This enabled participants to agree, disagree or provide alternative insight to the questions asked and the proposed consensus (Cuhls, 2005). This section begins with identifying typical HVAC relevant to the New Zealand context and is then broken into the two secondary research aims addressed by the Delphi process.

4.3.1 DEFINING TYPICAL HVAC SYSTEMS

Continuous Commissioning assessments are specific to types of HVAC. This thesis aims to address the most commonly applied CCx assessments for a typical range of HVAC systems. Typical HVAC systems have been identified from a New Zealand based study which formed a consensus on the most common HVAC systems contained within large non-residential buildings (Gates, 2013). The following HVAC systems and variations were used to develop and structure the Delphi questions for defining CCx assessments and potentially required data points:

- Central Air Handling Units (AHU):
  - Constant Air Volume (CAV) AHU
  - Variable Air Volume (VAV) AHU
- On-floor Terminal Air Units:
  - Constant Air Volume (CAV) Box
  - Variable Air Volume (VAV) Box
  - Fan Coil Unit (FCU)
- Chilled Water Loop (CHW):
  - Constant Flow CHW
  - Variable Flow CHW
- Hot Water Loop (HHW):
  - Constant Flow HHW
  - Variable Flow HHW
  - Domestic Hot Water (DHW) Loop

While specific system operating descriptions are beyond the scope of this thesis, system schematics were developed to provide context to the Delphi questions in round one (Appendix 10.5).

4.3.2 CONTINUOUS COMMISSIONING ASSESSMENTS

As previously defined, Continuous Commissioning (CCx) assessments assess HVAC and environmental data against an optimal sequence of operation and performance indicators (Keuhn and Mardikar, 2013). The aim of this part of the Delphi Survey process was to create a complete list of CCx assessments and develop a consensus on the top five applied to typical HVAC systems. Figure 6 presents the process followed for the development of CCx assessment questions, provides examples of the questions asked at each survey round and how responses were processed. Relevant standards and guidelines were assessed for control strategies and CCx assessments applicable to the previously defined HVAC systems. The resources were used to develop a comprehensive list of assessments (Appendix 10.3) to present to participants to form a consensus on the top five.

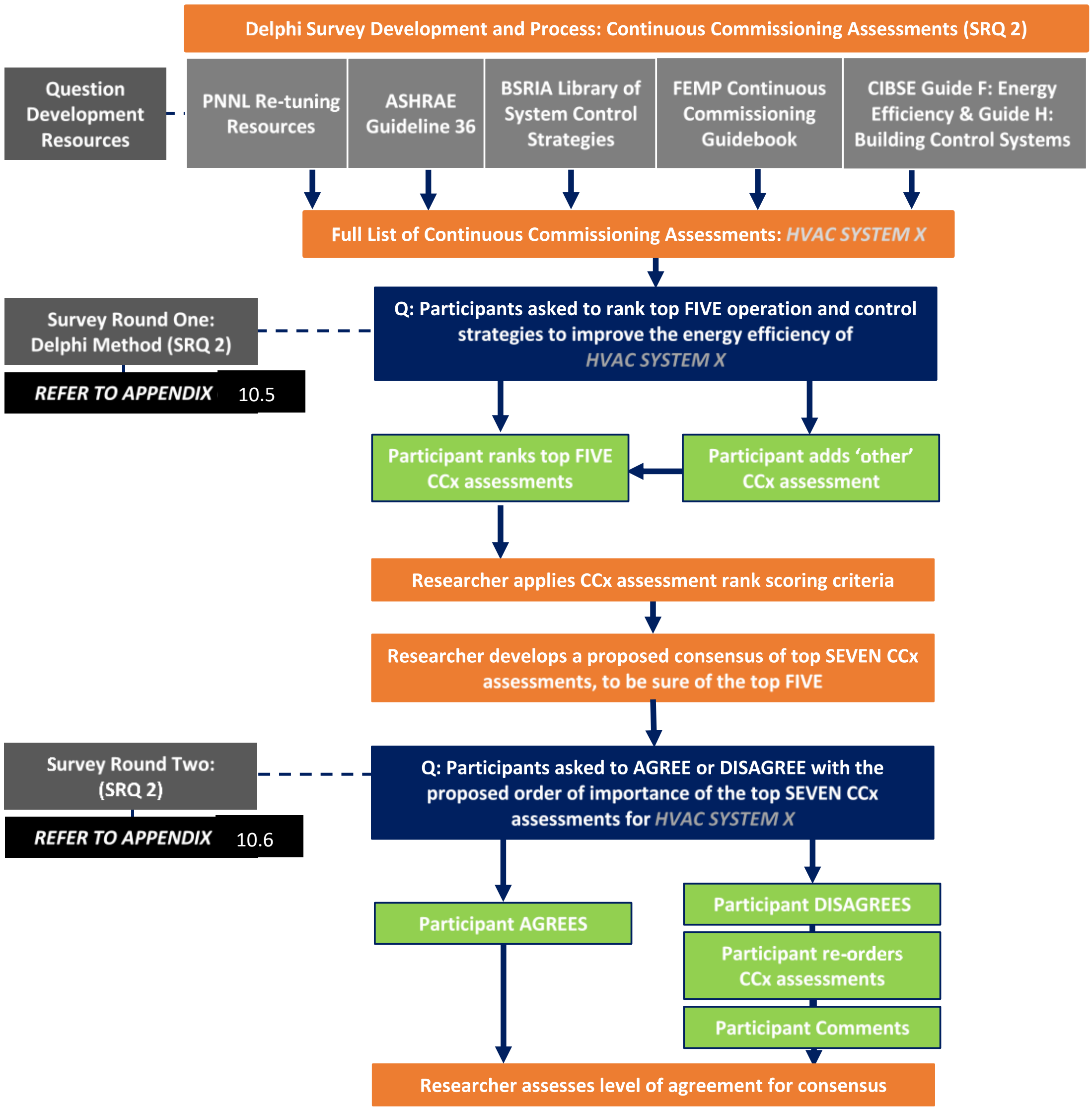

Figure 6: Development of CCx Assessment Questions and Response Assessment Process

Participants were asked to rank CCx assessments based on the top five strategies they would apply to each HVAC system. Due to the complexity of HVAC systems, not all control strategies or assessments could be applied to every system type. For example, suitable CCx assessments for VAV AHUs may not be applicable to CAV AHUs. For this reason, participants were invited to identify and rank any additional assessments they would apply to VAV AHU, assuming all CAV assessments would also be carried out.

4.3.2.1 RANK SCORING CRITERIA

Asking participants to rank assessments from one to five in round one allowed for rank scoring criteria to be applied to be able to propose a consensus for round two.

A two-part rank scoring process was applied to give confidence to the proposed consensus for round two. The first part of the rank scoring process was to calculate a total rank score for each CCx assessment. This involved counting the number of participants who assigned a rank to each CCx assessment, followed by the assignment of values, i.e. rank 1=5, rank 2=4, rank 3=3, rank 4=2, 5=1, summed to calculate the total rank score.

The second step to the process was scaling each total rank score by the number of participants who identified it within the top five. This is because if a greater number of participants identify an assessment within the top five, this assessment was considered of higher value than an assessment which scored the highest total rank score by fewer people. Therefore, in order to quantify the importance of majority, the percentage of people who ranked an assessment within the top five has scaled the score calculated by the count of ranks. An example of the impact of this scaling process is presented in Table 21 with example values where CCx assessments may result in the same total rank score. By scaling this score, definitive ranks could be obtained and was more reflective of the group opinion, important to proposing a consensus.

Table 21: Example of impact of scaling total rank scores (n=10)

Rank (Score)	1 (5)	2 (4)	3 (3)	4 (2)	5 (1)	Rank Score	Total Count Top 5	% Participants Top 5	Scaled Score	Final Rank
Assessment 1	2	1	1	0	3	20	7	70%	14	1
Assessment 2	4	0	0	0	0	20	4	40%	8	3
Assessment 3	0	2	0	3	0	20	5	50%	10	2

4.3.2.2 WHY PRESENT TOP SEVEN IF ONLY WANT TOP FIVE

The top seven ranked CCx assessments for each HVAC type were provided in the second survey round, while only a consensus on the top five was sought. This provided an opportunity for participants to disagree with the proposed consensus and potentially allowing "grey zone" assessments which were on the edge of being within the top five to be promoted (example in Table 22). Providing the top seven assessments gave confidence in the agreement formed around the top five.

Table 22: Example of the Grey Zone for CCx Assessments

Rank	Scaled Rank Score	Assessment	Confidence of Assessment falling in top Five
1	85.8	Zonal thermal dead band and Set Point review	High Confidence
2	66.8	Heating and cooling fighting	
3	26.0	Zonal supply air temperature	
4	22.8	FCU proportional control	Grey Zone
5	20.6	Zonal afterhours operation	
6	19.7	Zonal optimum start/stop	
7	16.6	Demand control ventilation	
8	5.0	Summer and winter operation	
9	4.4	Heating and cooling coil lockout temperatures	
10	2.1	Assessment of terminal air velocity	
11	0.4	Other: Re-commissioning system components e.g. dampers, actuators	
12	0.2	Other: Sensor Calibration	
13	0.1	Zonal economiser function	
14	0.1	Zonal night purge	
15	0.1	Other: BMS Programming/Commissioning Check	Low Confidence

4.3.3 DATA TRENDING REQUIREMENTS

Data trending needs to be clearly distinguished from data monitoring and control points – as while a point may be monitored in order to control HVAC, it is not necessarily stored at intervals for future analysis of trends. This part of the Delphi survey process aimed to identify the minimum data points and trending intervals required to carry out the top CCx assessments applied to typical HVAC (SRQ 3). Figure 7 presents the process followed for the development of data point trending questions, provides examples of the questions asked at survey rounds two and three, and how responses were processed.

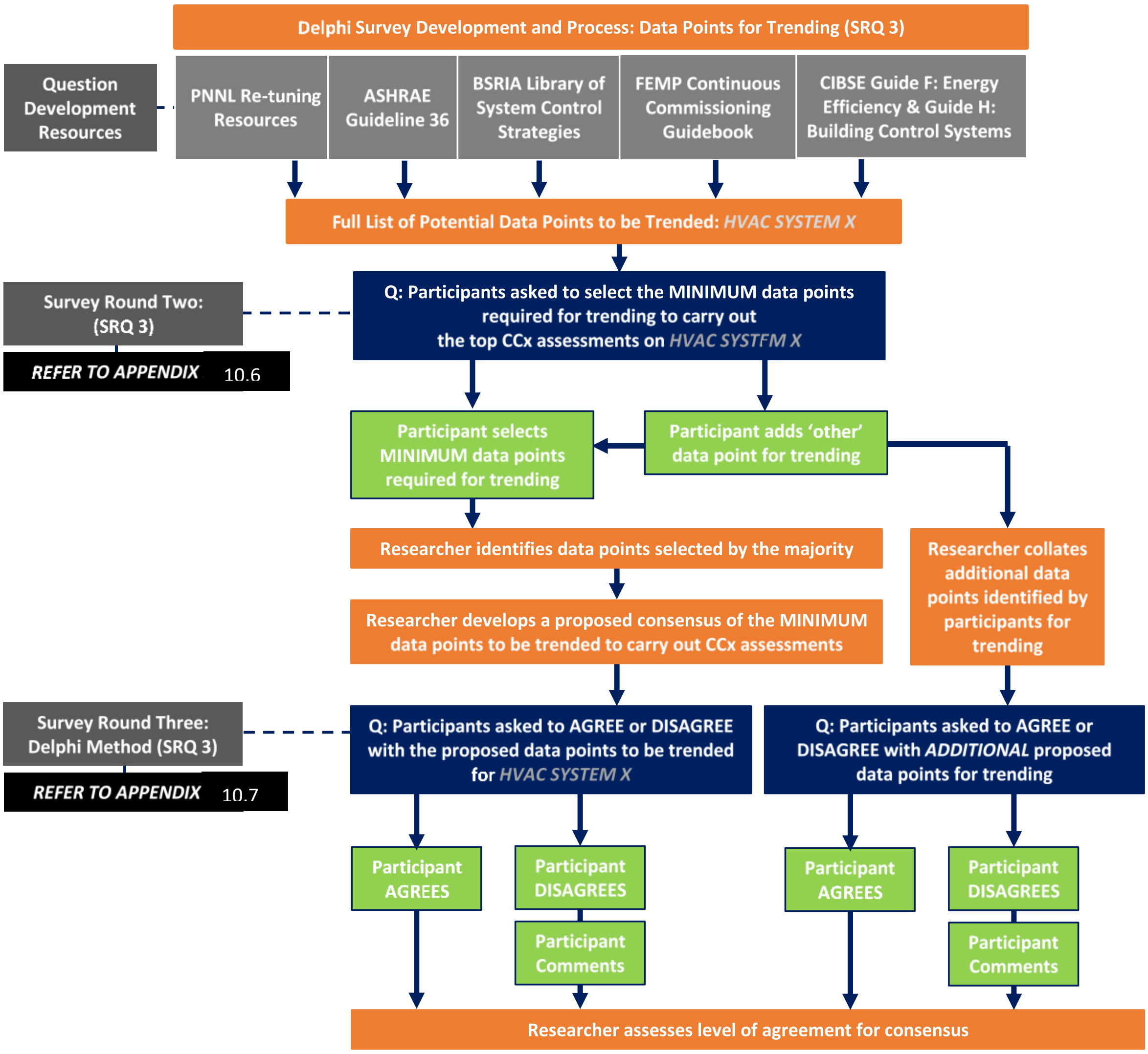

Figure 7: Development of Data Point Questions and Response Assessment Process

The same standards and guidelines assessed for CCx assessments were also assessed for the types of data points which might be associated with each typical HVAC system (Appendix 10.4). The resources were used to develop a comprehensive list of data points from which, participants could identify the minimum points required to carry out the top five CCx assessments. Following the initial round of asking participants to report the minimum data points required, the responses were assessed in order to propose a consensus in the final round. Unlike the CCx assessments, the participants were not asked to rank the data points in order of importance. Therefore, an alternative assessment had to be applied to propose a consensus.

Gracht (2012) defines majority as more than 50% of respondents having the same opinion. Majority was used to develop a proposed consensus, based on the proportion of participants which recognised a data point as being required (Gracht, 2012). This process was applied to all data points to form the consensus proposed in the final survey round.

4.3.4 DEALING WITH ‘OTHER’ CCX ASSESSMENTS AND DATA POINTS

Participants had the opportunity to identify ‘other’ CCx assessments which they considered important. Where participants defined other CCx assessments or data points, each entry was manually assessed against the following criteria:

- Can the “other” be categorised as any of the existing items presented within the survey? A difference in terminology being the only difference.
- Is the “other” reported by multiple participants? Therefore, should it be considered to establish an additional item in the following round?

4.3.5 ASSESSING CONSENSUS

The responses collected for the proposed census for both CCx assessments and minimum data points had to be assessed against a definition of consensus, in order to determine whether the level of agreement could be considered as consensus. As previously identified, Gracht (2012) defined majority as more than 50% of respondents having the same opinion, however, a higher level of agreement is needed to be considered as consensus (Diamond et al., 2013). Figure 8 presents the process of developing the final consensus for CCx assessments and minimum data requirements. Overall, consensus was defined where the level of agreement was greater than 70%.

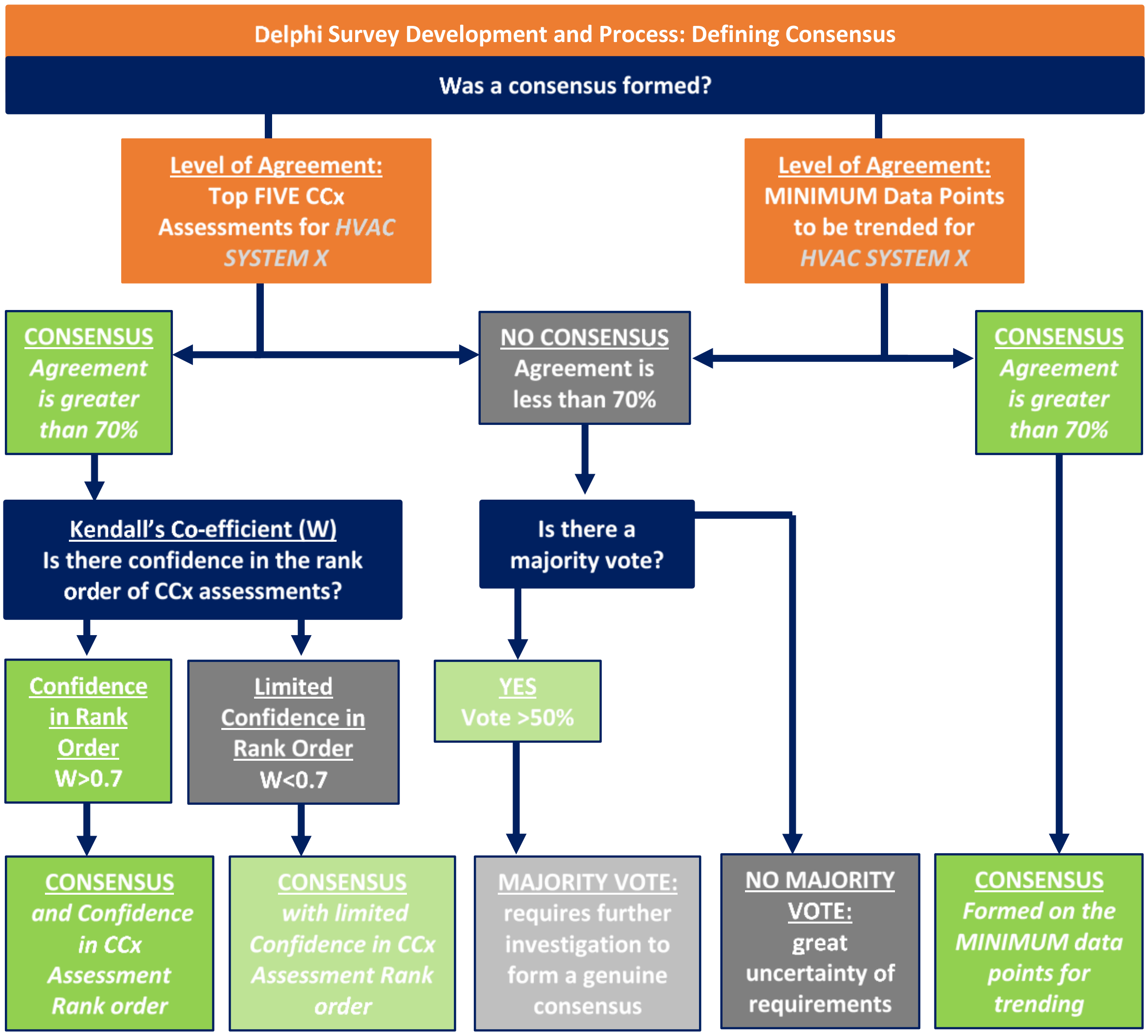

Figure 8: Defining and Assessing Consensus

For the CCx assessments, as the assessments were ordered by level of importance, an additional assessment could be applied to assess the confidence in the order of ranks. Kendall's Co-efficient of concordance (W) was used by applying a formula (Benard and Elteren, 1953), that develops a score for each respondent that can be combined with other respondents' scores to establish a coefficient between zero (no agreement) and one (total agreement) (Okoli and Pawlowski, 2004).

Table 23: Kendall's Co-efficient of Concordance Interpretation (Schmidt, 1997)

Kendall's Coefficient (W)	Interpretation	Confidence Ranks
0.1	Very weak agreement	None
0.3	Weak agreement	Low
0.5	Moderate agreement	Fair
0.7	Strong agreement	High
0.9	Unusually strong agreement	Very High

5 RESULTS PART ONE: THE ROLE AND FUNCTIONAL REQUIREMENTS OF BMS WITHIN CONTINUOUS COMMISSIONING PROCESSES IN NEW ZEALAND

This chapter reports and discusses participant responses to the standard survey questions asked in round one and round three as highlighted in Table 24. New Zealand HVAC and control experts with experience in Continuous Commissioning were asked about the characteristics of their Continuous Commissioning process and asked to report on the importance and satisfaction of BMS capabilities and overall at each stage of the CCx process. The results reported in this section are not used to form a consensus but to document CCx in practice and gain the opinions of BMS and BMS function throughout the CCx process.

Table 24: Reporting the Results of Standard Questionnaires

Survey Round	SRQ Reference	Aim	Survey Method
Round 1	SRQ 5	Identify characteristics of Continuous Commissioning Processes carried out by participants	Standard Questionnaire *(SRQ6 - Closed Questions)* *(SRQ1 - Importance and Satisfaction Scale)*
	SRQ 1	Identify the importance and satisfaction of BMS facilitating stages of the Continuous Commissioning process.	
	SRQ 2	Identify common CCx assessments applied to improve the energy efficiency of typical HVAC.	Delphi Method
Round 2	SRQ 2	Form a consensus from R1: Part B	Delphi Method
	SRQ 3	Identify the minimum data points and data interval required for CCx assessments	Delphi Method
Round 3	SRQ 3	Form a consensus from R2: Part B	Delphi Method
	SRQ 4	Identify the importance and satisfaction of BMS capabilities in relation to CCx.	Standard Questionnaire *(Importance and Satisfaction Scale)*

5.1 CHARACTERISTICS OF CCX PROCESS AND TOOLS IN NEW ZEALAND (SRQ 5)

The aim of this part of the survey was to develop an understanding of how Continuous Commissioning is being carried out by the participants. This section specifically reports and discusses participant responses to the following questions in relation to each participant's CCx process:

- *What type of Continuous Commissioning Tools are used by NZ professionals?*
- *How do participants typically access BMS to carry out CCx?*
- *How do participants typically import data from BMS to their CCx tool?*
- *How frequently do participants carry out CCx Assessments?*
- *Do participants typically use manual or automated data analysis methods?*

Survey participants were first asked to identify the type of Continuous Commissioning tool most comparable to their Continuous Commissioning process. Figure 9 presents the count of participants with each type of CCx tool. Over 75% of participants reported having a manual data processing tool such as an in-house spreadsheet or a manual assessment solely through a BMS interface. Three participants (10%) identified having a bespoke in-house software which could be a mixture of manual and automated data processing and assessment. Two participants specifically identified the use of automated analytics, whether licensed software or analytics embedded within a BMS. The three remaining participants indicated they did not use a tool to carry out Continuous Commissioning, instead carrying out field investigations such as onsite equipment testing, or spot checks of operating data. Two of the three participants who do not use a CCx tool are HVAC commissioners, who typically carry out onsite commissioning.

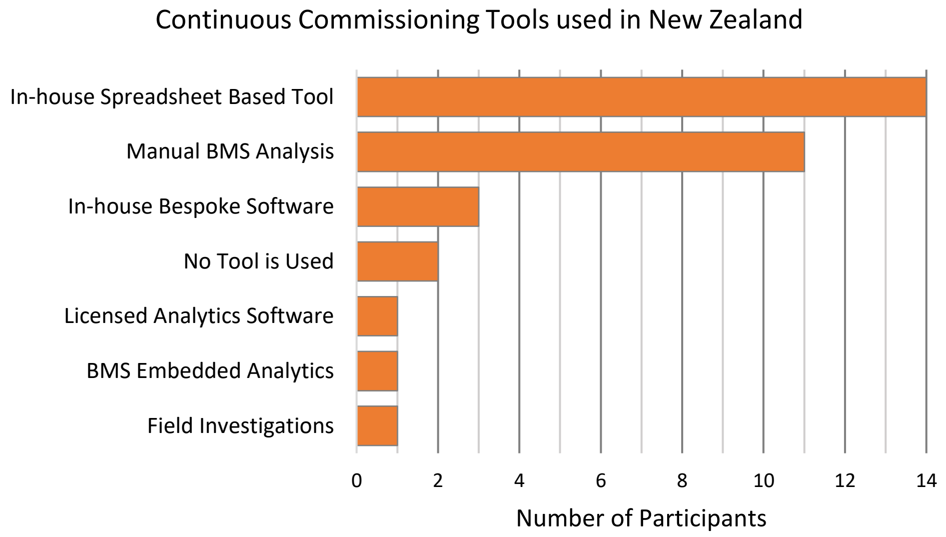

Figure 9: Continuous Commissioning Tools used in New Zealand (n=33)

The high proportion of manual and bespoke methods reported by participants indicates there is no universal tool used to undertake Continuous Commissioning in New Zealand. This finding is comparable to international literature, for example Friedman and Piette (2001) identified “there is little overlap in current tools” referring to the variance in data processing and assessment capabilities of CCx tools. The same study carried out by Friedman and Piette suggested future CCx tools would likely be embedded into BMS to reduce manual data management and analysis time (Friedman and Piette, 2001).

Despite Friedman et al.’s study being carried out in 2001, seventeen years later, Figure 9 suggests BMS embedded analytics is still not a common method of Continuous Commissioning, meaning manual data management and assessment is still a time-consuming aspect of Continuous Commissioning.

As few participants utilise automated and BMS embedded analytical CCx tools, the results reported in this chapter primarily reflect the role of BMS in manual and bespoke CCx processes due to the experience of the surveyed participants. The following sub-sections report on the characteristics of participant CCx processes.

5.1.1 BMS ACCESS

Participants were asked about the access they typically have to BMS to carry out Continuous Commissioning. Figure 10 shows the majority of participants reported having remote access to BMS (70%), a quarter reported having onsite access (24%), while two participants reported having no direct access to BMS (6%), obtaining data via external parties.

By understanding how continuous commissioners are accessing BMS, it gives an indication of the current access capabilities of typical BMS, used by the participants. For example, it is suggested a quarter of BMS used for Continuous Commissioning do not have remote access capabilities and have to be accessed onsite. Aside from participants specifically carrying out field investigations, not having remote access is likely a limitation to implementing Continuous Commissioning. This limitation is further reflected by the reported importance and satisfaction of remote BMS access capabilities in Section 5.2.2.2.

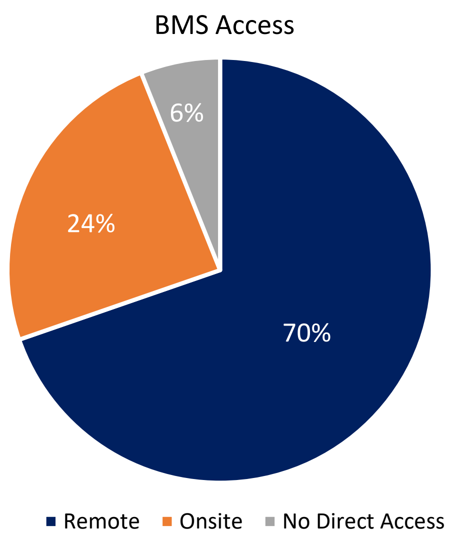

Figure 10: Typical Access to BMS (n=33)

Whether participants access BMS remotely or onsite, the results indicate the majority of continuous commissioners are using BMS directly. This is important as continuous commissioners are likely using BMS in a way that is different from maintenance and BMS contractors who check day-to-day operations without a rigorous assessment of energy efficient performance. Current BMS may not be designed anticipating such assessments and use of data.

5.1.2 DATA IMPORT METHOD

Participants were asked about the method they used to import data into their CCx tool (Figure 11). Over two-thirds of participants reported using a manual method (68%), while 13% reported using an automatic method. The remaining participants (19%) reported they referred to data trends directly in the BMS, therefore no data import/export method was required.

The distribution of data import methods continues to suggest there are functional limitations of BMS restricting the method of data import/export. It is expected if an automated data export function was available and easily set up, it would be utilised to reduce the time spent on manual processing. This limitation is further reflected by the high reported importance and low reported satisfaction of automated data export capabilities of BMS reported in Section 5.2.3.1.

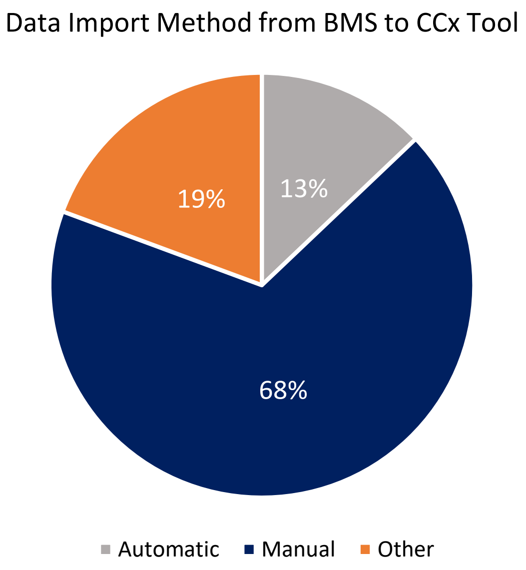

Figure 11: Typical Data Import Method from BMS to CCx Tool (n=33)

It is worth noting, the participants who reported an automatic data import method did not all use the same type of CCx tool. There was a mixture of in-house spreadsheets and bespoke and licensed software used by participants with automatic data import, suggesting BMS with automatic data import capabilities does not necessarily determine the type of CCx tool used.

5.1.3 FREQUENCY OF ASSESSMENT

Participants were asked about how often they carry out Continuous Commissioning assessments (Figure 12). As previously identified, this study includes ongoing and periodic assessments of HVAC operation. 65% of participants reported carrying out their CCx assessments periodically, while 32% reported ongoing assessments.

The distribution of results for this characteristic is comparable to the data import method. By comparing individual participant responses, it was found that those who use a manual data import method only carry out data assessments periodically. The high proportion of periodic assessments could be suggestive that currently most BMS are unable to provide a continuous stream of data.

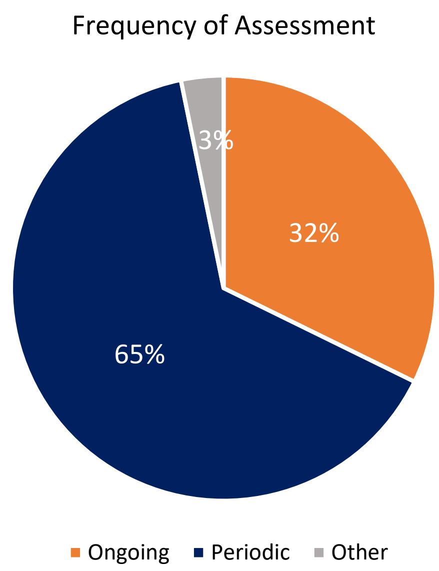

Figure 12: Frequency of Continuous Commissioning Assessments (n=33)

5.1.4 DATA ANALYSIS METHOD

Participants were asked to identify whether they carried out a manual or automated assessment method of BMS data (Figure 13). The majority of participants reported they carried out a manual assessment of HVAC data (84%), while few participants reported having an automated data assessment method (13%).

The same participants who indicated the use of automated data analysis, carried out their assessments continuously and automatically import data from BMS. Based on these results, the manual application of data analytics continues to indicate there is limited standardisation of Continuous Commissioning procedures being carried out.

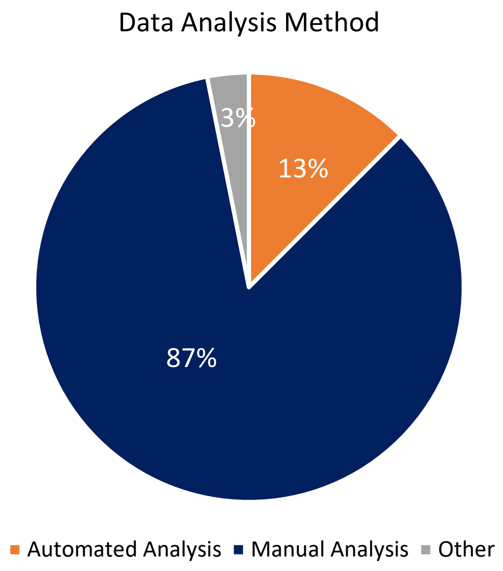

Figure 13: BMS Data Analysis Method (n=33)

5.2 THE REPORTED IMPORTANCE AND SATISFACTION OF BMS AT STAGES OF THE CONTINUOUS COMMISSIONING PROCESS (SRQ 1 & SRQ 4)

This section of Chapter 5 reports and discusses the distribution of reported importance and satisfaction of BMS facilitating each stage of the Continuous Commissioning process (SRQ 1). This section also reports on the importance and satisfaction of typical BMS capabilities and features which correspond to stages of the CCx process (SRQ 4).

BMS are perceived to play a pivotal role in the CCx process as highlighted by existing literature (Liu et al., 2002). The aim of this part of the survey was to understand what BMS features and capabilities are important to carrying out Continuous Commissioning and whether participants are currently satisfied with BMS providing these functions. By understanding what BMS functions are important to Continuous Commissioning, the functions can be suggested as a focus for BMS development to facilitate Continuous Commissioning.

This section specifically reports and discusses the distribution of perceived importance and satisfaction to obtain answers to the following questions:

- How important are BMS to facilitating the six stages of the CCx process?
- How satisfied are participants with BMS fulfilling the requirements to facilitate Continuous Commissioning at each stage?
- What BMS capabilities and features are important to facilitating CCx?
- Are participants satisfied with the capabilities and features being provided by typical BMS?
- Are there gaps between reported importance and satisfaction?

5.2.1 HOW TO READ IMPORTANCE AND SATISFACTION CHARTS

This section presents a summary of the way importance and satisfaction scores are reported in charts and how each chart type can be interpreted. Each chart was selected to convey the distribution of results in different ways. Importance and satisfaction (I&S) scores reported for BMS facilitating each stage of the CCx process are presented as frequency distribution charts to convey the distribution of participant responses:

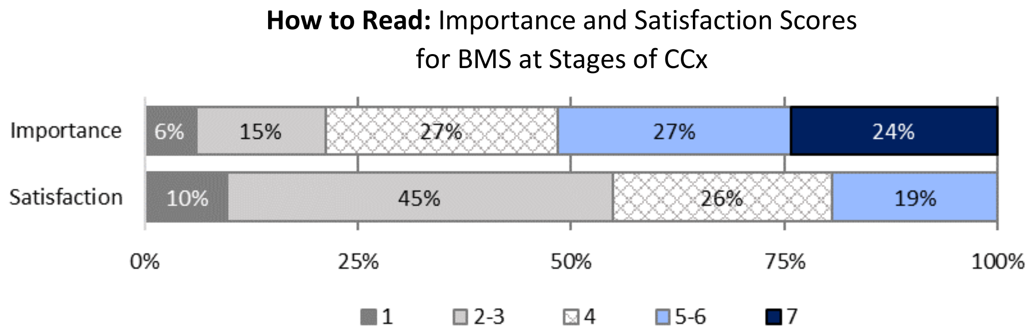

Figure 14: Chart Example: Importance and Satisfaction Scores for BMS at Stages of the CCx Process

For the purpose of assessing the results, the seven-point interval scales have been grouped into five categories (Figure 14). '1' and '7' are the extremities, not at all important/extremely important, or extremely dissatisfied/satisfied, respectively. Scores '2-3' and '5-6' are classified as reporting some level dissatisfaction/satisfaction or some level of unimportance/importance, respectively. '4' remains as the neutral interval for each scale.

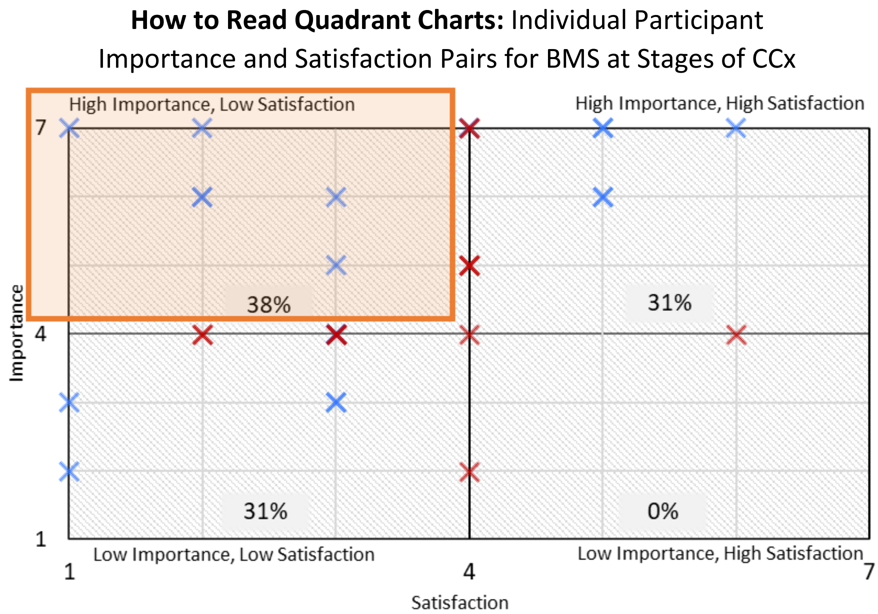

Figure 15: Quadrant Chart Example: Importance and Satisfaction Pairs for BMS at Stages of CCx

A limitation of presenting the distribution of importance and satisfaction scores as the chart in Figure 14 is that each participant's pairing of importance and satisfaction score is not identifiable. Quadrant charts containing each participant's scoring pair are provided in Appendix 10.8. These charts enabled further understanding of the distribution of high importance and low satisfaction pairs (highlighted in orange in Figure 15). The percentages presented on these quadrant charts indicate the distribution of importance and satisfaction pairs within each quadrant. These percentages do not include pairs of data which fall on a neutral line (4) as the specific positioning of these responses cannot be determined. The consequence of not including neutral pairs within these percentages is that the perceived distribution of results may become unreliable. This consequence is overcome by deriving the median level of importance and satisfaction across all participant responses, including neutral responses (example provided in Figure 17). Therefore, while neutral pairs are not accounted for within the quadrant percentages provided in Appendix 10.8, they are still considered throughout the overall analysis of results. Darker marker plots indicate multiple participants have reported the same importance and satisfaction scores.

Figure 16 and Figure 17 show the ways in which the reported importance and satisfaction of BMS capabilities are presented throughout this chapter.

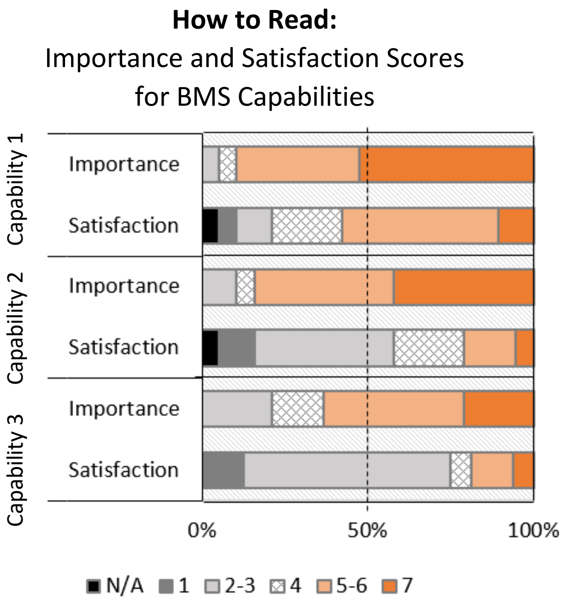

Figure 16: Chart Example: Importance and Satisfaction Scores for BMS Capabilities

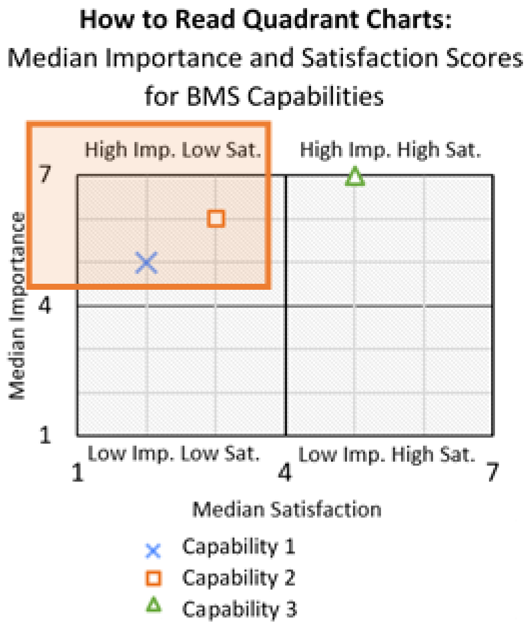

Figure 17: Quadrant Chart Example: Median Importance and Satisfaction Scores for BMS Capabilities

Much like Figure 14, Figure 16 presents the distribution of I&S scores reported by participants on a range of BMS capabilities. The BMS capabilities have been grouped throughout this chapter based on the types of function and the stage of CCx they are likely most associated with. The additional interval "N/A" in Figure 16 was added for BMS capability charts to represent the number of participants who identified the capability as "Not Typically Available" in place of a satisfaction score of one to seven.

Figure 17 presents the median importance and satisfaction scores derived from all participant scores. The BMS capability quadrant charts aim to make a clear representation of the BMS capabilities which are considered most important to the CCx process but participants are typically dissatisfied with their performance. Any median BMS capability scores presented in the top left quadrant as highlighted in orange are considered to require the most attention and development to better meet the needs of continuous commissioners. Much like Figure 15, any median scores falling on the neutral lines (4) become harder to interpret. It must be noted; the median satisfaction scores only represent the median score of participants who provided a score (one to seven) and does not include participants who identified the capability as "Not Typically Available". Therefore, satisfaction scores represented by charts report the median level of satisfaction of the BMS capability when it is available. Figure 16 charts aim to account for this by representing the proportion of participants who identified the capability as typically unavailable (N/A).

5.2.2 MONITORING HVAC OPERATION

Participants were asked to report on the overall importance of BMS monitoring HVAC operation in the CCx process and to report their overall satisfaction of BMS providing the required data outputs and system functions at this stage (Figure 18).

All participants identified BMS to be highly important in facilitating CCx, with 79% of participants identifying BMS as extremely important, rendering it crucial to providing the functions required to effectively monitor the operation of HVAC equipment. However, the perceived satisfaction of BMS providing this function is relatively low, with only 6% of all participants claiming BMS extremely satisfy their needs at this stage of CCx. While 67% of participants indicate some level of satisfaction, the large difference in the distribution of importance and satisfaction scores indicates the needs of continuous commissioners are potentially not fully achieved by the current functions provided by BMS. This reinforces the potential need for a clearer definition of data point trending requirements for CCx assessments.

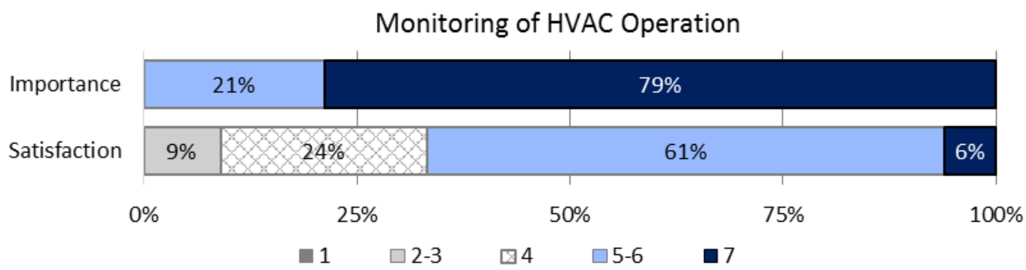

Figure 18: User Perceptions of BMS Facilitating the Monitoring of HVAC Operation (n=33)

In contrast to Figure 18, Figure 19 presents the response of participants when asked whether BMS in general immediately provide the minimum data required to carry out CCx, followed by whether they eventually provide the minimum data (HVAC data trends). Figure 19 reports that the data required to carry out CCx cannot typically be obtained immediately by a continuous commissioner from a BMS. This makes it evident BMS are not typically set up to record and store HVAC data trends when the BMS is initially installed.

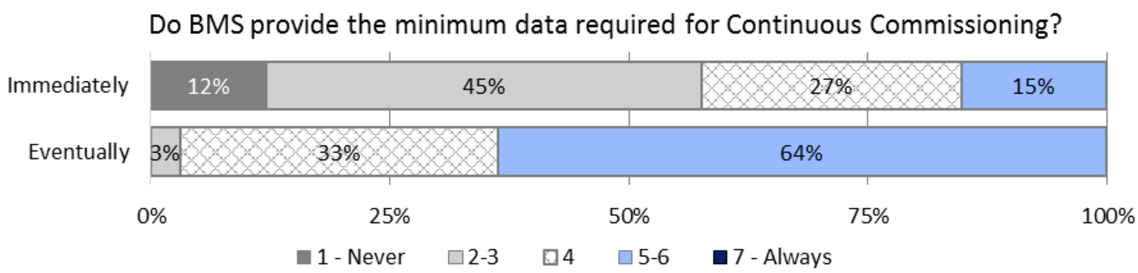

Figure 19: Data Accessibility (n=33)

Despite this, 64% of participants report that BMS are able to eventually provide the minimum data required for CCx, therefore BMS data availability is a time dependent issue, succeeding a specification of the required data, rather than a functional limitation of BMS. It should be noted, no participants have reported BMS as always eventually providing the required data, indicating not all required data points may be available even after being requested.

