Occupant comfort and engagement in green buildings: Examining the effects of knowledge, feedback and workplace culture

by

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ABSTRACT

Buildings are seen as a key potential contributor to the mitigation of climate change, spurring increased attention in recent years to their design, performance and evaluation. The successful delivery of green buildings requires balancing energy and resource efficiency while providing a comfortable, healthy and productive environment within economic means. Occupant comfort and behaviour can have a significant impact on green building performance, and yet very little is known about how their comfort is shaped and behavioral patterns formed, particularly in the commercial setting. Through the post-occupancy evaluation of six Canadian office buildings, three green and three conventionally designed, this thesis examines the behavioural, socio-psychological and contextual factors that influence comfort and user engagement in green buildings. In Chapter 2, occupants' knowledge of how the building performs and comfort is provided is compared to an expert baseline, and a gap identified between their expressed desire to learn and the information available to them. Comfort is viewed both as a trigger of changes to user behaviour (discomfort leads to action) and an outcome from changes to user behaviour (action leads to improved or diminished comfort). In Chapter 3, the incorporation of feedback into building design, implementation and use is compared for two green buildings, and found to influence occupants' self-rated knowledge of the building, perceptions of building performance, and use of controls and complaints. Lack of effective feedback in one of the buildings leads occupants to view themselves as passive (rather than active) participants in establishing comfort conditions. In Chapter 4, a company's move from a conventional to a green building is examined through the lens of cultural and contextual factors shaping design and operation decisions. These factors are shown to potentially significantly influence occupant comfort and behavior in the new building, with gains in satisfaction and productivity difficult to disentangle from green building or workplace design factors. Combined, these results provide evidence that knowledge, expectations, feedback and culture all play an important role in shaping occupant comfort and comfort-related behaviour in green buildings, and shed light on the limitations of current post-occupancy evaluation method to capture the complexities of user experience.

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GLOSSARY

This thesis draws insights from across multiple disciplines. In an effort to clarify terminology, a short glossary is provided below:

Comfort - A physical condition, a feeling of contentment or a sense of well-being (Chappells and Shove, 2004). In buildings, comfort may be experienced in the physiological sense (thermal comfort, visual comfort, air quality, acoustics) as well as in psychological, behavioural and social / collective senses.

Feedback – Learning from what you are doing, or from what you and others have done, to understand where you are, and to inform and improve what you are about to do (Bordass *et al.*, 2006). In buildings, feedback can be considered information flow through a number of processes and scales over the lifetime of a building.

Green building – A building designed to have superior environmental performance compared to its conventional counterpart. By increasing the efficiency with which energy, resources and materials are used over the building's lifetime, green building strives to balance environmental responsibility, occupant comfort and well-being, community development and economics of building construction and operation (CaGBC, 2004).

Intelligent building - A building that provides a sustainable, responsive, effective and supportive environment within which individuals and organizations can achieve their objectives (*Intelligent Buildings International*). 'Intelligence' may refer to building form, automated technologies, integrated information and communications infrastructure, space management, organizational intelligence and occupant intelligence (Cole and Brown, 2009).

Inhabitant – An alternative term for occupant, representing a building user who participates actively, and with agency, in the maintenance of comfort conditions and the performance of the building (Cole *et al.,* 2008)

Post-occupancy evaluation (POE) – The systemic evaluation of building performance and/or opinion about buildings in use from the perspective of the people who operate and use them.

Occupant – A person who occupies a building, a building user.

Occupant knowledge – Occupants' awareness and understanding of building environmental features and control systems, gained through their immediate experience in the building, and tempered by a broad range of influences such as tacit knowledge, context and culture.

Organizational culture – The pattern of shared key values and beliefs that give members of an organization a sense of identity, a commitment to something larger than the self, a common set of rules to guide and shape their behaviour and enhanced social system stability (Smircich, 1983; Davis, 1984).

Workplace culture – The norms and values attached to the workplace and its use, relating to nature of work, manner of work (i.e. individual, team or service-based), mobility, flexibility, and formality.

Workplace design – The programming, design and arrangement of workspace with the aim to effectively allocate resources and support the achievement of business and organizational goals.

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For Gertrud Borkenhagen
(Omi)

CO-AUTHORSHIP STATEMENT

In all three of the following research papers my contributions include: a) identification of research questions, b) research design, c) performance of research activities, d) data analysis and e) manuscript preparation.

Paper I (Chapter 2): *Influence of occupants' knowledge on comfort expectations and behaviour*
In this chapter I conducted the literature review, conceived of the structure, justified the methodological approach, produced tables and figures, conducted data analysis and wrote the manuscript. Ray Cole provided early insights into the paper framing and key concepts ("performance gaps in green buildings"), and provided comments for revision on several drafts. John Robinson and three anonymous reviewers for *Building Research and Information* provided constructive comments on the scope of the work, related literature, and limitations of findings.

Paper II (Chapter 3): *Feedback and adaptive behaviour in green buildings*
In this chapter, I conducted the literature review, developed the paper outline, produced tables and figures, conducted data analysis and wrote the manuscript. Hadi Dowlatabadi helped with conceptual development, provided valuable insights into adata analysis and interpretation of findings, and provided comments for revisions. Ray Cole helped to refine the structure of the paper and provided comments for revisions.

Paper III (Chapter 4): *Evaluating user experience in green buildings in relation to workplace culture and context*
In this chapter, I conducted the literature review, conceived of the structure, produced figures, and wrote the manuscript. Ray Cole and John Robinson contributed to early conceptual development, helped to refine the structure of the paper and clarify findings, and provided comments for revisions. Hadi Dowlatabadi contributed to the interpretation of results and provided comments for revisions.

1. INTRODUCTION

1.1. PROBLEM STATEMENT

Building performance and its evaluation have earned increased attention in recent years, particularly with respect to green buildings. The building sector has been identified as a key potential contributor to the mitigation of climate change (Metz *et al.,* 2007; Urge-Vorsatz *et al.*, 2007), and governments around the world are mandating improved transparency and accountability in building performance evaluation to ensure that buildings produce significantly less greenhouse gas emissions. Initiatives such as the European Energy Performance Building Directive[1] (Wouters and van Dijk, 2007) and the State of California's Assembly Bill 1103[2] (Secretary of State of California, 2007), are helping to both calibrate industry expectations by moving towards more consistent results and confidence in projections, as well as share real operating results to help improve the management of existing buildings and close the feedback loop (Bordass *et al.,* 2004).

Much of the emphasis to date in meeting building performance objectives has been on optimizing energy and resource efficiency, as reflected in mainstream green building rating systems such as LEED® (Leadership in Energy and Environmental Design). As Bordass (2009) writes, "saving energy and carbon has been seen as mostly a technical challenge (e.g. doing things more efficiently) or an economic one of payback periods, [and] internal rates of return". However, green buildings need to do more than effectively use natural resources within economic means. They must also support the health and wellbeing of their occupants so that the 'human resource' can contribute to (rather than impede) the building's sustainability (Weiss *et al.,* 2004).

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[1] The European Energy Performance Building Directive requires that member states develop and implement a list of measures around the calculation of the energy performance of buildings, the minimum requirements for energy performance of buildings and the energy performance certification of building. As part of the U.K.'s implementation of the EPBD, all commercial building owners are required to produce Energy Performance Certificates on the sale, let or construction of property buildings, and large public sector buildings are required to produce Display Energy Certificates showing the building's actual energy used over a year compared to benchmark.

[2] The State of California's Assembly Bill No. 1103 requires electric or gas utilities to maintain energy consumption data for non-residential buildings for uploading to the United States Environmental Protection Agency's (EPA's) Energy Star Portfolio Manager program. Effective January 2010, all non-residential building owners must disclose to prospective buyers and lenders the EPA's Energy Star Portfolio Manager data and scores for a building that is being sold, leased, financed or refinanced.

Evidence from recent post-occupancy evaluations suggests that, although green buildings have the potential to enhance indoor environmental quality, they often fall short. While some of the best green buildings can rank higher than the best conventional buildings in terms of user experience (comfort, health and productivity), a few of the lowest scoring buildings on user experience are also reported as being green (Abbaszadeh *et al.*, 2006; Leaman and Bordass, 2007). This has important implications since occupant comfort and comfort-related behaviour can impact a building's energy and environmental performance, particularly in green buildings which are thought to be "more fragile in their performance, so it is more important that everything works well together" (Leaman and Bordass, 2007).