5.2.2.1 BMS RELIABILITY

Participants were asked to report on the overall importance and satisfaction of BMS reliability within the CCx process, such as the reliability of monitoring and trending of HVAC data. BMS reliability is a capability which was assessed separately as it was highlighted within literature as a hurdle to the success of CCx.

All participants reported a level of importance of BMS reliability (

Figure 20), which comes as no surprise as previously stated, the effectiveness of the Continuous Commissioning process is dependent on the quality (and reliability) of the data available (Liu et al., 2013). Some conclusions made within literature highlighted the limited reliability of BMS and BMS data due to inconsistencies in control logic, sensor calibration and hardware faults (Cutler et al., 2016; Hung, 2010; Ahmad et al., 2016). However, opposing to literature, the majority of participants within this study have reported some level of satisfaction (67%) in BMS being a reliable source of data. While only 6% are extremely satisfied with BMS reliability, 61% of participants are relatively satisfied, suggesting the poor reliability of BMS reported within literature is in fact not the largest hurdle and limitation of BMS within the CCx process.

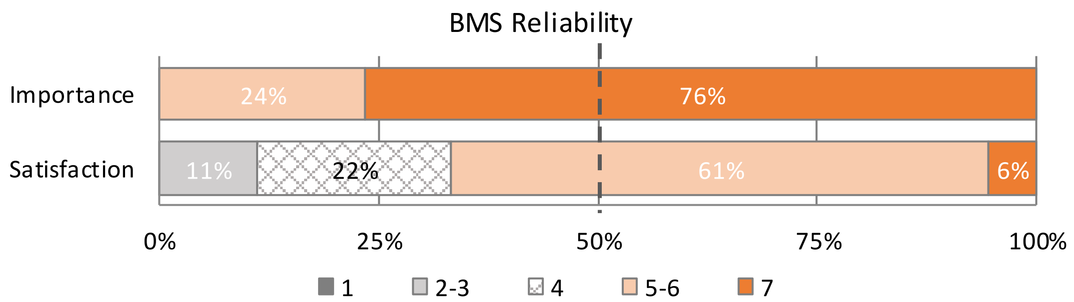

Figure 20: Importance and Satisfaction of BMS Reliability (n=19)

Analyses of user perceptions on BMS data extraction and formatting capabilities are reported in sections 5.2.3.1 and 5.2.4.1. These sections begin to highlight the limitations of BMS are in the exchange of data between BMS and CCx tools.

5.2.2.2 HVAC DOCUMENTATION ACCESS WITHIN BMS

Participants were presented with capabilities provided by BMS for documenting HVAC systems: schematics with real-time data display, equipment event logs and equipment meta-data. They were asked to report on the importance of each capability in relation to facilitating Continuous Commissioning and to rate their satisfaction of BMS providing these capabilities based on their experiences (Figure 21).

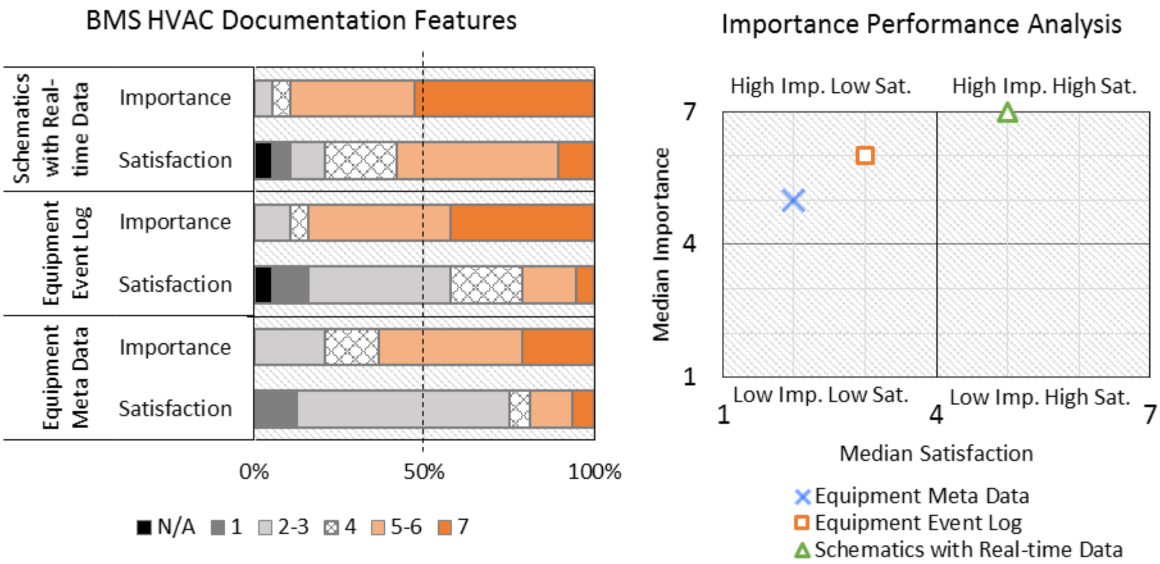

Figure 21: Importance and Satisfaction Analysis: BMS HVAC Documentation Features

BMS providing schematics with real-time data display was one of the most important HVAC documentation features reported by participants. The majority of participants also reported some level of satisfaction in this feature meeting the requirements to facilitate CCx. Contrary to this, the majority of participants are dissatisfied with equipment event logs and equipment meta-data capabilities of BMS, despite being identified as important to facilitating Continuous Commissioning by participants and across literature. This highlights a need for BMS capabilities to be improved to adequately provide documentation of HVAC system function, maintenance and operating details in order to facilitate Continuous Commissioning.

5.2.3 DATA EXTRACTION

Participants were asked to report on the overall importance of BMS in exporting data and to report their overall satisfaction of BMS providing the functions needed to effectively deliver the required data outputs (Figure 22).

The distribution of reported importance of BMS in facilitating the extraction of data (Figure 22), is similar to the distribution of reported importance of BMS in the monitoring of HVAC (Figure 18). There is a strong connection between the ability to monitor HVAC operation and extract the data to utilise for CCx. However, the large variance in perceived satisfaction of these functions suggests while continuous commissioners are primarily satisfied with the data monitored by BMS, there is a greater proportion of dissatisfaction in the ability to extract this data.

The perceived satisfaction of extracting data from a BMS is on average satisfactory, with an even distribution of participants being somewhat dissatisfied and somewhat satisfied, compared to 91% of participants indicating a BMS is somewhat important or extremely important at this stage of the CCx process. The distribution of reported importance and satisfaction scores highlights a need for improved BMS functionality in being able to extract data to facilitate the CCx process.

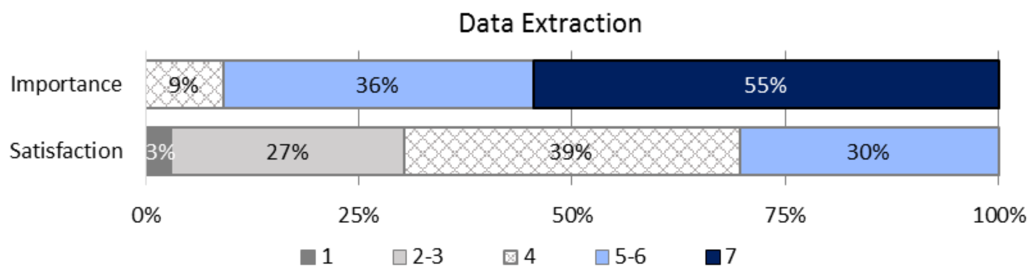

Figure 22: User Perceptions of BMS Facilitating Data Extraction (n=33)

5.2.3.1 BMS DATA EXTRACTION CAPABILITIES

Participants were asked to report the perceived importance and satisfaction on BMS capabilities which could facilitate the extraction of data for CCx and CCx tools, including: remote and online access, automatic data export and speed of data extraction (Figure 23).

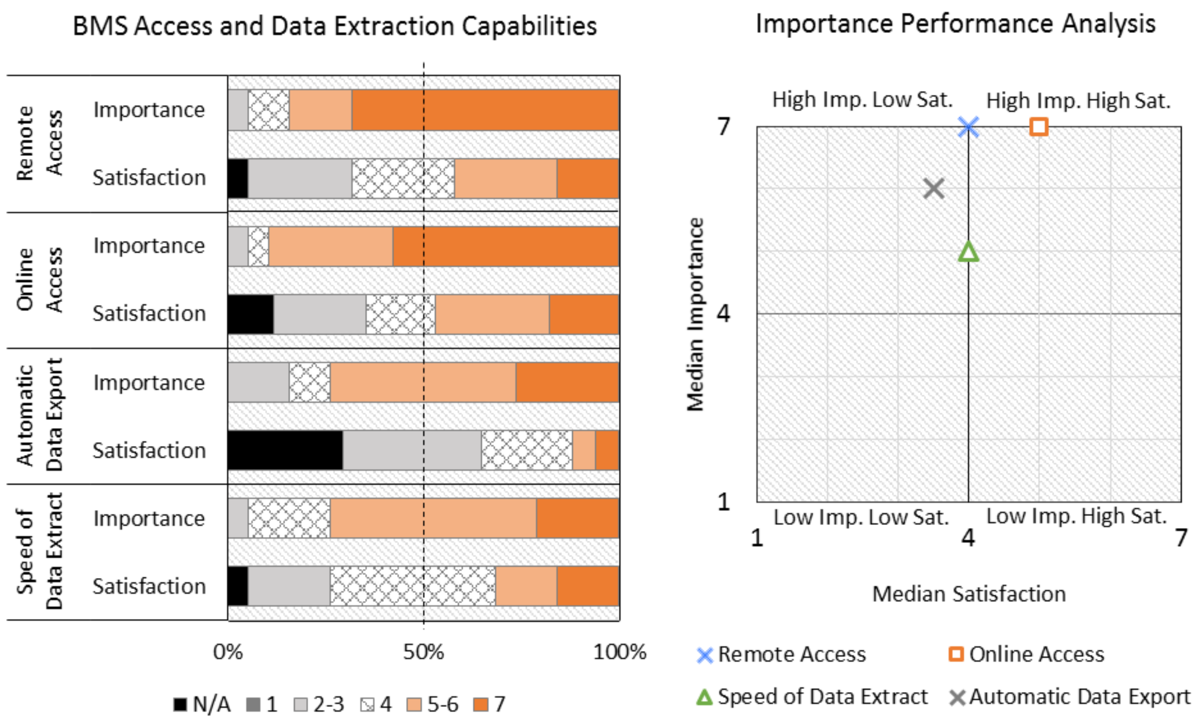

Figure 23: Importance and Satisfaction Analysis: BMS Access and Data Extraction Capabilities

Remote access to BMS was one of the most important HVAC documentation features reported by participants and reported more important than online access. However, the median level of satisfaction reported by participants for remote BMS access was undecided. This suggests there is room for improvement of the effectiveness of this capability to facilitate CCx. Further investigation is required to determine the specific cause of the relatively low level of satisfaction.

The automatic data export capability of BMS was reported as relatively important to facilitating the CCx process. However, there is a high level of dissatisfaction reported by participants where this function is considered available, while 29% of participants recognise this function is not typically provided by BMS at all. These results are suggestive of why many of the CCx processes reported by the participants involve manual data extraction and processing. Improving the capabilities of BMS to provide automatic and continuous streams of data would help overcome some of the hurdles encountered through the initial set up of CCx, as identified in literature.

5.2.4 DATA PROCESSING

Participants were asked to report on the overall importance of BMS being able to process data into a usable form for CCx and to report their overall satisfaction of BMS providing processed data effectively (Figure 24).

In order for assessments to be carried out on operation data, the data needs to be in a usable form. There is a clear variance in the distribution of reported importance of a BMS in processing data into a usable form (Figure 24). While 51% of participants report it to have importance, 49% of participants have a neutral viewpoint or see BMS as unimportant to facilitating this stage of CCx. The split view points of the group of respondents begins to suggest the varying CCx process carried out by individual participants could be a factor determining the importance of BMS at this stage. While the raw survey data was assessed further to find a correlation between the CCx characteristics used by participants who reported low importance, there was no consistent factor.

55% of participants reported some level of dissatisfaction with the processing capabilities of BMS to provide data in a usable form. When looking at participants who reported a level of dissatisfaction, these participants were more likely to have a manual data extraction method and manual CCx tool.

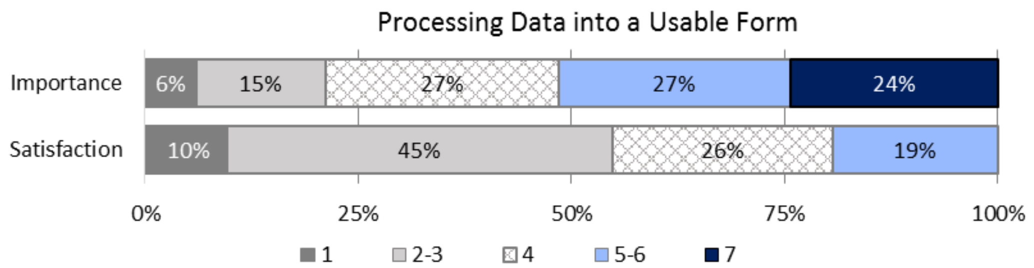

Figure 24: User Perceptions of BMS Facilitating Data Processing (n=33)

The more usable the data, the less manual processing time is required and the easier it becomes to apply CCx assessments. The relatively high median importance (5) and relatively low median satisfaction (3) of BMS in processing data into a usable form is reflective of some of the key issues encountered through the implementation of CCx within literature. The quality of data and the usability of this data is crucial to the CCx process (Liu et al., 2013). However, some of the key hurdles encountered through the implementation of CCx processes and tools is the lack of standardisation in BMS data and it not being provided in a usable form. This is a huge limitation of BMS for CCx tools as without standard, usable data formats, manual data processing is needed, which can be a time consuming and costly task. The results presented in Figure 24 justify the need for a more standardised format of data to be provided by BMS.

5.2.4.1 BMS CAPABILITIES TO CUSTOMISE DATA EXPORTS

Participants were asked to report the perceived importance and satisfaction on BMS capabilities which enable data trends and exports to be customised in a usable format. BMS capabilities covered in this section include: the abilities to specify the data points, timeframe and format for the data export file, the clarity of data point naming conventions, the ability to customise these, and the ability to specify aggregated data points[6] (Figure 25).

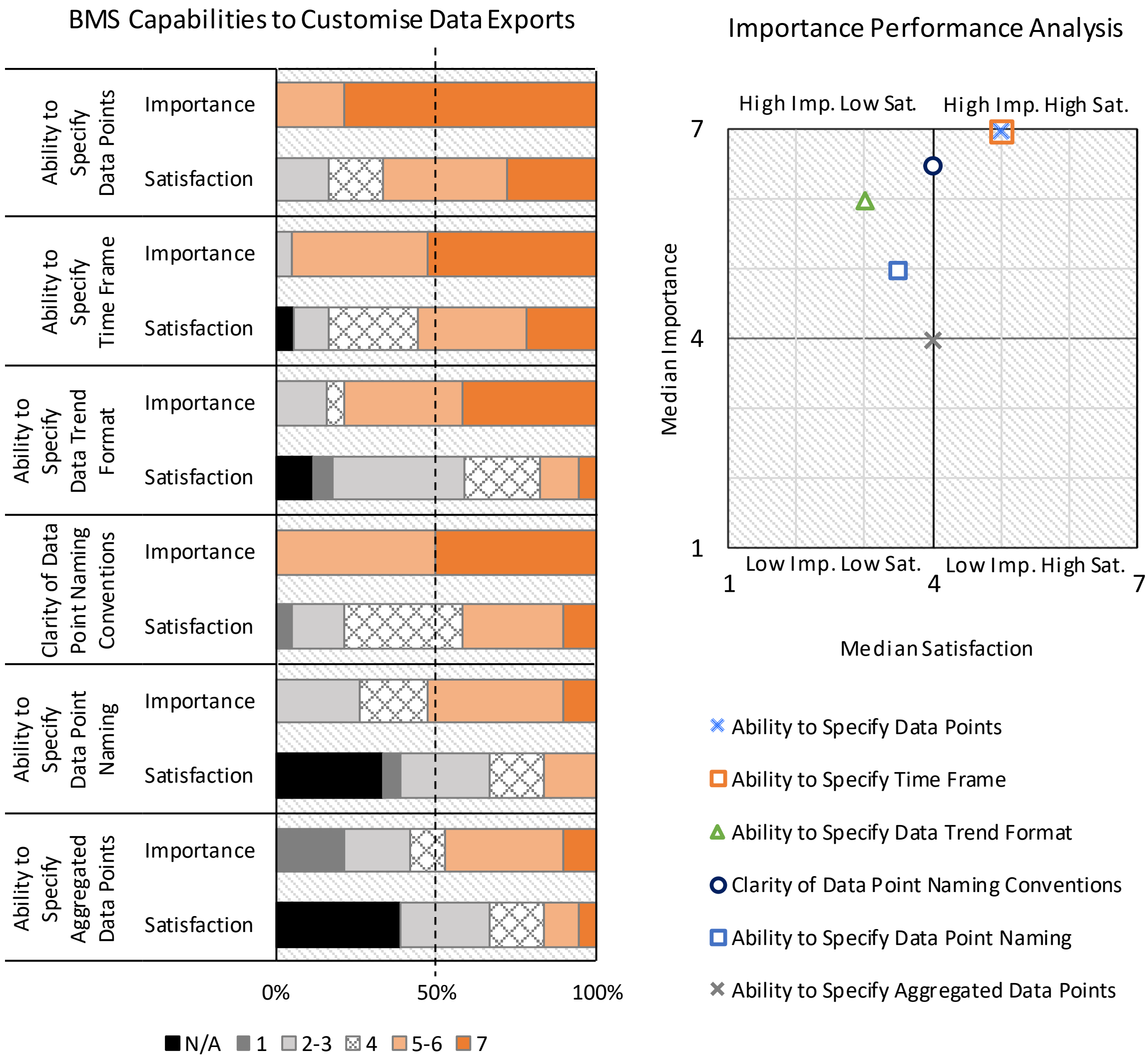

Figure 25: Importance and Satisfaction Analysis: BMS Capabilities to Customise Data Exports (n=19)

All participants identified the ability to specify data points to be exported and the clarity of their naming conventions as important to facilitating the CCx process. The reported level of satisfaction by the majority of participants is for the ability to specify the data points required for CCx is acceptable, while the clarity of data point naming conventions has a relatively even distribution of

[6] Aggregated data points are data trends derived from multiple data points, for example, to highlight the maximum, minimum or average temperature within a thermal zone.

satisfaction, dissatisfaction and undecided. It is interesting to note the clarity of data point naming conventions is reported with a higher importance than the ability for continuous commissioners to actually specify their own data point names. However, 33% of participants state this feature is not a typical capability of current BMS. Considering the majority of participants still recognise this function as important to facilitating CCx, it should be the focus of future BMS developments.

5.2.5 DATA ANALYSIS

Participants were asked to report on the overall importance of a BMS facilitating data analysis, for example being able to analyse HVAC operating data through embedded CCx analytics. Participants were also asked to report their overall satisfaction of BMS effectively providing data analysis functions to diagnose operating issues and areas for improving energy efficiency (Figure 26).

Figure 26 shows a similar distribution of importance rankings for the role of BMS in analysing data compared to the role of BMS in processing data into a usable form, with responses again at both extremes of the scale. The relatively even distribution of high, neutral and low importance of BMS at this stage continues to suggest the characteristics of each respondent’s CCx process may begin to influence the perceived importance of a BMS at this stage (Figure 26). However, all participants but one, who reported a BMS as important (5-7) at this particular stage of the CCx process, also reported a low or neutral level of satisfaction. The same participants reported the use of a manual data import method and analysis.

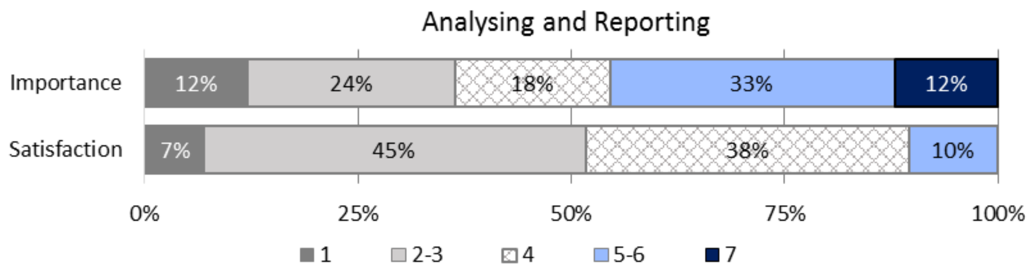

Figure 26: User Perceptions of BMS Facilitating Data Analysis (n=33)

Participants who deemed BMS as important in providing data analysis and reporting capabilities are currently not satisfied with these functions provided by BMS. Data visualisation capabilities of BMS are an example of how BMS can be used to facilitate the analysis and reporting of HVAC operation performance. The importance and satisfaction of BMS visualisation capabilities are reported in section 5.2.5.1, where the visualisation capabilities requiring the greatest level of performance improvement are identified.

5.2.5.1 BMS DATA VISUALISATION AND USABILITY FEATURES

Participants were asked to report the perceived importance and satisfaction of data visualisation and usability features being provided by BMS. The features covered in this section include: usability of the overall graphical user interface (GUI), ease of navigation, clarity of BMS language and terminology, real-time data display, the ability to customise trend lines and scatter plots and the provision of additional data features (Figure 27).

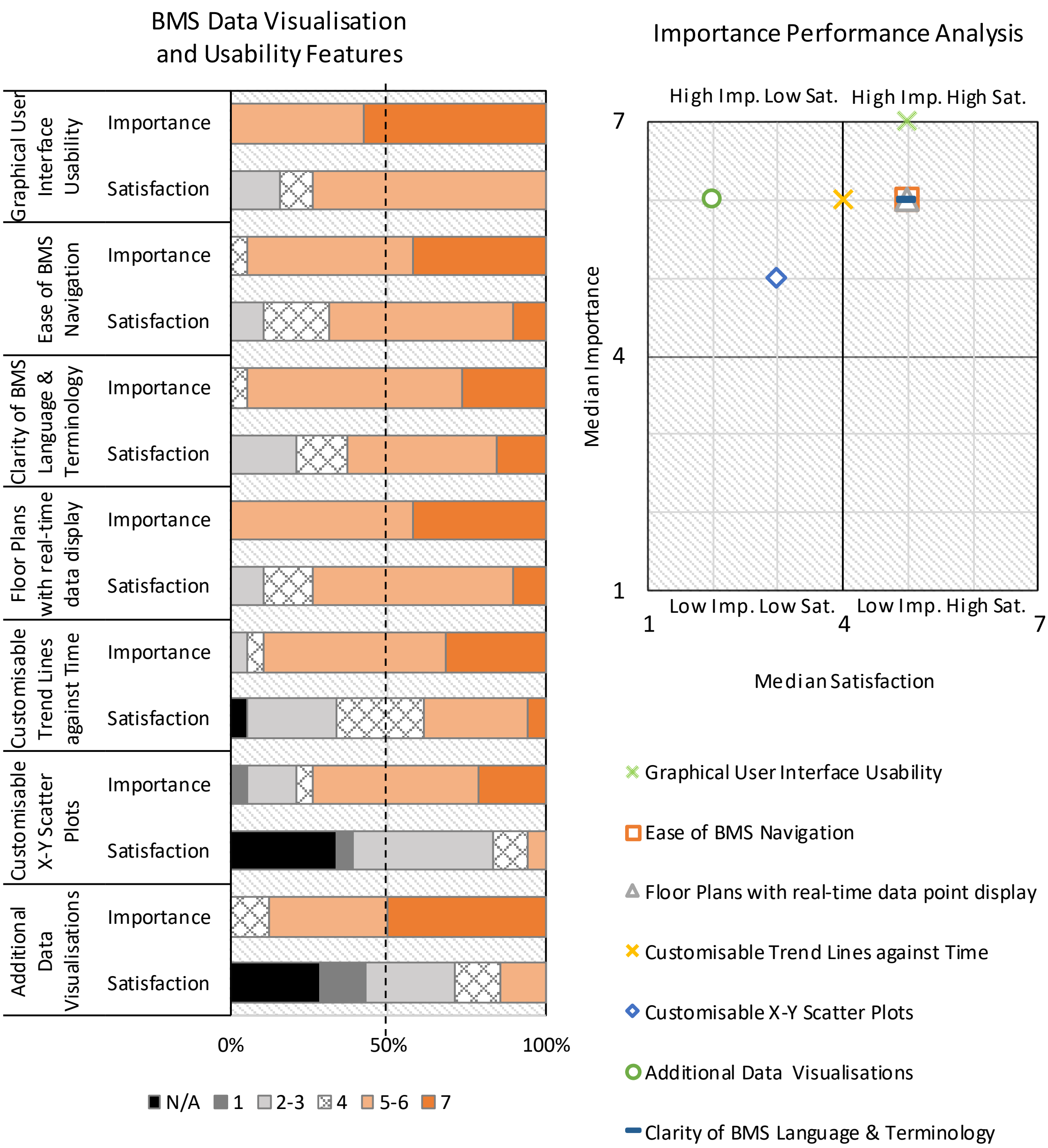

Figure 27: Importance and Satisfaction Analysis: BMS Data Visualisation and Usability Features (n=19)

All participants identified the usability of the GUI and real-time data point displays as important features of BMS needed to facilitate the CCx process. Overall, the majority of participants are relatively satisfied with the usability of BMS, including the GUI, ease of navigation and clarity of terminology. The reported level of importance and satisfaction is most disparate for data visualisation features of BMS, such as visualising data trend lines and creating scatter plots. In some cases, multiple participants have reported some of these basic visualisation features as unavailable on current BMS. The relatively high importance and low satisfaction reported for BMS visualisation features is suggestive of why most CCx assessments, analysis and reporting has to be carried out externally to BMS.

5.2.6 THE IMPLEMENTATION OF STRATEGIES

The role of a BMS in implementing energy saving strategies determined through CCx assessments was reported as important by 66% of all participants, with 36% reporting this as extremely important (Figure 28). This indicates while BMS are crucial to the extraction of data to carry out CCx, they are also crucial to implementing energy saving control strategies. The satisfaction of BMS in enabling this is comparatively lower. While 46% of participants perceive some level of satisfaction, 36% of participants are not satisfied with the current functions of BMS in facilitating the implementation of control changes, although there were not participants who were extremely dissatisfied. The distribution of reported satisfaction indicates there is room to improve the way BMS facilitate making control and operational changes to HVAC performance. As previously identified, the majority of continuous commissioners are using BMS directly. While the direct use of BMS is likely to vary at the implementation stage of Continuous Commissioning due to the potential requirement of re-programming BMS, continuous commissioners could be indicating a need for a more direct way for them to make operational changes to improve HVAC energy efficiency. This begins to suggest a need for the future design of BMS to anticipate use by professionals of non-programming backgrounds.

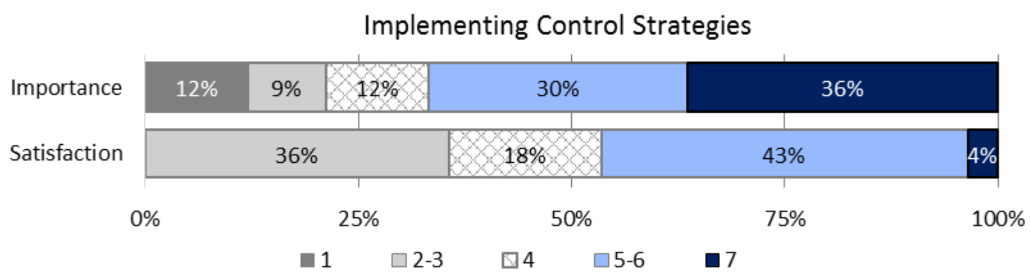

Figure 28: User Perceptions of BMS Facilitating the Implementation of Control Strategies (n=33)

5.2.6.1 EASE OF BMS CONTROL ADJUSTMENTS AND UPGRADES

Participants were asked to report on the importance and satisfaction of BMS capabilities which increase the ease at which HVAC control adjustments and BMS upgrades can be made (Figure 29, Figure 25).

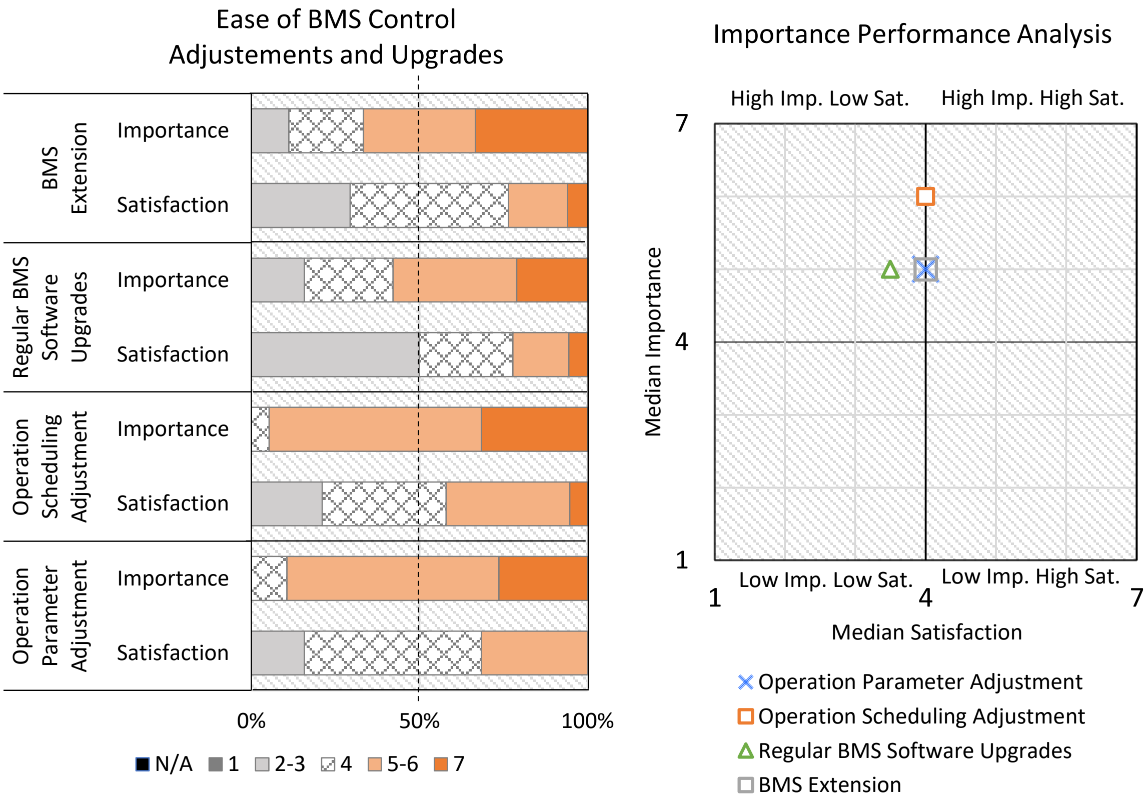

Figure 29: Importance and Satisfaction Analysis: Ease of BMS Control Adjustments and Upgrades (n=19)

The most important capabilities of BMS in facilitating the implementation of control changes is the ability for continuous commissioners to make basic schedule and parameter adjustments. These might include adjusting the operating period of equipment and heating and cooling set points respectively. The importance of these capabilities is further reflected by these types of improvements being reported in the top CCx assessments for air distribution systems. Despite the high level of importance reported by the majority of participants across all capabilities presented in Figure 29, there is a relatively low reporting of satisfaction. In particular, the majority of participants are dissatisfied with the provision of regular BMS software upgrades. This is a potential limitation of BMS being able to meet some of the capability requirements for facilitating the Continuous Commissioning process.

5.2.7 MEASUREMENT AND VERIFICATION

The perceived importance and satisfaction of BMS in enabling measurement and verification (M&V) refers to the ability of a BMS to provide evidence in energy savings following the implementation of improved control strategies. 60% of participants report BMS as having high importance in the measurement and verification stage of CCx (Figure 30). The perceived importance and satisfaction of BMS during the M&V stage of CCx was expected to be comparable to the initial stage of monitoring HVAC operation due to the assumption that the data required to carry out CCx, would be the same data which could be used to verify the performance of improved control strategies. However, M&V requires a measurement of energy and cost savings as a result of energy efficiency measures (Webster et al., 2015). It is likely because of this the perceived satisfaction of BMS in enabling M&V is much lower than that of monitoring operation. 43% of participants are dissatisfied with BMS facilitating M&V, despite an acknowledgement of high importance. This begins to suggest BMS do not necessarily have energy metering functions to measure and verify the performance of CCx strategies.

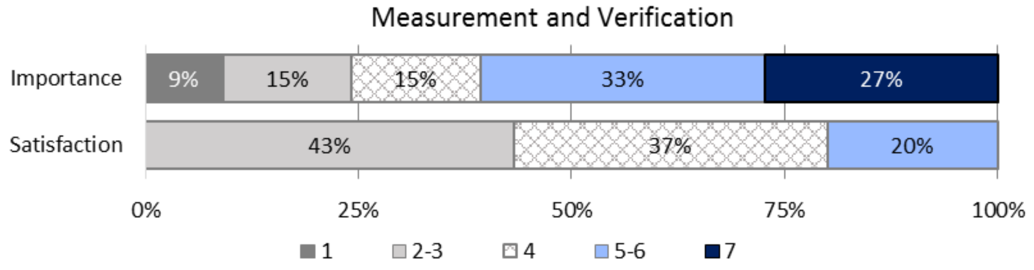

Figure 30: User Perceptions of BMS Facilitating Measurement and Verification (n=33)

5.2.7.1 ACCESS TO SUB-METER ENERGY DATA IN BMS

In parallel to the questions asked about energy sub-metering requirements as part of the Delphi method (results reported in section 6.6), participants were asked to identify whether they thought building energy data should be accessible through BMS. 68% of participants agreed energy data should be accessible through BMS with all other trend data required for CCx. 32% of participants disagreed stating BMS are not typically set up with the accuracy or storage capabilities required to meter energy data and that the BMS should be maintained solely as a HVAC control and monitoring device. This suggests if BMS were equipped to effectively meter and store energy data this would be useful to facilitating the CCx process, particularly during the M&V stage.

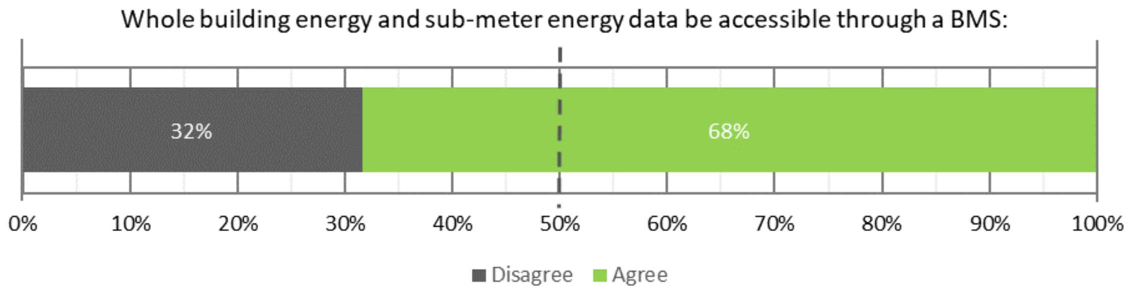

Figure 31: BMS Access to Whole Building Energy and Sub-meter Energy Data (n=19)

6 RESULTS PART TWO: A CONSENSUS OF CCX ASSESSMENTS AND BMS DATA TRENDING REQUIREMENTS BY HVAC SYSTEM TYPE

This chapter reports and discusses participant responses to the Delphi survey questions asked in round one, two and three, as highlighted in Table 25. The Delphi survey questions aimed to develop a consensus on the Continuous Commissioning (CCx) assessments (SRQ 2) applied to typical HVAC systems (section 4.3.1), from which a consensus aimed to be developed on the minimum data trending requirements (SRQ 3) for implementing the CCx assessments.

Participant responses to the Delphi survey questions were collected following the processes presented in section 4.3, for CCx assessments (**Error! Reference source not found.**) and data point trending (Figure 7).

The level of agreement on the proposed consensus for CCx assessments and data points for trending were calculated, from which a genuine consensus could be determined (refer section 3.4.1.1). A genuine consensus was found where the level of participant agreement was greater than seventy percent (Schmidt, 1997).

Table 25: Reporting the Results of the Delphi Method

Survey Round	SRQ Reference	Aim	Survey Method
Round 1	SRQ 5	Identify characteristics of Continuous Commissioning Processes carried out by participants	Standard Questionnaire *(SRQ6 - Closed Questions)* *(SRQ1 - Importance and Satisfaction Scale)*
	SRQ 1	Identify the importance and satisfaction of BMS facilitating stages of the Continuous Commissioning process.	
	SRQ 2	Identify common CCx assessments applied to improve the energy efficiency of typical HVAC.	Delphi Method
Round 2	SRQ 2	Form a consensus from R1: Part B	Delphi Method
	SRQ 3	Identify the minimum data points and data interval required for CCx assessments	Delphi Method
Round 3	SRQ 3	Form a consensus from R2: Part B	Delphi Method
	SRQ 4	Identify the importance and satisfaction of BMS capabilities in relation to CCx.	Standard Questionnaire *(Importance and Satisfaction Scale)*

This chapter is broken down by HVAC systems, followed by data trending requirements. The first section, Air Handling Units (AHU), reports the development of the final consensus of the top five CCx assessments applied to this system, and the minimum data points required for trending to carry out these assessments. The following system sections present a summary of whether a consensus was formed, with reference to the top five CCx assessments and required data points in the Appendices.

6.1 CENTRAL AIR HANDLING UNITS (AHU)

6.1.1 CONTINUOUS COMMISSIONING ASSESSMENTS FOR AIR HANDLING UNITS

Participants were presented with an example schematic of each HVAC system. An example of the Air Handling Unit (AHU) schematic is presented in Figure 32. Participants were asked to rank the top five CCx assessments applied to improve the energy efficiency of that system, based on a complete list defined by literature for Constant (CAV) and Variable Air Volume (VAV) AHUs (refer Appendix 10.3.1).

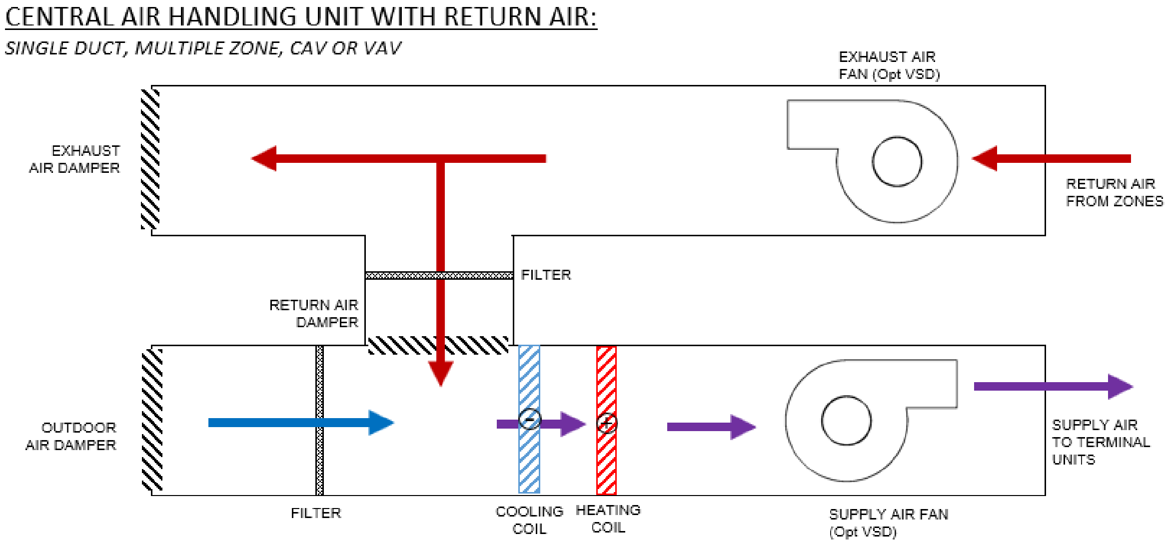

Figure 32: Exemplar Schematic of Air Handling Unit with Return Air (Authors Image)

The top seven CCx assessments for CAV AHUs were identified based on the rank scoring process reported in section 4.3.2.1 and proposed as a consensus of the top AHU assessments in the following survey round. Table 26 presents the proposed consensus for CAV AHUs CCx assessments, from which participants were asked to agree or disagree with the top five. The level of agreement and the confidence in the order of ranks is presented in Figure 33 and Table 27.

Table 26: Top 7 CAV AHU CCx Assessments

Central AHU: Top 7 Constant Air Volume Assessments
1. AHU Afterhours Operation *(Scheduling)*
2. AHU Heating and Cooling Coils Fighting
3. Economiser
4. Demand Control Ventilation
5. AHU Discharge Air Temperature Reset
6. AHU optimum Start/Stop
7. Assessment of AHU Fan Speeds e.g. SAF vs RAF

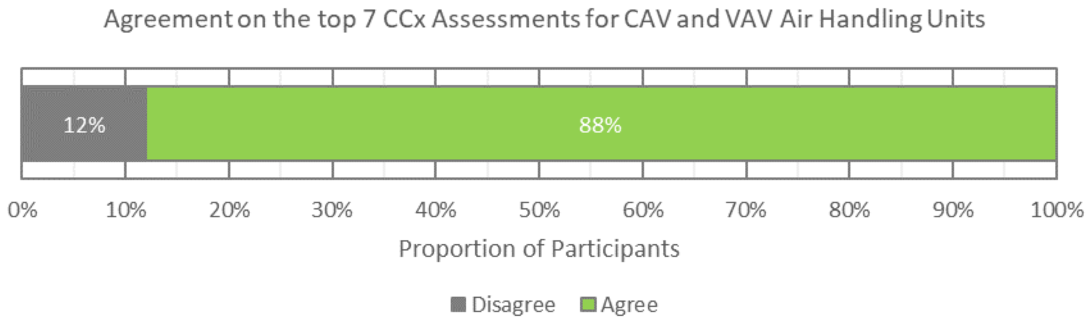

Figure 33: Level of Agreement on the Top Five CCx Assessments for AHUs (n=25)

A consensus was formed by participants on the top five CCx assessments applied to Air Handling Units. Eighty-Eight percent of participants agreed the top five CCx assessments presented in Table 26 were the most important assessments to be applied to central AHUs when looking to improve their energy performance. By calculating Kendall's co-efficient of concordance, additional confidence is provided to the ranked order of these assessments.

Table 27: Confidence in the Order of Ranks for AHU CCx Assessments

Kendall's Co-efficient of Concordance (W)	Interpretation (Schmidt, 1997)
0.93	Unusually Strong Agreement

In order to account for the potential variation in applicable CCx assessments for VAV compared to CAV AHUs, participants were asked to indicate whether any VAV only assessments (Table 28) were considered more important than the top seven AHU assessments which are applicable to both. While a majority vote could be identified (64%), a definitive consensus around this was not formed (level of agreement is less than 70%). Figure 34 shows the majority of participants disagreed that any of the additional VAV AHU assessments were more important than those presented in Table 26.

Table 28: Additional VAV AHU CCx Assessments

Additional Variable Air Volume CCx Assessments
1. Duct Static Pressure Reset
2. Assessment of AHU damper positions
3. Night purge
4. Assessment of Air Velocity
5. AHU Heating and Cooling Coil Lockout

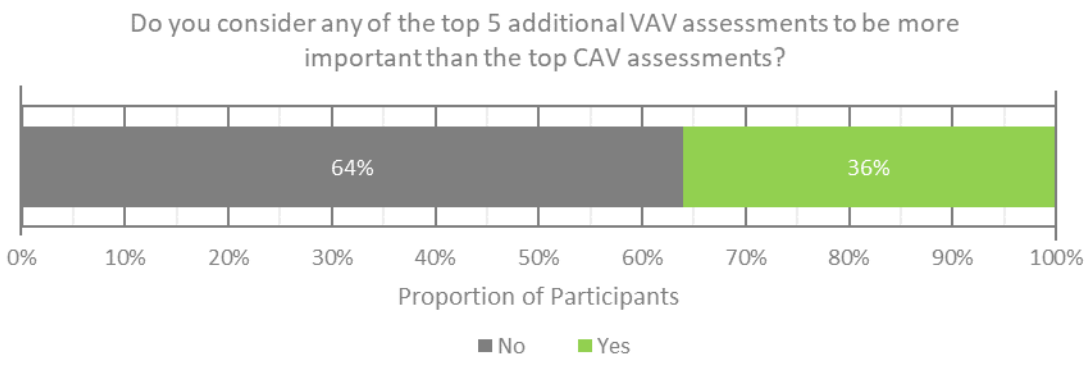

Figure 34: Level of Agreement on VAV only CCx Assessments being more Important than top CAV assessments (n=25)

6.1.2 DATA POINTS TO BE TRENDED FOR AIR HANDLING UNITS

The second part of the Delphi survey process asked participants to identify the minimum data points required for trending to carry out the top five CCx assessments. Participants were presented with a complete list of the data points for central AHUs identified in literature as data points to be controlled by BMS, but not specifically trended (Appendix 10.4.1). Table 29 presents the proposed and final consensus of the minimum CAV and VAV AHU data points required for trending. Consensus among participants is recognised as an "X".

Table 29: Minimum Data Points to be Trended for Air Handling Units

Data Points for Trending	Unit	Data Points to be Trended for Constant Air Volume AHU	Data Points to be Trended for Variable Air Volume AHU
Outdoor Air Temperature	°C	**X**	**X**
Mixed Air Temperature	°C	**X**	**X**
Return Air Temperature	°C	**X**	**X**
Primary Supply Air Temperature	°C	**X**	**X**
Duct Static Pressure	Pa	**Not Required**	**X**
Return Air Damper Position	%	**X**	**X**
Outdoor Air Damper Position	%	**X**	**X**
Exhaust Air Damper Position	%	**X**	**X**
Supply Fan Status	On/Off	**X**	**X**
Supply Air Fan Speed	%	**X**	**X**
Return/Exhaust Fan Status	On/Off	**X**	**X**
Return/Exhaust Fan Speed	%	**X**	**X**
Ahu Cooling Valve Position	%	**X**	**X**
Ahu Heating Valve Position	%	**X**	**X**
Supply Airflow	l/s	**Not Required**	**X**
Return/Exhaust Airflow	l/s	**Not Required**	**X**
Return Air CO_2 Sensor	ppm	**X**	**X**
Supply Air CO_2 Sensor	ppm	**X**	**X**
Outdoor Air Filter Pressure Differential	Pa	**X**	**X**

A consensus was formed among participants, with 95% of participants agreeing with the proposed consensus of data points in Table 29. Figure 35 presents this very high level of agreement, giving confidence in the minimum data points required for trending AHUs.

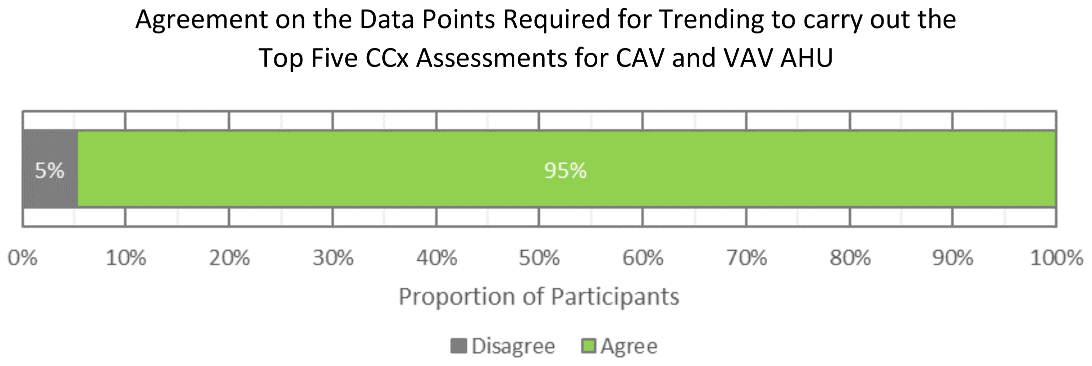

Figure 35: Level of Agreement on the Data Points Required for Trending the Top Five CCx Assessments for AHU

In the final round of the survey, participants were also presented with additional data points which were considered important for trending by multiple participants in the previous round. Participants were asked to agree or disagree with the additional data points (Table 30) being a minimum requirement for carrying out the previously defined CCx assessments.

Table 30: Additional Proposed Data Points for Trending AHU

Additional Proposed Data Points for Trending	Unit	Additional Data Points to be Trended for Constant Air Volume AHU	Additional Data Points to be Trended for Variable Air Volume AHU
Return Duct Static Pressure	Pa	X	X
Outdoor Air Relative Humidity	%	X	X
Return Air Relative Humidity	%	X	X
AHU Operating Load	kW	X	X

While the majority of participants (58%) agreed that these additional data points should be trended, no consensus was formed. Forty-two percent of participant disagreed with the need to trend these data points, stating they were "nice-to-have" rather than essential.

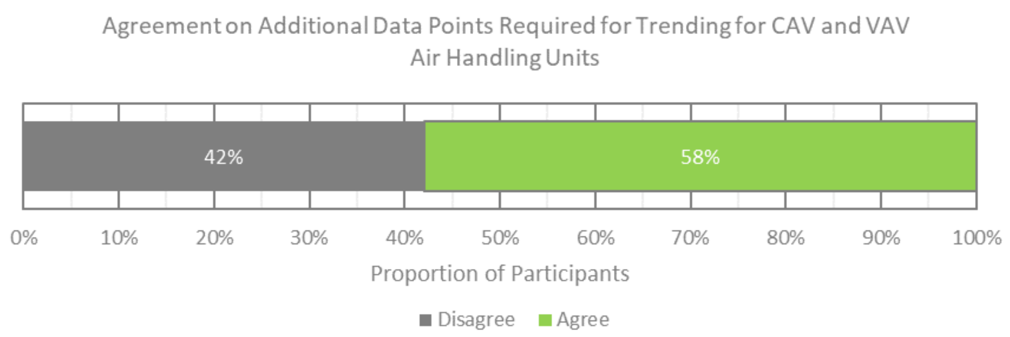

Figure 36: Level of Agreement on Additional Data Points for AHUs

6.1.3 SUMMARISING THE FORMED CONSENSUSES

Table 31 summarises the consensuses formed for the top CCx assessments and minimum data points to be trended for Constant and Variable Air Volume Air Handling Units. The same process of developing consensus for CCx assessments and data points as reported within this section (6.1) has been followed for each HVAC system. For simplicity, a summary table like Table 31 is presented for all other systems, with the detail of the final consensus (lists of CCx assessments and data points and level of agreement charts) are presented in corresponding appendices, referenced within the first column of the table.

Table 31: Air Handling Units: Level of Agreement for CCx Assessments and Data Point Trending

HVAC System Type	Survey Item	Consensus (X >70%) X = Level of Agreement	Kendall's Co-efficient of Concordance (W)	Majority (70> X% >50)	Results Outcome
Constant Air Volume (CAV) AHU **(Appendix 10.10.1)**	Level of agreement on the order of importance of the top CCx assessments.	CONSENSUS (X=88%)	CONFIDENCE IN RANK ORDER (W = 0.93)	N/A	CONSENSUS AND CONFIDENCE RANK ORDER
Variable Air Volume (VAV) AHU **(Appendix 10.10.2)**	Level of agreement on VAV only CCx assessments being more important than the top CAV assessments.	NO CONSENSUS	N/A	MAJORITY (X=64%)	MAJORITY VOTED AGAINST VAV ONLY ASSESSMENTS BEING MORE IMPORTANT THAN CAV
Data Points: CAV and VAV AHU **(Appendix 10.10.3 & 10.10.4)**	Level of agreement on the MINIMUM data points to be trended	CONSENSUS (X=95%)	N/A	N/A	CONSENSUS
	Level of agreement on ADDITIONAL data points to be trended	NO CONSENSUS	N/A	MAJORITY (X=58%)	MAJORITY VOTED FOR ADDITIONAL DATA POINTS TO BE TRENDED

6.2 ON-FLOOR TERMINAL AIR UNITS

Table 32 presents a summary of the level of agreement of participants on the top Continuous Commissioning assessments and minimum data points required for trending typical on-floor terminal air units. A consensus was formed on the top CCx assessments applied to CAV terminal units and Fan Coil Units (FCU). Kendall's co-efficient for each of these on-floor systems shows a high level of confidence in the order of rankings. The majority of participants (68%) voted against VAV unit only assessments being more important than those already identified as the top five for CAV units. Therefore, the consensus formed on the top five CCx assessments applied to CAV can be considered as a consensus on the top five VAV assessments.

A consensus was formed on the minimum data points required for trending for CAV, VAV and FCU terminal air units. Additional data points were proposed for trending FCUs. Unlike the additional data points proposed for trending AHUs, the additional FCU data points were considered important by the majority of participants.

Table 32: On-floor Terminal Air Units: Level of Agreement for CCx Assessments and Data Point Trending

HVAC System Type	Survey Item	Consensus (X >70%) X = Level of Agreement	Kendall's Co-efficient of Concordance (W)	Majority (70> X% >50)	Results Outcome
CAV Terminal Air Units (Appendix 10.11.1)	Level of agreement on the order of importance of the top CCx assessments.	CONSENSUS (X=72%)	CONFIDENCE IN RANK ORDER (W = 0.90)	N/A	CONSENSUS AND CONFIDENCE RANK ORDER
VAV Terminal Air Units (Appendix 10.11.2)	Level of agreement on VAV only CCx assessments being more important than the top CAV assessments.	NO CONSENSUS	N/A	MAJORITY (X=68%)	MAJORITY VOTED AGAINST VAV ONLY ASSESSMENTS BEING MORE IMPORTANT THAN CAV
Fan Coil Units (FCU) (Appendix 10.11.3)	Level of agreement on the order of importance of the top CCx assessments.	CONSENSUS (X=76%)	CONFIDENCE IN RANK ORDER (W = 0.84)	N/A	CONSENSUS AND CONFIDENCE RANK ORDER
CAV, VAV and FCU Terminal Unit Data Points (Appendix 10.11.4 & 10.11.5)	Level of agreement on the MINIMUM data points to be trended	CONSENSUS (X=74%)	N/A	N/A	CONSENSUS
	Level of agreement on ADDITIONAL data points to be trended for FCU	NO CONSENSUS	N/A	MAJORITY (X=61%)	MAJORITY VOTED FOR ADDITIONAL DATA POINTS TO BE TRENDED

6.3 CHILLED WATER LOOP

Table 33 presents a summary of the level of agreement of participants on the top Continuous Commissioning assessments and minimum data points required for trending typical Chilled Water Loops (CHW). The level of agreement on the top five CCx assessments to be applied to Constant Flow (CF) CHW loops was not high enough to achieve a consensus. However, there is still a level of confidence provided in the order of rankings based on Kendall's W. Like the other HVAC systems reported, a consensus was not formed on whether CCx assessments for Variable Flow (VSD) CHW assessments were considered more important than those applicable to both CF and VSD. The majority voted against the VSD assessments being more important

A consensus was formed on the minimum data points required for trending both CF and VSD CHW loop systems. The additional data points proposed for trending CHW systems were considered required for trending by the majority of participants (58%). Further investigation would be required in order to develop a consensual agreement.

Table 33: Chilled Water Loop: Level of Agreement for CCx Assessments and Data Point Trending

HVAC System Type	Survey Item	Consensus (X >70%) X = Level of Agreement	Kendall's Co-efficient of Concordance (W)	Majority (70> X% >50)	Results Outcome
Constant Flow (CF) Chilled Water Loop (Appendix 10.12.1)	Level of agreement on the order of importance of the top CCx assessments.	NO CONSENSUS	CONFIDENCE IN RANK ORDER (W = 0.80)	MAJORITY (X=67%)	MAJORITY VOTE AND CONFIDENCE RANK ORDER
Variable Flow (VSD) Chilled Water Loop (Appendix 10.12.2)	Level of agreement on VSD only assessments being more important than the top CF assessments.	NO CONSENSUS	N/A	MAJORITY (X=60%)	MAJORITY VOTED AGAINST VSD ONLY ASSESSMENTS BEING MORE IMPORTANT THAN CF
CF and VSD Chilled Water Loop Data Points (Appendix 0 & 10.12.4)	Level of agreement on the MINIMUM data points to be trended	CONSENSUS (X=89%)	N/A	N/A	CONSENSUS
	Level of agreement on ADDITIONAL data points to be trended	NO CONSENSUS	N/A	MAJORITY (X=58%)	MAJORITY VOTED FOR ADDITIONAL DATA POINTS TO BE TRENDED

6.4 HOT WATER LOOP

Table 34 presents a summary of the level of agreement of participants on the top Continuous Commissioning assessments and minimum data points required for trending typical Hot Water Loops (HHW). Much like the level of agreement reported on Chilled Water Loops, the level of agreement on the top five CCx assessments to be applied to Constant Flow (CF) HHW loops was not high enough to achieve a consensus. There is still some level of confidence provided in the order of rankings based on Kendall's W. The majority of participants (68%) voted against the Variable HHW system assessments being more important than those already presented.

The high level of agreement for the minimum data points required for trending formed a definitive consensus for trending requirements of constant and variable flow HHW systems and domestic hot water (DHW).

Table 34: Hot Water Loop: Level of Agreement for CCx Assessments and Data Point Trending

HVAC System Type	Survey Item	Consensus (X >70%) X = Level of Agreement	Kendall's Co-efficient of Concordance (W)	Majority (70> X% >50)	Results Outcome
Constant Flow (CF) Hot Water Loop (Appendix 10.13.1)	Level of agreement on the order of importance of the top CCx assessments.	NO CONSENSUS	CONFIDENCE IN RANK ORDER (W = 0.84)	MAJORITY (X=64%)	MAJORITY VOTE AND CONFIDENCE RANK ORDER
Variable Flow (VSD) Hot Water Loop (Appendix 0)	Level of agreement on VSD only assessments being more important than the top CF assessments.	NO CONSENSUS	N/A	MAJORITY (X=68%)	MAJORITY VOTED AGAINST VSD ONLY ASSESSMENTS BEING MORE IMPORTANT THAN CF
CF and VSD Hot Water Loop Data Points (Appendix 10.13.3 & 10.13.4)	Level of agreement on the MINIMUM data points to be trended	CONSENSUS (X=89%)	N/A	N/A	CONSENSUS
	Level of agreement on ADDITIONAL data points to be trended	CONSENSUS (X=89%)	N/A	N/A	CONSENSUS FOR ADDITIONAL DATA POINTS TO BE TRENDED
Domestic Hot Water Loop Data Points (Appendix 10.13.5)	Level of agreement on the MINIMUM data points to be trended	CONSENSUS (X=79%)	N/A	N/A	CONSENSUS

6.5 HVAC DATA TRENDING REQUIREMENTS

In the second survey round, participants were asked to determine what proportion of each typical HVAC equipment should be trended. For example, this question aimed to determine whether it was necessary to trend data on all on-floor terminal air units, of which are numerous in large non-residential buildings. This part of the Delphi survey also aimed to identify the minimum and ideal data trending intervals required for providing the level of detail needed to apply Continuous Commissioning (CCx) assessments.

Table 35 presents a summary of the level of agreement of participants on the data trending requirements for all typical HVAC systems covered in this thesis. A consensus was formed around the proportion of HVAC equipment types that should have the previously defined data points trended for. There was a clear consensus amongst participants (95%) that all central HVAC equipment should be trended, for example when there are multiple AHUs, all should be trended for optimal assessment for potential for energy savings. The level of agreement among participants on the proportion of on-floor air systems to be trended was reduced (89%), however a consensus was still formed on all on-floor terminal air units to be trended. The participants who disagreed stated trending all on-floor systems could result in too much information, and that a representative sample could be sufficient.

A consensus was formed on the minimum and ideal data trending intervals required to carry out CCx assessments. Seventy-four percent of participants agreed data points trended at 15 minutes or less to be the minimum level of granularity needed to effectively implement CCx assessments, while five minutes or less would be ideal to provide additional insights and more detailed diagnostic assessments for reducing energy consumption. However, one participant noted that smaller data intervals may not necessarily provide additional insight and that the most appropriate data interval is dependent on each specific CCx assessment.

A consensus was not formed on data storage requirements, however, the majority of participants (68%) agreed on the minimum period of time HVAC data should be stored for was three months, with the ideal being at least two years. This relatively low level of agreement is likely due to the most appropriate data storage periods being dependent on whether Continuous Commissioning has been implemented or is going to be implemented. For example, if CCx was underway and the trended data was being stored and assessed continuously or periodically, three months of data storage could be sufficient for back up. While the initial implementation of CCx might require data trends dating back for at least two years to provide indicative operating trends of equipment across multiple seasons.

Table 35: Level of Agreement on Data Trending Requirements for all systems

HVAC System Type	Survey Item	Consensus (X >70%) X = Level of Agreement	Majority (70> X% >50)	Results Outcome	
Central HVAC Systems (AHU, CHW, HHW) **(Appendix 10.14.1)**	Level of agreement on the MINIMUM proportion of components to be trended per central plant type	CONSENSUS (X=95%)	N/A	CONSENSUS	ALL CENTRAL SYSTEM COMPONENTS SHOULD BE TRENDED
On-floor HVAC Systems (CAV, VAV, FCU)	Level of agreement on the MINIMUM proportion of components to be trended per on-floor plant type	CONSENSUS (X=89%)	N/A	CONSENSUS	ALL ON-FLOOR SYSTEM COMPONENTS SHOULD BE TRENDED
ALL HVAC SYSTEMS **(Appendix 0 & 0)**	Level of agreement on the MINIMUM and IDEAL data trending intervals for all systems	CONSENSUS (X=74%)	N/A	CONSENSUS	**MINIMUM = 15min or less** **IDEAL = 5min or less**
	Level of agreement on the MINIMUM and IDEAL data storage periods	NO CONSENSUS	MAJORITY (X=68%)	MAJORITY VOTED IN AGREEMENT WITH THE PROPOSED DATA STORAGE PERIODS	**MINIMUM = 3 months** **IDEAL = At least 2 years**

6.6 HVAC ENERGY SUB-METERING REQUIREMENTS

Participants were asked about energy sub-metering of HVAC as requirements to facilitating Continuous Commissioning. Table 36 presents the level of agreement on energy sub-metering requirements as defined by participants.

A consensus was formed on the requirement of energy sub-metering for all HVAC types. All central plant equipment such as AHUs, Chillers, Cooling Towers, Boilers and Heat Pumps should have an individual energy sub-meter, metering data at 15-minute intervals or less to facilitate the CCx process. Participants agreed energy sub-metering of individual on-floor terminal air units was not required, however a consensus was formed on these units being metered as a whole at the floor level.

As previously identified in Chapter 5, the majority of participants agree energy sub-metering data should be accessible via BMS to facilitate Continuous Commissioning

Table 36: Level of Agreement on Energy sub-metering requirements

HVAC System Type	Survey Item	Consensus (X >70%) X = Level of Agreement	Majority (70> X% >50)	Results Outcome	
All HVAC Systems **(Appendix 10.15.1)**	Level of agreement on the MINIMUM energy sub-metering and trending interval requirements	CONSENSUS (X=84%)	N/A	CONSENSUS	ALL CENTRAL SYSTEM COMPONENTS SHOULD METERED @ 15min or less
Large Pumps, total On-floor plant, total central plant **(Appendix 10.15.2)**	Level of agreement on ADDITIONAL energy sub-metering and trending interval requirements	CONSENSUS (X=79%)	N/A	CONSENSUS	ON-FLOOR UNITS SHOULD BE METERED BY FLOOR AND LARGE PUMPS @ 15min or less
Energy Metering **(Section 5.2.7.1)**	Level of agreement on the whole building energy and sub-metered energy data to be accessible via BMS	CONSENSUS (X=68%)	N/A	MAJORITY VOTED IN AGREEMENT WITH ABILITY TO ACCESS ENERGY DATA IN BMS	

7 CONCLUSION

This research began with the aim of consulting Continuous Commissioning (CCx) practitioners about the requirements of Building Management Systems (BMS) to facilitate CCx. After an investigation of literature (Chapter 2) identifying some of the key limitations of BMS within the CCx process and the refinement needed to make a robust survey process (Chapter 3), the refined research aim was to answer the question:

What data and functional capabilities are required of a Building Management System to facilitate the Continuous Commissioning of typical HVAC systems?

The systematic literature review revealed that BMS are crucial for providing the data required to carry out Continuous Commissioning assessments (section 2.2). However, BMS and data collection were also highlighted as the biggest hurdles to the implementation of Continuous Commissioning. In order to answer the refined research question (Section 3), the aim was to develop a comprehensive guideline outlining the data trending and functional requirements of a BMS to facilitate Continuous Commissioning.

The literature review and the research strategy identified four secondary research questions to be answered in achieving this aim (section 3.2). Answering these questions became the objective of this thesis. A fifth secondary research question was added to enable a better understanding of the context and characteristics of Continuous Commissioning in New Zealand. The goal of the fifth research question was to provide a sound basis for future research that might look to extrapolate the results from New Zealand to the international context where BMS and HVAC equipment originate. This set of questions became the basis for the survey. This concluding chapter is organised around the refined research question, and these five secondary questions, structured in the following way, concluding with a recommended programme for future research and development.

- *What do Continuous Commissioning processes look like in New Zealand?*
- *At what stages of the Continuous Commissioning process are BMS most important and are BMS meeting the needs of continuous commissioners?*
- *What non-control capabilities of BMS are important to facilitating Continuous Commissioning; are BMS providing these capabilities at a satisfactory level to facilitate Continuous Commissioning?*
- *What common Continuous Commissioning assessments are applied to improve the energy efficiency of typical HVAC systems?*
- *What data points and trending frequency is required to carry out Continuous Commissioning assessments?*

The primary and secondary research questions have been answered through the development of a comprehensive guideline (Section 9), outlining the data trending and functional requirements of a BMS to facilitate Continuous Commissioning.

7.1 WHAT DO CONTINUOUS COMMISSIONING PROCESSES LOOK LIKE WITHIN NEW ZEALAND?

The literature review revealed that no research papers transparently report the characteristics of the Continuous Commissioning process implemented, i.e. from the way the BMS is accessed, to the details of the data import method (Chapter 2).

Understanding the way in which Continuous Commissioning is carried out, such as the level of automation, was key to assessing the stages of Continuous Commissioning where Building Management Systems are reported as important, as the level of automation of a Continuous Commissioning process is likely to be dependent on the capabilities provided by existing BMS.

The standard questionnaire was designed primarily to understand the nature of the group of people responding to the Delphi Survey which was the central focus of this research. In the process, the general questions helped develop an understanding not only of the level of experience amongst the respondents, but also their view of the state of the art in data gathering for CCx.

The majority of participants reported using manual or bespoke methods to implement CCx. BMS were also reported as typically not being initially set up to record and store the HVAC data trends needed for CCx. While data monitoring was identified as the most important way for BMS to facilitate CCx, it is apparent that the required data is not always immediately available. The survey participants reported that BMS are not always able to provide a continuous, automated stream of HVAC data trends.

It is also apparent that BMS are not initially set up to record and store HVAC trends and therefore not set up in a way which best facilitates CCx. This suggests that BMS installation manuals and capabilities are either not focused on or not aware of CCx potential.

Amongst the participants, there is no universal Continuous Commissioning tool. The survey results conveyed that Continuous Commissioning analyses are typically applied externally to the Building Management System, which was re-iterated in international literature. This is reflected by the relatively reserved level of importance reported for BMS at stage four of the CCx process – analysing and reporting.

The majority of participants report they are accessing Building Management Systems directly for Continuous Commissioning, i.e. they are not receiving information via third parties. This raises the question – are Building Management Systems designed with this in mind? – The relatively low level of satisfaction reported by participants suggests this is not the case.

The majority of participants also reported having a manual data import method i.e. a manual exchange of data between the Building Management System and their Continuous Commissioning tool. The disparity is greatest between reported levels of importance of and satisfaction with the provision of data by Building Management Systems for stage two of the CCx process - data extraction.

The ability to automatically extract and import data is likely to have a significant influence on the frequency at which Continuous Commissioning can be carried out. For example, if a Building Management System cannot provide a continuous stream of data to a Continuous Commissioning tool, Continuous Commissioning assessments are more likely to be carried out periodically, and while they may be ongoing, they are unlikely to be continuous.

This in turn may influence the feasibility of carrying out an automated assessment of BMS data, and thus interfere with the potential to build automated, or semi-automated reporting as part of a Continuous Commissioning process.

These characteristics of Continuous Commissioning processes are based on a survey of New Zealand practitioners. HVAC and BMS technologies installed within New Zealand non-residential buildings are provided by international suppliers, meeting international standards. As noted by the World Business Council for Sustainable Development (2009), automated data export/imports from BMS which enable continuous and automated assessments of HVAC operation, is likely the most efficient and therefore cost-effective way to implement Continuous Commissioning. There is no indication from these results that the technology is deployed in a significantly different manner elsewhere in the world.

Overall the characteristics of Continuous Commissioning processes reported by participants begin to suggest there are functional limitations of current BMS used for Continuous Commissioning in New Zealand. It is likely the high proportion of manual and periodic assessments is indicative of limitations of BMS in providing continual and automated streams of data.

If the right data is not requested, is not accessible, or is not output in a usable form from a BMS, there is a greater demand of time and effort, as well as an increased margin of error during data manipulation. The use of manual and bespoke tools suggests there is limited standardisation to the way CCx is carried out.

7.2 AT WHAT STAGES OF THE CONTINUOUS COMMISSIONING PROCESS ARE BMS MOST IMPORTANT; ARE BMS MEETING THE NEEDS OF CONTINUOUS COMMISSIONERS?

As noted in Chapter 2, no existing research has measured the importance of Building Management Systems at the various stages of the Continuous Commissioning process. Literature reported most of the hurdles to Continuous Commissioning as being due to a lack of data availability – leading to high upfront cost of implementing Continuous Commissioning, which is potentially a barrier to its uptake.

By understanding the perceived level of importance and satisfaction reported by continuous commissioners of BMS facilitating stages of the CCx process, the areas of which the capabilities of BMS need to be improved were highlighted.

Table 37 presents a summary of the median importance and satisfaction scores reported by participants on the role of Building Management Systems at each stage of the Continuous Commissioning process. The majority of participants (>50%) recognised Building Management Systems as having some level of importance during all but one stage of Continuous Commissioning. That was the analysis and reporting stage.

Table 37: Importance and Satisfaction of BMS at stages of the Continuous Commissioning Process

Continuous Commissioning Stage	Median BMS Importance	Median BMS Satisfaction
1. Monitoring HVAC Operation	Extremely Important (7)	Satisfied (5)
2. Data Extraction	Extremely Important (7)	Neither Satisfied nor Dissatisfied (4)
3. Processing Data into a Usable Form	Important (5)	Dissatisfied (3)
4. Analysing and Reporting	Neither Important nor Unimportant (4)	Dissatisfied (3)
5. Implementing Control Strategies	Important (5)	Neither Satisfied nor Dissatisfied (4)
6. Measurement and Verification	Important (5)	Neither Satisfied nor Dissatisfied (4)

Participants were in strong agreement that, in regards to CCx processes, BMS are extremely important for (1) monitoring HVAC operating data and (2) providing the ability to extract the data.

The majority of participants expressed some level of dissatisfaction with BMS (considered as not meeting minimum requirements), at two stages of the Continuous Commissioning process: processing data into a usable form and, analysing and reporting on areas for improvement. At all remaining stages of Continuous Commissioning, participants reported an even distribution of satisfaction and dissatisfaction, typically resulting in a median response of neither satisfied nor dissatisfied. This suggests BMS typically meet the minimum requirements to carry out Continuous Commissioning, while there is great room for improvement. The only stage of the Continuous Commissioning process at which the majority of participants reported a level of satisfaction was for (1) Monitoring of HVAC operation, which is the primary role of BMS.

Comparing the two columns in Table 37, the greatest differences between the median importance and median satisfaction scores are reported for stages 1, 2 and 3 of the CCx process. There is also a consistent level of disparity between the two columns. For most items in the first column, BMS are seen as important, but for most items in the second column, they are identified as currently not meeting minimum requirements to facilitate CCx.

Based on an assessment of reported importance and satisfaction by participants, BMS do not always provide the minimum data required for Continuous Commissioning. According to the majority of participants, BMS are rarely able to immediately provide the minimum data available to carry out Continuous Commissioning. This means BMS are rarely set up to be used for post occupancy assessment of HVAC operation – beyond day to day monitoring of equipment.

7.2.1 WHAT NON-CONTROL CAPABILITIES OF BMS ARE IMPORTANT AND ARE BMS PROVIDING NON-CONTROL CAPABILITIES AT A SATISFACTORY LEVEL TO FACILITATE CONTINUOUS COMMISSIONING?

This section provides additional detail to the previous section which reported the overall importance and satisfaction of BMS in facilitating the Continuous Commissioning process. The most important BMS capabilities and features for facilitating CCx are presented and the perceived satisfaction of their provision. BMS suppliers will find use in being able to associate certain features of BMS to facilitating the CCx process and therefore energy efficiency.

CCx processes rely on BMS to provide usable data and make control improvements, but the requirement of non-control features of BMS such as data extraction capabilities, visualisations and usability are not clearly defined in the literature, nor whether BMS provide these capabilities to a satisfactory level (Section 2).

Participants were asked to rate the level of importance and satisfaction of various BMS features, grouped by type of function. The purpose was to highlight any type of BMS functions or specific features which are considered important, but which are not delivering a minimum level of satisfaction to facilitate the Continuous Commissioning process. The median importance and satisfaction of BMS capabilities are summarised in Table 38.

Table 38: Median Importance and Satisfaction of BMS Capabilities

BMS Capability Type	BMS Capability	Median Importance	Median Satisfaction
HVAC Documentation Access within BMS	Schematics with Real-time data	Extremely Important (7)	Satisfied (5)
	Equipment Event log	Very Important (6)	Dissatisfied (3)
	Equipment Meta-data	Important (5)	Very Dissatisfied (2)
BMS Access and Data Extraction Capabilities	BMS Reliability	Extremely Important (7)	Satisfied (5)
	Remote BMS access	Extremely Important (7)	Neither Satisfied nor Dissatisfied (4)
	Online Access	Extremely Important (7)	Satisfied (5)
	Automatic Data Export	Very Important (6)	Somewhat Dissatisfied (3.5)
	Speed of Data Extract	Important (5)	Neither Satisfied nor Dissatisfied (4)
BMS Capabilities to Customise Data Exports	Specify data points	Extremely Important (7)	Satisfied (5)
	Specify time frame	Extremely Important (7)	Satisfied (5)
	Specify data trend format	Very Important (6)	Dissatisfied (3)
	Specify data point naming	Important (5)	Somewhat Dissatisfied (3.5)
	Specify aggregated data points	Neither important or unimportant (4)	Neither Satisfied nor Dissatisfied (4)
BMS Data and System Usability	Graphical user interface usability	Extremely Important (7)	Satisfied (5)
	Clarity of data point naming conventions	Very Important (6.5)	Neither Satisfied nor Dissatisfied (4)
	Ease of BMS navigation	Very Important (6)	Satisfied (5)
	Clarity of BMS Language Terminology	Very Important (6)	Satisfied (5)
BMS Data Visualisation Features	Additional Data Visualisations	Very Important (6)	Very Dissatisfied (2)
	Floor Plans with real-time data display	Very Important (6)	Satisfied (5)
	Customisable Trend lines against time	Very Important (6)	Neither Satisfied nor Dissatisfied (4)
	Customisable X-Y Scatter Plots	Important (5)	Dissatisfied (3)
Ease of BMS Control Adjustments and Upgrades	BMS Extension	Important (5)	Neither Satisfied nor Dissatisfied (4)
	Regular BMS Software Upgrades	Important (5)	Somewhat Dissatisfied (3.5)
	Operation Scheduling Adjustment	Very Important (6)	Neither Satisfied nor Dissatisfied (4)
	Operation Parameter Adjustment	Important (5)	Neither Satisfied nor Dissatisfied (4)

All participants attributed a level of importance to BMS reliability and opposing to literature, the majority of participants reported some level of satisfaction in BMS being a reliable source of data. This finding suggests that poor reliability of BMS reported within literature is potentially not the greatest hurdle and limitation of BMS within the CCx process, other findings within this research point back to the provision of usable data by BMS.

BMS capabilities with the greatest level of importance are attributed to BMS access, data extraction data usability and overall BMS usability. The relatively low median satisfaction score presented for each BMS capability suggests there is large room for improving these capabilities to better facilitate the Continuous Commissioning process.

7.3 WHAT COMMON CONTINUOUS COMMISSIONING ASSESSMENTS ARE APPLIED TO IMPROVE THE ENERGY EFFICIENCY OF TYPICAL HVAC SYSTEMS?

Common CCx assessments needed to be defined in association with typical HVAC systems within large non-residential buildings to be able to define the data required for trending.

A consensus was formed on the top five Continuous Commissioning assessments applied to each typical HVAC system. These CCx assessments are presented in the high-level specification presented in Section 9. The top five assessments for each system were used to develop a consensus on the minimum data points required for trending.

7.4 WHAT DATA POINTS AND TRENDING FREQUENCY IS REQUIRED TO CARRY OUT CONTINUOUS COMMISSIONING ASSESSMENTS?

A consensus was formed on the data points and trending requirements to carry out the top five CCx assessments on typical HVAC systems. Section 9 includes the minimum data points to be trended and the minimum and ideal data trending interval and storage period. The granularity of data is important to CCx.

A consensus was also formed on the energy sub-metering requirements according to Continuous Commissioners. This consensus is considered applicable to facilitating the implementation of NABERSNZ energy efficiency ratings, as a lack of sub-metering was identified as the greatest hurdle to its application. The guideline developed from this research presents the HVAC systems and data interval for energy metering to facilitate CCx.

7.5 FUTURE RESEARCH AND DEVELOPMENT

The concluding findings of this research are considered to have great potential in the future development of Building Management Systems (BMS) within the Continuous Commissioning (CCx)process. The findings from this research aim to bridge the gap between BMS and CCx through a high-level specification (Chapter 9) of the minimum data points to be trended to carry out CCx assessments for typical HVAC and the BMS capabilities considered important to facilitating CCx.

While this research associate's data points with the top five CCx assessments applied to typical HVAC, it has not been able to associate specific data points to each individual CCx assessment due to limitations of the survey and time available to carry it out. An ideal next step is to extend this research further by associating specific data points to each CCx assessment. This would enable any CCx assessment to be implemented individually based on a specification of required data points.

The top CCx assessments and minimum data trending requirements could also be developed for other HVAC systems not covered by the scope of this research. Additional HVAC systems to be considered include:

- Heat recovery systems
- Dual duct AHU
- Trench heaters/ underfloor air distribution
- Different HHW loop types
- Diff CHW loop types
- Chilled beams

Another avenue for extending this research is to produce a case study, where the developed guideline is assessed against an existing BMS. Key questions to be investigate could include:

- Can the guideline be used to cross check whether the BMS has the functions important to facilitating CCx?
- Are the data points required for trending the typical HVAC systems available in the building without the need for additional data loggers?

Alternatively, the guideline could be used to specify new BMS. Key questions to be investigated could include:

- Is the guideline useful for clients, facilities managers and BMS suppliers to help them understand what should be specified for a BMS to ensure ease of implementing CCx or post-occupancy performance reviews?
- Could this guideline produce cost savings through the reduced BMS set up time during the implementation of CCx?

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Enabling Continuous Commissioning through Building Management Systems

A HIGH-LEVEL GUIDE TO SPECIFYING BMS TO FACILITATE CCX

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An output of a thesis

submitted to the Victoria University of Wellington

in fulfilment of the requirements for the degree of

Masters of Building Science

Victoria University of Wellington

1 PURPOSE AND SCOPE

This document summarises the findings of the Master of Building Science research project 'Enabling Continuous Commissioning through Building Management Systems', presenting the results which can be used to develop a specification for the requirements of building management systems (BMS) to facilitate the continuous commissioning of typical HVAC systems.

The top five Continuous Commissioning (CCx) assessments and the minimum data points required to be trended for these assessments are presented for typical HVAC systems, a consensus formed by New Zealand based Continuous Commissioners.

This guide is anticipated to be used to indicate what functions and data trending requirements *should be considered* for existing BMS upgrades or the specification of new BMS, however, not to be considered as a substitute for a complete BMS specification.

This guideline does not go into detail about how Continuous Commissioning and specific assessments are carried out, but the way in which BMS facilitate this process through the data and functional capabilities they could provide. The data and functional capabilities are explored at a high level such as defining what would ideally be provided by BMS, not how they are specifically coded or programmed within BMS.

1.1 HVAC SYSTEMS COVERED BY THIS GUIDE

Typical HVAC systems have been identified from a New Zealand based study which formed a consensus on the most common HVAC systems contained within large non-residential buildings (Gates, 2013). While these systems are typical to New Zealand, they are sourced from suppliers which can be found internationally. Therefore, there is no reason to believe the information presented in this guideline would not be internationally applicable in most circumstances.

System and functional descriptions of the HVAC systems reported in this are beyond the scope of this guideline, however system schematics are presented to provide context to CCx assessments and data.

Continuous Commissioning assessments and data point trending requirement are reported by this guideline for the following HVAC systems and variations are covered by this guideline:

- Central Air Handling Units (AHU):
  - Constant Air Volume (CAV) AHU
  - Variable Air Volume (VAV) AHU
- On-floor Terminal Air Units:
  - Constant Air Volume (CAV) Box
  - Variable Air Volume (VAV) Box
  - Fan Coil Unit (FCU)
- Chilled Water Loop (CHW):
  - Constant Flow CHW
  - Variable Flow CHW
- Hot Water Loop (HHW):
  - Constant Flow HHW
  - Variable Flow HHW
  - Domestic Hot Water (DHW) Loop

1.2 GUIDELINE STRUCTURE

This guideline is broken down by the typical HVAC systems previously defined, followed by HVAC and energy sub-meter data trending requirements, and BMS capabilities important to the CCx process. The following chapters aim to answer the following questions:

- What are the top five assessments which should be applied as a minimum for implementing CCx to this system?
- What are the minimum data points which should be trended for this system as a minimum to be able to carry out the top CCx assessments?
- What proportion of components of that type of system should be assessed?
- What interval should the data be trended at and how long should it be stored at as a minimum?
- What energy sub-metering should be implemented, at what recording interval?
- What are the most important BMS capabilities required to facilitate CCx?
- What capabilities are not typically provided at a satisfactory level to facilitating CCx?

1.3 RELEVANT ACRONYMS AND ABBREVIATIONS

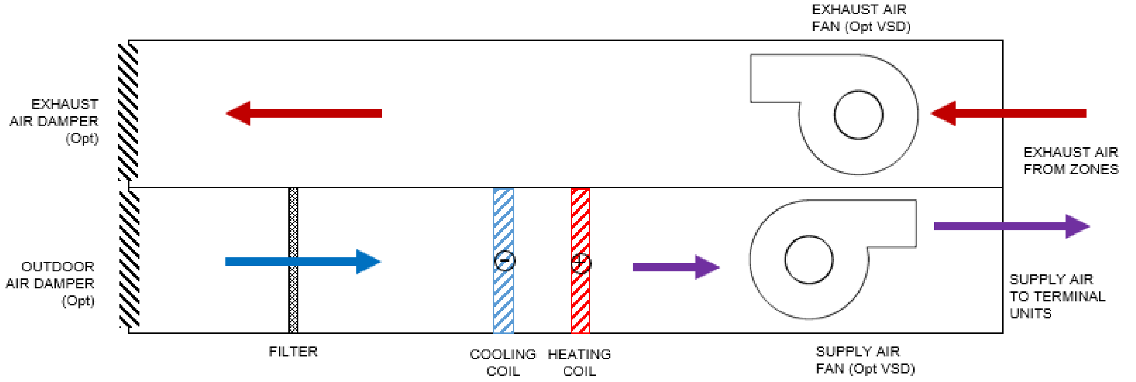
Relevant Organisations	
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BEES	Building Energy End-use Study
BRANZ	Building Research Association of New Zealand
CIBSE	Charted Institute of Building Services Engineers
EECA	Energy Efficiency and Conservation Authority of New Zealand
EMANZ	Energy Management Association of New Zealand
FMANZ	Facilities Management Association of New Zealand
NREL	National Renewable Energy Laboratory
PNNL	Pacific North-West National Laboratory
TAMU	Texas A&M University
Energy and Heating, Ventilation and Air-Conditioning Equipment	
HVAC	Heating, Ventilation, and Air Conditioning
AHU	Air Handling Unit
BMS	Building Management System
CO2	Carbon Dioxide
VAV	Variable Air Volume
CAV	Constant Air Volume
FCU	Fan Coil Unit
VSD	Variable Speed Drive
Energy Efficiency Improvement Processes	
FDD	Fault Detection and Diagnostics
CCx	Continuous Commissioning
RCx	Recommissioning

2 CENTRAL AIR HANDLING UNITS

2.1 TYPICAL SYSTEM SCHEMATICS

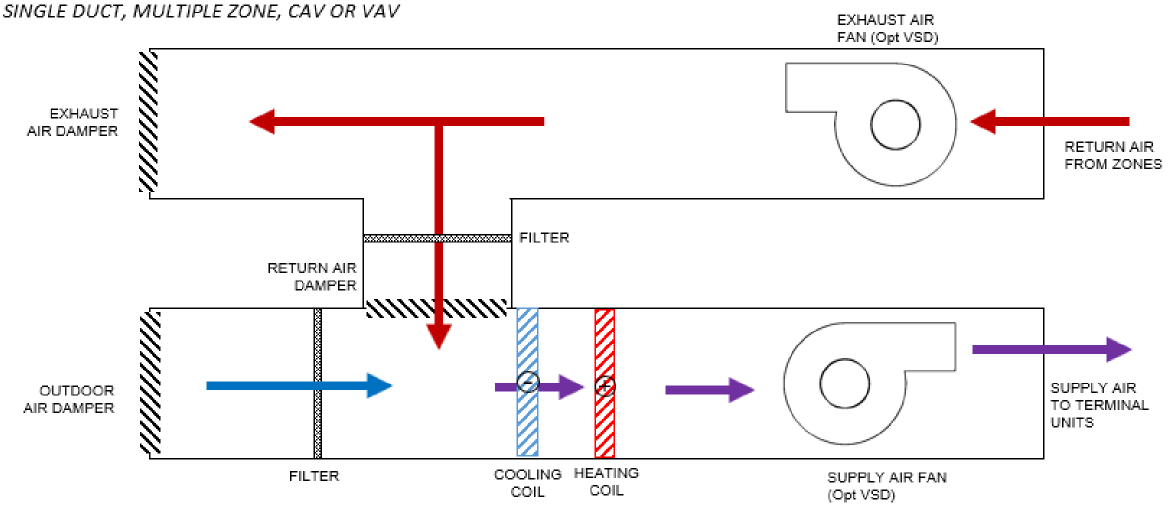
CENTRAL AIR HANDLING UNIT, FRESH AIR ONLY:

SINGLE DUCT, MULTIPLE ZONE, CAV OR VAV



CENTRAL AIR HANDLING UNIT WITH RETURN AIR:

SINGLE DUCT, MULTIPLE ZONE, CAV OR VAV



2.2 TOP FIVE CCX ASSESSMENTS TO BE APPLIED

Top 5 Air Handling Unit CCx Assessments (CAV or VAV)	System Type Applicability	
	Constant Volume Air Handling Unit (CAV)	Variable Air Volume Air Handling Unit (VAV)
1. Afterhours Operation or Scheduling	Y	Y
2. Heating and Cooling Coils Fighting	Y	Y
3. Economiser Mode	Y	Y
4. Demand Control Ventilation	Y	Y
5. Discharge Air Temperature Reset	Y	Y

2.3 MINIMUM DATA POINTS TO BE TRENDED

Minimum Data Points to be Trended	Unit	System Type Applicability	
		Constant Volume Air Handling Unit (CAV)	Variable Air Volume Air Handling Unit (VAV)
Outdoor Air Temperature	°C	**X**	**X**
Mixed Air Temperature	°C	**X**	**X**
Return Air Temperature	°C	**X**	**X**
Primary Supply Air Temperature	°C	**X**	**X**
Duct Static Pressure	Pa	**N/R**	**X**
Return Air Damper Position	%	**X**	**X**
Outdoor Air Damper Position	%	**X**	**X**
Exhaust Air Damper Position	%	**X**	**X**
Supply Fan Status	On/Off	**X**	**X**
Supply Air Fan Speed	%	**X**	**X**
Return/Exhaust Fan Status	On/Off	**X**	**X**
Return/Exhaust Fan Speed	%	**X**	**X**
AHU Cooling Valve Position	%	**X**	**X**
AHU Heating Valve Position	%	**X**	**X**
Supply Airflow	l/s	**N/R**	**X**

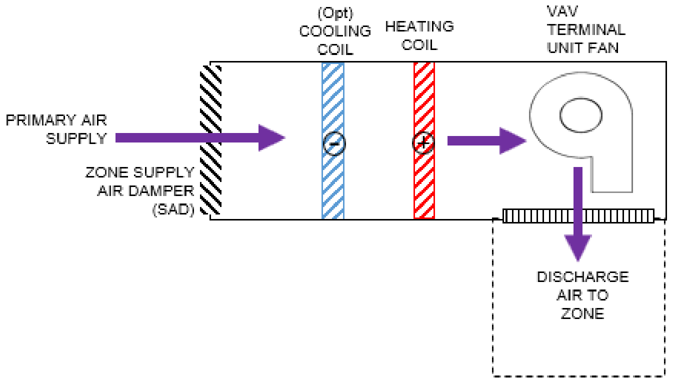
N/R = Not Required. This data point is not required to carry out the top five Continuous Commissioning assessments for these systems.