A fine balance exists between optimizing energy and resource efficiency in green buildings and providing a comfortable, healthy and productive indoor environment. Green buildings often rely on natural conditioning to meet the comfort needs of end-users, employing a combination of passive strategies to provide indoor conditions that are more closely linked to daily and seasonal variations outside. Environmental control systems may either be designed to accommodate active user engagement, or to intelligently respond and adapt to changing external conditions and needs with minimal user engagement. Both approaches rely on effective feedback to inform users of design intention and the environmental consequences of their actions. Feedback is particularly important where environmental systems and control are new to designers, operators and users, and matching technological and management capability is crucial (Cohen *et al.,* 1999).

In practice, very little is known about user perception and behavioural responses to feedback in green buildings. Those who view occupants as active participants in facilitating comfort assume they understand building systems and controls with which they are expected to engage and will make appropriate and intelligent choices when opening and closing windows, blinds, switches and other manual controls. Those who view occupants as passive recipients of indoor comfort conditions assume they will trust building automated systems to deliver the expected and desired outcomes. Rarely do post-occupancy evaluations take into consideration occupants' knowledge of the building they inhabit or their expectations of how the building should or ought to perform. The provision of feedback, to occupants, operators and designers, is seldom recognized as a key element to the successful use, implementation and design of buildings. Finally, there is little understanding of the cultural context within which buildings and users exist, where shared values and norms can influence design and operation decisions and how users experience and engage with a building.

1.2. RESEARCH PURPOSE AND CONTRIBUTION

The purpose of this research is to provide an in depth examination of the behavioural, socio-psychological and contextual factors influencing comfort and user engagement in green buildings. Three underlying questions shaped the research design and focus of the manuscripts: (1) How well do occupants understand the buildings they inhabit, and what role does this knowledge play in shaping their comfort expectations and behaviour? (2) How do occupants learn to behave in buildings and which forms of feedback are the most appropriate and effective at communicating the consequences of their actions? (3) How do the contextual factors of organizational culture and workplace design interact with green building design in shaping occupants' experience? These questions are approached through the post-occupancy evaluation of six Canadian office buildings each representing varying degrees of 'greenness' and feedback on the one hand, and distinct workplace cultures on the other.

Since much of the existing work on the drivers of building energy use have been directed towards the residential sector, this thesis contributes new research in that it focuses on occupant comfort and behaviour in commercial buildings. Feedback tools effective at influencing behaviour change in the residential setting may not generate the same effect in the commercial setting, where users respond to different incentives, and often share the space they control with a greater number of people. The research expands the current post-occupancy evaluation discourse by introducing the potential roles of occupant knowledge, expectation, behaviour, feedback, and broader contextual factors into the discussion of user experience. The questions asked are pertinent since the incorporation of new means of understanding and evaluating human factors could ultimately improve the relevance and accuracy of post-occupancy evaluation method. The findings have implications not only for improving occupant comfort and satisfaction in green buildings, but also for optimizing their energy and environmental performance.

1.3. OCCUPANT COMFORT AND BEHAVIOUR IN GREEN BUIDLINGS: SELECT CONCEPTS

Understanding the building as a complex system requires an integration of insights and approaches from technical/engineering and social science domains in order to appreciate the interactions and interdependencies of both physical and human elements. Thus, this research draws from a range of related literatures, including: building design and engineering, sociology of comfort and energy use, environmental and social psychology, building performance evaluation (including post-occupancy evaluation), intelligent buildings, organizational theory, and workplace design. Key concepts drawn from the literatures relating to occupant comfort and behaviour in green buildings collectively serve to inform the chapters that follow, and are briefly introduced below.

1.3.1. 'Conventional' and 'emerging' approaches to comfort

The provision of comfort in buildings and the experience of comfort by occupants in buildings are both well understood to be context dependent (Cooper 1998, Crowley 2001, Ackerman 2002). Comfort provision is shaped by design requirements, priorities and assumptions about building occupants' activities, age, clothing etc., and the types and costs of available environmental control technologies. Experienced comfort is shaped by the intersection of physiology – as a result of the body's exchange and interaction with the environment, with socio-psychological, behavioural, cultural and contextual factors (Cole *et al.,* 2008).

Conventional approaches to comfort provision have tended to assume that: a) occupants are passive recipients of indoor conditions provided through centralized, automated means; b) comfort is experienced primarily in the physiological sense; c) indoor comfort conditions should be held within relatively tight margins; and d) there is a universally applicable set of optimum comfort conditions which, when embodied in standards, shape and define design criteria for occupancy (Cole *et al.*, 2008).

A new context for understanding comfort provision and experience is being driven by the widespread uptake of green building design with more progressive expectations for building performance, and experience from post-occupancy evaluation studies revealing that occupancy patterns, use of controls, and building operation and management may influence building performance more than previously assumed. Moreover, the argument that searching for and maintaining a universally applicable set of comfort conditions in buildings may commit society to an unsustainable path of energy use has led to increased efforts by social and environmental scientists to re-examine standards and expectations of comfort, particularly in the context of climate change (Chappells and Shove, 2004).

Emerging approaches to comfort consider that: a) occupants will take a more active role in shaping indoor conditions through improved means for personal control (*e.g.* Leaman and Bordass, 1995; Bauman, 1999; Brager *et al.,* 2004); b) comfort is experienced in the psychological, behavioural and social (or collective) sense, not only physiological (*e.g.* Baker and Standeven, 1997; de Dear and Brager, 2001; Cole *et al.*, 2008); and c) indoor comfort conditions should be variable and diverse rather than uniform and static. Ultimately, the future of comfort remains "fluid, contested and controversial" and "the range of possible responses is much wider than currently contemplated by energy and environmental policy-makers" (Chappells and Shove, 2005, p.33).

1.3.2. The debate between personal and automated control

Central to the emerging dialogue around comfort provision is a tension around where, within the building, control and intelligence should reside (Cole and Brown, 2009). In their *Post-Occupancy Review of Buildings and their Engineering* (PROBE) studies, Cohen *et al.* (1999) observe that "notwithstanding all the implications of supposedly advanced automation, our experience is that the best intelligence in most buildings lies in the occupants themselves" (p.2). Placing responsibility for comfort conditioning in the hands of building occupants implies that they will make appropriate and intelligent choices when interacting with building systems (*e.g.* opening and closing windows, blinds, switches and other accessible manual controls).

In practice, occupants tend to be "satisficers" not "optimizers", operating the most convenient rather than logically appropriate controls, using controls only when a crisis of discomfort is reached rather than continually optimizing conditions, overcompensating for relatively minor annoyances, and leaving systems in their switched on state rather than turning them off again later (Leaman and Bordass, 2001). In addition, the sheer complexity of high-tech building systems can be a major deterrent for efficient and effective building operation (Bordass and

Leaman, 1997). A key lesson is, therefore, that whether personal or automated control is pursued, building systems must be both readily accessible and comprehensible to users and accompanied by a willingness to use them (Cole and Brown, 2009).

1.3.3. Feedback and occupant engagement

Feedback, provided during the design, delivery, and operation of buildings, has been recognized as a key component to ensuring a building's ability to fulfill the functions of its intended use (Preiser and Vischer, 2005). Feedback in buildings may be considered as acting on a number of different timescales and through a variety of processes. At the building in-use scale, numerous studies show that feedback may been successfully used to influence occupants' household energy consumption, particularly when the feedback is frequent, consequence-driven, and can be addressed through a practical response (Lutzenhiser, 1993; Abrahamse *et al.*, 2005). Other studies show that the use of feedback is subject to influence from many non-economic factors that shape occupants' energy-related behaviour in the home, including: daily schedule, beliefs and preferences concerning health and comfort, folk theories about how technologies function (e.g. thermostats, air conditioners), and personal strategies for dealing with all machines (Kempton, 1986; Kempton *et al.,* 1992).

In commercial settings, such as the workplace, where demands, incentives, responsibilities and the means for users to interact with building systems differ from the residential setting, feedback mechanisms and their ability to change behaviour are less well understood. How much and what kind of information is valuable to occupants, and how this information should be delivered, are important questions to be addressed (Cole *et al.*, 2008). Feedback in green buildings is particularly important, not only to support the transition of users and operators to new indoor environments, technologies, and expectations around comfort, but also to motivate environmentally responsible behaviour. Green buildings may offer an opportunity to teach lessons about sustainability, linking individual actions to larger social and ecological issues, through demonstration (e.g. signs and exhibitions), direct experience and observation, and active involvement (Bonnett and Olgyay, 2009).

1.3.4. Green buildings, technology and culture

The shaping of comfort and consumption practices by socio-technical systems is represented by large and growing body of literature. Rybczynski (1987) describes the evolution of domestic comfort, reviewing the development of ideas such as privacy, domesticity, efficiency, ease, and commodity, and how – as a consequence – comfort came to be associated with different meanings. Ackerman (2002) explores Americans' relationship to air conditioning, revealing important shifts occurring over time in the places and ways in which cooling was used by different classes and genders. Shove (2003) investigates how daily rituals including the heating and cooling of homes have come to be seen as 'normal', influencing both cultural convention and habit. Extending the socio-technical model to green building design, Cole *et al.* (2008) propose that the "collective social and institutional renegotiation of 'normal practice' is a real possibility in the changing context of new design" (p.7).

The widespread adoption of green building practice requires consideration of social and cultural factors typically omitted from techno-economic models of technology transfer. As Shove and Guy (2000) argue, technological, social and political aspects of energy efficiency cannot be separated. In their work applying a socio-technical model to building energy efficiency, they contend that: (1) decisions about energy should not be isolated from their social and cultural context; (2) designers should explicitly acknowledge the network of actors involved in the production and use of more energy efficient buildings and associated technologies; and (3) energy efficiency knowledge does not only derive from the top-down, but also evolves from local contexts and users' everyday experiences. In accordance with this last point, the successful uptake of environmental strategies, systems and practice in green buildings will ultimately depend on the consideration given in design of user needs, habits, expectations and norms.

1.4. RESEARCH OBJECTIVES

The goal of this thesis is to assess, from an interdisciplinary perspective, the role of behavioural, socio-psychological, and contextual factors in shaping the comfort and engagement of occupants in green buildings. The specific objectives of the research, addressed in individual chapters, are as follows:

Chapter 2

- To examine, in a green and a conventionally-designed building, occupants knowledge levels about how their building performs and comfort is provided compared to an expert baseline.
- To assess whether certain building environmental systems and controls are more intuitively comprehensible and usable than others.
- To evaluate why occupants engage or choose not to engage with building controls available to them.
- To examine the role of expectations in shaping occupant comfort and behaviour.
- To assess the relationship between occupant knowledge, comfort and use of controls.

Chapter 3

- To examine, in two different green buildings, how occupants learn about how their building performs and comfort is provided.
- To examine the role of feedback in shaping occupants' perception of building greenness and energy efficiency.
- To assess the role of feedback in shaping occupant comfort, use of controls and complaints in two green buildings.
- To assess the relationship between occupant knowledge, comfort, use of controls and complaints, and perception of building performance.

Chapter 4

- To examine, in the move from a conventionally designed to green building, the relationship between organizational culture, workplace design and green building design in shaping design and operation decisions.
- To assess the relative influence of culture, workplace design and green aspects on user experience in buildings.

1.5. RESEARCH STRATEGY

1.5.1. Building recruitment

Buildings were selected on the basis of meeting several key criteria that would allow both for individual feasibility as well as comparison across domains:

- Context, including building history, terms of tenure, physical and operational context.
- Degree of 'greenness' evident in the building's design and operation. The LEED® rating system was used as a framework of evaluation for 'greenness'. Buildings were identified as 'green' if they had made demonstrated and strategic commitments in the areas of energy and atmosphere, indoor environmental quality, and material finish, all areas which explicitly relate to occupants' comfort and interaction with space.
- Workplace culture, the norms and values attached to the workplace and its use relating to nature of work, manner of work (i.e. individual, team or service-based), mobility, flexibility, and formality. For the purposes of this study we defined three workplace cultures of interest as "academic", "public sector", and "private sector".

A sample survey pack issued to participants to be recruited to the study is provided in Appendix B. While most of the organizations and companies approached to participate in the study seemed to be interested, indicating that the timing was right and the research had value, several difficulties and delays occurred in recruiting case-study buildings. These difficulties related to: knowing which level of authority to initially approach; managing expectations of employees in terms of improvements to their workspace following survey completion; conflicting interest and timelines; concern over security; and concerns over disruption of the occupants. The difficulty was, therefore, not so much in garnering corporate interest in post-occupancy evaluation research, but rather carrying that interest through to commitment.

Six buildings in total were recruited for participation in the study (see Table 1.1). Two buildings are located at the University of British Columbia (UBC) in Vancouver, B.C., one green designed and one conventionally designed, both under the same ownership (UBC) with a similar workplace culture ('academic') and types of occupants (engineers). A third building located in

Sidney, B.C. is green designed and represents a 'public sector' building, owned and staffed by the Canadian Federal Government. A fourth building located in Whistler, B.C. is conventionally designed and also represents a 'public sector' building, owned and occupied by the Municipality of Whistler. A fifth building is a conventionally designed office tower located in Toronto, Ontario, headquarter to a large Canadian company and representing a 'private sector' building. The sixth building is a new green designed building to which the company moved from the conventional building in the fall of 2008. The latter set of buildings provides a unique opportunity to evaluate user experience pre- and post- move.

	Workplace culture		
Design	*Academic*	*Public sector*	*Private sector*
Conventional	Frank Forward	Whistler Municipal Hall	Headquarter Building 1
Green	Fred Kaiser	Gulf Islands Operations Centre	Headquarter Building 2

Table 1.1 Building recruitment strategy

A detailed description of the buildings is provided below. Pictures of the buildings and further description of environmental features and systems appear in the subsequent chapters. At the request of building owners, post-occupancy evaluation reports were completed for Whistler Municipal Hall, Gulf Islands Operations Centre, and Headquarter Buildings 1 and 2 (for sample report, see Appendix I). Although Whistler Municipal Hall was not included in any substantive analysis in the thesis, it was retained in the introductory and conclusion chapters in order to convey the initial study design and methodological approach, and to demonstrate the challenges and variability of conducting post-occupancy evaluation research in practice; this is further discussed in Chapter 5 under Strengths and Limitations. For privacy purposes, the identity of the private sector company has been protected throughout this thesis.

Frank Forward building

The Frank Forward building, located at the University of British Columbia in Vancouver, B.C. is home to the Materials and Mining Engineering Departments. Constructed in 1968, it is 5 stories high, with gross floor area of 4 929m^2, and comprises office, lab, and administrative space. The building has operable windows, and a central forced air heating and ventilation system but no mechanical cooling.

Fred Kaiser building

The Fred Kaiser building, also located at the University of British Columbia, is home to the Electrical and Computer Engineering Department as well as the Dean's Office of Applied Science. Completed in 2005, it is 5 stories high, has a gross floor area of 9 026m^2, and comprises office, computer lab, and administrative space. It was designed to meet LEED®-Gold standards, with key environmental features including: in-slab radiant heating and cooling, fan-assisted natural ventilation, operable windows for all perimeter zones, water efficient fixtures, and photovoltaic panels providing DC power for emergency lighting.

Gulf Islands Operations Centre

The Gulf Islands Operations Centre, located in Sidney, B.C., is a 1 045m^2, 3-storey facility designed to accommodate the Gulf Islands National Park Reserve operations and administrative staff. Completed in 2005, it was the first building in Canada to receive the LEED®-NC Platinum designation, with key environmental features including: extensive natural lighting, operable windows, an ocean-based geo-exchange heat pump system providing all heating and hot water needs, photovoltaic panels supplying 20% of the building's energy needs, a ventilation system supplying 100% outdoor air, and low-emission material and finishes.

Whistler Municipal Hall

The Whistler Municipal Hall, located in Whistler, B.C., is a 2.5-storey, timber frame building serving the Resort Municipality of Whistler's council, departments, operations and administrative staff. Originally built as a restaurant in the 1970s, the building was moved to its current location in the 1980s, where a concrete foundation and basement level were added to the structure. With a gross floor area of 1 669m^2, the building has operable windows, central forced-air ventilation, and in-floor radiant heating and cooling. Additional air-conditioning units were added to cool and ventilate the building's north and south ends.