3 ON-FLOOR TERMINAL AIR UNITS

3.1 TYPICAL SYSTEM SCHEMATICS

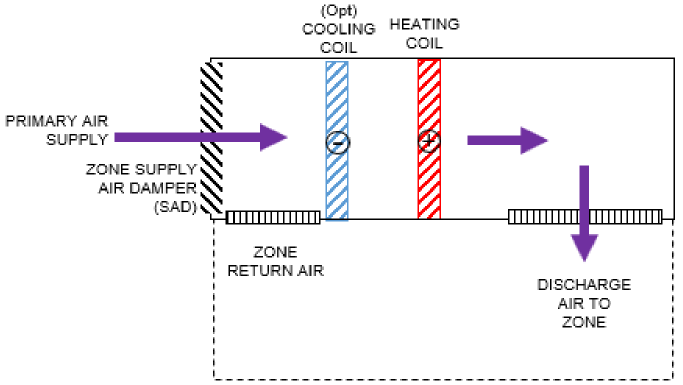
VAV TERMINAL UNIT:

FAN ASSIST VAV, WITH REHEAT AND OPTIONAL COOLING



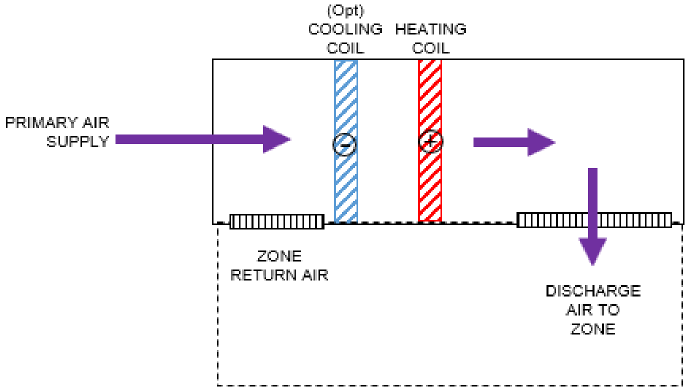
VAV TERMINAL UNIT:

REHEAT AND OPTIONAL COOLING with DIRECT RETURN AIR



CAV TERMINAL UNIT:

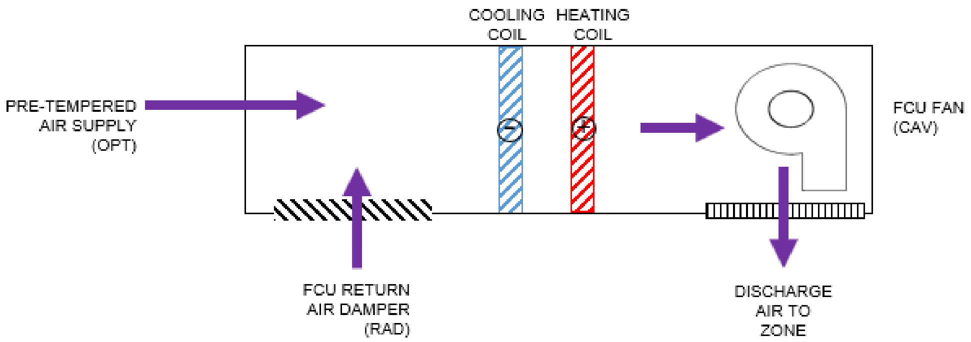
REHEAT AND OPTIONAL COOLING with DIRECT RETURN AIR



3.1.1 FAN COIL UNIT SCHEMATICS

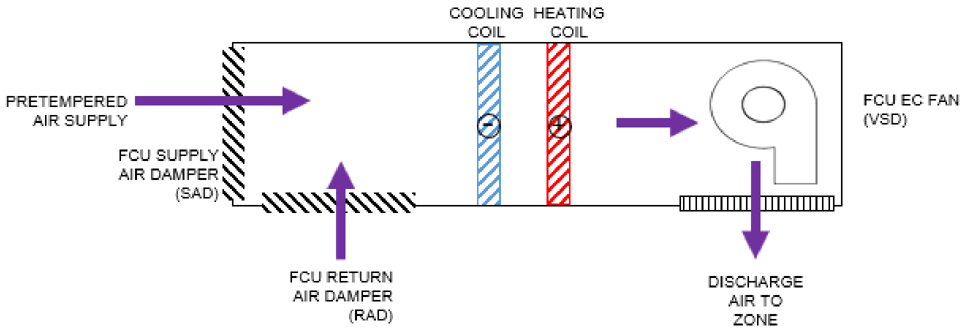
CONSTANT VOLUME FAN COIL UNIT:

HEATING AND COOLING WITH OPTIONAL PRE-TEMPERED AIR



VARIABLE VOLUME (EC) FAN COIL UNIT:

HEATING AND COOLING WITH PRE-TEMPERED AIR



3.2 TOP FIVE CCX ASSESSMENTS TO BE APPLIED

Terminal Air Units: Top Five Constant Air Volume Assessments
1. Zonal Thermal Dead band and Setpoint Review
2. Terminal Unit Heating and Cooling Fighting
3. Zonal Supply Air Temperature Reset
4. Zonal Afterhours Operation *(Scheduling)*
5. Zonal Optimum Start/Stop

3.2.1 FAN COIL UNITS

Terminal Air Units: Top Five Fan Coil Units Assessments
1. Zonal Thermal Dead band and Setpoint Review
2. Terminal Unit Heating and Cooling Fighting
3. Zonal Supply Air Temperature Reset
4. FCU Proportional Control
5. Zonal Afterhours Operation *(Scheduling)*

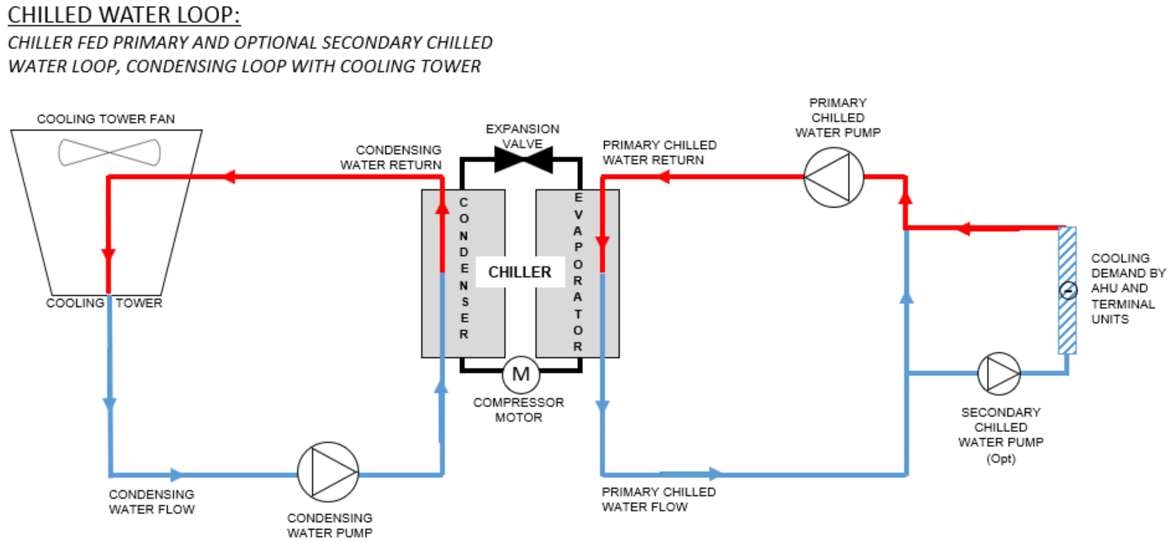
3.3 MINIMUM DATA POINTS TO BE TRENDED

Data Points for Trending	Data Unit	CAV Boxes	VAV Boxes	VAV with Fan Assist	Fan Coil Units	EC Fan Coil Units
TU: Damper Position	%	N/A	X	X	N/A	N/A
TU: Heating Coil Valve Position	%	X	X	X	X	X
TU: Cooling Coil Valve Position	%	X	X	X	X	X
TU: Discharge Air Temperature	°C	X	X	X	X	X
TU: Discharge Airflow	l/s	N/A	X	X	X	X
TU: Fan Status	On/Off	N/A	N/A	X	X	X
TU: Fan Speed	%	N/A	N/A	X	X	X
Zone Temperature	°C	X	X	X	X	X
Zone CO2	ppm	X	X	X	X	X

N/A = Not Applicable. This data point is not considered applicable to the type of system being assessed.

4 CHILLED WATER LOOP

4.1 TYPICAL SYSTEM SCHEMATIC



4.2 TOP FIVE CCX ASSESSMENTS TO BE APPLIED

Top Five Chilled Water Loop Assessments
1. Chilled Water Flow Temperature Reset
2. Chiller Staging
3. Afterhours Operation of all System Components
4. Chiller Operation Lockout on Outdoor Air Temperature
5. Condensed Water Temperature Reset

4.3 MINIMUM DATA POINTS TO BE TRENDED

Data Points for Trending	Data Unit	Constant Flow CHW Loop	Variable Flow CHW Loop
Primary Chilled Water Supply Temperature	°C	X	X
Primary Chilled Water Return Temperature	°C	X	X
Condenser Supply Temperature	°C	X	X
Condenser Return Temperature	°C	X	X
Primary Pump Status	On/Off	X	X
VFD Primary Pump Speed	%	X	X
Secondary Pump Status	On/Off	X	X
VFD Secondary Pump Speed	%	X	X
Chiller Status	On/Off	X	X
Chilled Water Flow	l/s	X	X
Chilled Water Differential Pressure	ΔPa	N/A	X
Cooling Tower Fan Status	On/Off	X	X
Cooling Tower Fan Speed	%	X	X
Cooling Tower Inlet Temperature	°C	X	X
Cooling Tower Outlet Temperature	°C	X	X

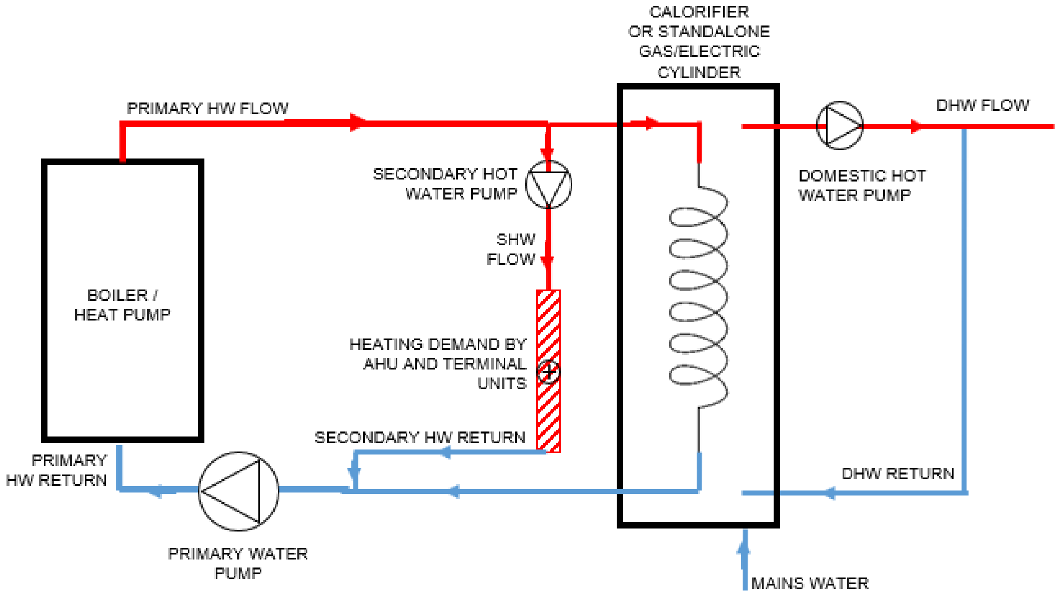
N/A = Not Applicable. This data point is not considered applicable to the type of system being assessed.

5 HOT WATER LOOP

5.1 TYPICAL SYSTEM SCHEMATIC

HOT WATER LOOP:

BOILER OR HEAT PUMP FED PRIMARY AND SECONDARY HOT WATER LOOP,
DOMESTIC HOT WATER LOOP WITH CALORIFIER



5.2 TOP FIVE CCX ASSESSMENTS TO BE APPLIED

Top Five: Hot Water Loop Assessments
1. Hot Water Flow Temperature Reset
2. Boiler or Heat Pump Operation Lockout on Outdoor Air Temperature
3. Boiler or Heat Pump Staging
4. Afterhours Operation of all System Components
5. Boiler or Heat Pump Optimum Start/Stop

5.3 MINIMUM DATA POINTS TO BE TRENDED

Data Points for Trending	Data Unit	Constant Flow HHW	Variable Flow HHW
Primary Hot Water Supply Temperature	°C	X	X
Primary Hot Water Return Temperature	°C	X	X
Hot Water Flow Rate	l/s	N/A	X
Primary Pump Status	On/Off	X	X
VFD Primary Pump Speed	%	N/A	X
Secondary Pump Status	On/Off	X	X
VFD Secondary Pump Speed	%	N/A	X
Boiler/Heat Pump Status	On/Off	X	X
Boiler/Heat Pump Outlet Temperature	°C	X	X

Data Points for Trending	Data Unit	DHW Loop
Domestic Hot Water Pump Status	On/Off	X
Domestic Hot Water Flow Temperature	°C	X
Domestic Hot Water Return Temperature	°C	X
Domestic Hot Water Flow Rate	l/s	N/A

N/A = Not Applicable. This data point is not considered applicable to the type of system being assessed.

6 HVAC DATA TRENDING REQUIREMENTS

6.1 MINIMUM AND IDEAL DATA TRENDING INTERVALS

Minimum Trending Interval	Ideal Trending Interval
15 Minutes (or less)	5 Minutes or less

6.2 MINIMUM AND IDEAL DATA STORAGE PERIODS

Minimum Data Storage	Ideal Data Storage
At least 3 months	More than 2 years

7 ENERGY SUB-METERING REQUIREMENTS

HVAC Equipment Type Energy Sub-Metering	Energy Sub-Meter Data Trending Interval
▪ Air Handling Units	**15 Minutes or Less**
▪ Chillers	
▪ Cooling Towers	
▪ Boilers/Heat Pumps	
▪ Large Pumps (>3kW)	
▪ Total On-floor HVAC	
▪ Total Central HVAC Plant	

8 BMS FUNCTIONAL CONSIDERATIONS

This section presents the median level of importance and satisfaction reported by a group of Continuous Commissioners on a range of BMS capabilities for facilitating CCx. most important features of a BMS in relation to continuous commissioning/building tuning

The BMS functions presented in this section of the guideline are indicative of what functions could be considered important to facilitating continuous commissioning, however no consensus was formed and therefore may be considered limited by the experience and characteristics of the research participants and their continuous commissioning process. A BMS function considered important by one continuous commissioner may not be considered important by another as the continuous commissioning procedure carried out is likely to vary. For example, if no continuous commissioning tool is specifically used and assessments of data are carried out through a manual analysis within the BMS or analytics are imbedded within the BMS, the data export capabilities of the BMS may not be considered important.

BMS Capability Type	BMS Capability	Median Importance	Median Satisfaction
HVAC Documentation Access within BMS	Schematics with Real-time data	Extremely Important (7)	Satisfied (5)
	Equipment Event log	Very Important (6)	Dissatisfied (3)
	Equipment Meta-data	Important (5)	Very Dissatisfied (2)
BMS Access and Data Extraction capabilities	Remote BMS access	Extremely Important (7)	Neither Satisfied nor Dissatisfied (4)
	Online Access	Extremely Important (7)	Satisfied (5)
	Automatic Data Export	Very Important (6)	Somewhat Dissatisfied (3.5)
	Speed of Data Extract	Important (5)	Neither Satisfied nor Dissatisfied (4)
BMS Capabilities to Customise Data Exports	Specify data points	Extremely Important (7)	Satisfied (5)
	Specify time frame	Extremely Important (7)	Satisfied (5)
	Specify data trend format	Very Important (6)	Dissatisfied (3)
	Specify data point naming	Important (5)	Somewhat Dissatisfied (3.5)
	Specify aggregated data points	Neither important or unimportant (4)	Neither Satisfied nor Dissatisfied (4)
BMS data and system usability	Graphical user interface usability	Extremely Important (7)	Satisfied (5)
	Clarity of data point naming conventions	Very Important (6.5)	Neither Satisfied nor Dissatisfied (4)
	Ease of BMS navigation	Very Important (6)	Satisfied (5)
	Clarity of BMS Language Terminology	Very Important (6)	Satisfied (5)
BMS Data Visualisation Features	Additional Data Visualisations	Very Important (6)	Very Dissatisfied (2)
	Floor Plans with real-time data display	Very Important (6)	Satisfied (5)
	Customisable Trend lines against time	Very Important (6)	Neither Satisfied nor Dissatisfied (4)
	Customisable X-Y Scatter Plots	Important (5)	Dissatisfied (3)
Ease of BMS Control Adjustments and Upgrades	BMS Extension	Important (5)	Neither Satisfied nor Dissatisfied (4)
	Regular BMS Software Upgrades	Important (5)	Somewhat Dissatisfied (3.5)
	Operation Scheduling Adjustment	Very Important (6)	Neither Satisfied nor Dissatisfied (4)
	Operation Parameter Adjustment	Important (5)	Neither Satisfied nor Dissatisfied (4)

10 APPENDICES

10.1 APPENDIX: SYSTEMATIC LITERATURE REVIEW PROCESS DOCUMENTATION

10.1.1 APPENDIX: PUBLICATION COUNT BY DATABASE & SYSTEMATIC PROCESS STAGE

	Search Databases	Search A (BMS)	Search B (CCx)	A and B Duplicates	Search C	Search D	Screening Criteria 1	Screening Criteria 2	Screening Criteria 3	Relevance Rank 1
Academic Databases	Google Scholar	997	995	**318**				18		
	ProQuest Dissertations and Theses Global	296	381	**105**			118	24		
	ProQuest Science Journals	71	78	**22**	N/A	N/A			N/A	**35**
	SAGE Journals	10	12	**1**			1	1		
	Science Direct	545	827	**187**			94	19		
	Scopus	38	10	**3**			1	1		
	Taylor and Francis Online	91	118	**75**			41	6		
International Industry Websites	ASHRAE				29	N/A	17		16	
	CIBSE				65	N/A	18		9	
	BRE				65	N/A	4		1	
	Facilities.Net		N/A		N/A	100	100	N/A	20	**10**
	ACEEE				N/A	71	71		41	
New Zealand Websites	BRANZ				24	N/A	8		7	
	EMANZ				N/A	8	8		3	
	FMANZ		N/A		N/A	13	13	N/A	1	**6**
	EECA				N/A	1	1		1	
									Total Publications Reviewed	**51**

10.1.2 APPENDIX: LITERATURE QUALITY ASSURANCE SCORING MATRIX

Quality Assurance (QA) Check	QA Characteristic	Definition	Score
Author Bias	Independent	The author is an independent researcher, and does not work for any of the funding bodies.	**1**
	Dependent	The author is associated with an organisation which has potential to benefit directly from the publication.	**2**
	Both	There are multiple authors varying in potential bias.	**2**
Funding Bias	No	No funding is acknowledged, or funding was from an academic institution or research body.	**1**
	Yes	The publication has been funded by an organisation with the potential to benefit directly from the publication.	**2**
	Unknown	It is not clear if the publication was funded by a potentially beneficial source.	**2**
Evidence or Claim	Evidence	A research methodology is clearly defined and the data collected is reported.	**1**
	Claim	There is no clear research methodology and a lack of evidence provided against claims.	**2**
Level of Academic Peer-Review (Witt, 2014)	Journal Article	High level of academic peer-review with thorough referencing.	**1**
	Conference Paper		**1**
	Thesis	Some level of academic peer-review with thorough referencing.	**2**
	Book		**2**
	Standard	Limited academic peer-review with few references.	**3**
	Report		**3**
	Magazine Article	Limited to no peer-review with limited to no references.	**4**
	Online Multi-Media		**4**

Note: The lower the quality assurance score, the higher the credibility of the publication.

10.2 APPENDIX: SURVEY PARTICIPANT COUNT PER ROUND

Survey Round	Building Services Engineer	Building Energy Specialist	HVAC Continuous Commissioner	BMS Contractor	HVAC Commissioner	Other	Total
Round One	14	11	2	2	1	3	**33**
Round Two	11	9	2	1	0	2	**25**
Round Three	8	7	2	1	0	1	**19**

10.3 APPENDIX: CCX ASSESSMENT SURVEY DEVELOPMENT

10.3.1 APPENDIX: CCX ASSESSMENTS IN LITERATURE: AIR HANDLING UNITS

Continuous Commissioning Assessments: Air Handling Units	Reference within Resources				
	PNNL Resources	ASHRAE Guideline 36	BSRIA Library of System Control Strategies	CIBSE Guide F and H	FEMP Continuous Commissioning Guidebook
Afterhours Operation or Scheduling	X	X	X	X	X
Heating and Cooling Coils Fighting	X	X		X	
Demand Control Ventilation	X	X	X	X	
Economiser Mode	X	X		X	X
Discharge Air Temperature Reset	X	X			X
Relative Fan Speed Assessment *e.g. Supply Air Fan Speed vs Exhaust Air Fan Speed*		X	X		
Optimum Start/Stop		X	X	X	
Summer and Winter Operation Assessment			X		
Multi-Fan Staging	X	X			
Sequencing Multiple AHUs					
Duct Static Pressure Reset	X	X	X	X	X
Fresh Air Filter Pressure Difference		X		X	
Assessment of Relative Damper Positions *e.g. Outdoor Air Damper vs Exhaust Air Damper*		X	X		
Night Purge	X			X	X
Heating and Cooling Coil Lockout	X	X			X
Minimum Outdoor Airflow	X	X		X	X

10.3.2 APPENDIX: CCX ASSESSMENTS IN LITERATURE: ON-FLOOR TERMINAL UNITS

Continuous Commissioning Assessments: Terminal Air Units	Reference within Resources				
	PNNL Resources	ASHRAE Guideline 36	BSRIA Library of System Control Strategies	CIBSE Guide F and H	FEMP Continuous Commissioning Guidebook
Zonal Night Purge		X	X		
Zonal Economiser Function					
Zonal Thermal Dead Band Setpoint Review	X	X			
Zonal Demand Control Ventilation		X			
Heating and Cooling Fighting - Terminal Unit					
Terminal Unit Heating and Cooling Coil Lockouts	X			X	
Zonal Optimum Start/Stop			X		
Zonal Supply Air Temperature	X				
Zonal Afterhours Operation	X				
Assessment of Terminal Unit Air Velocity	X	X	X	X	
Summer and Winter Operation	X				

10.3.3 APPENDIX: CCX ASSESSMENTS IN LITERATURE: CHILLED WATER LOOPS

Continuous Commissioning Assessments: Chilled Water Loop	Reference within Resources				
	PNNL Resources	ASHRAE Guideline 36	BSRIA Library of System Control Strategies	CIBSE Guide F and H	FEMP Continuous Commissioning Guidebook
Chilled Water Flow Temperature Reset	X	Beyond Scope	Beyond Scope	X	X
Chilled water loop Diff Pressure Reset	X			X	X
Chiller operation lockout on OAT	X			X	
Waterside Economiser	X				
Chiller staging	X				X
Staging of CHW pumps	X			X	
Chiller optimum start/stop	X				
Chilled water variable flow under partial conditions	X			X	X
Chiller pump interlock	X			X	
Condensed water temp reset				X	X
Cooling tower differential temp	X			X	
After-hours operation CHWL	X				
Chiller anti-cycling	X				X

10.3.4 APPENDIX: CCX ASSESSMENTS IN LITERATURE: HOT WATER LOOPS

Continuous Commissioning Assessments: Hot Water Loop	Reference within Resources				
	PNNL Resources	ASHRAE Guideline 36	BSRIA Library of System Control Strategies	CIBSE Guide F and H	FEMP Continuous Commissioning Guidebook
HW Flow + Return Temperatures	Beyond Scope	Beyond Scope	X		X
Hot water loop Differential Pressure Reset				X	
Boiler/HP operation lockout on OAT				X	
Staging of hot water pumps				X	X
Boiler/HP staging			X	X	X
Hot water variable flow under partial loads			X	X	
Boiler/HP and pump interlock					
Optimum start/stop			X	X	
DHW pressure reset				X	
DHW temp reset			X		
After-hours operation HHWL					

10.4 APPENDIX: DATA POINT SURVEY DEVELOPMENT

10.4.1 APPENDIX: DATA POINTS IN LITERATURE: AIR HANDLING UNITS

Data Points: Air Handling Units	Reference within Resources				
	PNNL Resources	ASHRAE Guideline 36	BSRIA Library of System Control Strategies	CIBSE Guide F and H	FEMP Continuous Commissioning Guidebook
Outdoor Air Temperature	x	x	x	x	x
Mixed Air Temperature	x	x			x
Return Air Temperature	x	x	x	x	x
Primary Supply Air Temperature	x	x	x		x
Duct Static Pressure	x	x	x		x
Return Air Damper Position	x	x	x		x
Outdoor Air Damper Position	x	x	x		x
Exhaust Air Damper Position		x	x		
Supply Fan Status	x	x	x		x
Supply Air Fan Speed	x	x	x		x
Return/Exhaust Fan Status		x			
Return/Exhaust Fan Speed		x			
AHU Cooling Valve Position	x	x	x		x
AHU Heating Valve Position	x	x	x		x
Supply Airflow		x	x	x	x
Return/Exhaust Airflow		x	x	x	x
Return Air CO_2 Sensor			x		x
Supply Air CO_2 Sensor					x
Fresh Air Filter Pressure Differential		x	x		

10.4.2 APPENDIX: DATA POINTS IN LITERATURE: ON-FLOOR UNITS

Data Points: Terminal Air Units	Reference within Resources				
	PNNL Resources	ASHRAE Guideline 36	BSRIA Library of System Control Strategies	CIBSE Guide F and H	FEMP Continuous Commissioning Guidebook
TU: Damper Position	X	X	X		
TU: Heating Coil Valve Position	X	X	X		
TU: Cooling Coil Valve Position	X	X			
TU: Discharge Air Temperature	X	X	X		X
TU: Discharge Airflow	X	X	X		X
TU: Fan Status		X			
TU: Fan Speed		X			
Zone Temperature		X			X
Zone CO_2		X			

10.4.3 APPENDIX: DATA POINTS IN LITERATURE: CHILLED WATER LOOPS

Data Points: Chilled Water Loop	Reference within Resources				
	PNNL Resources	ASHRAE Guideline 36	BSRIA Library of System Control Strategies	CIBSE Guide F and H	FEMP Continuous Commissioning Guidebook
Primary Chilled Water Supply Temperature	X		X	X	X
Primary Chilled Water Return Temperature	X		X	X	X
Condenser Supply Temperature	X				
Condenser Return Temperature	X				
Primary Pump Status	X		X		
VFD Primary Pump Speed					X
Secondary Pump Status	X		X		
VFD Secondary Pump Speed					
Chiller Status	X				
Chilled Water Flow	X				
Chilled Water Differential Pressure	X			X	X
Cooling Tower Fan Status	X		X		
Cooling Tower Fan Speed	X				
Cooling Tower Inlet Temperature				X	
Cooling Tower Outlet Temperature				X	

10.4.4 APPENDIX: DATA POINTS IN LITERATURE: HOT WATER LOOPS

Data Points: Hot Water Loop	Reference within Resources				
	PNNL Resources	ASHRAE Guideline 36	BSRIA Library of System Control Strategies	CIBSE Guide F and H	FEMP Continuous Commissioning Guidebook
Primary Hot Water Supply Temperature	X		X		X
Primary Hot Water Return Temperature	X		X		X
Hot Water Flow Rate	X		X		
Primary Pump Status			X		X
VFD Primary Pump Speed					
Secondary Pump Status			X		X
VFD Secondary Pump Speed					
Boiler/Heat Pump Status			X		X
Boiler/Heat Pump Outlet Temperature			X		
Domestic Hot Water Pump Status			X	X	X
Domestic Hot Water Flow Temperature				X	X
Domestic Hot Water Return Temperature					
Domestic Hot Water Flow Rate				X	

10.5 APPENDIX: SURVEY ROUND ONE

Thank you for your interest in this project.

Research Overview:

The purpose of this survey is to identify a comprehensive range of Building Management System (BMS) requirements for Continuous Commissioning (CCx) and to form a consensus from experienced industry professionals. The outputs of the survey will be used to establish a comprehensive guideline outlining the key data and functions required of a BMS to carry out typical CCx assessments on New Zealand-typical Heating, Ventilation, and Air Conditioning (HVAC) systems.

The Survey:

The structure of this survey is based on the Delphi method of collection, consisting of multiple rounds to form an informed consensus on what "could be" or "should be" implemented within industry. This research will consist of three rounds. Each round of questions will inform the following round, with an element of feedback provided through the compilation of the previous round's responses. This enables participants to agree, disagree or provide alternative insight to the questions asked and the proposed consensus.

Your Participation:

The online surveys can be completed anywhere at any time and is anticipated to take no more than 15 minutes to complete each round.

By completing this survey you are voluntarily authorising consent to the researcher to use the information gathered in the survey and discuss it annonymously within the research project.

Further Information:

If you have any questions or require further clarification, please don't hesitate to contact me or my supervisor:

Survey Round 1: Typical Continuous Commissioning Assessments

In survey one you will answer questions about the types of data based Continuous Commissioning (CCx) assessments or control strategies applied to typical Heating, Ventilation and Air-Conditioning Systems (HVAC) within New Zealand's Non-Residential Buildings.

Continuous Commissioning (CCx):

For the purpose of this research, continuous commissioning is defined as an ongoing or periodical assessment of the operational performance of HVAC systems and components. Under this definition, the term CCx may also be known as building tuning, system optimisation, monitoring and targeting, measurement and verification and fault detection and diagnostics (FDD). This research goes beyond the assessment of energy metering, by identifying operational and control based CCx assessments and strategies. This research focuses on assessments and strategies primarily implemented for the optimisation of energy performance, while maintaining occupant satisfaction.

Building Management Systems (BMS):

The term Building Management Systems is used to encompass all building control and monitoring systems, including Building Automation Systems (BAS), Building Automation and Control Systems (BACS), Energy Management Systems (EMS), Building Energy Management Systems (BEMS) and Direct Digital Control Systems (DDC). This research focuses on the data monitored by BMS and the features and functions of BMS which are needed to facilitate Continuous Commissioning.

<< >>

Q1.0 Email Address

This is collected to ensure the survey is only answered once.

Please type email address here:

Q1.1 Building Operation and Control Role:

Please identify the role which is most applicable to your area of expertise:

- ○ Building Services Engineer
- ○ Building Energy Specialist or Manager
- ○ BMS Contractor
- ○ HVAC Continuous Commissioner (Incl. System Optimisation and Building Tuning)
- ○ HVAC Commissioner
- ○ Other (please specify) [text box]

Q1.2 Building Operation and Control Experience:

How many years of experience do you have in this role?

0-1 yrs	2-5 yrs	6-10 yrs	11-15 yrs	16-20 yrs	>21 yrs
○	○	○	○	○	○

Q1.3 Continuous Commissioning Experience:

Continuous Commissioning experience may include fault detection and diagnostics (FDD), building tuning, monitoring and targeting, measurement and verification.

Based on the definition of Continuous Commissioning provided, how many years of experience do you have in continuous commissioning?

No Experience	0-1 yrs	2-5 yrs	6-10 yrs	11-15 yrs	16-20 yrs	>21 yrs
○	○	○	○	○	○	○

<< >>

Display logic: Section 2 questions will not appear if the participant has acknowledged "No Experience" in Continuous Commissioning

Q2.0 Background Information: Your Continuous Commissioning Process

This section will ask you questions about your continuous commissioning process and the use, importance and satisfaction of Building Management Systems within this process. This section will be used to identify background information and will not be used to form a consensus. Responses to questions in Section 3.0 will be used to form a consensus.

Q2.1 Based on the options below, please identify the type of Continuous Commissioning tool most comparable to your Continuous Commissioning process:

- ○ Licensed Software *e.g. SkySpark*
- ○ In-house Spreadsheet Based Tool *e.g. Excel*
- ○ In-house Software as a Service *e.g. Bespoke Software*
- ○ BMS Embedded Analytics *e.g. Visual Alert Dashboard*
- ○ Manual BMS Analysis *e.g. Non-Visual Assessment of Real-Time Operation*
- ○ Other *(Please Specify)* ______
- ○ A CCx tool is not used

Q2.2 Please select the characteristics below which are most comparable to your Continuous Commissioning method:

BMS

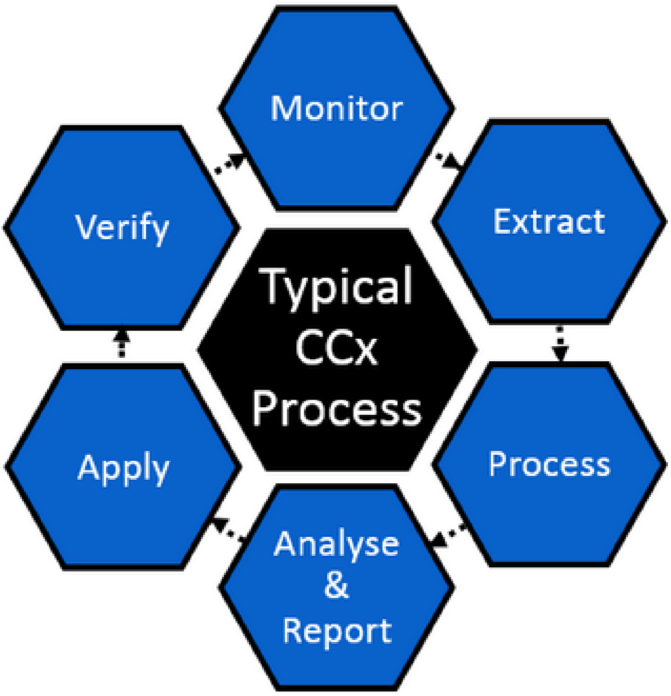
BMS Access:
If other please specify: ______ [▼]

Data Import Method from BMS to CCx Tool:
If other please specify: ______ [▼]

Frequency of Assessment:
If other please specify: ______ [▼]

Data Analysis Method:
If other please specify: ______ [▼]

Typical Continuous Commissioning Process:



Q2.3 Based on the typical stages of Continuous Commissioning shown above, rate the overall *importance* of Building Management Systems at each stage:

	Building Management System Importance 1 = Not at all important 7 = Extremely Important						
	1	2	3	4	5	6	7
1. Monitoring HVAC Operation	○	○	○	○	○	○	○
2. Extracting Data	○	○	○	○	○	○	○
3. Processing Data to a Usable Form for Analysis	○	○	○	○	○	○	○
4. Analysing Data	○	○	○	○	○	○	○
5. Implementing Strategies	○	○	○	○	○	○	○
6. Measurement and Verification	○	○	○	○	○	○	○

Display Logic: For any CCx stage with an importance of 1 (Not at all important) in question 2.3, that stage will not appear in the following question as it is assumed a BMS is not used at this stage.

Q2.4 Rate your overall *satisfaction* of Building Management Systems in providing the required data outputs and system functions for the stages of Continuous Commissioning, where BMS are considered important:

Building Management System Satisfaction
1 = Extremely Dissatisfied   7 = Extremely Satisfied

	1	2	3	4	5	6	7
1. Monitoring HVAC Operation	○	○	○	○	○	○	○
2. Extracting Data	○	○	○	○	○	○	○
3. Processing Data to a Usable Form for Analysis	○	○	○	○	○	○	○
4. Analysing Data	○	○	○	○	○	○	○
5. Implementing Strategies	○	○	○	○	○	○	○
6. Measurement and Verification	○	○	○	○	○	○	○

<< >>

Q2.4 When initially implementing Continuous Commissioning, do Building Management Systems *immediately* provide the minimum data required to carry out assessments?

Never 1	2	3	4	5	6	Always 7
○	○	○	○	○	○	○

Q2.5 Do Building Management Systems *eventually* provide the minimum data required to facilitate your Continuous Commissioning process?

Never 1	2	3	4	5	6	Always 7
○	○	○	○	○	○	○

<< >>

3.0 HVAC Operation Assessments and Control Strategies:

This section focuses on forming a consensus of common energy efficiency assessments applied to typical HVAC components. Typical HVAC components have been identified from existing research as 'most-common' within New Zealand's Non-Residential Building stock. Exemplar schematics of each system and component are presented throughout the survey.

Typical HVAC Components:

- Central Air Handling Units
  - Variable Air Volume (VAV) - Fresh Air Only or with Return Air
  - Constant Air Volume (CAV) - Fresh Air Only or with Return Air
- Terminal Air Units
  - VAV Box (VAV Terminal Unit)
  - CAV Box (CAV Terminal Unit)
  - Water Based Fan Coil Units (FCU)
- Chilled Water Loop
  - Chillers
  - Condensers
  - Cooling Towers
  - Chilled Water Pumps
- Hot Water Loop
  - Boilers
  - Heat Pumps
  - Calorifiers
  - Hot Water Pumps
  - Domestic Hot Water Pumps

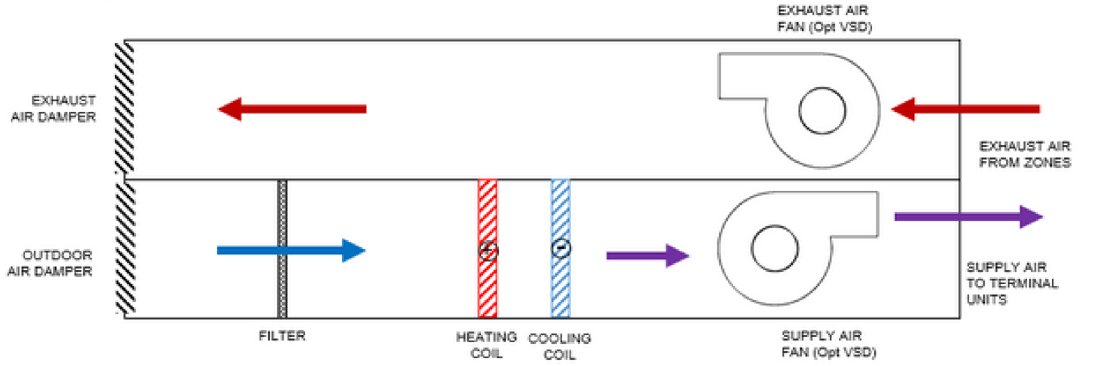
<< >>

3.1.0 Central Air Handling Units:

The following exemplar schematics can be used as a reference to aid the questions below.

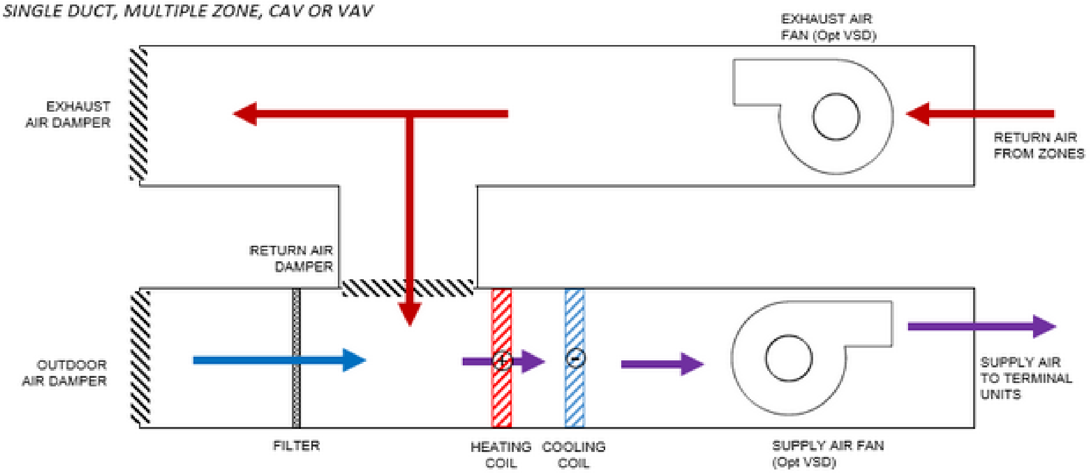
CENTRAL AIR HANDLING UNIT, FRESH AIR ONLY:

SINGLE DUCT, MULTIPLE ZONE, CAV OR VAV



CENTRAL AIR HANDLING UNIT WITH RETURN AIR:

SINGLE DUCT, MULTIPLE ZONE, CAV OR VAV



Q3.1.1 *Drag*, *Drop* and *Rank* the top FIVE operation and control strategies presented below that you would assess to improve the energy efficiency of a Constant Air Volume Air Handling Unit. (Box 1)

Q3.1.2 *Drag*, *Drop* and *Rank* any ADDITIONAL assessments you would apply to a Variable Air Volume AHU. It is assumed that all assessments applied to a CAV AHU will also be applied to a VAV AHU. (Box 2)

Items can be dragged from the list into the box. Please ensure you order your assessments based on most likely to assess for improving energy efficiency.

Items

Demand Control Ventilation *(if return air AHU)*

Night Purge

Economiser

Duct Static Pressure Reset

AHU Heating and Cooling Coil Lockouts

Multiple Fan Staging

Assessment of AHU Fan Speeds

Assessment of AHU Damper Positions

Optimum Start/Stop

AHU Discharge Air Temperature Reset

AHU Sequencing

Heating and Cooling Fighting

After-hours Operation (Scheduling)

Assessment of Air Velocity

Summer and Winter Operation

Filter Pressure Difference

Humidification

Other 1 (please specify)

Box 1: Top 5 Assessments for Constant Air Volume AHU

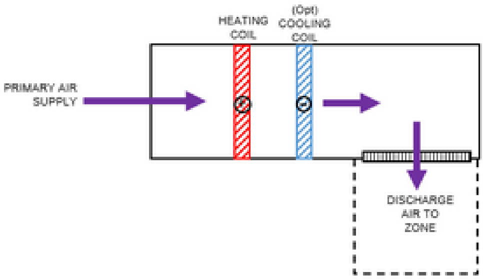
Box 2: Additional Assessments for Variable Air Volume AHU

3.2.0 Terminal Air Units:

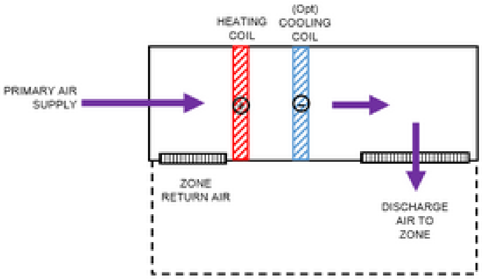
The following exemplar schematics can be used as a reference to aid the questions below.