Headquarter Building 1

Headquarter Building 1 is a 16 300m^2, 6-storey office building located in Toronto, Ontario. Built in 1974, the building is of concrete construction with sealed, reflective-glazed windows, and conditioned through a central forced air ventilation and cooling system, and radiant perimeter heating. As the headquarters, it is the central location for all company operations, information technology, real estate, marketing, human resources, finance, and accounting. The building is leased from a property management company.

Headquarter Building 2

Headquarter Building 2 is a 9 300m^2, 2-storey office building, also located in Toronto, Ontario. Completed in 2008, the building was designed to LEED®-NC Silver standard, with key environmental features including: extensive natural lighting, views to the outdoors for 90% of spaces, daylight and occupancy sensors, CO_2 sensor-activated ventilation, and low-emission materials and finishes. While custom designed and built, the building remains leased from the development company.

1.5.2. Data collection

There are over 150 possible post-occupancy analysis methods currently available worldwide (Leaman, 2003). While there is no industry-accepted definition or standardized method for conducting post-occupancy evaluation, all approaches necessarily contain two components: measurement and assessment. In part due to a strong interest on the part of study participants to learn how well their building was performing with respect to benchmark, the Building Use Studies (BUS) Ltd. occupant survey was selected from the available tools for capturing background data, occupant satisfaction with the building and workplace, occupant comfort and perceived personal control. The BUS survey was developed by and for a U.K. consortium (including Building Use Studies Ltd. and William Bordass Associates) as part of the PROBE series carried out from 1995-2000. The survey is now widely used in post-occupancy evaluations around the world, with over 350 buildings comprising the BUS performance benchmark, and a separate international benchmark for green buildings. The BUS Occupant Questionnaire License Agreement is provided in Appendix C. To accompany the BUS occupant survey, a new module was developed that addressed occupants' knowledge of building environmental features and systems, perception of building environmental performance, awareness and engagement with control opportunities available to them, and perception of workplace and organizational culture. A sample of the complete survey is provided in Appendix D.

The survey was implemented in the six buildings from the period of April 2008 – April 2009. In each building, the survey was conducted over the web and ran for approximately one week, or until the minimum response rate of 30% was achieved, as per industry standard for web-based POE surveys (Centre for the Built Environment, 2009). Sample size calculations for each building are provided in Appendix E. In addition to surveying end-users, for the purposes of Chapter 3 the project architect of the Fred Kaiser building and Gulf Islands Operations Centre were interviewed to further understand from their perspective, the feedback that formed part of the design, handover and operation of the building. The interview guide used in these discussions is provided in Appendix F.

Physical microclimate data were collected at the same time as the survey as objective measurements of indoor environmental quality to complement to the subjective occupant satisfaction data. The data collection sheet for indoor environmental quality measurements and workplace observation is provided in Appendix G, along with a list of instruments used in Appendix H. While analysis of the physical microclimate data was not included in the manuscripts due to inadequate spatial and temporal resolution of sampling, an example of how this data may be used is provided in Appendix I: Sample Post-Occupancy Evaluation Report for the Gulf Islands Operations Centre.

A more detailed description of the research methodology can be found in each of the individual chapters, in particular Chapters 2 and 3.

1.6. STRUCTURE AND OVERVIEW OF DISSERTATION

This is a manuscript-based thesis, consisting of an introductory chapter, 3 research chapters, and a concluding chapter. The research chapters (Chapters 2-4) are written as stand-alone manuscripts that are either submitted to journals, accepted for publication or already published – as noted at the beginning of the respective chapter. Each manuscript includes a literature review, discussion of methods, analysis, conclusions and list of references (unlike a monograph-based thesis). Manuscripts are arranged in order of completion, and should be understood to reflect the author's perspective and intellectual development of ideas at the time at which the paper was submitted for publication. The introductory and concluding chapters (Chapters 1 and 5) serve as an opportunity to synthesize the research and clarify the larger picture.

An overview of the five chapters is presented below. Each research chapter incorporates a case-study comparison of two buildings, selected in order to allow for the pursuit of objectives specific to that chapter (see Table 1.2).

Chapter 1 sets the context for the thesis by describing the problem, reviewing key concepts in the literature, stating the research purpose and contribution, and justifying the methodological approach. This section also serves as an introduction to the six buildings recruited for participation, and provides an overview of the thesis structure and individual manuscripts.

Chapter 2 is an exploratory paper on the nature of the gap between assumed and actual comfort-related behaviour of occupants in buildings. The notion of physiological comfort is extended to include behavioural and socio-psychological aspects of comfort, in particular occupants' knowledge of the building, expectations around its performance, and use of building and personal controls. The paper's main findings, which concern the influence of prior knowledge on human interaction with buildings and the relationship with their perceptions and values, open up a new avenue for exploring feedback in building design and point to more work needed.

Chapter 3 extends the concept of occupants' a priori knowledge in relation to their comfort and behaviour in buildings in-use, to explore the *formation of* knowledge and behavioural patterns in response to feedback received through the design, implementation and use phases of a building. Feedback is considered in the broader sense as information flow through a number of processes and scales over the lifetime of a building. Both knowledge and comfort are viewed as fluid concepts shaped by occupants' adaptive behaviour (engaging with building controls and complaints) and the subsequent response.

Chapter 4 broadens the scope of analysis further to look at the merging of green design with workplace design and organizational culture, in a company's move from a conventional to a green designed headquarters building. Pre and post-occupancy evaluation reveals significant gains in occupant comfort, productivity, health and wellbeing. The analysis demonstrates the challenges of disentangling design factors from the culture and situational context within which design and operation decisions are made in attributing performance improvements, with implications for post-occupancy method.

Chapter 5 summarizes thesis objective and key findings from the research, and offers implications for comfort theory, green building design, building rating/certification schemes and related policy. The strengths and limitations of the research are reviewed, and directions for further research proposed.

	Workplace culture		
Design intent	*Academic*	*Public sector*	*Private sector*
Conventional	Frank Forward	Whistler Municipal Hall	Headquarter Building 1
Green	Fred Kaiser	Gulf Islands Operations Centre	Headquarter Building 2

Chapter 2 Chapter 3 Chapter 4

Table 1.2 Pairing of buildings by manuscript for post-occupancy evaluation and analysis.

The UBC Behavioural Research Ethics Board Certificate of Approval for the research conducted in this thesis is found in Appendix A.

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2. INFLUENCE OF OCCUPANTS' KNOWLEDGE ON COMFORT EXPECTATIONS AND BEHAVIOUR[3]

2.1. INTRODUCTION

The primary objectives of this paper are to explore the influence that occupant knowledge may have on their behaviour and comfort and the nature of the gap between assumed and actual behaviour of occupants in green buildings. By assumed comfort, the authors refer to the referenced set of indoor environmental conditions prescribed by national standards, which in turn shape and define acceptable indoor conditions for occupancy. Comfort criteria are considered primarily in physiological terms and occupants are assumed to interact with building controls and systems in a prescribed and predictable manner, via provided means accessible to them in the building design. The term 'knowledge' in this context refers to occupants' awareness and understanding[4] of building environmental features and control systems, gained through their immediate experience in the building, while tempered by a broad range of influences such as tacit knowledge, contextual, and cultural influences.

It has been previously argued that in order for green buildings to perform effectively in the context of a low-carbon future, a shift is required from conceptualizing the occupant as a passive recipient of a set of indoor conditions, to the inhabitant who may play a more active role in the maintenance and performance of their building (Cole *et al.*, 2008). The paper attempts to understand and characterize better the 'active inhabitant' and to examine the design of building systems and their integration with communication and feedback tools to support the transition of occupants' expectations to new indoor environments and responsibilities.

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[3] A version of this chapter has been published. Brown, Z. and R. Cole (2009) Influence of occupant knowledge on comfort expectations and behaviour. *Building Research and Information*, 37(3):227-245.

[4] A difference exists between 'awareness' and 'understanding' with respect to the level of user engagement with buildings. Awareness refers to an individual's ability to be conscious of, feel or perceive an object or condition, whereas understanding implies a deeper recognition of how the object or condition came about, its purpose or function, and its relationship to the self. With respect to building environmental systems, an individual who 'understands' the personal controls available to them is more likely to make appropriate and intelligent choices when maintaining or altering environmental conditions in the workplace.

Green buildings, in contrast to their conventional counterparts, often rely on natural conditioning to meet the comfort needs of end-users. A combination of passive strategies may be employed to provide indoor comfort conditions resulting in indoor conditions that are more closely linked to daily and seasonal variations outside. Building environmental control systems are designed to accommodate more direct forms of active user engagement through the opening and closing of windows, blinds, switches, and other manual controls. As a result, the successful performance of green buildings depends in a large part on variation and diversity in environmental conditions, where both the building systems and inhabitants interact and adapt in response to changing external conditions and needs. This process has been described as "interactive adaptivity" (Cole *et al.*, 2008, p. 333), and refers to the ongoing, bidirectional dialogue between building and user in which the outcome is not predetermined by building design parameters or performance metrics, but is rather an evolving process.

Placing the responsibility for comfort conditioning in the hands of building inhabitants implies that they will make appropriate and intelligent choices, and necessitates a shift in the quantity and quality of understanding and communication about the consequences of exerting environmental control. This is especially the case because green buildings are often:

> more fragile in their performance, so it is more important that everything works well together. (Leaman and Bordass, 2007, p. 672)

The extent to which green buildings are actually being designed with user engagement in mind becomes a focal point of this paper, examined through the lens of a Canadian multiple-building post-occupancy evaluation study. This study addresses a number of related questions such as:

- Are a higher quantity and quality of personal control being provided?
- Are certain building environmental systems more intuitive to understanding and use than others?
- Why do end-users engage or choose not to engage with controls available to them?
- How do they learn, and what is the most appropriate form of communicating building performance?

- What is the role of expectations in terms of shaping user experience of comfort and indoor environmental behaviour?

In practice, very little is known about how inhabitants interpret and understand the environmental features and systems of the buildings in which they live and work, and the role this knowledge plays in shaping comfort and energy use patterns. Contemporary green buildings seldom communicate how building systems function or broader 'lessons' of their upstream and downstream ecological consequences (Orr, 1999). Research to date has focused on the residential sector, examining the decision-making behaviour of homeowners around thermal comfort and electricity consumption. By contrast, the research presented here investigates, in a commercial setting, inhabitants' knowledge of building environmental features and systems, and awareness of control and feedback opportunities available to them. A web-based survey has been designed to capture knowledge levels as compared with an expert baseline for six Canadian office buildings of varying degrees of energy efficiency, two of which are reported below. By focusing on the influence of prior knowledge and expectations on human interaction with buildings, the paper extends the scope and emphasis of post-occupancy evaluations and offers a broader context for interpreting the results of such evaluations as useful feedback to building design.

2.2. PERFORMANCE GAPS IN GREEN BUILDINGS

There are two key performance gaps in relation to green building of relevance to this paper:

- the gap between predicted and actual performance of buildings
- the gap between assumed and actual comfort and assumed and actual comfort-related behaviour within buildings

2.2.1. Energy and environmental performance

Building performance and its evaluation have earned increased attention in recent years, particularly as applied to green buildings. The building sector has been identified as a key potential contributor to efforts to mitigate climate change (Metz *et al.*, 2007; Urge-Vorsatz *et al.,* 2007), and governments are demanding increased accountability from design professionals to ensure that buildings produce significantly less – or no – greenhouse gas emissions. Such mandates are challenging the design community to address the well-known gap that exists between predicted and actual environmental performance of the built infrastructure. In the UK, it has been noted that CO_2 emissions from green buildings are commonly two or even three times as much as predicted (Bordass, 2001). In the US, a study by the New Buildings Institute (2008) found that 30% of LEED[5]-rated buildings perform better than expected, 25% perform worse than expected, and a handful of LEED buildings have serious energy consumption problems.

Bordass *et al.* (2004) refer to this occurrence as the 'credibility gap', alluding to the loss of credibility when design expectations of energy efficiency and actual fuel consumption outcomes differ substantially. They suggest that credibility gaps arise:

> not so much because predictive techniques are 'wrong', but because the assumptions often used are not well enough informed by what really happens in practice because few people who design buildings go on to monitor their performance. (p. 1)

In accordance with this view, Hinge *et al.* (2008) review international efforts underway to understand gaps in green building performance and point to a widespread failure of design to take into account the realities of commercial operation in establishing design intents that are realistic and achievable.

2.2.2. Occupant comfort and behaviour

A second 'performance gap' has to do with the assumed and actual comfort and comfort-related behaviour of buildings inhabitants. Although green buildings have the potential to deliver enhanced indoor environmental quality, recent post-occupancy satisfaction studies suggest that this is not always the case. Leaman and Bordass (2007) compared user experiences in conventional and green buildings and found that green buildings scored better on ventilation/ air, health, design, image, lighting, comfort overall, and perceived productivity. However, while the best green buildings ranked higher than the best conventional buildings, a few of the lowest scoring were also green buildings. Abbaszadeh *et al.* (2006) compared occupant satisfaction in

[5] Leadership in Energy and Environmental Design (LEED) is a trademarked and registered term. It is a third-party certification programme developed by the US Green Building Council (USGBC) in 2000 and an accepted benchmark for the design, construction, and operation of green buildings in the US and Canada. A Canadian version of LEED was developed in 2004.

21 LEED-rated buildings with 160 non-green buildings using the University of California Berkeley Center for the Built Environment's (CBE) Occupant Indoor Environmental Quality Survey. Occupants in green buildings were more satisfied with thermal comfort, air quality, office furnishings, cleaning and maintenance, but overall dissatisfied with lighting and acoustics.

Amongst the range of potential factors that can impact the comfort/behavioural 'performance gap', the following are identified with relevance to this study:

- Practical/design:
    - *Complexity*: High-technology buildings that are relatively complex to operate and require dedicated management to achieve optimal performance (Bordass and Leaman, 1997). Overly complex or non-intuitive control interfaces.
    - *Simplicity*: Low-technology buildings (i.e., passively ventilated or heated) that are simple to operate in principle but poorly understood by the operator and inhabitants (Cole *et al.*, 2008).
    - *Usability*: Systems that may not have been be usable or manageable in the first place (Bordass *et al.*, 2004).
    - *Accessibility*: Tenant fit-out that clashes with design intentions and changes the building and its energy systems substantially, for example, thermostats hidden behind desks, carpet layered over under-floor air distribution vents.
    - *Responsiveness*: A lack of immediate and relevant feedback on the effect of operating building and personal controls.
- Behavioural/situational:
    - *Prior experience*: Users accustomed to different levels of control and responsibility that are embedded in routines of domestic life and commercial practice (Shove, 2002), both more automated and tightly controlled conditions (e.g., prior work environment), and more variable and manually controlled conditions (e.g., home).
    - *Time spent in the building*: Users who have spent shorter or longer amounts of time in a building, which affects the weight of prior experience and influences performance expectations.

- *Knowledge and information*: Users' lack of awareness or understanding of the building's environmental systems and features, and action strategies that can be taken to influence comfort conditions.
- *Satisficing (versus optimizing)*: Users behaving in such a way to meet perceived needs without going to extremes, for example, operating the most convenient rather than logically appropriate controls, using controls only when a 'crisis of discomfort is reached' rather than continually optimizing conditions, and leaving systems in their switched on state rather than toggling them back again later (Leaman and Bordass, 2001).
- *Emergent properties and unintended consequences*: Control systems that irritate end-users and are therefore bypassed. Overcompensation in reactions to relatively minor annoyances (Bordass *et al.*, 2004; Leaman, 1999).

- Social/psychological:[6]
  - Individual sense of responsibility: Users with a lesser sense of personal responsibility may also be less likely to engage in environmentally responsible behaviour (Hines *et al.*, 1987).
  - *Perception and attunement to surrounding environment:* Users' perception of environmental control systems may depend on how attuned (aware or responsive) they are to the type of stimulus, and how relevant or useful they perceive personal control to be relative to their own actions and goals (Gibson, 1979, cited in McArthur and Baron, 1983) in the building.
  - *Expectations of building performance:* Users may have high or low expectations of how the building would or should perform, which can influence their perceived comfort and comfort-related behaviour.
  - *Social ('normative') influence*: Users who do not expect to have to engage with environmental control systems in the workplace due to prevalent social norms around 'passive' occupancy and resource-intensive practices of organizations (Guy and Shove, 2000).

[6] For social/psychological factors, the authors draw from the environmental and social psychology literature, particularly studies dealing with gaps between the possession of environmental knowledge and awareness, and the display of pro-environmental behaviour, as reviewed by Kollmus and Agyeman (2002) as well as the ecological psychology and constructivist technology literature dealing with how people learn about technology and the environment.