Constant Air Volume Unit Variations:

CAV TERMINAL UNIT:
REHEAT AND OPTIONAL COOLING

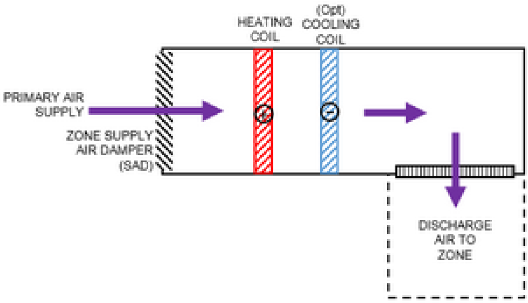


CAV TERMINAL UNIT:
REHEAT AND OPTIONAL COOLING with DIRECT RETURN AIR

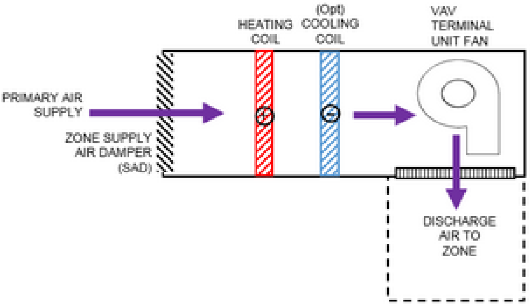


Variable Air Volume Unit Variations:

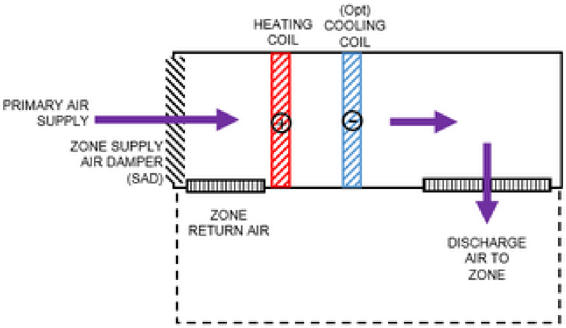
VAV TERMINAL UNIT:
REHEAT AND OPTIONAL COOLING



VAV TERMINAL UNIT:
FAN ASSIST VAV, WITH REHEAT AND OPTIONAL COOLING



VAV TERMINAL UNIT:
REHEAT AND OPTIONAL COOLING with DIRECT RETURN AIR



Q3.2.1 *Drag*, *Drop* and *Rank* the top FIVE operation and control strategies presented below that you would assess to improve the energy efficiency of a Constant Air Volume Terminal Unit. (Box 1)

Q3.2.2 *Drag*, *Drop* and *Rank* any ADDITIONAL assessments you would apply to a Variable Air Volume Terminal Unit. It is assumed that all assessments applied to a CAV Unit will also be applied to a VAV Unit. (Box 2)

Items can be dragged from the list into the box. Please ensure you order your assessments based on most likely to assess for improving energy efficiency.

Items

Zonal Night Purge

Zonal Economiser Function

Zonal Thermal Dead Band and Set Point Review

Zonal Demand Control Ventilation *(if return air direct from zone)*

Heating and Cooling Fighting

Terminal Unit Heating and Cooling Coil Lockouts

Zonal Optimum Start/Stop

Zonal Supply Air Temperature

Zonal After-hours Operation

Assessment of Terminal Unit Air Velocity

Summer and Winter Operation

Other 1 (please specify)

Other 2 (please specify)

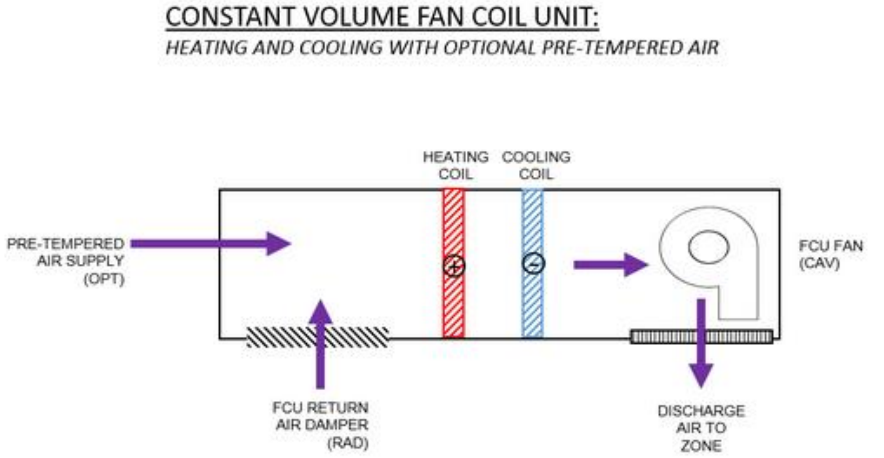
Other 3 (please specify)

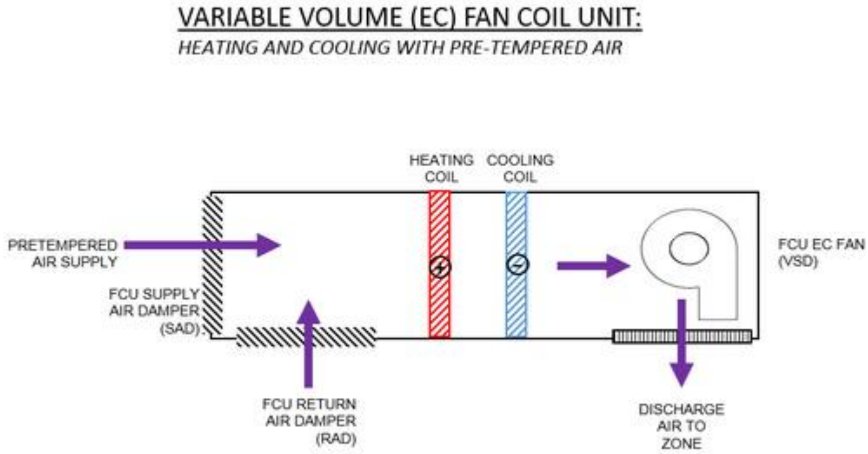
Box 1: Constant Air Volume Terminal Unit Top 5 Energy Efficiency Assessments

Box 2: Additional Assessments for Variable Air Volume Terminal Unit

Terminal Air Units: Fan Coil Units

The following exemplar schematics can be used as a reference to aid the question below.





Q2.2.3 *Drag*, *Drop* and *Rank* the top FIVE operation and control strategies presented below that you would assess to improve the energy efficiency of a typical Fan Coil Unit.

Items can be dragged from the list into the box. Please ensure you order your top ten assessments based on most likely to assess for improving energy efficiency.

Items

Zonal Night Purge

Zonal Economiser Function

Zonal Thermal Dead Band and Set Point Review

Zonal Demand Control Ventilation *(if return air direct from zone)*

Heating and Cooling Fighting

FCU Heating and Cooling Coil Lockouts

FCU Proportional Control

Zonal Optimum Start/Stop

Zonal Supply Air Temperature

Zonal After-hours Operation

Assessment of Terminal Unit Air Velocity

Summer and Winter Operation

Other 1 (please specify)

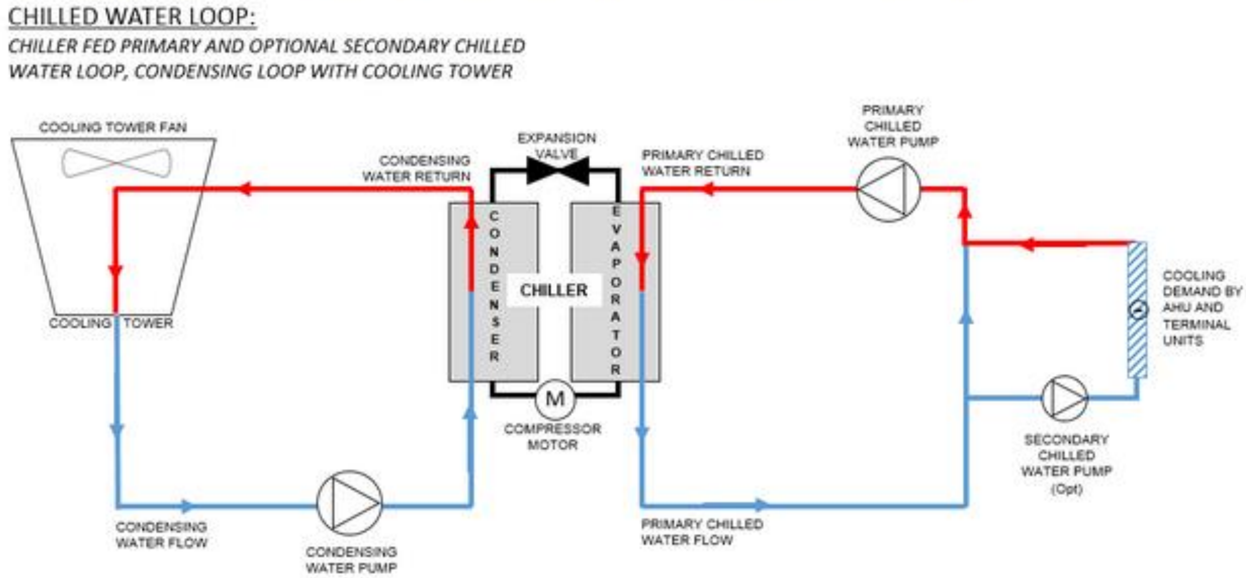
Other 2 (please specify)

Other (please specify)

Typical Fan Coil Unit Top 5 Energy Efficiency Assessments

3.3.0 Chilled Water Loop:

The following exemplar schematic can be used as a reference to aid the questions below.



Q3.3.1 ***Drag***, ***Drop*** **and** ***Rank*** **the top FIVE operation and control strategies presented below that you would assess to improve the energy efficiency of a Constant Flow Chilled Water Loop. (Box 1)**

Q3.3.2 ***Drag***, ***Drop*** **and** ***Rank*** **any ADDITIONAL assessments you would apply to a Variable Flow Chilled Water Loop. It is assumed that all assessments applied to a Constant Loop will also be applied to a Variable Loop. (Box 2)**

Items can be dragged from the list into the box. Please ensure you order your top ten assessments based on most likely to assess for improving energy efficiency.

Items

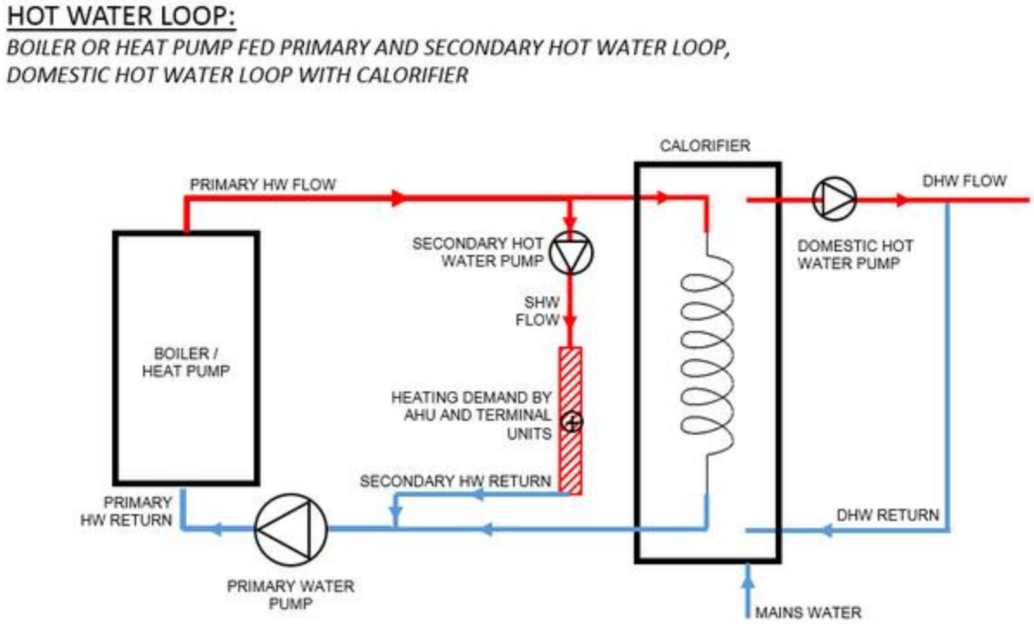
- Chilled Water Flow and Return Temperature Reset
- Chilled Water Loop Differential Pressure Reset
- Chiller Operation Lockout on Outdoor Air Temperature
- Waterside Economiser
- Chiller Staging
- Staging of Chilled Water Pumps
- Chiller Optimum Start/Stop
- Chilled Water Variable Flow under Partial Load Conditions
- Chiller and Pump Interlock
- Condensed Water Temperature Reset
- Cooling Tower Differential Temperature
- After-hours Operation of all System Components
- Chiller Anti-Cycling Control
- Other 1 (please specify)

Box 1: Constant Flow Chilled Water Loop top 5 Energy Efficiency Assessments

Box 2: Additional Assessments for Variable Flow Chilled Water Loop

3.4.0 Hot Water Loops:

The following exemplar schematic can be used as a reference to aid the questions below.



Q3.4.1 *Drag*, *Drop* and *Rank* the top FIVE operation and control strategies presented below that you would assess to improve the energy efficiency of a Constant Flow Boiler or Heat Pump Hot Water Loop. (Box 1)

Q3.4.2 *Drag*, *Drop* and *Rank* any ADDITIONAL assessments you would apply to a Variable Flow Hot Water Loop. It is assumed that all assessments applied to a Constant Loop will also be applied to a Variable Loop. (Box 2)

Items can be dragged from the list into the box. Please ensure you order your top ten assessments based on most likely to assess for improving energy efficiency.

Items

Hot Water Flow and Return Temperature Reset

Hot Water Loop Differential Pressure Reset

Operation Lockout based on Outdoor Air Temperature

Staging of Hot Water Pumps

Boiler or Heat Pump Staging

Hot Water Variable Flow under Partial Load Conditions

Boiler or Heat Pump and Loop Pumps Interlock

Optimum Start/Stop

Anti-Cycling Control

Domestic Hot Water Pressure Reset

Domestic Hot Water Temperature Reset

After-hours Operation of all System Components

Other 1 (please specify)

Box 1: Constant Flow Hot Water Loop Top 5 Energy Efficiency Assessments

Box 2: Additional Assessments for Variable Flow Hot Water Loop

10.6 APPENDIX: SURVEY ROUND TWO

Research Reminder:

The purpose of this research is to identify a comprehensive range of Building Management System (BMS) requirements for Continuous Commissioning (CCx) and to form a consensus from experienced industry professionals. The outputs of the survey will be used to establish a comprehensive guideline outlining the key data and functions required of a BMS to carry out typical CCx assessments on New Zealand-typical Heating, Ventilation, and Air Conditioning (HVAC) systems.

Continuous Commissioning (CCx):

For the purpose of this research, continuous commissioning is defined as an ongoing or periodical assessment of the operational performance of HVAC systems and components for the optimisation of energy performance, while maintaining occupant satisfaction.

Building Management Systems (BMS):

This research focuses on the data monitored by BMS and the features and functions of BMS which are needed to facilitate Continuous Commissioning.

Confidentiality:

This research is confidential. This means that the researchers named below will be aware of your identity but the research data will be combined and your identity will not be revealed in any reports, presentations, or public documentation.

Further Information:

If you have any questions or require further clarification, please don't hesitate to contact me or my supervisor:

>>

Survey Round Two: Forming a Consensus and HVAC Data Trending

All participant responses from Round One have been compiled to present the top ranked continuous commissioning assessments for each typical HVAC component.

The first part of this survey will ask you to agree or disagree with the presented responses in order to form a consensus.

The second and third part of this survey round will also ask you to identify the minimum BMS data points and trending interval required to carry out the top assessments for each HVAC component.

<< >>

Email Address

This is collected to ensure the survey is only answered once.

Please type email address here:

<< >>

Part One: Forming a Consensus: Continuous Commissioning Assessments

This section will present the top assessments for each HVAC component as ranked by participants in the previous round.

A reminder that the scope of this study is limited to the HVAC components listed below:

- Central Air Handling Units
  - Variable Air Volume (VAV) - Fresh Air Only or with Return Air
  - Constant Air Volume (CAV) - Fresh Air Only or with Return Air
- Terminal Air Units
  - VAV Box (VAV Terminal Unit)
  - CAV Box (CAV Terminal Unit)
  - Water Based Fan Coil Units (FCU)
- Chilled Water Loop
  - Chillers
  - Condensers
  - Cooling Towers
  - Chilled Water Pumps
- Hot Water Loop
  - Boilers
  - Heat Pumps
  - Calorifiers
  - Hot Water Pumps
  - Domestic Hot Water Pumps

<< >>

1.1 Central Air Handling Units:

Constant Air Volume Air Handling Units:

The top seven continuous commissioning assessments for Constant Air Volume Air Handling Units have been defined based on participant responses in the previous round of questions. These are presented in order of ranked score below.

1.	AHU Afterhours Operation *(Scheduling)*
2.	AHU Heating And Cooling Coils Fighting
3.	Economiser
4.	Demand Control Ventilation
5.	AHU Discharge Air Temperature Reset
6.	AHU optimum Start/Stop
7.	Assessment of AHU Fan Speeds e.g. SAF vs RAF

Q1.1.1 Do you agree the assessments presented above are in order of importance when assessing the operation of a Constant Air Volume Air Handling Unit?

○ Agree

○ Disagree (please comment) __________

<< >>

Control Logic: Only if “disagree” is selected in the previous question (Q1.1.1) will the following question display:

Q1.1.2 Please re-order the top seven Constant Air Volume assessments based on your opinion of each assessment's importance. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

AHU Afterhours Operation *(Scheduling)* [ ]

AHU Discharge Air Temperature Reset [ ]

Economiser [ ]

Demand Control Ventilation [ ]

AHU Heating and Cooling Coils Fighting [ ]

AHU Optimum Start/Stop [ ]

Assessment of AHU Fan Speeds e.g. SAF vs RAF [ ]

<< >>

Variable Air Volume Air Handling Units:

In the previous survey round, participants were asked to identify any additional assessments they would carry out on Variable Air Volume AHUs in addition to those applied to CAV AHU. The five most commonly identified additional assessments are highlighted in light blue below.

Top Constant Air Volume AHU Assessments	Top Additional Variable Air Volume AHU Assessments
• AHU Afterhours Operation *(Scheduling)*	• Duct Static Pressure Reset
• AHU Heating And Cooling Coils Fighting	• Assessment of AHU damper positions
• Economiser	• Night purge
• Demand Control Ventilation	• Assessment of Air Velocity
• AHU Discharge Air Temperature Reset	• AHU Heating and Cooling Coil Lockout
• AHU optimum Start/Stop	
• Assessment of AHU Fan Speeds e.g. SAF vs RAF	

Q1.1.3 Of the five additional VAV assessments, do you consider any more important than the top seven CAV assessments, when assessing a Variable Air Volume Air Handling Unit?

- ○ No
- ○ Yes

<< >>

Control Logic: Only if “Yes” is selected in the previous question (Q1.1.3) will the following question display:

Q1.1.4 Please order the combined top twelve CAV and VAV assessments based on your opinion of each assessment's importance to assessing the operation of a Variable Air Volume AHU. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

AHU Afterhours Operation *(Scheduling)* [ ]

AHU Heating and Cooling Coils Fighting [ ]

Economiser [ ]

Demand Control Ventilation [ ]

AHU Discharge Air Temperature Reset [ ]

AHU Optimum Start/Stop [ ]

Assessment of AHU Fan Speeds e.g. SAF vs RAF [ ]

VAV: Duct Static Pressure Reset [ ]

VAV: Assessment of Relative AHU Damper Positions [ ]

VAV: Assessment of Air Velocity [ ]

VAV: Night Purge [ ]

VAV: AHU Heating and Cooling Coil Lockout [ ]

<< >>

1.2 Terminal Air Units:

Constant Air Volume Terminal Units:

The top seven continuous commissioning assessments for Constant Air Volume Terminal Units have been defined based on participant responses in the previous round of questions. These are presented in order of ranked score below.

1. Zonal Thermal Deadband and Setpoint Review
2. Terminal Unit Heating and Cooling Fighting
3. Zonal Supply Air Temperature Reset
4. Zonal Afterhours Operation *(Scheduling)*
5. Zonal Optimum Start/Stop
6. Zonal Demand Control Ventilation
7. Terminal Unit Heating and Cooling Coil Lockouts

Q1.2.1 Do you agree the assessments presented above are in order of importance when assessing the operation of a Constant Air Volume Terminal Unit?

○ Agree

○ Disagree (please comment) [ ]

<< >>

Control Logic: Only if "Disagree" is selected in the previous question (Q1.2.1) will the following question display:

Q1.2.2 Please re-order the top seven Constant Air Volume assessments based on your opinion of each assessment's importance. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

Zonal Thermal Deadband and Set Point Review [ ]

Terminal Unit Heating and Cooling Coils Fighting [ ]

Zonal Supply Air Temperature Reset [ ]

Zonal Afterhours Operation (Scheduling) [ ]

Zonal Optimum Start/Stop [ ]

Zonal Demand Control Ventilation [ ]

Terminal Unit Heating and Cooling Coil Lockouts [ ]

<< >>

Variable Air Volume Terminal Units:

In the previous survey round, participants were asked to identify any additional assessments they would carry out on Variable Air Volume terminal units in addition to those applied to CAV. The three most commonly identified additional assessments are highlighted in light blue below.

Top Constant Air Volume Terminal Unit Assessments	Top Additional Variable Air Volume Terminal Unit Assessments
• Zonal Thermal Deadband and Setpoint Review	• VAV: Assessment of terminal unit air velocity
• Terminal Unit Heating and Cooling Fighting	• VAV: Zonal Economiser function
• Zonal Supply Air Temperature Reset	• VAV: Zonal Night Purge
• Zonal Afterhours Operation *(Scheduling)*	
• Zonal Optimum Start/Stop	
• Zonal Demand Control Ventilation	
• Terminal Unit Heating and Cooling Coil Lockouts	

Q1.2.3 Of the three additional VAV assessments, do you consider any more important than the top seven CAV terminal unit assessments, when assessing a Variable Air Volume Terminal Units?

○ No

○ Yes

<< >>

Control Logic: Only if "Yes" is selected in the previous question (Q1.2.3) will the following question display:

Q1.2.4 Please order the combined top ten CAV and VAV box assessments based on your opinion of each assessment's importance to assessing the operation of a Variable Air Volume Terminal Unit. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

Zonal Thermal Deadband and Set Point Review [ ]

Terminal Unit Heating and Cooling Coils Fighting [ ]

Zonal Supply Air Temperature Reset [ ]

Zonal Afterhours Operation (Scheduling) [ ]

Zonal Optimum Start/Stop [ ]

Zonal Demand Control Ventilation [ ]

Terminal Unit Heating and Cooling Coil Lockouts [ ]

VAV: Assessment of Terminal Air Velocity [ ]

VAV: Zonal Economiser Function [ ]

VAV: Zonal Night Purge [ ]

<<   >>

Fan Coil Units:

The top seven continuous commissioning assessments for Fan Coil Units have been defined based on participant responses in the previous round of questions. These are presented in order of ranked score below.

1.	Zonal Thermal Deadband and Setpoint Review
2.	Terminal Unit Heating and Cooling Fighting
3.	Zonal Supply Air Temperature Reset
4.	FCU Proportional Control
5.	Zonal Afterhours Operation *(Scheduling)*
6.	Zonal Optimum Start/Stop
7.	Zonal Demand Control Ventilation

Q1.2.5 Do you agree the assessments presented above are in order of importance when assessing the operation of a Fan Coil Unit?

- ○ Agree
- ● Disagree (please comment) [ ]

<< >>

Control Logic: Only if "Disagree" is selected in the previous question (Q1.2.5) will the following question display:

Q1.2.6 Please re-order the top seven Fan Coil Unit assessments based on your opinion of each assessment's importance. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

- Zonal Thermal Deadband and Set Point Review ☐
- Terminal Unit Heating and Cooling Coils Fighting ☐
- Zonal Supply Air Temperature Reset ☐
- FCU Proportional Control ☐
- Zonal Afterhours Operation (Scheduling) ☐
- Zonal Optimum Start/Stop ☐
- Zonal Demand Control Ventilation ☐

<< >>

1.3 Chilled Water Loop:

Constant Flow Chilled Water Loop

The top seven continuous commissioning assessments for a Constant Flow Chilled Water Loop have been defined based on participant responses in the previous round of questions. These are presented in order of ranked score below.

1.	Chilled Water Flow Temperature Reset
2.	Chiller Staging
3.	Afterhours Operation of all System Components
4.	Chiller Operation Lockout on Outdoor Air Temperature
5.	Condensed Water Temperature Reset
6.	Chiller Optimum Start/Stop
7.	Staging of Chilled Water Pumps

Q1.3.1 Do you agree the assessments presented above are in order of importance when assessing the operation of a Constant Flow Chilled Water Loop?

- Agree
- Disagree (please comment)

<< >>

Control Logic: Only if "Disagree" is selected in the previous question (Q1.3.1) will the following question display:

Q1.3.2 Please re-order the top seven Constant flow Chilled Water Loop assessments based on your opinion of each assessment's importance. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

Chilled Water Flow Temperature Reset [ ]

Chiller Staging [ ]

Afterhours Operation of all System Components [ ]

Chiller Operation Lockout on Outdoor Air Temperature [ ]

Condensed Water Temperature Reset [ ]

Chiller Optimum Start/Stop [ ]

Staging of Chilled Water Pumps [ ]

<< >>

Variable Flow Chilled Water Loop:

In the previous survey round, participants were asked to identify any additional assessments they would carry out on Variable Flow Chilled Water Loops in addition to those applied to Constant Flow Loops. The three most commonly identified additional assessments are highlighted in light blue below.

Top Constant Flow Chilled Water Loop Assessments	Top Additional Variable Flow Chilled Water Loop Assessments
• Chilled Water Flow Temperature Reset	• Chilled Water Variable Flow under Partial Conditions
• Chiller Staging	• Chilled Water Loop Differential Pressure Reset
• Afterhours Operation of all System Components	• Waterside Economiser
• Chiller Operation Lockout on Outdoor Air Temperature	
• Condensed Water Temperature Reset	
• Chiller Optimum Start/Stop	
• Staging of Chilled Water Pumps	

Q1.3.3 Of the three additional Variable Flow assessments, do you consider any more important than the top seven Constant flow assessments, when assessing a Variable Flow Chilled Water Loop?

○ No

○ Yes

<< >>

Control Logic: Only if “Yes” is selected in the previous question (Q1.3.3) will the following question display:

Q1.3.4 Please order the combined top ten Constant and Variable Flow assessments based on your opinion of each assessment's importance to assessing the operation of a Variable Flow Chilled Water Loop. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

Chilled Water Flow Temperature Reset [ ]

Chiller Staging [ ]

Afterhours Operation of all System Components [ ]

Chiller Operation Lockout on Outdoor Air Temperature [ ]

Condensed Water Temperature Reset [ ]

Chiller Optimum Start/Stop [ ]

Staging of Chilled Water Pumps [ ]

VFD: Chilled Water Variable Flow under Partial Conditions [ ]

VFD: Chilled Water Loop Differential Pressure Reset [ ]

VFD: Waterside Economiser [ ]

<< >>

1.4 Hot Water Loops:

Constant Flow Hot Water Loop

The top seven continuous commissioning assessments for a Constant Flow Hot Water Loop have been defined based on participant responses in the previous round of questions. These are presented in order of ranked score below.

1.	Hot Water Flow Temperature Reset
2.	Boiler or Heat Pump Operation Lockout on Outdoor Air Temperature
3.	Boiler or Heat Pump Staging
4.	Afterhours Operation of all System Components
5.	Boiler or Heat Pump Optimum Start/Stop
6.	Domestic Hot Water Temperature Reset
7.	Hot Water Loop Differential Pressure Reset

Q1.4.1 Do you agree the assessments presented above are in order of importance when assessing the operation of a Constant Flow Hot Water Loop?

○ Agree

○ Disagree (please comment) [ ]

<< >>

Control Logic: Only if "Disagree" is selected in the previous question (Q1.4.1) will the following question display:

Q1.4.2 Please re-order the top seven Constant flow Hot Water Loop assessments based on your opinion of each assessment's importance. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

Hot Water Flow Temperature Reset

Boiler or Heat Pump Operation Lockout on Outdoor Air Temperature

Boiler or Heat Pump Staging

Afterhours Operation of all System Components

Boiler or Heatpump Optimum Start/Stop

Domestic Hot Water Temperature Reset

Hot Water Loop Differential Pressure Reset

<< >>

Variable Flow Hot Water Loop:

In the previous survey round, participants were asked to identify any additional assessments they would carry out on Variable Flow Hot Water Loops in addition to those applied to Constant Flow Loops. The three most commonly identified additional assessments are highlighted in light blue below.

Top Constant Flow Hot Water Loop Assessments	Top Additional Variable Flow Hot Water Loop Assessments
• Hot Water Flow Temperature Reset	• Hot Water Variable Flow under Partial Conditions
• Boiler or Heat Pump Operation Lockout on Outdoor Air Temperature	• Staging of Hot Water Pumps
• Boiler or Heat Pump Staging	• Boiler or Heat Pump and Pump Interlock
• Afterhours Operation of all System Components	
• Boiler or Heat Pump Optimum Start/Stop	
• Domestic Hot Water Temperature Reset	
• Hot Water Loop Differential Pressure Reset	

Q1.4.3 Of the three additional Variable Flow assessments, do you consider any more important than the top seven Constant flow assessments, when assessing a Variable Flow Hot Water Loop?

○ No

○ Yes

<< >>

Control Logic: Only if "Yes" is selected in the previous question (Q1.4.3) will the following question display:

Q1.4.4 Please order the combined top ten Constant and Variable Flow assessments based on your opinion of each assessment's importance to assessing the operation of a Variable Flow Hot Water Loop. Order the assessments by dragging and dropping each assessment into the preferred order.

Note: If you do not believe an assessment is applicable to the type of system being assessed, put an 'X' in the text box provided and drag it to the bottom of the ranking list.

Hot Water Flow Temperature Reset

Boiler or Heat Pump Operation Lockout on Outdoor Air Temperature

Boiler or Heat Pump Staging

Boiler or Heatpump Optimum Start/Stop

Afterhours Operation of all System Components

Domestic Hot Water Temperature Reset

Hot Water Loop Differential Pressure Reset

VFD: Hot Water Variable Flow under Partial Conditions

VFD: Staging of Hot Water Pumps

VFD: Boiler or Heat Pump and Pump Interlock

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Part Two: Defining Data Points for Trending

A BMS typically monitors data to control the operation of HVAC. A BMS is often not set up to continuously or periodically trend and store the data to allow for the future analysis of operation.

This section asks questions about the minimum data points required for BMS trending to facilitate continuous commissioning i.e. the assessment of energy efficient HVAC operation.

Data points are presented for each typical HVAC system based on the recommendations of international standards and guidelines as the minimum data points to be monitored in order to control HVAC.

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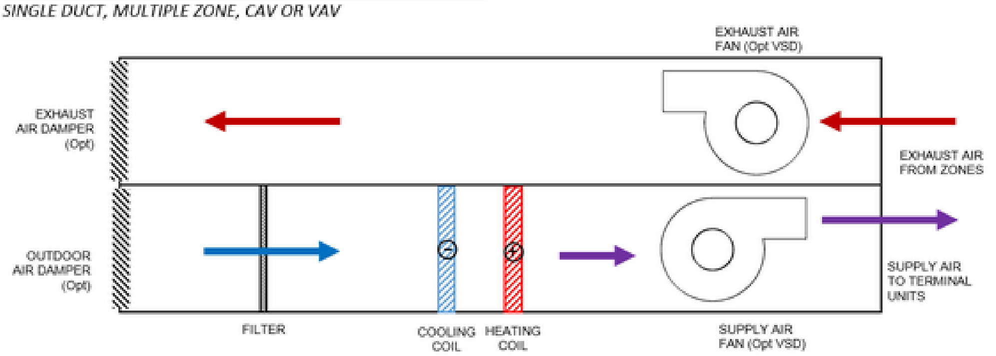
2.1 Central Air Handling Units:

The following *exemplar* schematics can be used as a reference to aid the questions below.

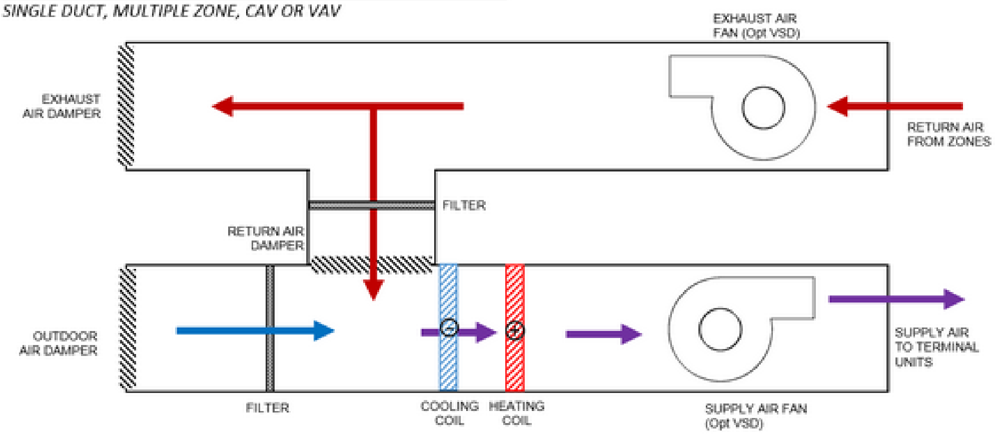
CENTRAL AIR HANDLING UNIT, FRESH AIR ONLY:

SINGLE DUCT, MULTIPLE ZONE, CAV OR VAV



CENTRAL AIR HANDLING UNIT WITH RETURN AIR:

SINGLE DUCT, MULTIPLE ZONE, CAV OR VAV



Top Constant Air Volume AHU Assessments	Top Additional Variable Air Volume AHU Assessments
• AHU Afterhours Operation *(Scheduling)*	• Duct Static Pressure Reset
• AHU Heating And Cooling Coils Fighting	• Assessment of AHU damper positions
• Economiser	• Night purge
• Demand Control Ventilation	• Assessment of Air Velocity
• AHU Discharge Air Temperature Reset	• AHU Heating and Cooling Coil Lockout
• AHU optimum Start/Stop	
• Assessment of AHU Fan Speeds e.g. SAF vs RAF	

Q2.1.1 In order to carry out the top AHU assessments given above, which data points below do you think should be trended as a minimum to facilitate continuous commissioning?

Select the data points to be trended for each typical AHU type (CAV and VAV).

	Not Required for Data Trending	Minimum Data Points for CAV AHU	Minimum Data Points for VAV AHU
Outdoor Air Temperature (°C)	☐	☐	☐
Mixed-Air Temperature (°C)	☐	☐	☐
Return Air Temperature (°C)	☐	☐	☐
Primary Supply Air Temperature (°C)	☐	☐	☐
Duct Static Pressure (Pa)	☐	☐	☐
Return Air Damper Position (%)	☐	☐	☐
Outdoor Air Damper Position (%)	☐	☐	☐
Exhaust Air Damper Position (%)	☐	☐	☐
Supply Fan Status (On/Off)	☐	☐	☐
Supply Air Fan Speed (%)	☐	☐	☐
Return/Exhaust Fan Status (On/Off)	☐	☐	☐
Return/Exhaust Fan Speed (%)	☐	☐	☐

(Continued)…

	Not Required for Data Trending	Minimum Data Points for CAV AHU	Minimum Data Points for VAV AHU
AHU Cooling Valve Position (%)	☐	☐	☐
AHU Heating Valve Position (%)	☐	☐	☐
Supply Airflow (l/s)	☐	☐	☐
Return/Exhaust Airflow (l/s)	☐	☐	☐
Return Air CO2 Sensor (ppm)	☐	☐	☐
Supply Air CO2 Sensor (ppm)	☐	☐	☐
Outdoor Air Filter Pressure Differential (Pa)	☐	☐	☐
Other Data Point 1:	☐	☐	☐
Other Data Point 2:	☐	☐	☐
Other Data Point 3:	☐	☐	☐
Other Data Point 4:	☐	☐	☐
Other Data Point 5:	☐	☐	☐

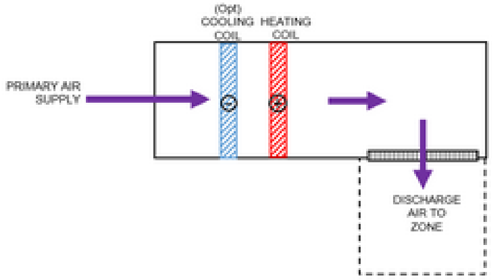
<< >>

2.2 Terminal Air Units:

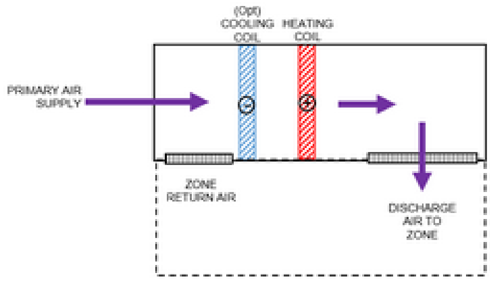
The following exemplar schematics can be used as a reference to aid the questions below.

Typical Constant Air Volume Unit :

CAV TERMINAL UNIT:
REHEAT AND OPTIONAL COOLING

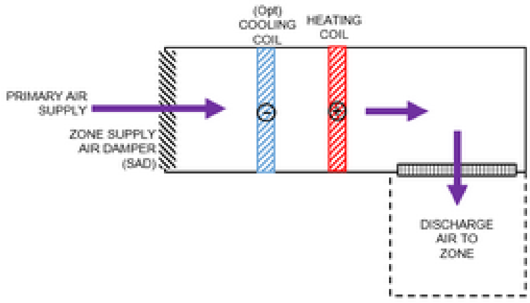


CAV TERMINAL UNIT:
REHEAT AND OPTIONAL COOLING with DIRECT RETURN AIR

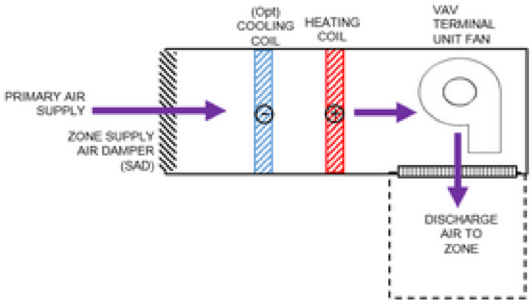


Variable Air Volume Unit Variations:

VAV TERMINAL UNIT:
REHEAT AND OPTIONAL COOLING

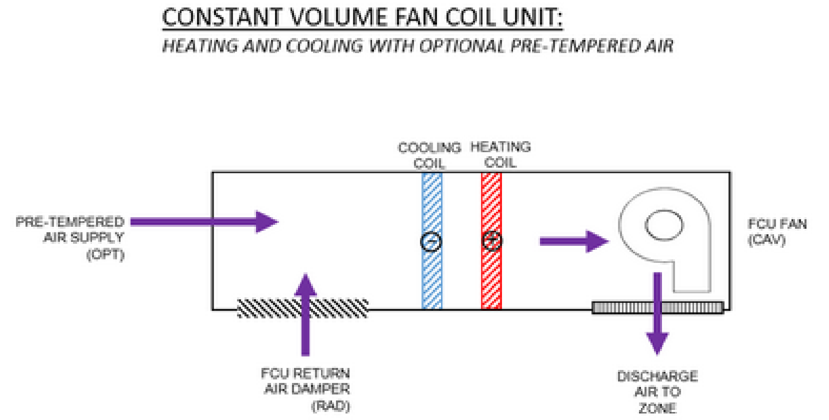


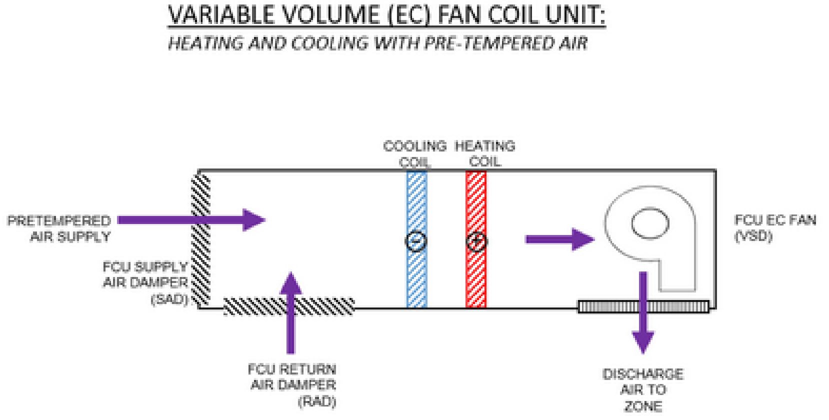
VAV TERMINAL UNIT:
FAN ASSIST VAV, WITH REHEAT AND OPTIONAL COOLING



(Continued...)

Fan Coil Unit Variations:





Top Constant Air Volume Terminal Unit Assessments	Top Additional Variable Air Volume Terminal Unit Assessments
• Zonal Thermal Dead band and Set point Review	• VAV: Zonal Economiser function
• Terminal Unit Heating and Cooling Fighting	• VAV: Zonal Night Purge
• Zonal Supply Air Temperature Reset	• VAV: Assessment of terminal unit air velocity
• Zonal Afterhours Operation *(Scheduling)*	**Additional Fan Coil Unit Assessment**
• Zonal Optimum Start/Stop	• FCU Proportional Control
• Zonal Demand Control Ventilation	
• Terminal Unit Heating and Cooling Coil Lockouts	

Q2.2.1 In order to carry out the top Terminal Air Unit (TU) assessments given above, which data points below do you think should be trended as a minimum to facilitate continuous commissioning?

(Continued…)

Select the data points for each individual terminal unit or select 'Trend for All' if you believe a data point should be trended for each terminal unit.

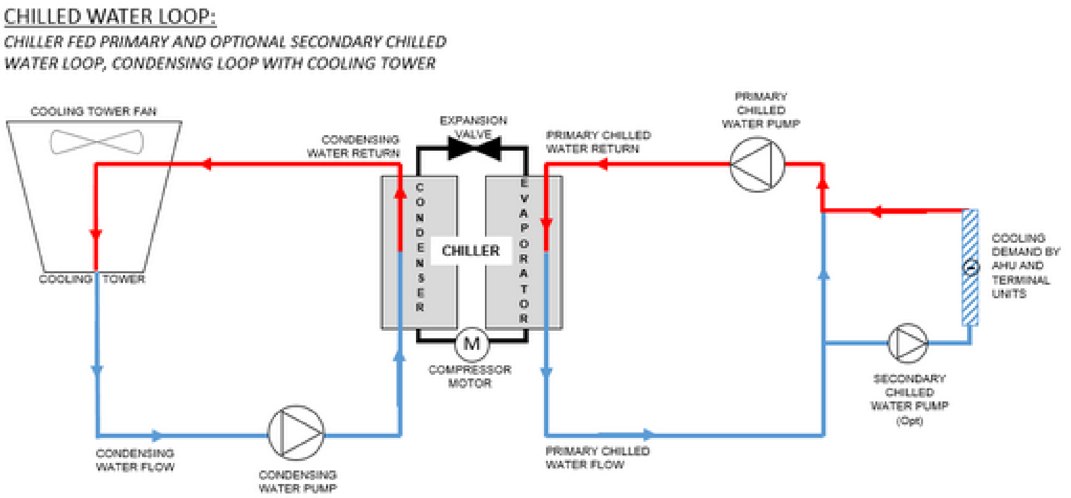
	Not Required for Trending	Trend for All	CAV Boxes	VAV Boxes	VAV with Fan Assist	Fan Coil Units	EC Fan Coil Units
TU: Damper Position (Open/Close)	☐	☐	☐	☐	☐	☐	☐
TU: Damper Position (%)	☐	☐	☐	☐	☐	☐	☐
TU: Heating Coil Valve Position (%)	☐	☐	☐	☐	☐	☐	☐
TU: Cooling Coil Valve Position (%)	☐	☐	☐	☐	☐	☐	☐
TU: Discharge Air Temperature (°C)	☐	☐	☐	☐	☐	☐	☐
TU: Discharge Airflow (l/s)	☐	☐	☐	☐	☐	☐	☐
TU: Fan Status (On/Off)	☐	☐	☐	☐	☐	☐	☐
TU: Fan Speed (%)	☐	☐	☐	☐	☐	☐	☐

	Not Required for Trending	Trend for All	CAV Boxes	VAV Boxes	VAV with Fan Assist	Fan Coil Units	EC Fan Coil Units
Zone Temperature (°C)	☐	☐	☐	☐	☐	☐	☐
Zone CO2 (ppm)	☐	☐	☐	☐	☐	☐	☐
Occupancy/Afterhours Mode (If Applicable)	☐	☐	☐	☐	☐	☐	☐
Other Data Point 1: ________	☐	☐	☐	☐	☐	☐	☐

(Continued…)

2.3 Chilled Water Loop:

The following exemplar schematic can be used as a reference to aid the questions below.