2.3. STUDY DESCRIPTION

The two performance gaps described are closely interrelated in the sense that occupant comfort and behaviour can have a significant impact on a building's energy and environmental performance. While the magnitude of the effect of individual and collective occupant behaviour can be difficult to isolate from other building and contextual factors, a number of studies are currently underway to collect data that would allow for quantifying this impact (Mahdavi *et al.*, 2008; Bourgeois *et al.*, 2005). What is known is that there is a fine balance between optimizing energy efficiency and providing comfortable, healthy and productive indoor environments, and that discomfort experienced by end-users will ultimately impact their acceptance and willingness to engage in positive environmental measures (Darby, 2008).

The focus of this paper is not as much on the practical/design issues that can lead to performance gaps in occupant comfort and behaviour. Rather, the work explores the behavioural, situational, and social– psychological aspects of comfort and user engagement with positive environmental practice, in particular how users understand the buildings they inhabit and the role that knowledge plays in shaping their comfort expectations and behaviour. This study builds on previous post-occupancy research of green buildings in use as compared with conventionally designed buildings (Abbaszadeh *et al.*, 2006; Leaman and Bordass, 2007). Like the previous work, occupant satisfaction is evaluated along with the building overall, the individual workplace and comfort. In adding to previous work, respondents were further asked:

- to rate their knowledge and perceptions of how the building performs and comfort is provided, compared with an expert baseline
- more detailed questions about energy-related behaviour in the building, and expectations of green building performance

2.3.1. Related work

Related work in the residential sector has focused on the use of energy feedback information to influence occupant behaviour around thermal comfort and household electricity consumption. The residential sector provides a large scope for learning about variation and drivers for occupant behaviour, given that in the average home:

> there is huge variability in terms of the acquisition, default setting and day-to-day use of heating systems and appliances, where ‘behaviour’ is central to consumption levels. (Lutzenhiser, 1993, cited in Darby, 2008, p. 501)

Abrahamse *et al.* (2005) review of 38 field intervention studies aimed at reducing household energy consumption. Both ‘antecedent’ interventions (those which target underlying behavioural determinants of energy use, e.g., attitudes, knowledge) and consequence interventions (those which use positive or negative consequences to influence behaviour, e.g., feedback and rewards) are evaluated. They conclude that information often leads to increased knowledge levels, but not necessarily behavioural changes or reduced energy use. Feedback, on the other hand, can lead to reduced energy consumption, especially if it is frequent.

Darby (2006) reviews three types of feedback strategies used to communicate with residential energy consumers: direct feedback in the home, indirect feedback via billing, and inadvertent feedback as a by-product of technical, household or social change. Darby’s work suggests that feedback has a significant role to play in raising energy awareness and bringing about reduced consumption of the order of 5–15%. Improving feedback will not only:

> produce short-term results but [also] will alter the way in which people think of energy, control usage, and are able to adapt to changes in energy systems . . . it will [allow] energy users to experiment and develop their own methods of energy management, based on data that are specific to them and that they trust. (Darby, 2008, p. 502)

In the academic sector, the communication of responsibility can be increasingly observed particularly in green buildings which may be designed for inherent legibility, for example, through exposed or experiential building systems, or equipped with ‘add-ons’ such as building information sessions and instructional signage. Some of the most recent developments include the introduction of smart meters, kiosks and real-time web-based feedback in effort to make building performance factors more amenable to understanding and control. These types of interventions have also been associated with real changes in energy use and behaviour (for example, Peterson *et al.*, 2007).

2.3.2. Rationale

The rationale for the research is four-fold:

- The majority of research to date been conducted in the residential sector. Feedback tools effective at influencing behaviour change in the residential setting may not generate the desired effect in a commercial setting where users respond to different incentives, and often share the space they can control with a greater number of people, thereby creating a different social and behavioural dynamic.
- The successful performance of green buildings depends not only on their design, but also on matching technological and management sophistication. To enable inhabitants to solve operational problems, building systems must be readily accessible and comprehensible to users, and clearly accompanied by a willingness to use them (Cohen *et al.*, 1999).
- There is a 'knowledge gap' between inhabitants' desire to learn and the availability of information to them. A common recommendation made by post-occupancy evaluation researchers is that users need to be better educated about their building's environmental control systems. However, more often than not, tenants will move into a building with very little explanation about how it has been designed to operate or how their use of spaces and equipment affect its energy usage (Brown and Cole, 2008).
- Inhabitant knowledge and behaviour can have real impacts not only on building energy performance, but also on comfort and satisfaction with the indoor environment. Existing post-occupancy evaluation tools such as questionnaires are limited in their ability to capture the wider range of behavioural, situational, and social–psychological measures that are known to influence how users experience buildings. The incorporation of additional means of understanding and evaluating human factors such as interviews, focus groups etc. could ultimately improve the relevance and accuracy of post-occupancy evaluation methodology.

2.4. METHDOLOGY

2.4.1. Building recruitment

A total of six office buildings were recruited for participation in the study: three green buildings and three conventionally designed. Two of the buildings – the Fred Kaiser building and the Frank Forward building both located at the University of British Columbia (UBC) in Vancouver, BC, Canada (and hereafter referred to simply as 'Fred Kaiser' and 'Frank Forward') – are the focus of this paper. Both buildings are under the same ownership (UBC) with a similar workplace culture (academic) and types of inhabitants (engineers) allowing for a common baseline of comparison. Importantly, for the purposes of this study, the buildings exhibit very different levels of green design (see below).When comparing the two buildings, there are a number of additional variables that may influence occupant knowledge and expectations and, as such, potentially compromise some of the findings, including: different engineering disciplines occupying the buildings, different heating and cooling systems, and the different ages of the buildings. However, for the purposes of this initial exploration, and given the pragmatic difficulty of identifying suitable buildings, the focus of the analysis remains on the comparison between green and conventionally designed buildings.

Fred Kaiser is home to the Electrical and Computer Engineering Department as well as the Dean's Office of Applied Science. Completed in 2005, it has a long, rectangular shape with a north–south axis and at five stories high has a gross floor area of 9 026 m^2 (Figure 2.1, Figure 2.2, and Figure 2.3). Designed to meet LEED-Gold standards, its key sustainability features include: in-slab radiant heating and cooling, fan-assisted natural ventilation with CO_2 sensor control, operable windows for all perimeter zones, water-saving features to reduce consumption by 40% over baseline (LEED-NC, v.1.0), and photovoltaic panels providing DC power for emergency lighting. An important feature is a mechanical air-conditioning system installed post-occupancy on the fifth floor to provide summer cooling specifically to the Dean's Office faculty and staff (Figure 2.4). Fred Kaiser is seen and recognized by the UBC Sustainability Office as one of six recent green buildings on campus, demonstrating environmentally friendly features and significant improvements in energy and electrical efficiency over the average campus building.

Figure 2.1 Fred Kaiser, exterior view

Figure 2.2 Fred Kaiser, a typical laboratory, east perimeter

Figure 2.3 Fred Kaiser, typical laboratory, core space

Figure 2.4 Fred Kaiser, fifth floor hallway with air-handling units

Inhabitants of Fred Kaiser are equipped with the following environmental control systems: thermostats (within set points) zoned at one per four people (office), and one per 20 (laboratory); cooling controls, integrated into the thermostats zoned at one per two people (fifth floor offices only); motion-controlled overhead lighting with occupant override at one per person (office), and one per ten people (laboratory). Fan-assisted natural ventilation is controlled by CO_2 sensors, subject to the influence of operable windows.

Frank Forward is shared between the Materials and Mining Engineering Departments and comprises office, laboratory, and administrative space. Constructed in 1968, it is five stories high with a gross floor area of 4 929 m^2 (Figure 2.5). The building layout is a modified ‘L’-shaped, with a north–south axis and an east–west axis. Most of the offices are located along the north perimeter, while laboratories, classrooms, and student workplaces make up the remaining areas (Figure 2.6, Figure 2.7, Figure 2.8). The building has operable windows for almost all perimeter zones, and a central forced air-heating and ventilation system (variable speed drive). As with many buildings on UBC campus, Frank Forward does not have a mechanical cooling system.

Figure 2.5 Frank Forward, exterior view

Figure 2.6 Frank Forward, typical office, north perimeter

Figure 2.7 Frank Forward, typical graduate work area, core space within a laboratory

Inhabitants of Frank Forward are equipped with the following environmental control systems: thermostats (within set-points) at one per eight people (office), and one per 16 (laboratory); on/off switches for overhead lighting at one per person (office), one per eight (laboratory). No cooling or ventilation controls are available except for operable windows. See Table 2.1 for comparison of building properties, attributes and systems in Fred Kaiser and Frank Forward.

Figure 2.8 Frank Forward, typical office, core space within a laboratory

	Fred Kaiser	**Frank Forward**
Building Properties		
Tenant	Electrical and Computer Engineering; Deans Office of Applied Science	Mining and Mechanical Engineering
Year of completion	2005	1968
Size	9,026 m^2	4,929 m^2
No. of floors	Five	Five
Heating system	In-slab radiant heating	Central forced-air heating
Cooling system	In-slab radiant cooling, plus mechanical air conditioning (5^{th} floor only)	None
Ventilation	Fan-assisted natural ventilation	Central forced-air ventilation
Personal Controls		
Heating	Thermostats: one per four people (office), one per 20 people (lab)	Thermostats: one per eight people (office), one per 16 people (lab)
Cooling	Thermostats (fifth floor only): one per two people (office)	None
Ventilation	CO_2 sensors, operable windows	Operable windows
Lighting	Motion-controlled with manual override: one per person (office), one per ten people (lab)	Manual switches: one per person (office), one per eight people (lab)

Table 2.1 Comparison of building properties, attributes and control systems for Fred Kaiser and Frank Forward

2.4.2. Data collection

Building users were surveyed in the spring of 2008 using the Building Use Studies (BUS) occupant questionnaire (Usable Buildings Trust, 2008), modified to include questions addressing occupants' knowledge and engagement with control opportunities available to them.[7] The Building Use Studies survey was selected for reasons of ownership of data, cost, ease of implementation, and access to the BUS international conducted via a web-based version and ran for approximately one week in each building. The sample population included all permanent occupants in the recruited buildings. A total of 108 people responded to the survey from Fred Kaiser, representing a response rate of 56% (confidence interval = 0.06), while 45 responded from Frank Forward, representing a response rate of 37% (confidence interval = 0.11), both within the typical range for web-based post-occupancy surveys (Zagreus *et al.,* 2004).

In order to generate an expert baseline against which to compare occupants' responses, the survey was also administered to one facilities manager or 'resident expert' for each building.[8] The comparison of so-called 'lay' knowledge to an expert baseline to elicit mental models is a standard procedure commonly employed in the risk perception and risk communication literature (for example, Slovic, 1987; Bostrom *et al.*, 1994).

Physical microclimate measurements were also conducted during the time of the administration of the survey. Spot measurement were taken of dry bulb temperature, humidity, globe temperature, CO_2, carbon monoxide, ambient noise, and lighting at four to six representative locations within each building. While measurements provided an additional layer of understanding about the building indoor environmental quality, results from the physical data are

[7] Additional questions on occupant knowledge are as follows. *This section asks about your knowledge and perception of how the building performs and comfort is provided.* (1) Would you consider this to be a green building? (2) How would you describe your level of knowledge about this building's environmental features and systems? (3) Would you like to learn more? (4) To the best of your knowledge, how is heating provided in your workspace? Who is responsible for controlling heating in your workspace? (5) How is cooling, fresh air, lighting . . . provided in your workspace? Who is responsible for controlling cooling, fresh air, lighting . . .? (6) Please identify any means by which you have learned about how the building performs and comfort is provided.

[8] The nature and scope of the project did not permit for the hiring of an external expert to serve both buildings. Therefore, a decision was made to use internal experts for the baseline. Experts were identified through personal recommendation from University Plant Operations followed by an informal interview process, with the aim to minimize variations in levels of expert understanding. For Fred Kaiser, the 'expert' was the departmental Director of Operations, and for Frank Forward the 'expert' was the Machine Shop Supervisor who also served as the primary facilities manager liaison for the building.

not included in this paper due to incomplete spatial and temporal representation to assess indoor conditions.

2.5. RESULTS

2.5.1. Occupant satisfaction

Results from the BUS questionnaire indicate that occupants in Fred Kaiser were more satisfied overall with the building design and its ability to meet workplace needs than in Frank Forward. Satisfaction in Fred Kaiser with the availability of meeting rooms, the usability of furniture, and the image the building presents to visitors was rated at 80% or more – statistically higher than the BUS benchmark. The suitability of storage arrangements was also higher than the BUS benchmark, although occupant satisfaction with storage was only 50%. The ability of facilities to meet occupants' needs for work, and effective use of space in the building both had satisfaction ratings close to 70% (72% needs, 67% space), which were statistically no different from the benchmark (Figure 2.9).

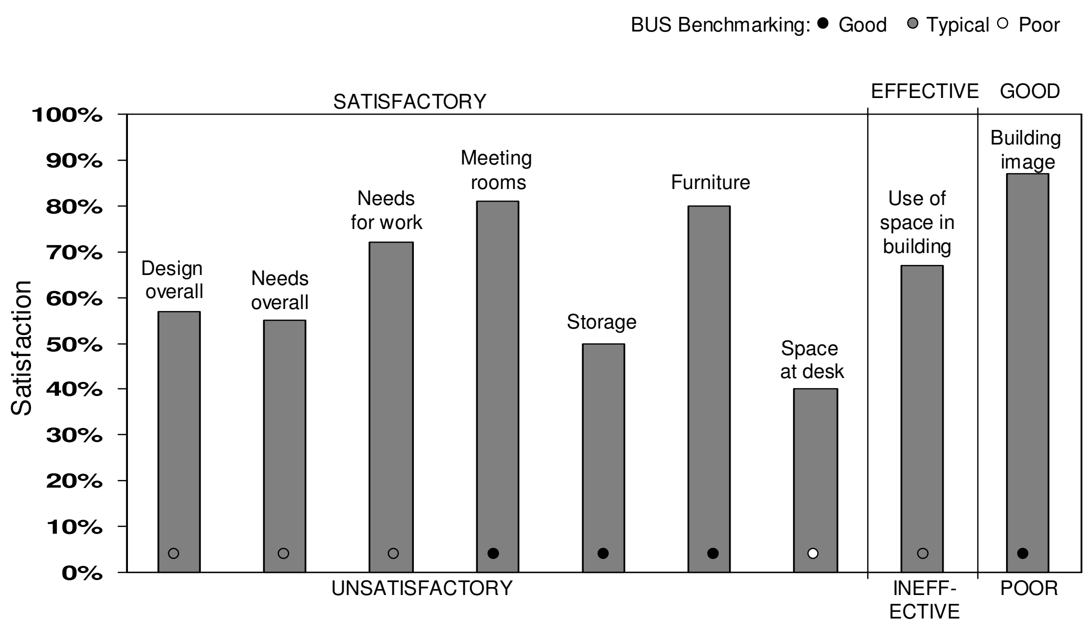

Figure 2.9 Fred Kaiser, occupant satisfaction with building design features

Overall building design, the ability to meet needs, and space at desk were rated lower than other variables in Fred Kaiser at 58%, 55% and 47%, respectively, with space at desk being statistically lower than the benchmark. Respondents pointed to design issues related to temperature and ventilation, fragile building features many of which had broken, an insufficient number of washrooms, a lack of access to drinking water, and poor sound isolation from the atrium and hallways. Regarding space, they indicated the need for larger desks, additional filing cabinets and drawers, and more room to meet with students and guests.