Top Constant Flow Chilled Water Loop Assessments	Top Additional Variable Flow Chilled Water Loop Assessments
• Chilled Water Flow Temperature Reset	• Waterside Economiser
• Chiller Staging	• Chilled Water Loop Differential Pressure Reset
• Afterhours Operation of all System Components	• Chilled Water Variable Flow under Partial Conditions
• Chiller Operation Lockout on Outdoor Air Temperature	
• Condensed Water Temperature Reset	
• Chiller Optimum Start/Stop	
• Staging of Chilled Water Pumps	

Q2.3.1 In order to carry out the top Chilled Water Loop assessments given above, which data points below do you think should be trended as a minimum to facilitate continuous commissioning?

Select the data points to be trended for each type of Chilled Water Loop (Constant and Variable Flow).

(Continued…)

	Not Required for Data Trending	Minimum Data Points for <u>Constant Flow</u> <u>Chilled Water Loops</u>	Minimum Data Points for <u>Variable Flow</u> <u>Chilled Water Loops</u>
Chilled Water Supply Temperature (°C)	☐	☐	☐
Chilled Water Return Temperature (°C)	☐	☐	☐
Condenser Supply Temperature (°C)	☐	☐	☐
Condenser Return Temperature (°C)	☐	☐	☐
Primary Pump Status (On/Off)	☐	☐	☐
VFD Primary Pump Speed (%)	☐	☐	☐
Secondary Pump Status (On/Off)	☐	☐	☐
VFD Secondary Pump Speed (%)	☐	☐	☐
Chiller Status (On/Off)	☐	☐	☐
Chilled Water Flow (l/s)	☐	☐	☐

	Not Required for Data Trending	Minimum Data Points for <u>Constant Flow</u> <u>Chilled Water Loops</u>	Minimum Data Points for <u>Variable Flow</u> <u>Chilled Water Loops</u>
Chilled Water Differential Pressure (Pa)	☐	☐	☐
Cooling Tower Fan Status (On/Off)	☐	☐	☐
Cooling Tower Fan Speed (%)	☐	☐	☐
Cooling Tower Inlet Temperature (°C)	☐	☐	☐
Cooling Tower Outlet Temperature (°C)	☐	☐	☐

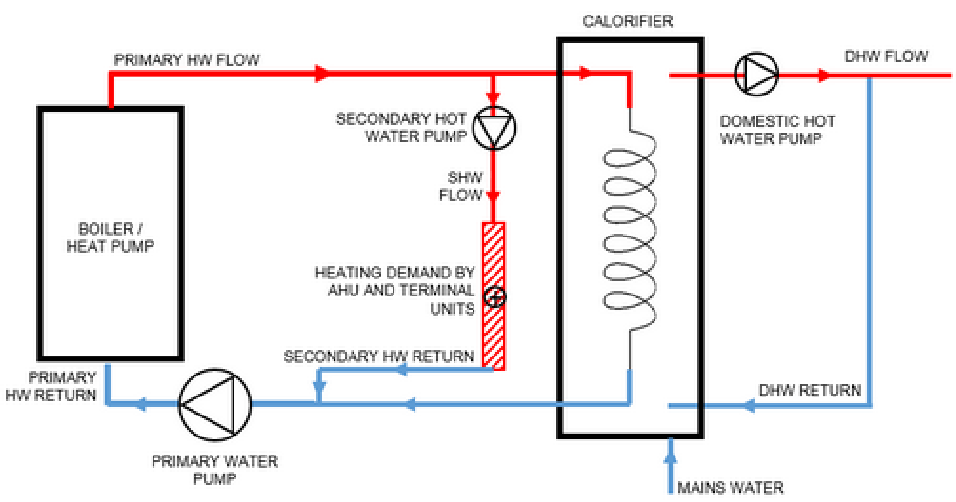
(Continued…)

2.4 Hot Water Loops:

The following exemplar schematic can be used as a reference to aid the questions below.

HOT WATER LOOP:

BOILER OR HEAT PUMP FED PRIMARY AND SECONDARY HOT WATER LOOP, DOMESTIC HOT WATER LOOP WITH CALORIFIER



Top Constant Flow Hot Water Loop Assessments	Top Additional Variable Flow Hot Water Loop Assessments
• Hot Water Flow Temperature Reset	• Staging of Hot Water Pumps
• Boiler or Heat Pump Staging	• Boiler or Heat Pump and Pump Interlock
• Boiler or Heat Pump Operation Lockout on Outdoor Air Temperature	• Hot Water Variable Flow under Partial Conditions
• Afterhours Operation of all System Components	
• Boiler or Heat Pump Optimum Start/Stop	
• Domestic Hot Water Temperature Reset	
• Hot Water Loop Differential Pressure Reset	

Q2.4.1 In order to carry out the top Hot Water Loop assessments given above, which data points below do you think should be trended as a minimum to facilitate continuous commissioning?

Select the data points to be trended for each type of Hot Water Loop (Constant and Variable Flow).

(Continued…)

	Not Required for Data Trending	Minimum Data Points for Constant Flow Hot Water Loops	Minimum Data Points for Variable Flow Hot Water Loops
Hot Water Supply Temperature (°C)	☐	☐	☐
Hot Water Return Temperature (°C)	☐	☐	☐
Hot Water Flow Rate (l/s)	☐	☐	☐
Primary Pump Status (On/Off)	☐	☐	☐
VFD Primary Pump Speed (%)	☐	☐	☐
Secondary Pump Status (On/Off)	☐	☐	☐
VFD Secondary Pump Speed (%)	☐	☐	☐
Boiler/Heat Pump Status (On/Off)	☐	☐	☐
Boiler/Heat Pump Outlet Temperature (°C)	☐	☐	☐
Domestic Hot Water Pump Status (On/Off)	☐	☐	☐
Domestic Hot Water Flow Temperature (°C)	☐	☐	☐
Domestic Hot Water Return Temperature (°C)	☐	☐	☐

	Not Required for Data Trending	Minimum Data Points for Constant Flow Hot Water Loops	Minimum Data Points for Variable Flow Hot Water Loops
Domestic Hot Water Flow Rate (l/s)	☐	☐	☐
Other Data Point 1: ______	☐	☐	☐
Other Data Point 2: ______	☐	☐	☐
Other Data Point 3: ______	☐	☐	☐
Other Data Point 4: ______	☐	☐	☐
Other Data Point 5: ______	☐	☐	☐

Part Three: Data Trending Requirements

It may not be necessary for all systems within a building to have data trended in order to pick up on inefficient operation. This section will ask you to identify the minimum proportion of HVAC component types that should have data trended and the most appropriate data interval.

Q3.1 Please recommend the minimum proportion of HVAC components to be trended with your previously defined data points.

	One Component	Components with Different Control Schedules	25% of Component Type	50% of Component Type	All Components
Air Handling Units	○	○	○	○	○
CAV and VAV Terminal Units	○	○	○	○	○
Fan Coil Units	○	○	○	○	○
Chillers	○	○	○	○	○
Boilers/Heat Pumps	○	○	○	○	○

Q3.2 Ideally would you trend data for every HVAC component?

○ Yes

○ No (please comment) __________

Q3.3 Please identify the minimum and ideal data trending interval you would recommend for continuous commissioning and identify how long data should be stored for.

	Data Trending Interval							Data Trending Storage							
	1 Minute	5 Minutes	10 Minutes	15 Minutes	30 Minutes	60 Minutes	Change of Value (COV)	1 Day	1 Week	1 Month	3 Months	6 Months	1 Year	2 Years	More than 2 Years
Minimum Data Trending Requirement	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Ideal Data Trending Requirement	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

<< >>

Q3.4 Energy metering is an important part of the Measurement and Verification stage of Continuous Commissioning. Please identify which systems you think should be sub-metered as a minimum requirement to carry out continuous commissioning.

	Minimum Energy Sub-metering Requirement per HVAC Component	
	No Sub-meter	Energy Sub-meter
Air Handling Units	●	○
CAV/VAV Terminal Units	○	●
Fan Coil Units	○	●
Chillers	○	●
Cooling Towers	●	○
Boilers/Heat Pumps	○	○
Other:	○	○

<< >>

Control Logic: Only the options where "energy sub-meter" is selected in the Question above (Q3.4) will come up in the following question:

Q3.5 What frequency of data trending do you recommend for each energy sub-meter?

	Energy Sub-meter Data Trending Interval							
	1 Minute	5 Minutes	10 Minutes	15 Minutes	30 Minutes	60 Minutes	Daily	Monthly
CAV/VAV Terminal Units	○	○	○	○	○	○	○	○
Fan Coil Units	○	○	○	○	○	○	○	○
Chillers	○	○	○	○	○	○	○	○

<< >>

This is the end of the Round 2 survey. If you would like to make any changes to your responses please go back now. If you are happy with your responses please press the submit button.

Please recognise if you encounter any issues during the completion of this survey.

If yes, please comment.

- ○ No
- ○ Yes [ ]

<< | Submit Responses

10.7 APPENDIX: SURVEY ROUND THREE

This is the third and final survey round. Thank you for your contribution to date and your participation in this final round.

Research Reminder:

The purpose of this research is to identify a comprehensive range of Building Management System (BMS) requirements for Continuous Commissioning (CCx) and to form a consensus from experienced industry professionals. The outputs of the survey will be used to establish a comprehensive guideline outlining the key data and functions required of a BMS to carry out typical CCx assessments on New Zealand-typical Heating, Ventilation, and Air Conditioning (HVAC) systems.

Further Information:

If you have any questions or require further clarification, please don't hesitate to contact me or my supervisor:

Survey Round Three: Forming a Consensus and BMS Capabilities

Participant responses from Round Two have been compiled to present the minimum data points recognised by the majority of participants to be trended to facilitate continuous commissioning.

The first and second part of this survey will ask you to agree or disagree with the responses presented from the previous survey round in order to form a consensus.

The third part of this survey will ask you to identify the importance and satisfaction of various BMS functions in relation to facilitating continuous commissioning.

Email Address

This is collected to ensure the survey is only answered once.

Please type email address here:

<<   >>

Part One: Forming a Consensus: Data Points

This section presents the minimum HVAC data points required for trending to facilitate continuous commissioning as identified by the majority of participants.

<<   >>

1.1 Central Air Handling Units:

Air Handling Units: Minimum Data Points

The majority of participants identified the following as the minimum data points to be trended to carry out continuous commissioning on CAV and VAV Air Handling Units:

Data Points for Trending	Unit	Data Points to be Trended for Constant Air Volume AHU	Data Points to be Trended for Variable Air Volume AHU
Outdoor Air Temperature	°C	X	X
Mixed Air Temperature	°C	X	X
Return Air Temperature	°C	X	X
Primary Supply Air Temperature	°C	X	X
Duct Static Pressure	Pa	Not Required	X
Return Air Damper Position	%	X	X
Outdoor Air Damper Position	%	X	X
Exhaust Air Damper Position	%	X	X
Supply Fan Status	On/Off	X	X
Supply Air Fan Speed	%	X	X
Return/Exhaust Fan Status	On/Off	X	X
Return/Exhaust Fan Speed	%	X	X
Ahu Cooling Valve Position	%	X	X
Ahu Heating Valve Position	%	X	X
Supply Airflow	l/s	Not Required	X
Return/Exhaust Airflow	l/s	Not Required	X
Return Air CO_2 Sensor	ppm	X	X
Supply Air CO_2 Sensor	ppm	X	X
Outdoor Air Filter Pressure Differential	Pa	X	X

Q1.1.1 Do you agree these data points are required for trending?

- ○ Agree
- ○ Disagree

Control Logic: If "disagree" is selected (Q1.1.1) the following question will display:

Q1.1.2 Please identify which data points you disagree with and provide reasoning as to why you disagree:

<< >>

Air Handling Units: Additional Data Points

Additional data points were acknowledged by some participants as also required for trending CAV and VAV Air Handling Units:

Additional Proposed Data Points for Trending	Unit	Additional Data Points to be Trended for Constant Air Volume AHU	Additional Data Points to be Trended for Variable Air Volume AHU
Return Duct Static Pressure	Pa	X	X
Outdoor Air Relative Humidity	%	X	X
Return Air Relative Humidity	%	X	X
AHU Operating Load	kW	X	X

Control Logic: If "disagree" is selected (Q1.1.3) question will display:

Q1.1.3 Do you agree these data points are also required for trending?

- [ ] Agree
- [x] Disagree

Q1.1.4 Please identify which additional data points you disagree with and provide reasoning as to why you disagree:

<< >>

1.2 Terminal Air Units:

Terminal Air Units: Minimum Data Points

The majority of participants identified the following as the minimum data points to be trended to carry out continuous commissioning on terminal CAV, VAV and Fan Coil Units:

Data Points for Trending	Data Unit	CAV Boxes	VAV Boxes	VAV with Fan Assist	Fan Coil Units	EC Fan Coil Units
TU: Damper Position	%	N/A	X	X	N/A	N/A
TU: Heating Coil Valve Position	%	X	X	X	X	X
TU: Cooling Coil Valve Position	%	X	X	X	X	X
TU: Discharge Air Temperature / Off-Coil Supply Air Temperature	°C	X	X	X	X	X
TU: Discharge Airflow	l/s	N/A	X	X	X	X
TU: Fan Status	On/Off	N/A	N/A	X	X	X
TU: Fan Speed	%	N/A	N/A	X	X	X
Zone Temperature	°C	X	X	X	X	X
Zone CO2	ppm	X	X	X	X	X

Q1.2.1 Do you agree these data points are required for trending?

- ○ Agree
- ● Disagree

Control Logic: If "disagree" is selected (Q1.2.1) question will display:

Q1.2.2 Please identify which data points you disagree with and provide reasoning as to why you disagree:

<< >>

Q1.2.3 There was no clear consensus on whether or not an Onfloor Damper's Open or Closed Position should be trended. Please select which Terminal Unit System would typically have an Onfloor Supply Air Damper with only an Open or Closed position i.e. not variable (%).

CAV Boxes	VAV Boxes	VAV with Fan Assist	Fan Coil Units	EC Fan Coil Units
☑	☐	☑	☐	☐

<< >>

Control Logic: Only selected options will display:

Q1.2.4 Please select which of these systems should have the data point Damper Position (Open/Closed) trended to facilitate continuous commissioning?

CAV Boxes	VAV with Fan Assist
☐	☐

<< >>

Terminal Air Units: Additional Data Points

An additional data point was acknowledged by some participants as being required for trending Fan Coil Units:

Additional Data Points for Trending	Data Unit	CAV Boxes	VAV Boxes	VAV with Fan Assist	Fan Coil Units	EC Fan Coil Units
FCU Filter Status	ΔPa	N/A	N/A	N/A	X	X

Q1.2.5 Do you agree this data point is also required for trending Fan Coil Units?

- Agree
- Disagree (please comment)

<< >>

1.3 Chilled Water Loop:

Chilled Water Loop: Minimum Data Points

The majority of participants identified the following as the minimum data points to be trended to carry out continuous commissioning on Constant and Variable Flow Chilled Water Loops.

Data Points for Trending	Data Unit	Constant Flow CHW Loop	Variable Flow CHW Loop
Primary Chilled Water Supply Temperature	°C	X	X
Primary Chilled Water Return Temperature	°C	X	X
Condenser Supply Temperature	°C	X	X
Condenser Return Temperature	°C	X	X
Primary Pump Status	On/Off	X	X
VFD Primary Pump Speed	%	X	X
Secondary Pump Status	On/Off	X	X
VFD Secondary Pump Speed	%	X	X
Chiller Status	On/Off	X	X
Chilled Water Flow	l/s	X	X
Chilled Water Differential Pressure	ΔPa	N/A	X
Cooling Tower Fan Status	On/Off	X	X
Cooling Tower Fan Speed	%	X	X
Cooling Tower Inlet Temperature	°C	X	X
Cooling Tower Outlet Temperature	°C	X	X

Control Logic: If “disagree” is selected (Q1.3.1) question will display:

Q1.3.1 Do you agree these data points are required for trending?

- ○ Agree
- ● Disagree

Q1.3.2 Please identify which data points you disagree with and provide reasoning as to why you disagree:

<< >>

Chilled Water Loop: Additional Data Points

Additional data points were acknowledged by some participants as also required for trending Constant and Variable Flow Chilled Water Loops:

Additional Data Points for Trending	Data Unit	Constant Flow CHW Loop	Variable Flow CHW Loop
Secondary Chilled Water Supply Temperature	°C	X	X
Secondary Chilled Water Return Temperature	°C	X	X
Compressor Speed	%	X	X
Compressor Status	On/Off	X	X
Condenser Water Pump Speed	%	X	X
Condenser Water Pump Status	On/Off	X	X
Compressor Load Output	kW	X	X
Chilled Water Flow Switch Status	Flow/No Flow	X	X

Q1.3.3 Do you agree these data points are also required for trending?

- Agree
- Disagree

<< >>

1.4 Hot Water Loops:

Hot Water Loop: Minimum Data Points

The majority of participants identified the following as the minimum data points to be trended to carry out continuous commissioning on Constant and Variable Flow Hot Water Loops.

Data Points for Trending	Data Unit	Constant Flow HHW	Variable Flow HHW
Primary Hot Water Supply Temperature	°C	X	X
Primary Hot Water Return Temperature	°C	X	X
Hot Water Flow Rate	l/s	N/A	X
Primary Pump Status	On/Off	X	X
VFD Primary Pump Speed	%	N/A	X
Secondary Pump Status	On/Off	X	X
VFD Secondary Pump Speed	%	N/A	X
Boiler/Heat Pump Status	On/Off	X	X
Boiler/Heat Pump Outlet Temperature	°C	X	X

Q1.4.1 Do you agree these data points are required for trending?

- ○ Agree
- ● Disagree

Control Logic: If "disagree" is selected (Q1.4.1) question will display:

Q1.4.2 Please identify which data points you disagree with and provide reasoning as to why you disagree:

<< >>

Hot Water Loop: Additional Data Points

Additional data points were acknowledged by some participants as also required for trending Constant and Variable Flow Hot Water Loops:

Data Points for Trending	Data Unit	Constant Flow HHW	Variable Flow HHW
Secondary Hot Water Supply Temperature	°C	X	X
Secondary Hot Water Return Temperature	°C	X	X
Calorifier Valve Position	%	X	X
Boiler/Heat Pump Load Output	kW	X	X

Q1.4.3 Do you agree these data points are also required for trending?

- (selected) Agree
- Disagree

<< >>

Domestic Hot Water: Minimum Data Points

The majority of participants identified the following as the minimum data points to be trended to carry out continuous commissioning on Domestic Hot Water Loops.

Data Points for Trending	Data Unit	DHW Loop
Domestic Hot Water Pump Status	On/Off	X
Domestic Hot Water Flow Temperature	°C	X
Domestic Hot Water Return Temperature	°C	X
Domestic Hot Water Flow Rate	l/s	N/A

Q1.4.5 Do you agree these data points are required for trending?

- Agree
- Disagree

<< >>

Part Two: Forming a Consensus: Data Point Trending Intervals

This section presents the minimum data trending intervals and the proportion of HVAC components required for trending as identified by the majority of participants.

<< >>

2.1.0 HVAC Components to be Trended:

The majority of participants identified the following as the minimum proportion of HVAC components to be trended per Central HVAC plant type.

HVAC Type	Proportion of Components to be Trended
• Air Handling Units	All Components
• Chillers	All Components
• Boilers/Heat Pumps	All Components

Q2.1.1 Do you agree the proportion of components above are required for trending?

- ○ Agree
- ○ Disagree (please comment) [ ]

<< >>

No clear majority of votes was achieved for the proportion of Terminal Air Units to be trended. The table below presents the proportion of onfloor components required for trending, identified by the greatest number of participants.

HVAC Type	Proportion of Components to be Trended
• CAV and VAV Terminal Units	All Components
• Fan Coil Units	All Components

Q2.1.2 Do you agree the proportion of components above are required for trending Terminal Air Units?

- ○ Agree
- ● Disagree

Q2.1.3 Please identify what proportion of Terminal Air Units you believe to be more appropriate for trending to carry out continuous commissioning:

- ○ Less than 50% of all Terminal Air Units
- ○ At least 50% of all Terminal Air Units
- ○ Other (please comment) [ ]

<< >>

Control Logic: If “disagree” is selected (Q2.1.2) question 2.1.3 will display.

2.2.0 HVAC Data Trending Intervals

The majority of participants identified the following as the minimum and ideal HVAC data trending interval required to carry out continuous commissioning:

Minimum Trending Interval	Ideal Trending Interval
15 Minutes or less	5 Minutes or less

Q2.2.1 Do you agree with the data trending intervals presented above?

- Agree
- Disagree (please comment)

<< >>

2.3.0 HVAC Data Storage

The majority of participants identified the following as the minimum and ideal data trending storage periods required to carry out continuous commissioning:

Minimum Data Storage	Ideal Data Storage
At least 3 months	More than 2 years

Q2.3.1 Do you agree with the data trending storage periods presented above?

- Agree
- Disagree (please comment)

<< >>

2.4.0 Energy Sub-Metering

The majority of participants identified the following requirements for energy sub-metering of HVAC components to facilitate continuous commissioning:

HVAC Equipment Type	Energy Sub-Meter	Energy Sub-Meter Data Trending Interval
• Air Handling Units	Required	15 Minutes or Less
• Individual CAV and VAV Terminal Units	Not Required	N/A
• Individual Fan Coil Units	Not Required	N/A
• Chillers	Required	15 Minutes or Less
• Cooling Towers	Required	15 Minutes or Less
• Boilers/Heat Pumps	Required	15 Minutes or Less

Q2.4.1 Do you agree with the energy sub-meter requirements presented above?

- ○ Agree
- ○ Disagree (please comment) ________

<< >>

Additional Energy Sub-Meters

Additional energy sub-meters were suggested by multiple participants as also required to facilitate continuous commissioning:

HVAC Equipment Type	Additional Energy Sub-Meter	Proposed Energy Sub-meter Interval
• Large Pumps (>3kW)	Required	15 Minutes or less
• Total Onfloor HVAC	Required	
• Total Central HVAC Plant	Required	

Q2.4.2 Do you agree with the additional energy sub-meters presented above?

- ○ Agree
- ○ Disagree

<< >>

Q2.4.3 Do you agree whole building energy and sub-meter energy data should be trended and accessible through a Building Management System to facilitate continuous commissioning?

- ○ Agree
- ○ Disagree (please comment)

<< >>

Part Three: Building Management System Capabilities

This section will ask you to rate the importance of BMS capabilities in relation to facilitating continuous commissioning and to rate your satisfaction of these capabilities based on BMS you have used.

This section refers to the non-control functions of BMS such as data extraction capabilities, access to documentation, visualisations and BMS usability.

<< >>

Q3.1.1 Data Extraction Capabilities - Importance

Rate the importance of Data Extraction Capabilities of BMS in relation to facilitating Continuous Commissioning:

	Data Extraction Capability Importance 1 = Not at all important 7 = Extremely Important						
	1	2	3	4	5	6	7
Remote Access to BMS Computer	O	O	O	O	O	O	O
Online Access to BMS interface	O	O	O	O	O	O	O
Speed of BMS software for data extraction	O	O	O	O	O	O	O
Ability to specify a time frame for data trend exports	O	O	O	O	O	O	O
Ability to pick and choose the data point trends to be exported	O	O	O	O	O	O	O
Ability to calculate mean, minimum and maximum values of selected data points	O	O	O	O	O	O	O
Ability to customise the data trend format and file type	O	O	O	O	O	O	O
Ability to set up an automatic export of data trend files	O	O	O	O	O	O	O
Other 1: Example 1	O	O	O	O	O	O	O
Other 2: Example 2	O	O	O	O	O	O	O

<< >>

Control Logic: For all "satisfaction questions, any text in Other boxes 1&2 will be brought forward:

Q3.1.2 Data Extraction Capabilities - Satisfaction

Based on BMS you have used, rate your overall satisfaction of these BMS in providing Data Extraction Capabilities:

	Typically Not Available	Data Extraction Capability Satisfaction 1 = Extremely dissatisfied 7 = Extremely Satisfied 1	2	3	4	5	6	7
Remote Access to BMS Computer	O	O	O	O	O	O	O	O
Remote Access to BMS Computer	O	O	O	O	O	O	O	O
Speed of BMS software for data extraction	O	O	O	O	O	O	O	O
Ability to specify a time frame for data trend exports	O	O	O	O	O	O	O	O
Ability to pick and choose the data point trends to be exported	O	O	O	O	O	O	O	O
Ability to calculate mean, minimum and maximum values of selected data points	O	O	O	O	O	O	O	O
Ability to customise the data trend format and file type	O	O	O	O	O	O	O	O
Ability to set up an automatic export of data trend files	O	O	O	O	O	O	O	O
Example 1	O	O	O	O	O	O	O	O
Example 2	O	O	O	O	O	O	O	O

<< >>

Q3.2.1 HVAC Documentation within BMS - Importance

Rate the importance of the following equipment documentation and data being accessible through a BMS in order to facilitate Continuous Commissioning:

	HVAC Documentation within BMS Importance 1 = Not at all important 7 = Extremely Important 1	2	3	4	5	6	7
HVAC Equipment Meta-Data *e.g. Co-efficient of performance, system specifications, scheduled operation, operation setpoints*	O	O	O	O	O	O	O
HVAC System Schematics with real-time data point display *e.g. 2D or 3D equipment schematics and dynamic displays*	O	O	O	O	O	O	O
Equipment Event Log *e.g. re-occurring system faults, periodic maintenance and documentation of changes to system control or scheduling*	O	O	O	O	O	O	O
Other 1:	O	O	O	O	O	O	O
Other 2:	O	O	O	O	O	O	O

<< >>

Q3.2.2 HVAC Documentation within BMS - Satisfaction

Based on BMS you have used, rate your overall satisfaction of BMS in providing access to equipment documentation:

HVAC Documentation within BMS Satisfaction
1 = Extremely dissatisfied 7 = Extremely Satisfied

	Typically Not Available	1	2	3	4	5	6	7
HVAC Equipment Meta-Data *e.g. Co-efficient of performance, system specifications, scheduled operation, operation setpoints*	○	○	○	○	○	○	○	○
HVAC System Schematics with real-time data point display *e.g. 2D or 3D equipment schematics and dynamic displays*	○	○	○	○	○	○	○	○
Equipment Event Log *e.g. re-occurring system faults, periodic maintenance and documentation of changes to system control or scheduling*	○	○	○	○	○	○	○	○

<< >>

Q3.3.1 BMS Data Visualisations - Importance

Rate the importance of data Visualisation Capabilities of BMS in relation to facilitating Continuous Commissioning:

BMS Data Visualisations Importance
1 = Not at all important 7 = Extremely Important

	1	2	3	4	5	6	7
Building Floor Plans with real-time data point display *e.g. Zone Temperatures*	○	○	○	○	○	○	○
Customisable Data Trend Lines against Time *e.g. Heat Pump On/Off vs Time*	○	○	○	○	○	○	○
Customisable X-Y Scatter Plots *e.g. Boiler Operation vs Outdoor Air Temperature*	○	○	○	○	○	○	○
Additional Data Visualisation Functions [ ]	○	○	○	○	○	○	○
Customisable Summary Dashboard	○	○	○	○	○	○	○
Other 1: [ ]	○	○	○	○	○	○	○
Other 2: [ ]	○	○	○	○	○	○	○

<< >>

Q3.3.2 BMS Data Visualisations - Satisfaction

Based on BMS you have used, rate your overall satisfaction of BMS in providing Data Visualisation Functions:

	BMS Data Visualisations Satisfaction 1 = Extremely Dissatisfied 7 = Extremely Satisfied							
	Typically Not Available	1	2	3	4	5	6	7
Building Floor Plans with real-time data point display *e.g. Zone Temperatures*	○	○	○	○	○	○	○	○
Customisable Data Trend Lines against Time *e.g. Heat Pump On/Off vs Time*	○	○	○	○	○	○	○	○
Customisable X-Y Scatter Plots *e.g. Boiler Operation vs Outdoor Air Temperature*	○	○	○	○	○	○	○	○
Additional Data Visualisation Functions [ ]	○	○	○	○	○	○	○	○
Customisable Summary Dashboard	○	○	○	○	○	○	○	○

<< >>

Q3.4.1 BMS Usability Features - Importance

Rate the importance of BMS usability features in facilitating Continuous Commissioning:

	BMS Usability Factors - Importance 1 = Not at all important 7 = Extremely Important						
	1	2	3	4	5	6	7
Clarity of BMS Language and Terminology	○	○	○	○	○	○	○
Clarity of Data Point Naming Conventions	○	○	○	○	○	○	○
Ability to Customise Data Point Naming Conventions	○	○	○	○	○	○	○
Ease of Operation Parameter Adjustment	○	○	○	○	○	○	○
Ease of Operation Scheduling Adjustment	○	○	○	○	○	○	○
Ease of BMS Navigation	○	○	○	○	○	○	○
Overall Graphical User Interface Usability	○	○	○	○	○	○	○
Regular BMS Software Upgrades	○	○	○	○	○	○	○
Ease of BMS Extension	○	○	○	○	○	○	○
BMS Reliability	○	○	○	○	○	○	○
Other 1: [ ]	○	○	○	○	○	○	○
Other 2: [ ]	○	○	○	○	○	○	○

<< >>

Q3.4.2 BMS Usability Features - Satisfaction

Based on BMS you have used, rate your overall satisfaction of BMS usability:

	BMS Usability Factors - Satisfaction 1 = Extremely Dissatisfied 7 = Extremely Satisfied							
	Typically Not Available	1	2	3	4	5	6	7
Clarity of BMS Language and Terminology	○	○	○	○	○	○	○	○
Clarity of Data Point Naming Conventions	○	○	○	○	○	○	○	○
Ability to Customise Data Point Naming Conventions	○	○	○	○	○	○	○	○
Ease of Operation Parameter Adjustment	○	○	○	○	○	○	○	○
Ease of Operation Scheduling Adjustment	○	○	○	○	○	○	○	○
Ease of BMS Navigation	○	○	○	○	○	○	○	○
Overall Graphical User Interface Usability	○	○	○	○	○	○	○	○
Regular BMS Software Upgrades	○	○	○	○	○	○	○	○
Ease of BMS Extension	○	○	○	○	○	○	○	○
BMS Reliability	○	○	○	○	○	○	○	○

<< >>

Q3.5 Additional Comments

Please provide any additional comments on the capabilities or usability of Building Management Systems in relation to facilitating Continuous Commissioning.

○ No Additional Comments

○ Additional Comments:

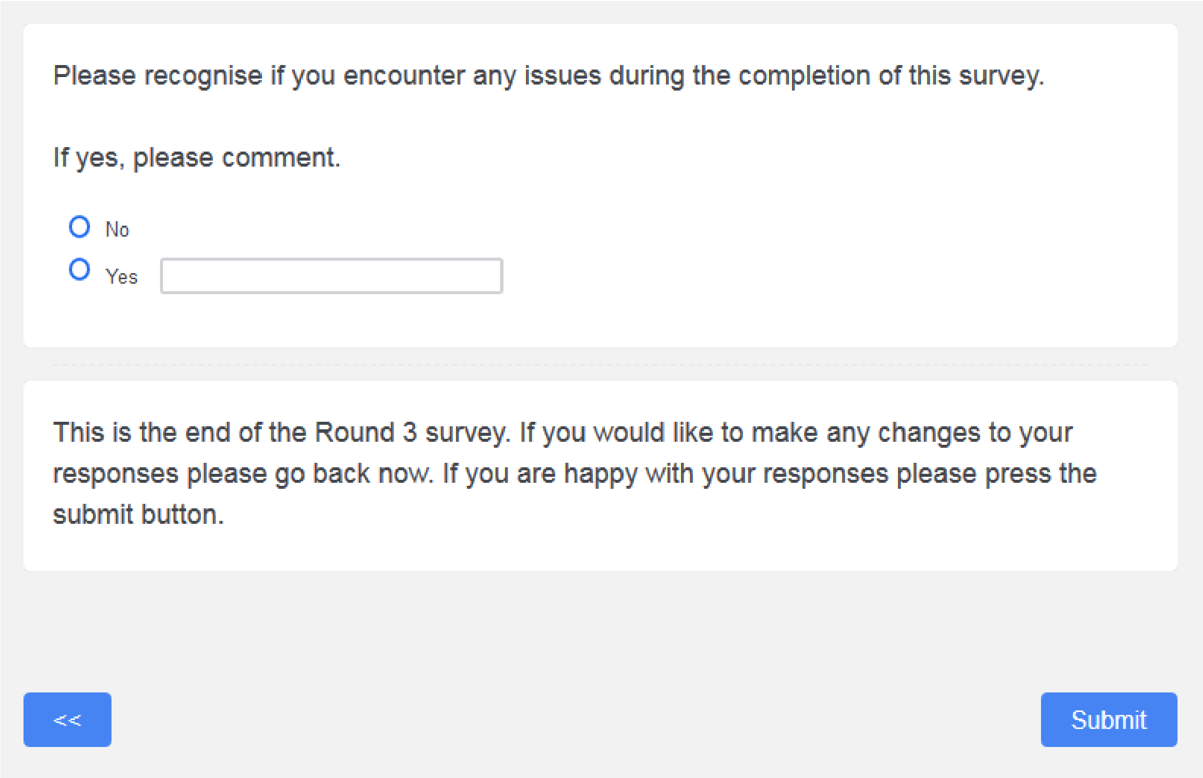
<< >>

Please indicate if you would like to receive a soft copy summary of the consensus of survey results:

○ Yes

○ No

<< >>


Please recognise if you encounter any issues during the completion of this survey.

If yes, please comment.

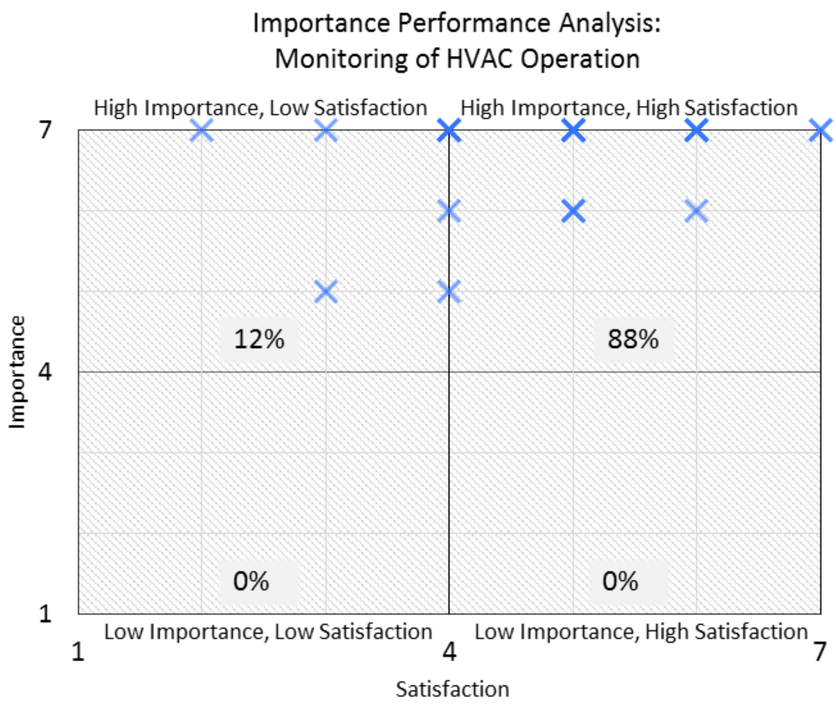
- No
- Yes

This is the end of the Round 3 survey. If you would like to make any changes to your responses please go back now. If you are happy with your responses please press the submit button.

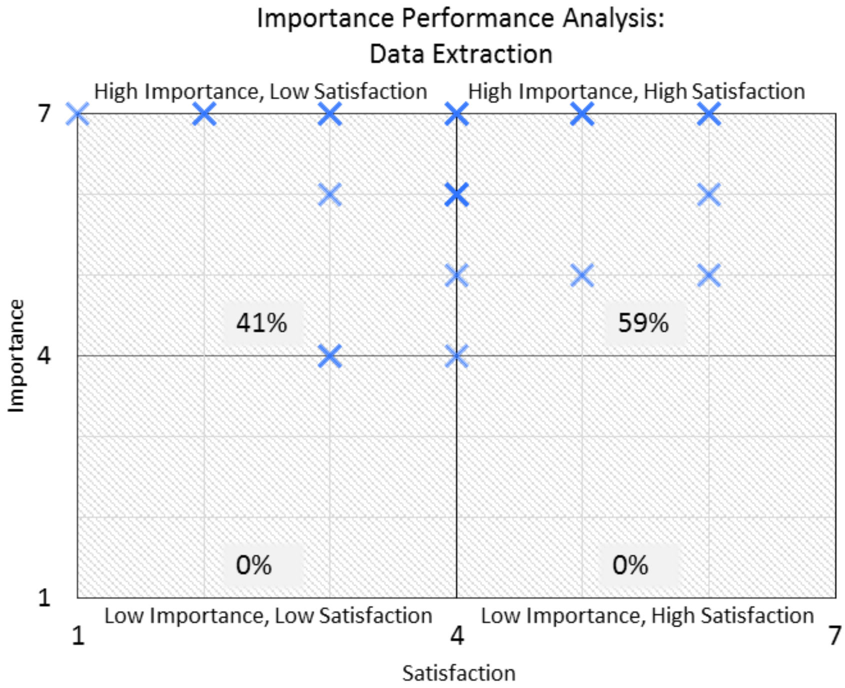
<< Submit

10.8 APPENDIX: IMPORTANCE AND SATISFACTION QUADRANT CHARTS FOR BMS AT STAGES OF CCX

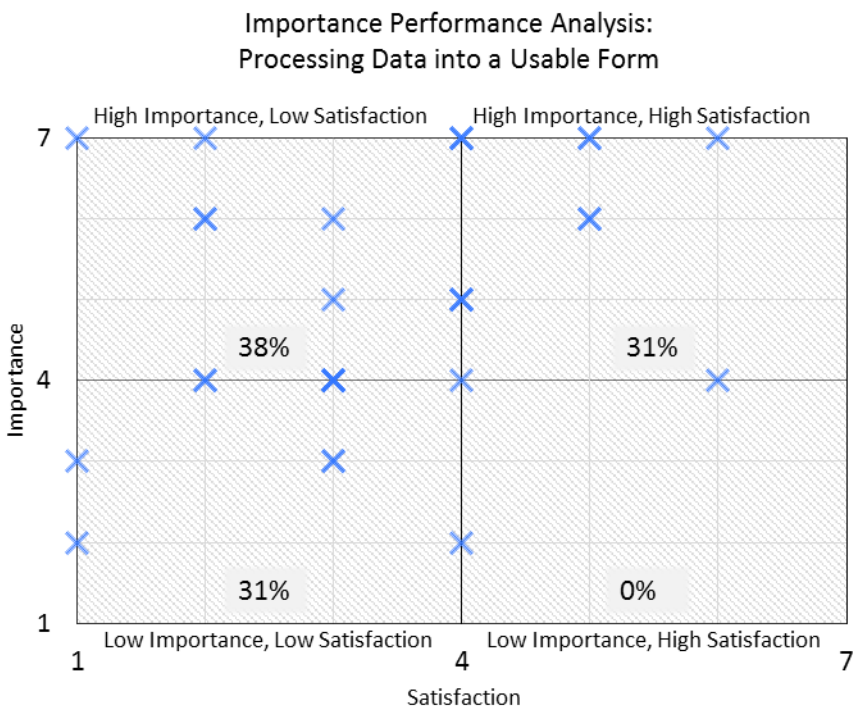
10.8.1 IMPORTANCE AND SATISFACTION QUADRANT CHART: MONITORING OF HVAC OPERATION



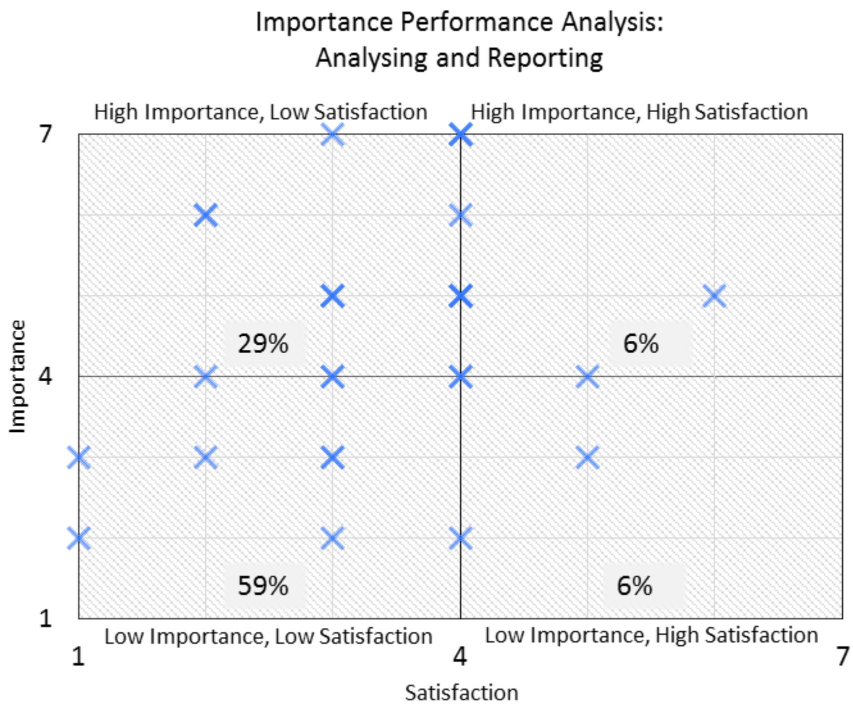
10.8.2 IMPORTANCE AND SATISFACTION QUADRANT CHART: DATA EXTRACTION



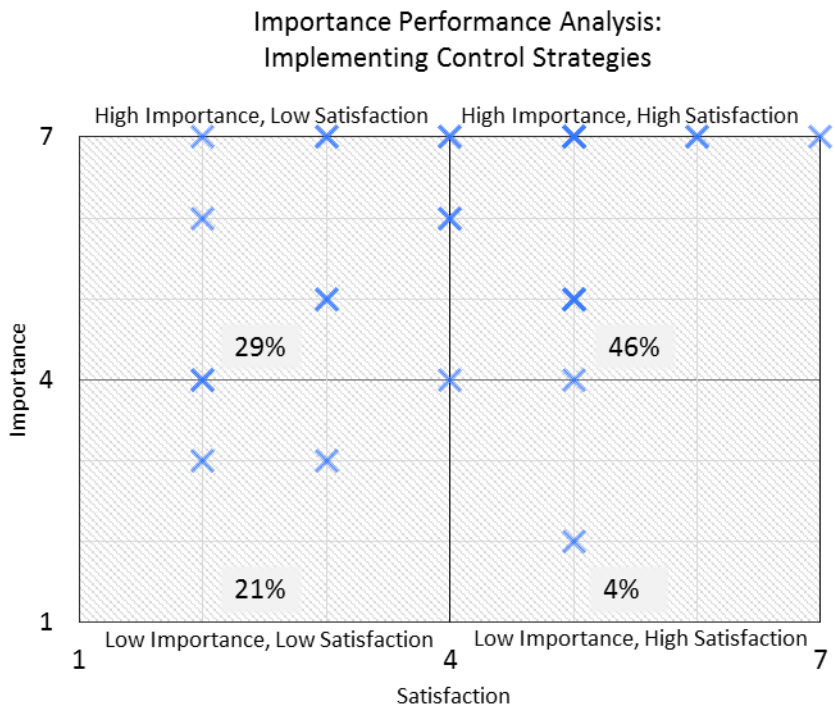
10.8.3 IMPORTANCE AND SATISFACTION QUADRANT CHART: DATA PROCESSING



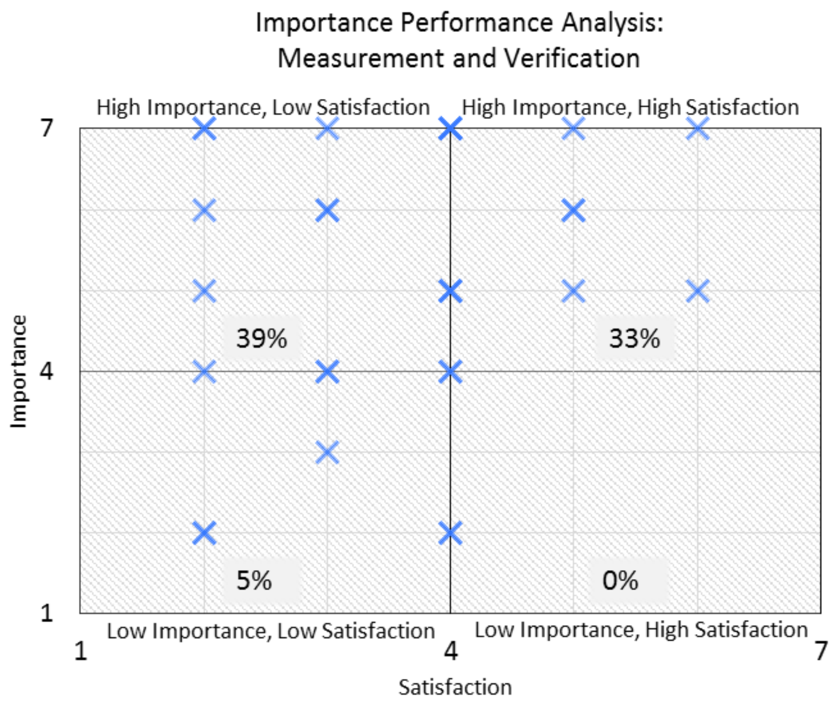
10.8.4 IMPORTANCE AND SATISFACTION QUADRANT CHART: DATA ANALYSIS



10.8.5 IMPORTANCE AND SATISFACTION QUADRANT CHART: IMPLEMENTATION OF STRATEGIES

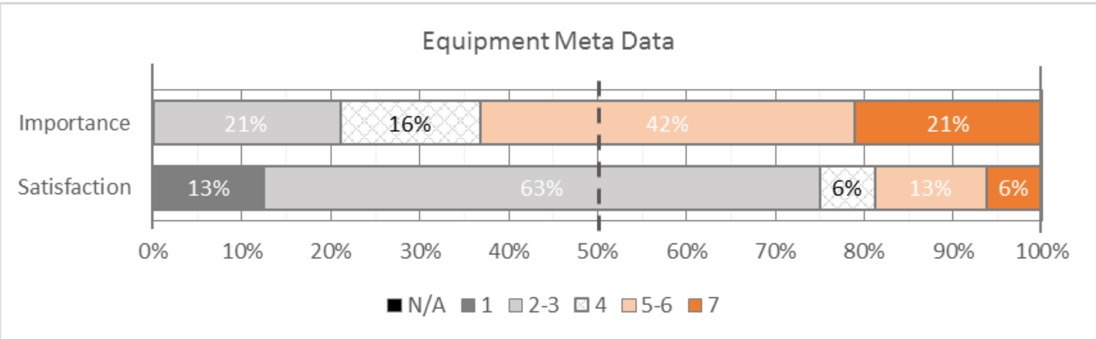


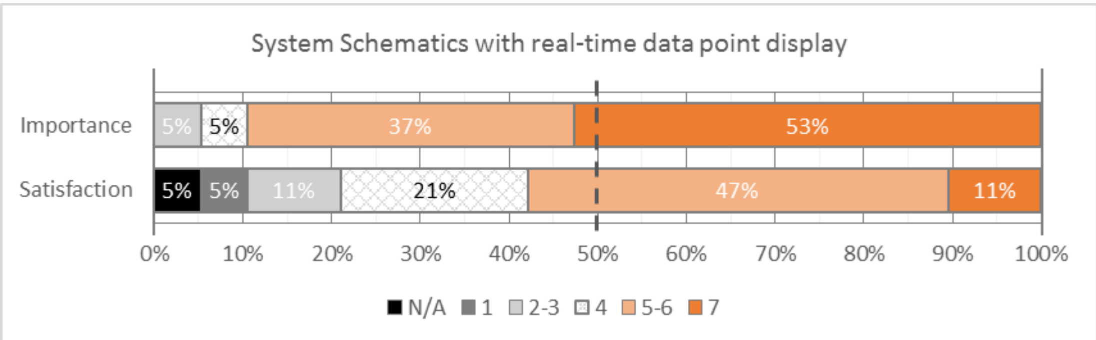
10.8.6 IMPORTANCE AND SATISFACTION QUADRANT CHART: MEASUREMENT AND VERIFICATION

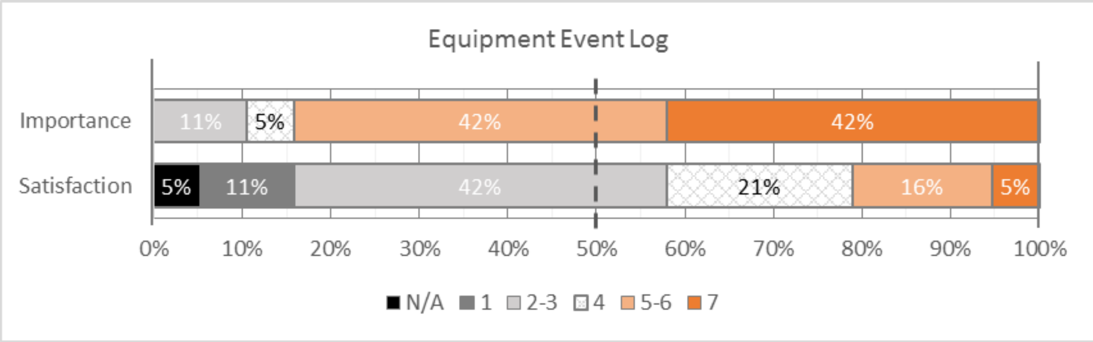


10.9 APPENDIX DETAILED IMPORTANCE AND SATISFACTION CHARTS FOR BMS CAPABILITIES

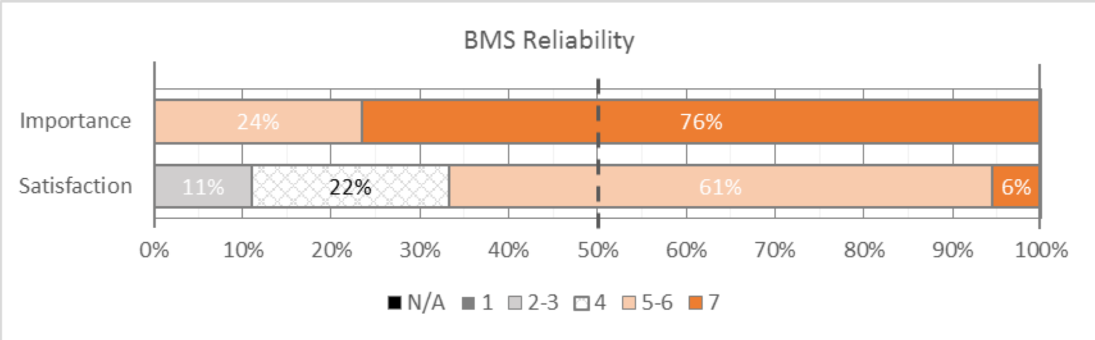
10.9.1 HVAC DOCUMENTATION ACCESS WITHIN BMS



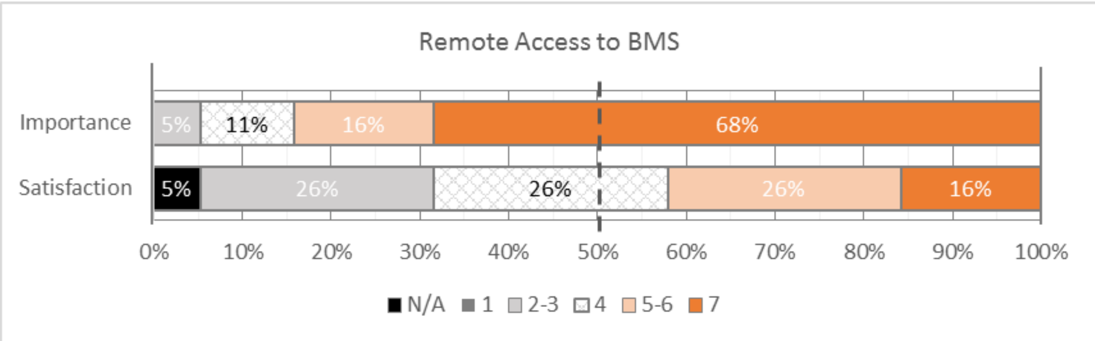


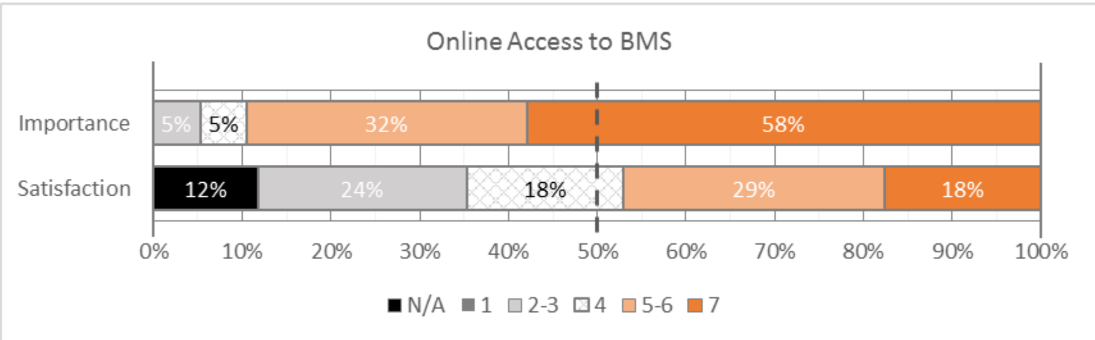


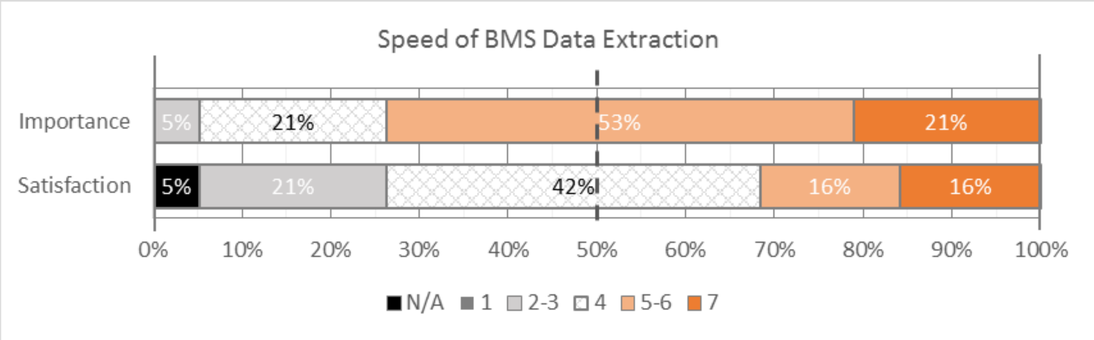
10.9.2 BMS RELIABILITY



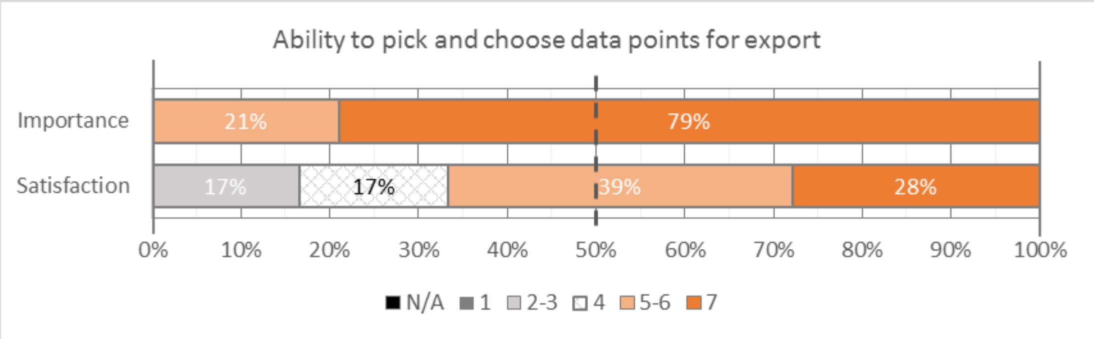
10.9.3 BMS DATA EXTRACTION CAPABILITIES



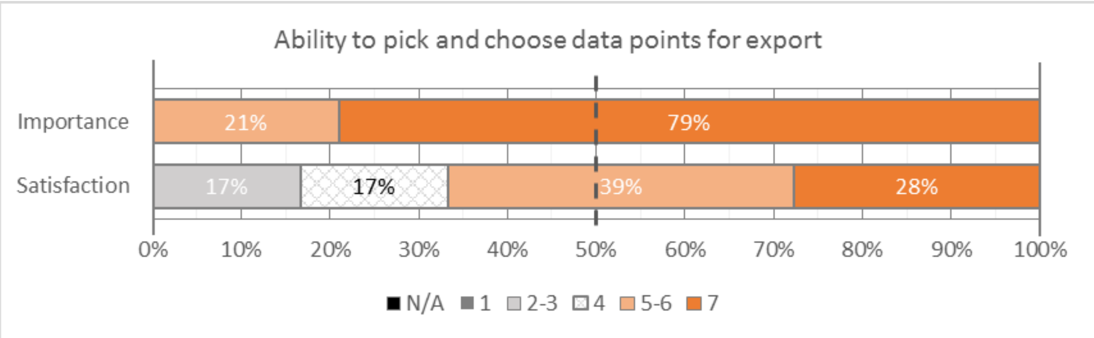




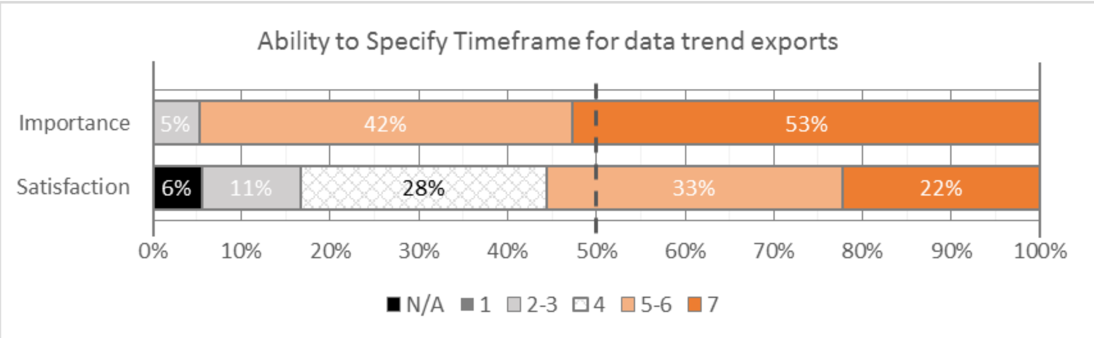
Speed of BMS Data Extraction
Importance
Satisfaction
5%
21%
53%
21%
5%
21%
42%
16%
16%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
N/A
1
2-3
4
5-6
7



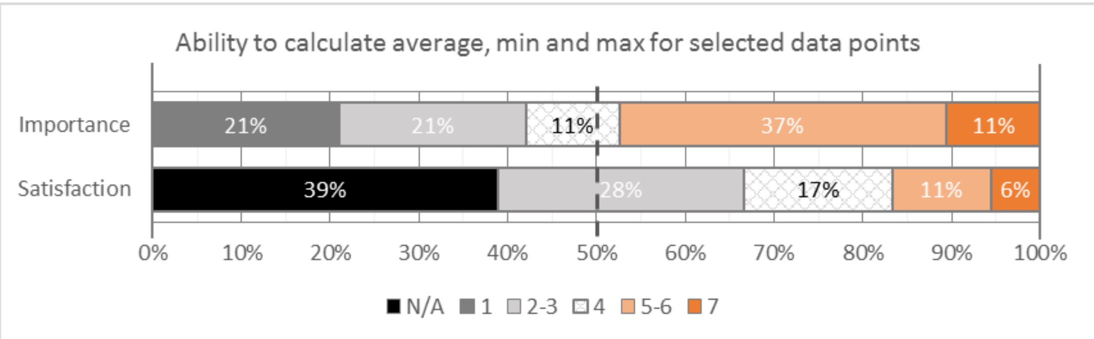
Ability to pick and choose data points for export
Importance
Satisfaction
21%
79%
17%
17%
39%
28%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
N/A
1
2-3
4
5-6
7



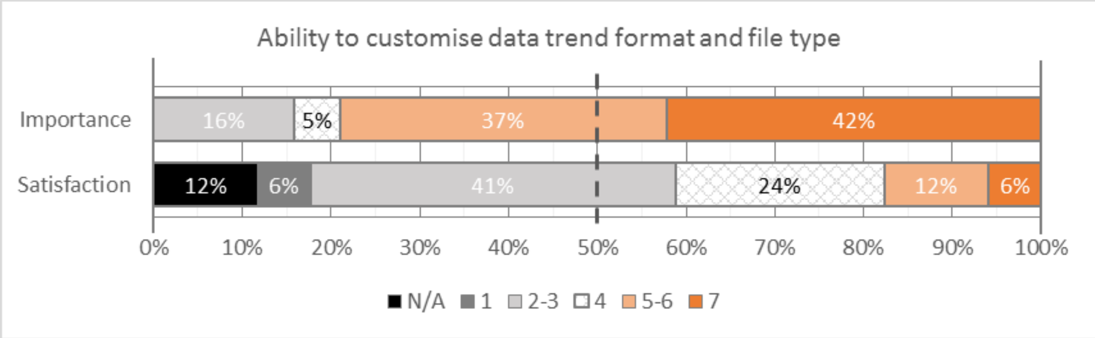
Ability to pick and choose data points for export
Importance
Satisfaction
21%
79%
17%
17%
39%
28%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
N/A
1
2-3
4
5-6
7

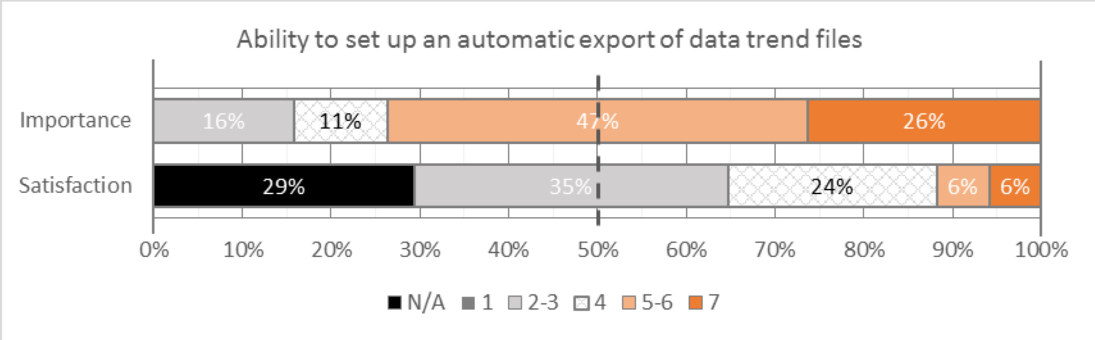


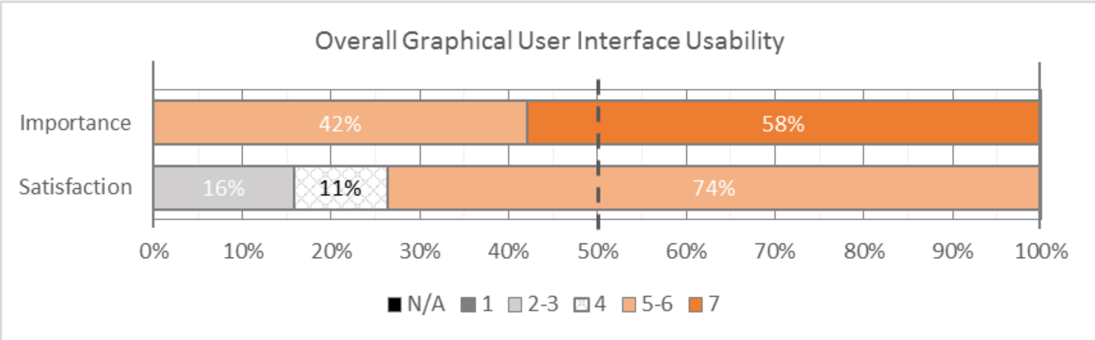
Ability to Specify Timeframe for data trend exports
Importance
Satisfaction
5%
42%
53%
6%
11%
28%
33%
22%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
N/A
1
2-3
4
5-6
7



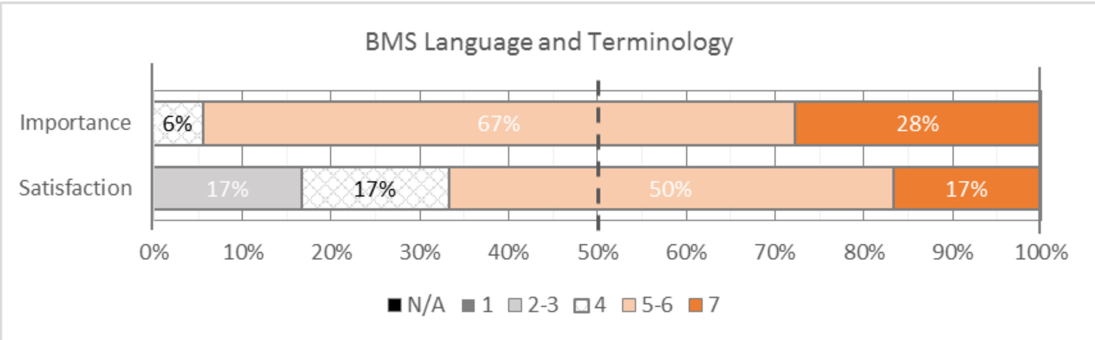
Ability to calculate average, min and max for selected data points
Importance
Satisfaction
21%
21%
11%
37%
11%
39%
28%
17%
11%
6%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
N/A
1
2-3
4
5-6
7

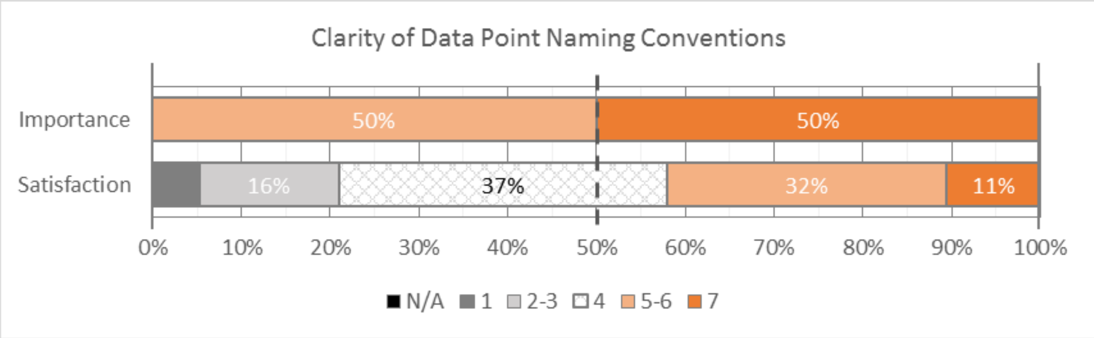


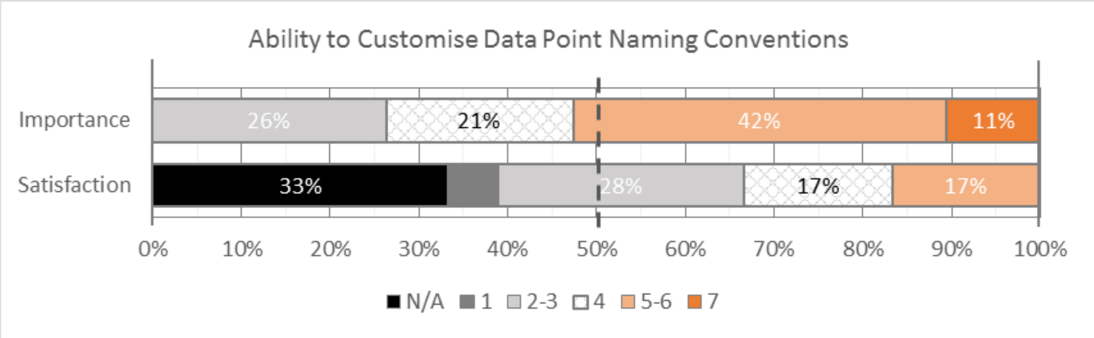


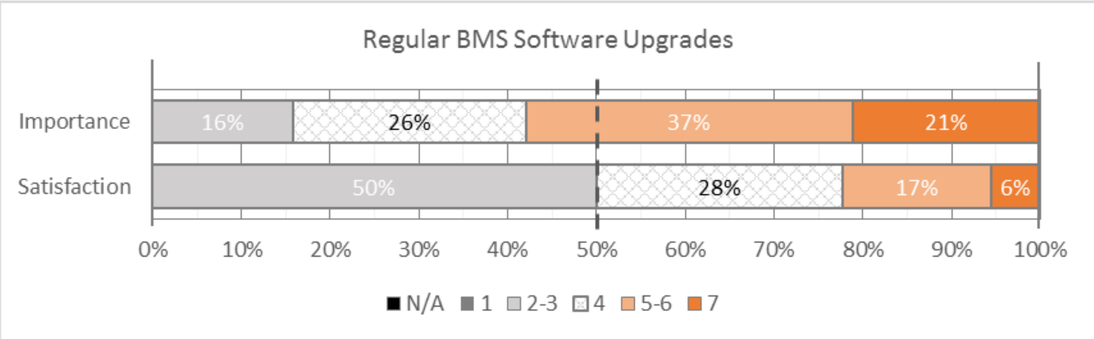


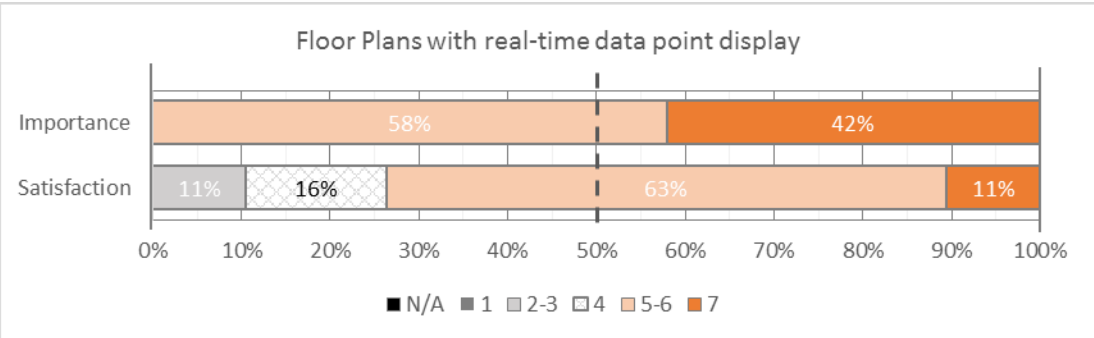
10.9.4 BMS USABILITY AND VISUALISATION FEATURES

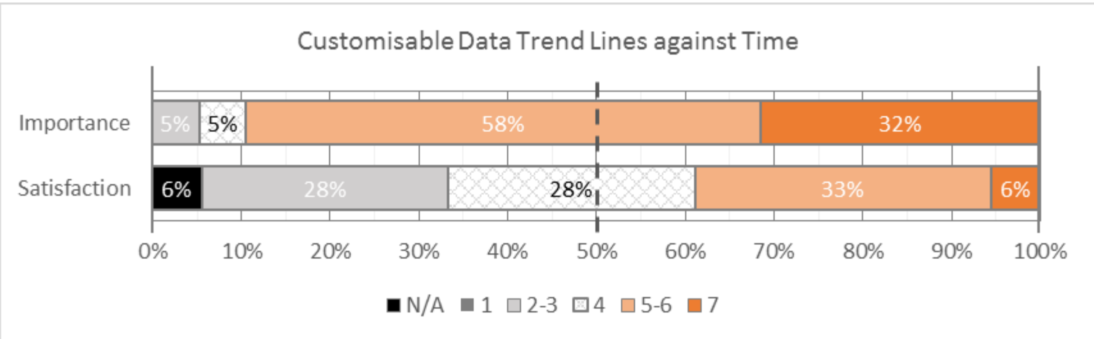


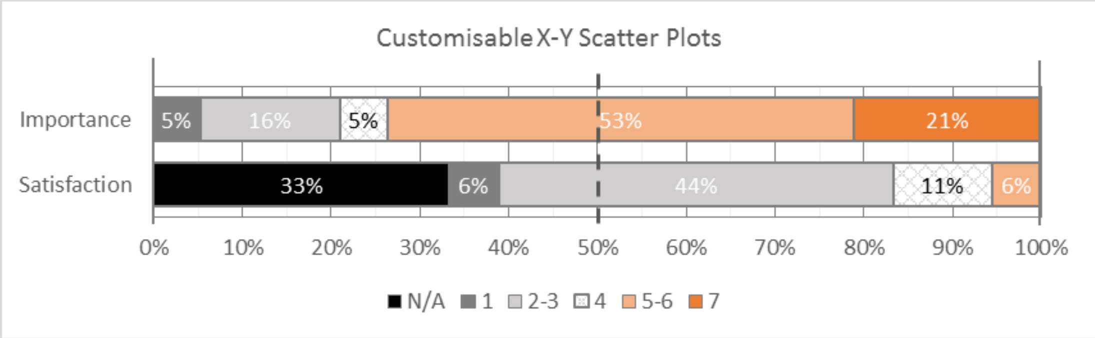

Clarity of Data Point Naming Conventions
Importance
Satisfaction
50%
50%
16%
37%
32%
11%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
N/A 1 2-3 4 5-6 7

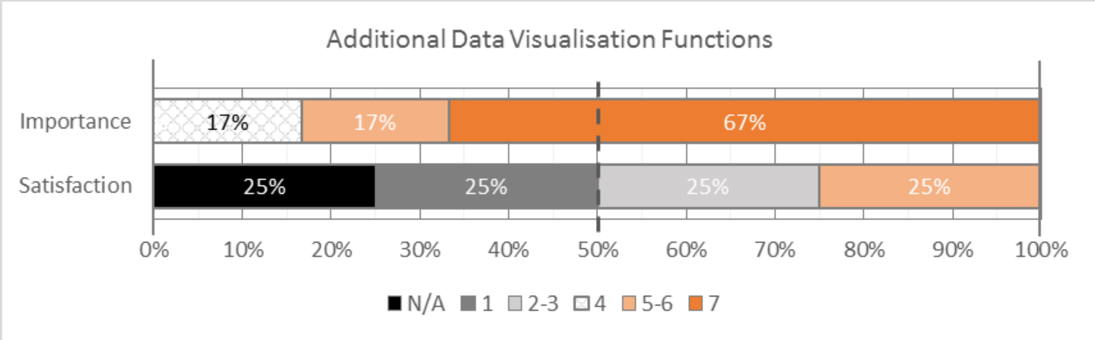

Ability to Customise Data Point Naming Conventions
Importance
Satisfaction
26%
21%
42%
11%
33%
28%
17%
17%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
N/A 1 2-3 4 5-6 7


Regular BMS Software Upgrades
Importance
Satisfaction
16%
26%
37%
21%
50%
28%
17%
6%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
N/A 1 2-3 4 5-6 7

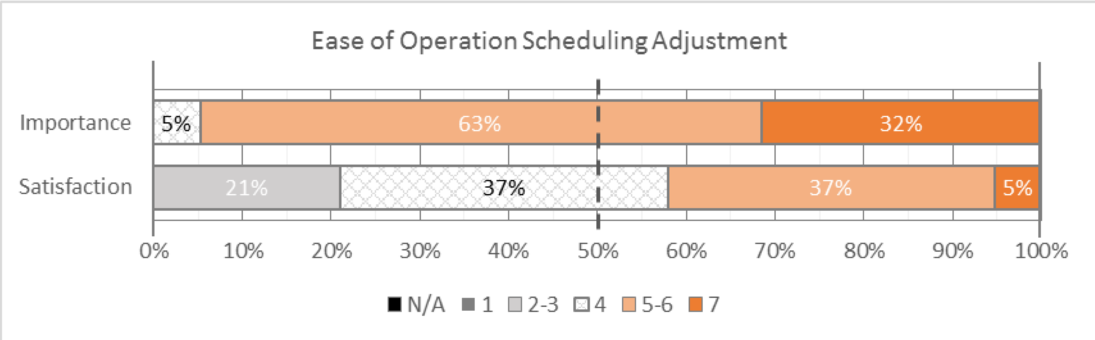

Floor Plans with real-time data point display
Importance
Satisfaction
58%
42%
11%
16%
63%
11%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
N/A 1 2-3 4 5-6 7

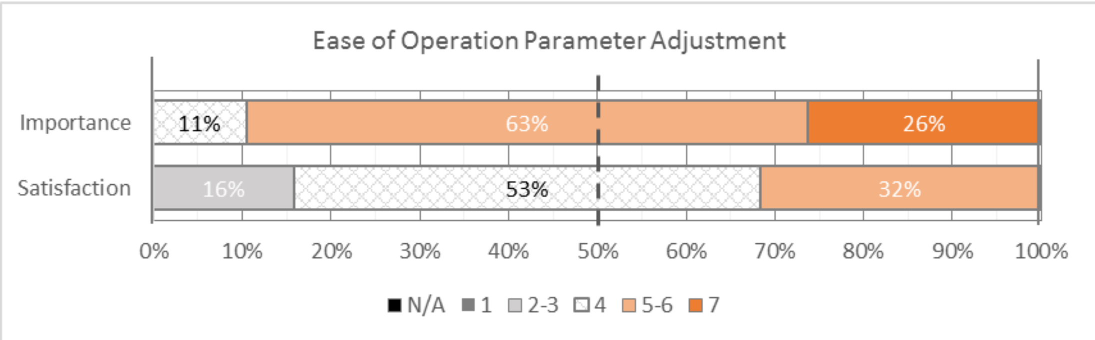

Customisable Data Trend Lines against Time
Importance
Satisfaction
5%
5%
58%
32%
6%
28%
28%
33%
6%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
N/A 1 2-3 4 5-6 7

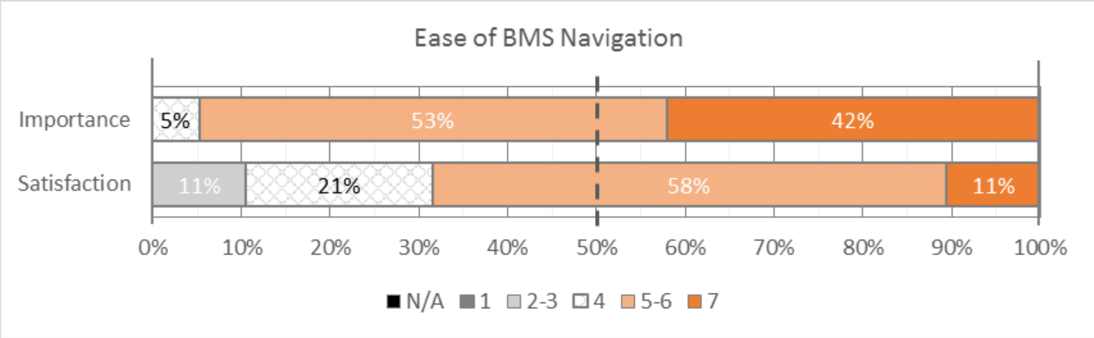


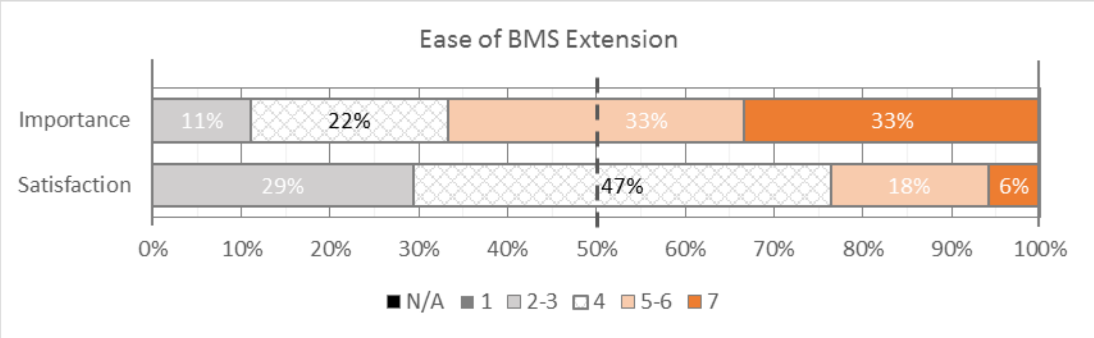


10.9.5 EASE OF BMS CONTROL ADJUSTMENTS





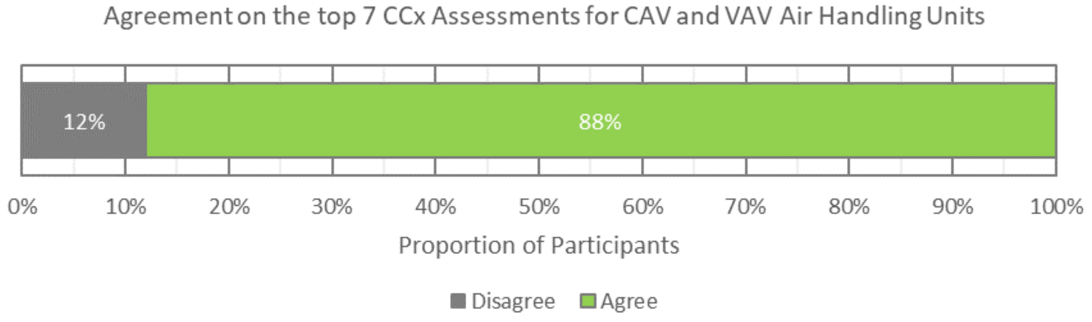

Ease of BMS Navigation
Importance
Satisfaction
5%
53%
42%
11%
21%
58%
11%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
N/A
1
2-3
4
5-6
7


Ease of BMS Extension
Importance
Satisfaction
11%
22%
33%
33%
29%
47%
18%
6%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
N/A
1
2-3
4
5-6
7

10.10 APPENDIX: CENTRAL AIR HANDLING UNITS (AHU)

10.10.1 APPENDIX: AHU TOP CCX ASSESSMENTS

Central AHU: Top 7 Constant Air Volume Assessments
1. AHU Afterhours Operation *(Scheduling)*
2. AHU Heating and Cooling Coils Fighting
3. Economiser
4. Demand Control Ventilation
5. AHU Discharge Air Temperature Reset
6. AHU optimum Start/Stop
7. Assessment of AHU Fan Speeds e.g. SAF vs RAF

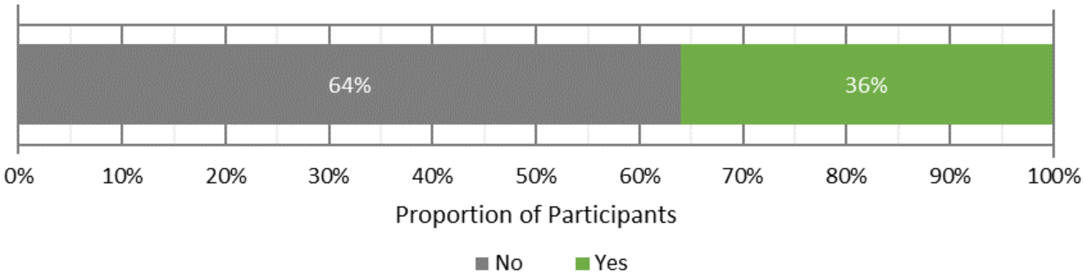


Kendall's Co-efficient of Concordance: CAV AHU Assessments	Interpretation (Schmidt, 1997)
0.93	Unusually Strong Agreement

10.10.2 APPENDIX: ADDITIONAL CCX ASSESSMENTS FOR VAV AHU

Additional Variable Air Volume CCx Assessments
1. Duct Static Pressure Reset
2. Assessment of AHU damper positions
3. Night purge
4. Assessment of Air Velocity
5. AHU Heating and Cooling Coil Lockout

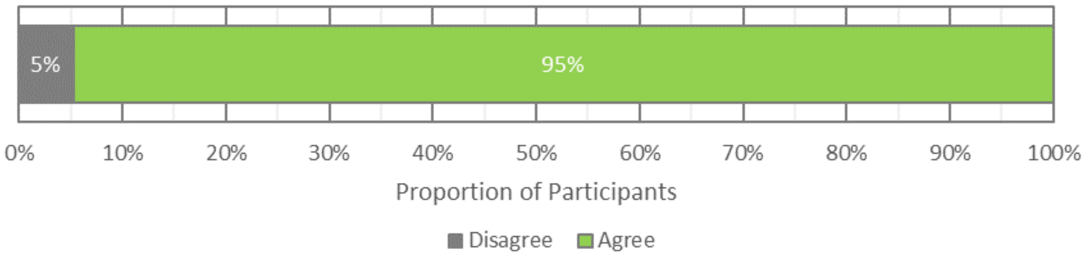
Do you consider any of the top 5 additional VAV assessments to be more important than the top CAV assessments?



10.10.3 APPENDIX: PROPOSED CONSENSUS OF MINIMUM DATA POINTS FOR AHU

Data Points for Trending	Unit	Data Points to be Trended for Constant Air Volume AHU	Data Points to be Trended for Variable Air Volume AHU
Outdoor Air Temperature	°C	**X**	**X**
Mixed Air Temperature	°C	**X**	**X**
Return Air Temperature	°C	**X**	**X**
Primary Supply Air Temperature	°C	**X**	**X**
Duct Static Pressure	Pa	**Not Required**	**X**
Return Air Damper Position	%	**X**	**X**
Outdoor Air Damper Position	%	**X**	**X**
Exhaust Air Damper Position	%	**X**	**X**
Supply Fan Status	On/Off	**X**	**X**
Supply Air Fan Speed	%	**X**	**X**
Return/Exhaust Fan Status	On/Off	**X**	**X**
Return/Exhaust Fan Speed	%	**X**	**X**
Ahu Cooling Valve Position	%	**X**	**X**
Ahu Heating Valve Position	%	**X**	**X**
Supply Airflow	l/s	**Not Required**	**X**
Return/Exhaust Airflow	l/s	**Not Required**	**X**
Return Air CO_2 Sensor	ppm	**X**	**X**
Supply Air CO_2 Sensor	ppm	**X**	**X**
Outdoor Air Filter Pressure Differential	Pa	**X**	**X**

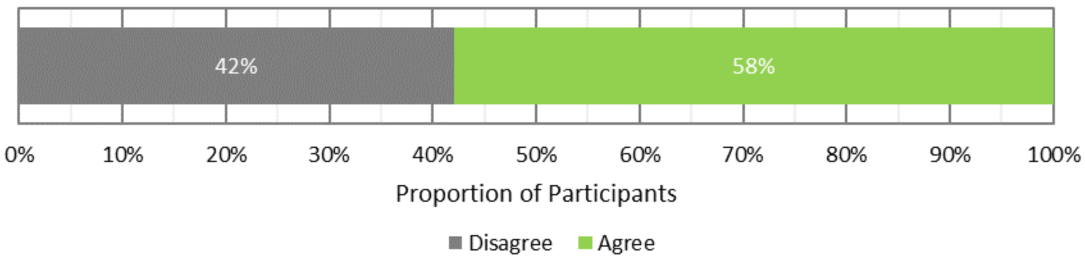
Agreement on Data Points Required for Trending to carry out top 7 CCx Assessments for CAV and VAV Air Handling Units



10.10.4 APPENDIX: ADDITIONAL DATA POINTS PROPOSED FOR AHU

Additional Proposed Data Points for Trending	Unit	Additional Data Points to be Trended for Constant Air Volume AHU	Additional Data Points to be Trended for Variable Air Volume AHU
Return Duct Static Pressure	Pa	X	X
Outdoor Air Relative Humidity	%	X	X
Return Air Relative Humidity	%	X	X
AHU Operating Load	kW	X	X

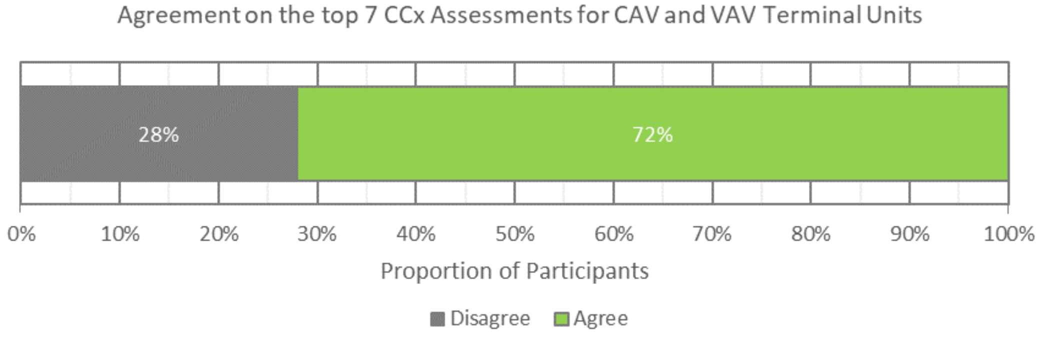
Agreement on Additional Data Points Required for Trending for CAV and VAV Air Handling Units



10.11 APPENDIX: ON-FLOOR TERMINAL AIR UNITS

10.11.1 APPENDIX: CAV TERMINAL UNITS TOP FIVE CCX ASSESSMENTS

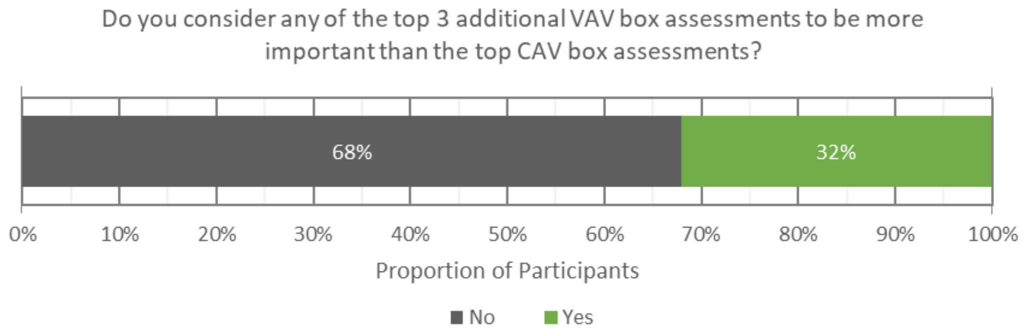
Terminal Air Units: Top 7 Constant Air Volume Assessments
1. Zonal Thermal Dead band and Setpoint Review
2. Terminal Unit Heating and Cooling Fighting
3. Zonal Supply Air Temperature Reset
4. Zonal Afterhours Operation *(Scheduling)*
5. Zonal Optimum Start/Stop
6. Zonal Demand Control Ventilation
7. Terminal Unit Heating and Cooling Coil Lockouts



Kendall's Co-efficient of Concordance	Interpretation (Schmidt, 1997)
0.90	Unusually Strong Agreement

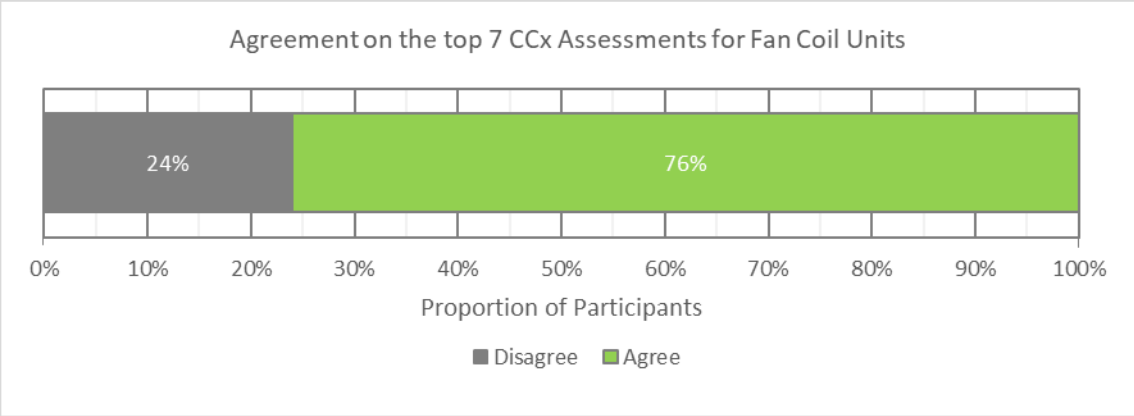
10.11.2 APPENDIX: ADDITIONAL CCX ASSESSMENTS FOR VAV TERMINAL UNITS

Terminal Air Units: Variable Air Volume Top 3 Additional Assessments
1. VAV: Assessment of terminal unit air velocity
2. VAV: Zonal Economiser function
3. VAV: Zonal Night Purge



10.11.3 APPENDIX: FAN COIL UNIT TOP FIVE CCX ASSESSMENTS

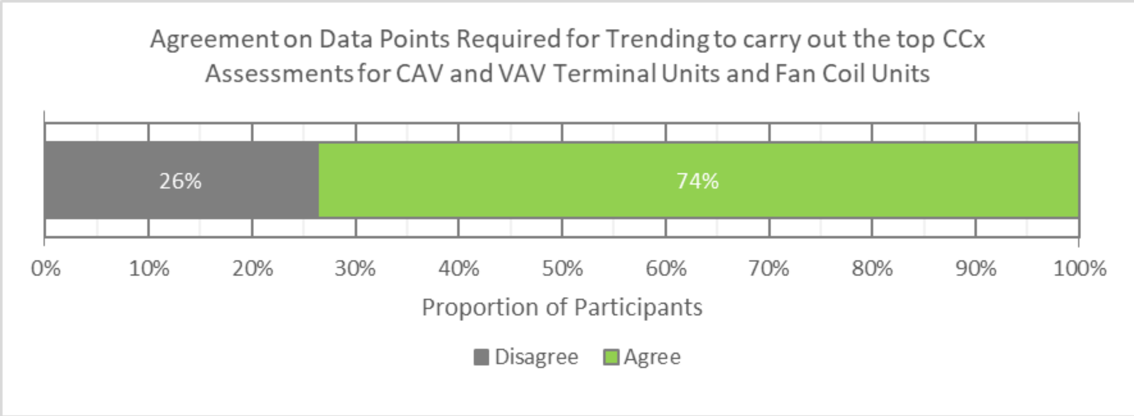
Terminal Air Units: Top 7 Fan Coil Units Assessments
1. Zonal Thermal Dead band and Setpoint Review
2. Terminal Unit Heating and Cooling Fighting
3. Zonal Supply Air Temperature Reset
4. FCU Proportional Control
5. Zonal Afterhours Operation *(Scheduling)*
6. Zonal Optimum Start/Stop
7. Zonal Demand Control Ventilation



Kendall's Co-efficient of Concordance	Interpretation (Schmidt, 1997)
0.84	Strong Agreement

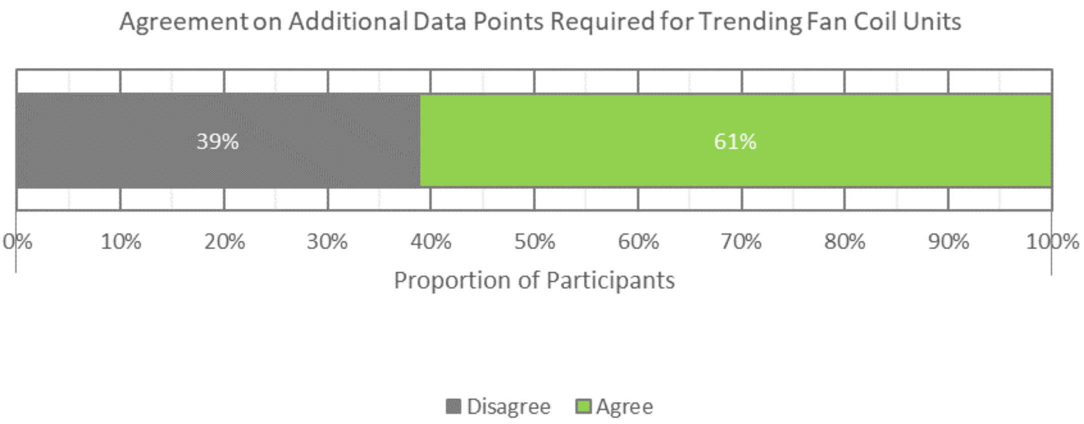
10.11.4 APPENDIX: PROPOSED CONSENSUS OF MINIMUM DATA POINTS FOR ON-FLOOR TERMINAL AIR UNITS

Data Points for Trending	Data Unit	CAV Boxes	VAV Boxes	VAV with Fan Assist	Fan Coil Units	EC Fan Coil Units
TU: Damper Position	%	N/A	X	X	N/A	N/A
TU: Heating Coil Valve Position	%	X	X	X	X	X
TU: Cooling Coil Valve Position	%	X	X	X	X	X
TU: Discharge Air Temperature	°C	X	X	X	X	X
TU: Discharge Airflow	l/s	N/A	X	X	X	X
TU: Fan Status	On/Off	N/A	N/A	X	X	X
TU: Fan Speed	%	N/A	N/A	X	X	X
Zone Temperature	°C	X	X	X	X	X
Zone CO2	ppm	X	X	X	X	X



10.11.5 APPENDIX: ADDITIONAL DATA POINTS PROPOSED FOR FAN COIL UNITS

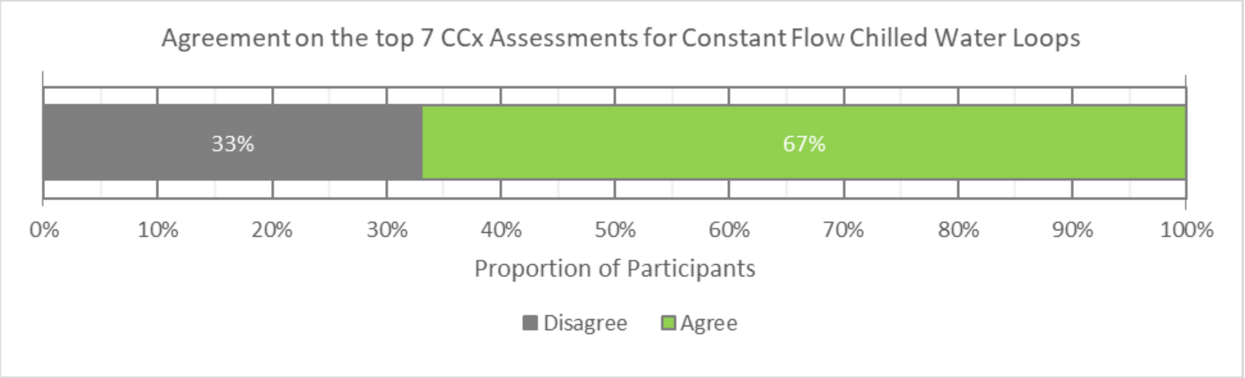
Additional Data Points for Trending	Data Unit	CAV Boxes	VAV Boxes	VAV with Fan Assist	Fan Coil Units	EC Fan Coil Units
FCU Filter Status	ΔPa	N/A	N/A	N/A	X	X



10.12 APPENDIX: CHILLED WATER LOOP (CHW)

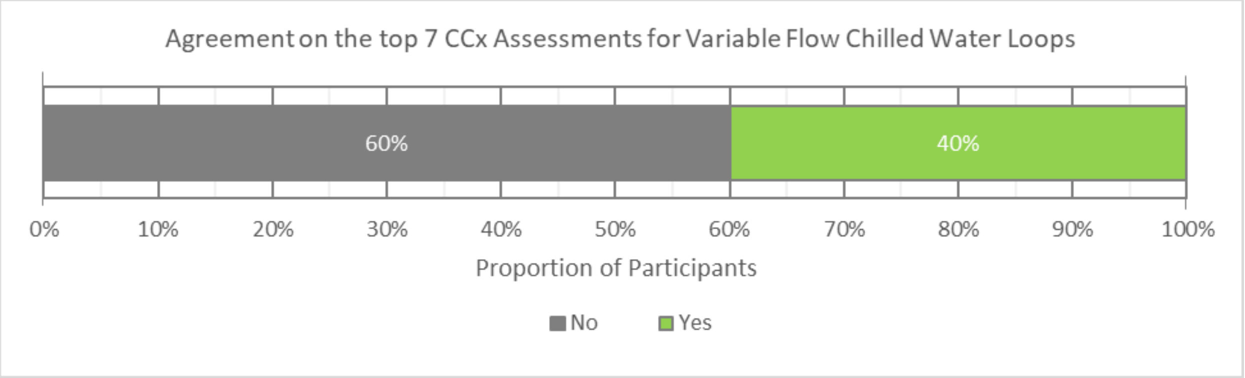
10.12.1 APPENDIX: CONSTANT FLOW CHW: TOP FIVE CCX ASSESSMENTS

Constant Flow Chilled Water Loop: Top 7
1. Chilled Water Flow Temperature Reset
2. Chiller Staging
3. Afterhours Operation of all System Components
4. Chiller Operation Lockout on Outdoor Air Temperature
5. Condensed Water Temperature Reset
6. Chiller Optimum Start/Stop
7. Staging of Chilled Water Pumps



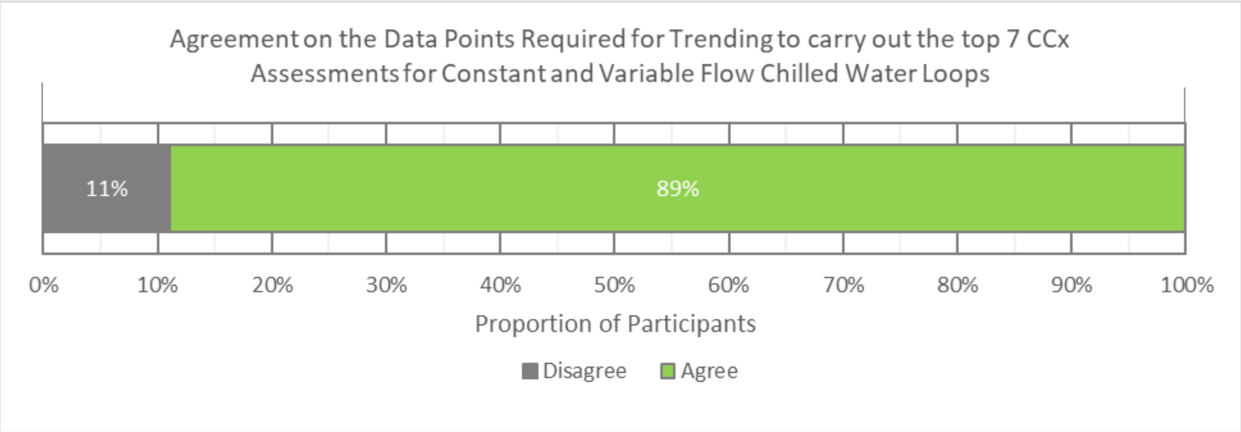
10.12.2 APPENDIX: ADDITIONAL CCX ASSESSMENTS FOR VARIABLE FLOW CHW

Variable Flow Chilled Water Loop: Additional Top 3 Assessments
1. Chilled Water Variable Flow under Partial Conditions
2. Chilled Water Loop Differential Pressure Reset
3. Waterside Economiser



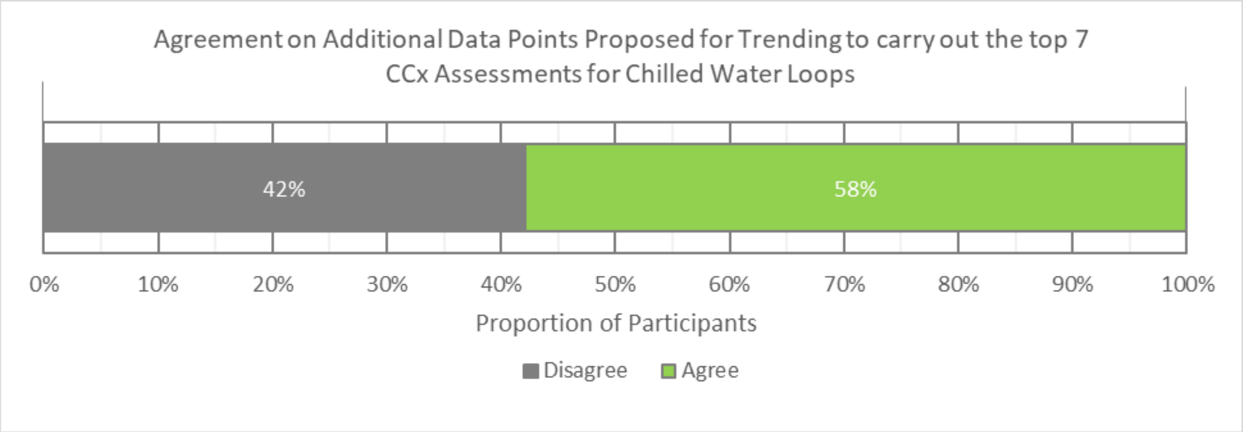
10.12.3 APPENDIX: PROPOSED CONSENSUS OF MINIMUM DATA POINTS FOR CHW

Data Points for Trending	Data Unit	Constant Flow CHW Loop	Variable Flow CHW Loop
Primary Chilled Water Supply Temperature	°C	X	X
Primary Chilled Water Return Temperature	°C	X	X
Condenser Supply Temperature	°C	X	X
Condenser Return Temperature	°C	X	X
Primary Pump Status	On/Off	X	X
VFD Primary Pump Speed	%	X	X
Secondary Pump Status	On/Off	X	X
VFD Secondary Pump Speed	%	X	X
Chiller Status	On/Off	X	X
Chilled Water Flow	l/s	X	X
Chilled Water Differential Pressure	ΔPa	N/A	X
Cooling Tower Fan Status	On/Off	X	X
Cooling Tower Fan Speed	%	X	X
Cooling Tower Inlet Temperature	°C	X	X
Cooling Tower Outlet Temperature	°C	X	X



10.12.4 APPENDIX: ADDITIONAL DATA POINTS PROPOSED FOR CHW

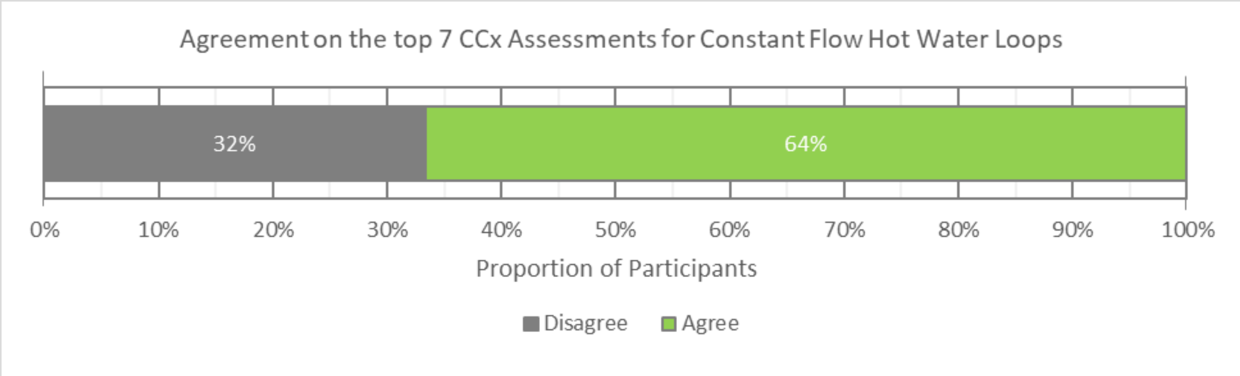
Additional Data Points for Trending	Data Unit	Constant Flow CHW Loop	Variable Flow CHW Loop
Secondary Chilled Water Supply Temperature	°C	X	X
Secondary Chilled Water Return Temperature	°C	X	X
Compressor Speed	%	X	X
Compressor Status	On/Off	X	X
Condenser Water Pump Speed	%	X	X
Condenser Water Pump Status	On/Off	X	X
Compressor Load Output	kW	X	X
Chilled Water Flow Switch Status	Flow/No Flow	X	X



10.13 APPENDIX: HOT WATER LOOP (HHW)

10.13.1 APPENDIX: CONSTANT FLOW HHW: TOP FIVE CCX ASSESSMENTS

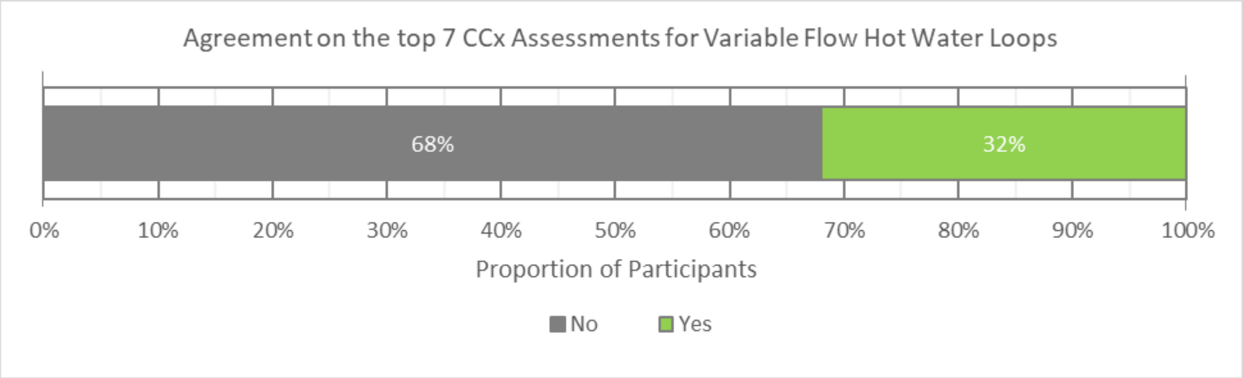
Constant Flow Hot Water Loop: Top 7 Assessments
1. Hot Water Flow Temperature Reset
2. Boiler or Heat Pump Operation Lockout on Outdoor Air Temperature
3. Boiler or Heat Pump Staging
4. Afterhours Operation of all System Components
5. Boiler or Heat Pump Optimum Start/Stop
6. Domestic Hot Water Temperature Reset
7. Hot Water Loop Differential Pressure Reset



Kendall's Co-efficient of Concordance	Interpretation (Schmidt, 1997)
0.84	Strong Agreement

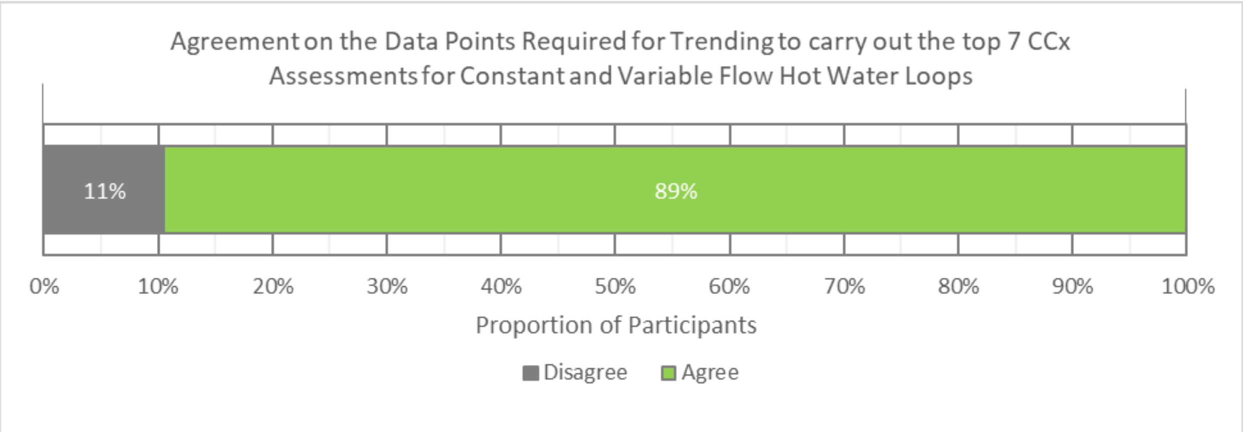
10.13.2 APPENDIX: ADDITIONAL CCX ASSESSMENTS FOR VARIABLE FLOW HHW

Variable Flow Hot Water Loop: Additional Top 3 Assessments
1. Hot Water Variable Flow under Partial Conditions
2. Staging of Hot Water Pumps
3. Boiler or Heat Pump and Pump Interlock



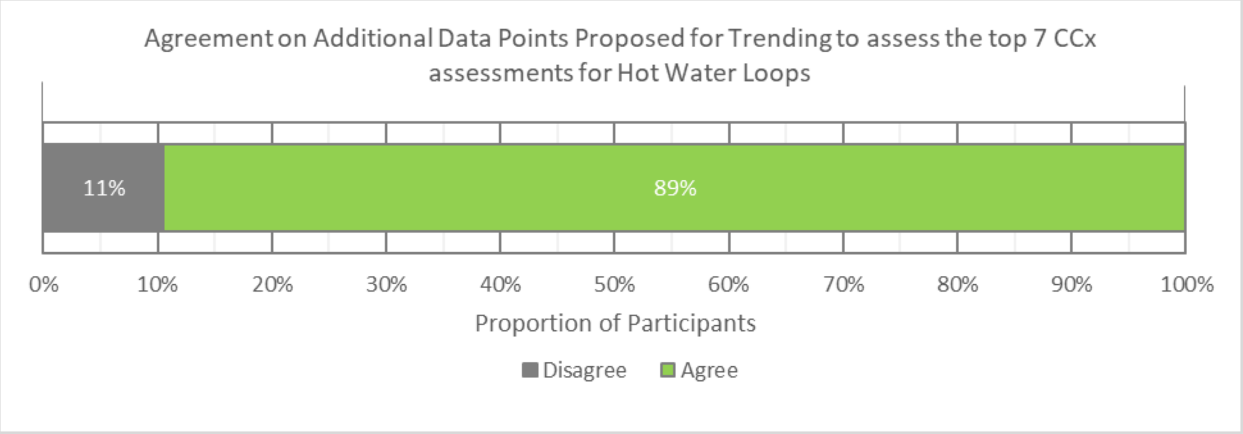
10.13.3 APPENDIX: PROPOSED CONSENSUS OF MINIMUM DATA POINTS FOR HHW

Data Points for Trending	Data Unit	Constant Flow HHW	Variable Flow HHW
Primary Hot Water Supply Temperature	°C	X	X
Primary Hot Water Return Temperature	°C	X	X
Hot Water Flow Rate	l/s	N/A	X
Primary Pump Status	On/Off	X	X
VFD Primary Pump Speed	%	N/A	X
Secondary Pump Status	On/Off	X	X
VFD Secondary Pump Speed	%	N/A	X
Boiler/Heat Pump Status	On/Off	X	X
Boiler/Heat Pump Outlet Temperature	°C	X	X



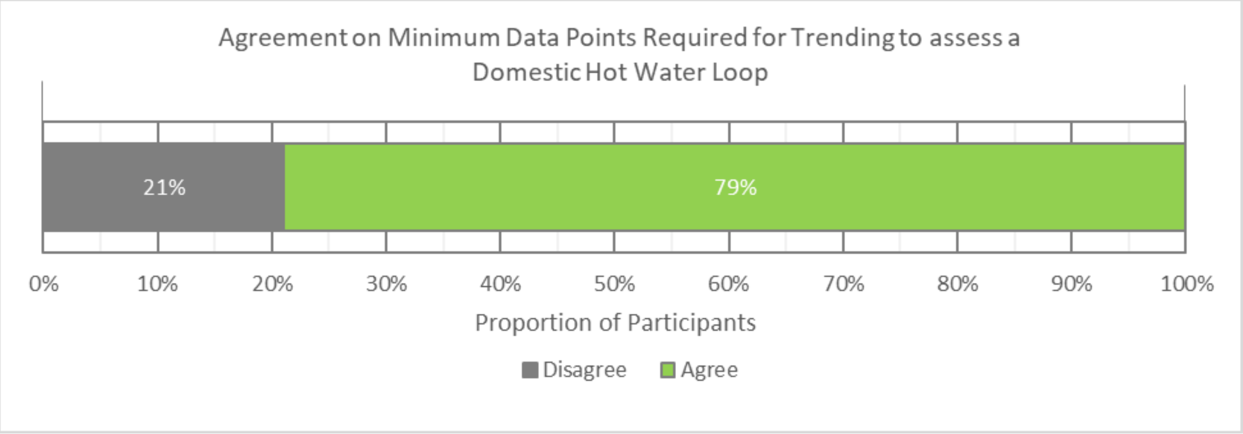
10.13.4 APPENDIX: ADDITIONAL DATA POINTS PROPOSED FOR HHW

Data Points for Trending	Data Unit	Constant Flow HHW	Variable Flow HHW
Secondary Hot Water Supply Temperature	°C	X	X
Secondary Hot Water Return Temperature	°C	X	X
Calorifier Valve Position	%	X	X
Boiler/Heat Pump Load Output	kW	X	X



10.13.5 APPENDIX: PROPOSED CONSENSUS OF MINIMUM DATA POINTS FOR DOMESTIC HOT WATER (DHW)

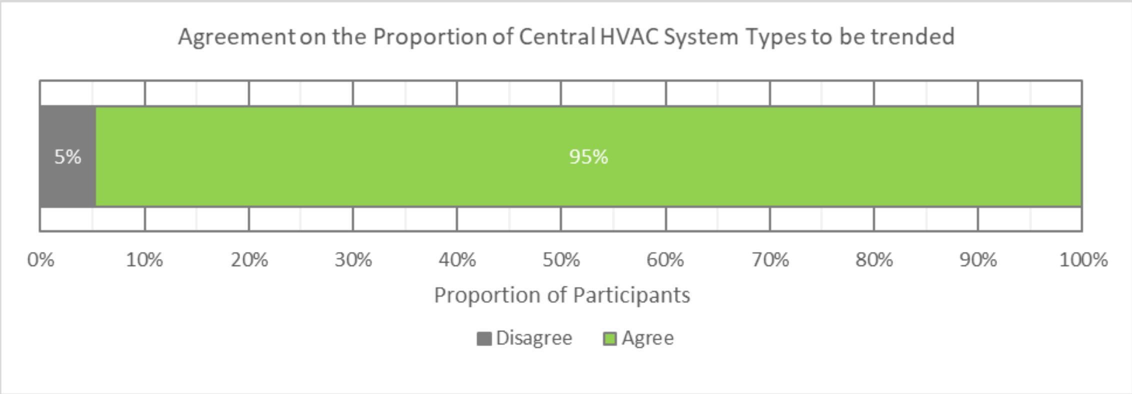
Data Points for Trending	Data Unit	DHW Loop
Domestic Hot Water Pump Status	On/Off	X
Domestic Hot Water Flow Temperature	°C	X
Domestic Hot Water Return Temperature	°C	X
Domestic Hot Water Flow Rate	l/s	N/A



10.14 APPENDIX: HVAC DATA TRENDING REQUIREMENTS

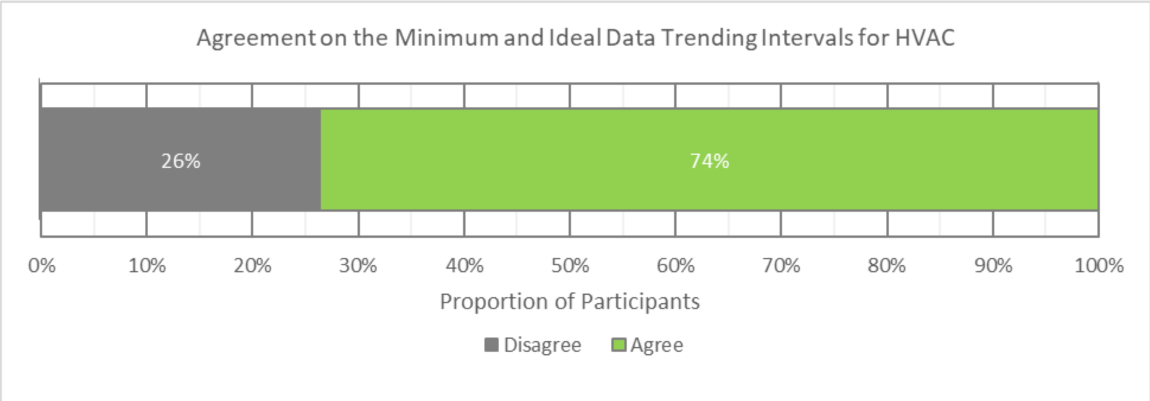
10.14.1 APPENDIX: MINIMUM PROPORTION OF CENTRAL HVAC SYSTEMS TO BE TRENDED

HVAC Type	Proportion of Components to be Trended
▪ Air Handling Units	All Components
▪ Chillers	All Components
▪ Boilers/Heat Pumps	All Components



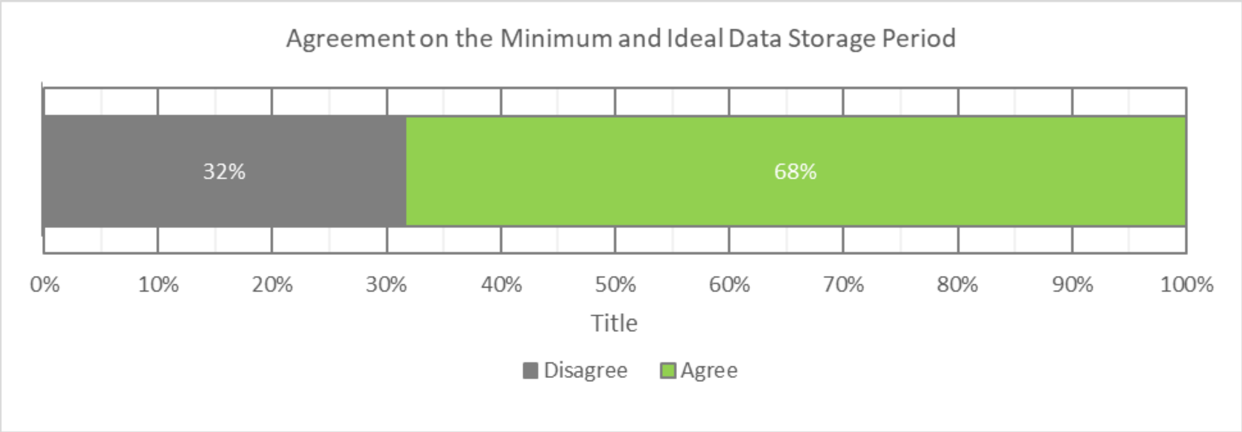
10.14.2 APPENDIX: MINIMUM AND IDEAL DATA TRENDING INTERVALS FOR ALL HVAC

Minimum Trending Interval	Ideal Trending Interval
15 Minutes (or less)	5 Minutes or less



10.14.3 APPENDIX: MINIMUM AND IDEAL DATA STORAGE INTERVALS FOR ALL HVAC

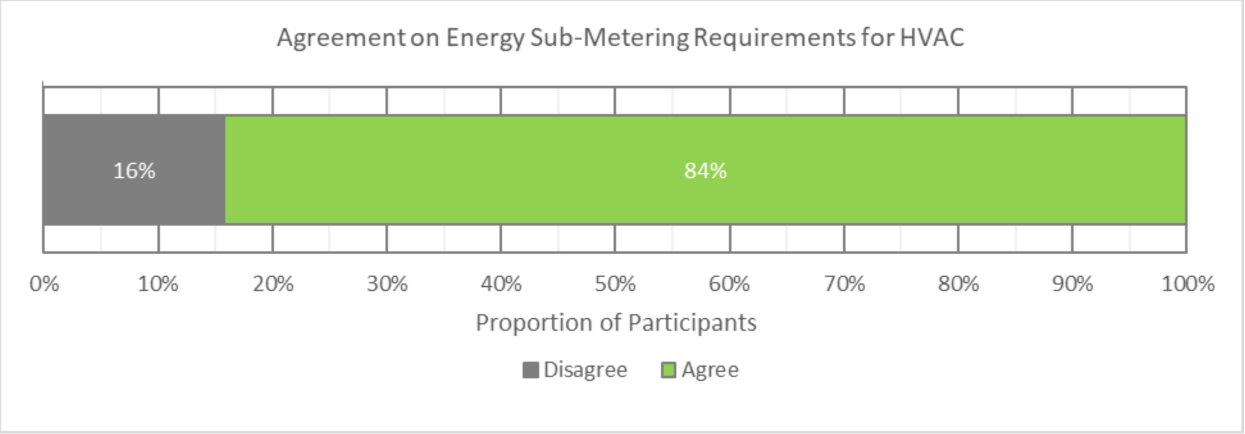
Minimum Data Storage	Ideal Data Storage
At least 3 months	More than 2 years



10.15 APPENDIX: ENERGY SUB-METERING REQUIREMENTS

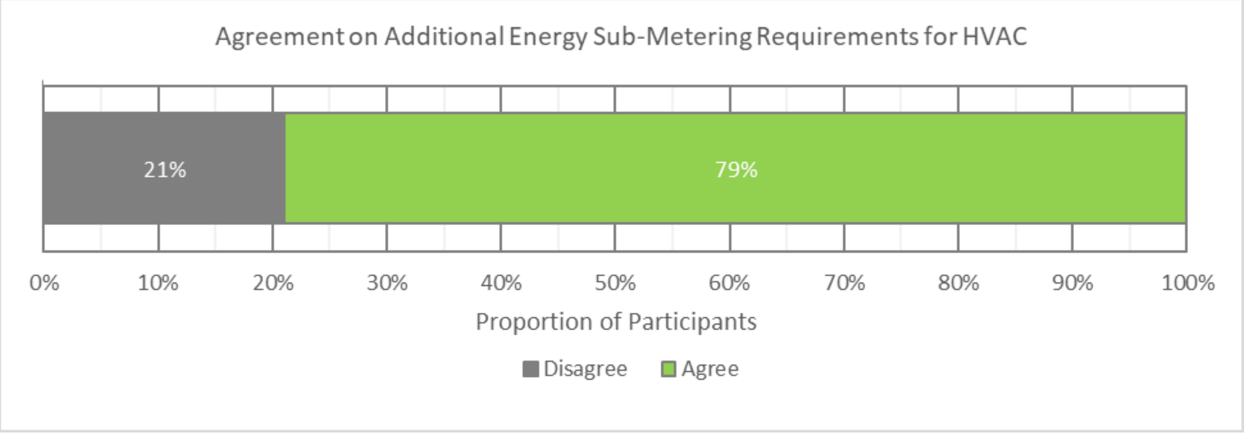
10.15.1 APPENDIX: HVAC ENERGY SUB-METERING REQUIREMENTS

HVAC Equipment Type	Energy Sub-Meter	Energy Sub-Meter Data Trending Interval
▪ Air Handling Units	Required	15 Minutes or Less
▪ Individual CAV and VAV Terminal Units	Not Required	N/A
▪ Individual Fan Coil Units	Not Required	N/A
▪ Chillers	Required	15 Minutes or Less
▪ Cooling Towers	Required	15 Minutes or Less
▪ Boilers/Heat Pumps	Required	15 Minutes or Less



10.15.2 APPENDIX: ADDITIONAL ENERGY SUB-METERING REQUIREMENTS

HVAC Equipment Type	Additional Energy Sub-Meter	Proposed Energy Sub-Meter Interval
▪ Large Pumps (>3kW)	Required	15 Minutes or less
▪ Total On-floor HVAC	Required	
▪ Total Central HVAC Plant	Required	



10.16 APPENDIX: PARTICIPANT INFORMATION SHEET

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

Enabling Continuous Commissioning through Building Management Systems

INFORMATION SHEET FOR PARTICIPANTS

Thank you for your interest in this project. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to take part, thank you for considering my request.

Researcher: Cara Askew, Master of Building Science Student, Victoria University of Wellington
Supervisor: Dr Michael Donn, School of Architecture, Victoria University of Wellington

Aim of the Study:

This project aims to establish a comprehensive guideline outlining the key data outputs and functions required of a BMS to carry out typical continuous commissioning (CCx) assessments. This research has been approved by the Victoria University of Wellington Human Ethics Committee (Application Number 0000025075).

Your Participation:

The structure of this survey is based on the Delphi method of collection, consisting of multiple rounds to form a consensus on what "could be" or "should be" implemented within industry. This research will consist of four rounds. Each round of questions will inform the following round, with an element of feedback provided through the compilation of the previous round's responses. This enables participants to agree, disagree or provide alternative insight to the questions asked and the proposed consensus.

Approximately one week will be allowed for following the completion of each round to compile responses to inform the following round's questions. The survey can be completed anywhere at any time by the participant and is anticipated to take no more than 15 minutes to complete each round. I will ask you questions about continuous commissioning assessments and Building Management System data outputs and functional requirements.

The aim of each round are described below:

Round 1: Identifying common continuous commissioning assessments applied to improve the energy efficiency of New Zealand-typical Heating Ventilation and Air Conditioning (HVAC).

Round 2: Forming a consensus from round 1 and identifying the data points required for each continuous commissioning assessment.

Round 3: Forming a consensus from round 2. Defining the level of frequency required of each data point and identifying the importance and satisfaction of BMS capabilities in relation to continuous commissioning.

Use of Survey Responses:

This research is confidential. This means that the researchers named below will be aware of your identity but the research data will be combined and your identity will not be revealed in any reports, presentations, or public documentation. Only my supervisor and I, will read the survey responses. Records of your surveys will be stored securely and will be destroyed when the thesis is completed.

Dissemination of the Research:

The data and information produced from survey responses will be used for my Master of Building Science Thesis. At completion of the research project, the thesis will be submitted to Victoria University of Wellington library. Outcomes of this research may also be presented in the form of seminar presentations and publications, but the identities of participants will remain hidden.

Your Rights as a Research Participant:

Participants are allowed to stop and withdraw from the experiment at any time without giving a reason. Participants are allowed to withdraw at any time up to until all the data from that participant has been collected (after each survey round is completed). If a participant withdraws, all the data and information provided from the participant will be destroyed. If you do decide to participate, you have the right to be able to read any reports of this research by emailing the researcher to request a copy.

Further Information:

If you have any questions, either now or in the future, or would like to receive further information about the project, please feel free to contact me or my supervisor:

Research Student:	**Research Supervisor:**
Name: Cara Askew **Email:** mailto:askewcara@myvuw.ac.nz	**Name**: Dr Michael Donn **Role**: A. Prof Building Environments **School**: School of Architecture and Design **Phone**: 04 4636221 **Email**: mailto:Michael.Donn@vuw.ac.nz

VUW Human Ethics Committee

Victoria University of Wellington requires that ethics approval to be obtained for research involving human participants. This study has been approved by the University Human Ethics Committee, and the Human Ethics Policy can be read at http://www.victoria.ac.nz/documents/policy/research-policy/human-ethics-policy.pdf. If you have any concerns about the ethical conduct of the research you may contact the Victoria University HEC Convenor: Associate Professor Susan Corbett. Email susan.corbett@vuw.ac.nz or telephone +64-4-463 5480.