In Frank Forward, satisfaction with the ability of facilities to meet occupants' needs for work, and space at desk, were the highest ranked variables, at 49% and 40% satisfaction, respectively, both no better or worse than the benchmark. All other building design variables, however, were ranked poorly and statistically lower than the benchmark (Figure 2.10). Common areas of concern related to the age of the building and its failure to adapt to changing needs, its inefficient layout, its unreliable elevators, a lack of facilities for graduate students, a lack of storage (for example, see Figure 2.11), leaky windows, and poor temperature control. Overall, Frank Forward ranked in the bottom 2 percentile points of all BUS benchmark buildings for occupant satisfaction.[9]

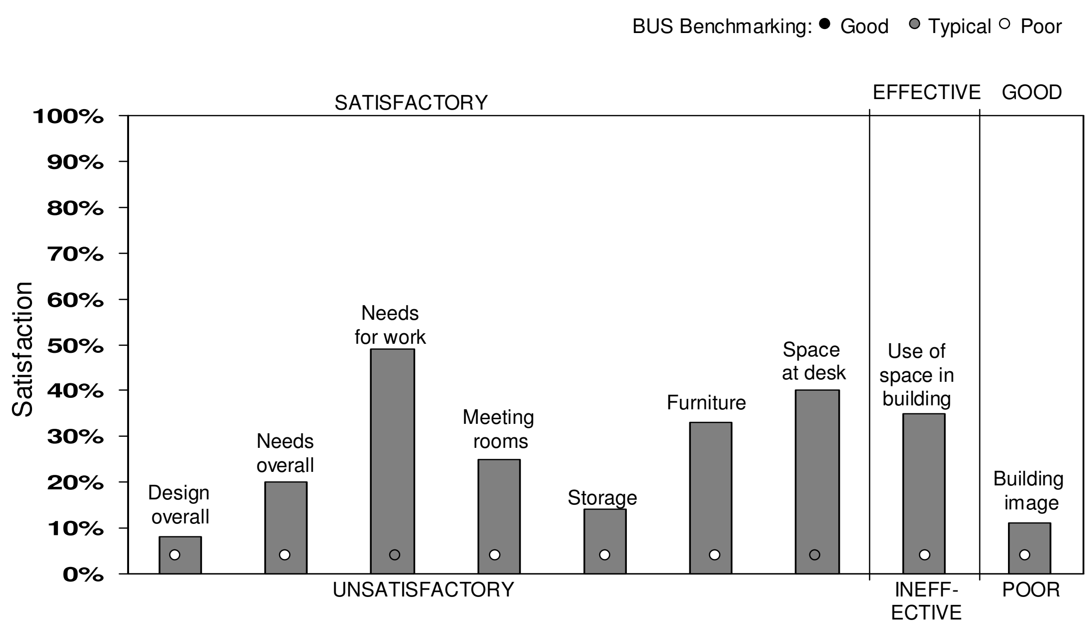

Figure 2.10 Frank Forward, occupant satisfaction with building design features

[9] It should be noted that the BUS benchmark comprises an international data set of mostly green buildings from the UK and Australia, and therefore biased with respect to the buildings included in this study, particularly Frank Forward. It would be expected that Frank Forward ranks closer to the normal distribution of a Canadian benchmark that included older and conventionally designed buildings.


Figure 2.11 Storage issues in Frank Forward

2.5.2. Indoor environmental quality

Occupant satisfaction with comfort conditions revealed a similar response profile for both Fred Kaiser and Frank Forward, even though overall comfort was rated significantly higher in Fred Kaiser than in Frank Forward ($p<0.01x10^{-4}$). In both buildings, temperature, air quality, and noise ranked statistically lower than benchmark, and lighting was the only comfort variable ranked higher than the scale midpoint in both buildings, and for Fred Kaiser higher than benchmark (Figure 2.12).

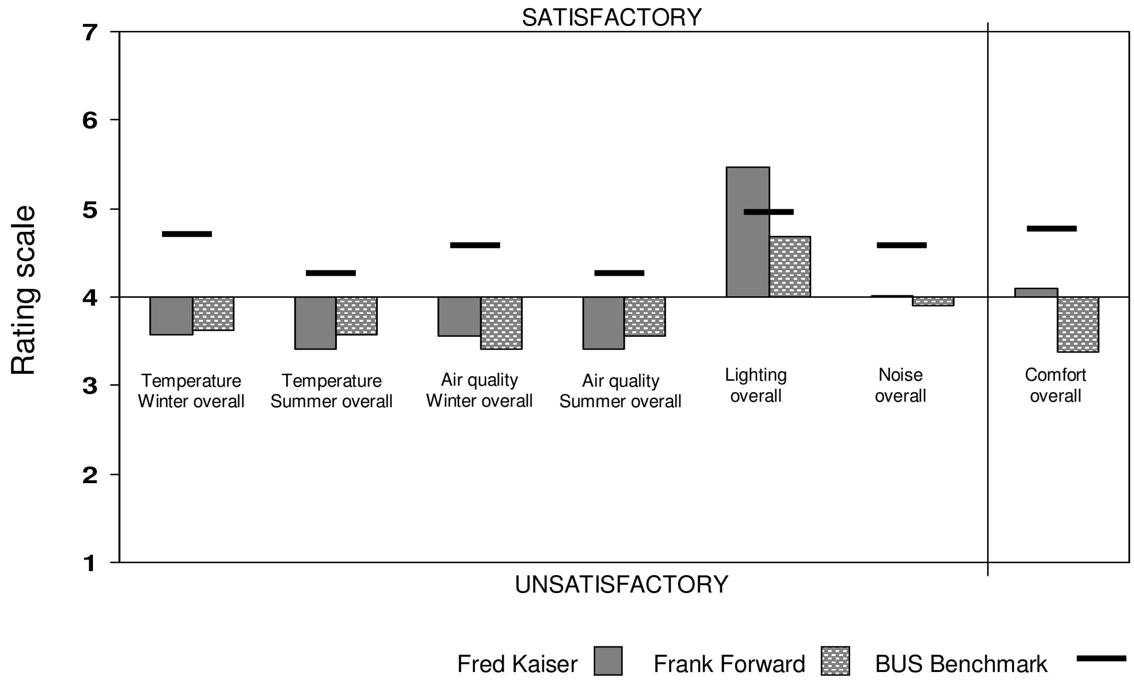

Figure 2.12 Occupant comfort in Fred Kaiser and Frank Forward compared with the BUS benchmark

Thermal comfort conditions in Fred Kaiser were perceived to be too cold in the winter with air conditions that were too still and stuffy, and too hot in the summer with air conditions that were too still and too dry. Overall, 54% of respondents were dissatisfied with temperature and air in winter overall, and 52% were dissatisfied with temperature and air in summer overall. There was no significant difference in satisfaction with thermal comfort conditions in winter or summer between the fifth floor (air-conditioned) and the rest of Fred Kaiser. Thermal comfort conditions in Frank Forward were also found to be too cold in the winter, with air conditions that were too dry and stuffy, and too hot in the summer with air conditions that were too still and stuffy. Overall, 57% of respondents were dissatisfied with temperature and air in winter overall, and 42–53% dissatisfied with temperature and air in summer overall.

Respondents in Fred Kaiser were evenly spread in their rating of satisfaction with noise overall in the building, with 46% satisfied and 44% dissatisfied. Complaints for noise related to high sound transmission between offices, a lack of privacy, atrium noise travelling upwards, and hallway noise from people having conversations and talking on mobile phones. Several respondents commented on the trade-off made between ventilation afforded from opening a door or window, and the increase in noise levels that would result. Noise overall in Frank Forward was also rated across the board in terms of satisfaction with 42% satisfied and 41% dissatisfied with acoustic conditions in the building. The main source of unwanted noise in Frank Forward came from machinery in the laboratories, since many of the workspaces are either within or adjacent to the laboratories.

In Fred Kaiser, 72% of respondents were satisfied with overall lighting conditions, which was statistically higher than the benchmark. Occupants were particularly satisfied with this aspect of the building design providing comments such as ‘Actually, this is the one thing that is just right!’ and ‘The lighting conditions are excellent.’ Those located in core spaces of the building complained about lack of windows and natural light, but in general lighting is an area of success in Fred Kaiser with little evidence of glare being an issue. In comparison, 62% of respondents were satisfied with overall lighting conditions in Frank Forward. Few comments specific to lighting were submitted, but those that were had to do with the lack of natural light in core areas of the building, and the excess of artificial light, particularly overhead fluorescents.

2.5.3. Personal control

Respondents in Fred Kaiser perceived more personal control on average over the indoor environment than in Frank Forward, despite the fact that the only significant identifiable different in quantity of personal control was cooling on the fifth floor of Fred Kaiser.
Figure 2.13 shows the range of personal control (from no to full control) perceived for each comfort variable, with lighting ranking the highest, followed by ventilation, noise, cooling and heating. The ranking of personal control is in part a reflection of the actual availability of controls in the buildings, with lighting switches and operable windows (ventilation) being the most widespread and accessible environmental control systems in both buildings.

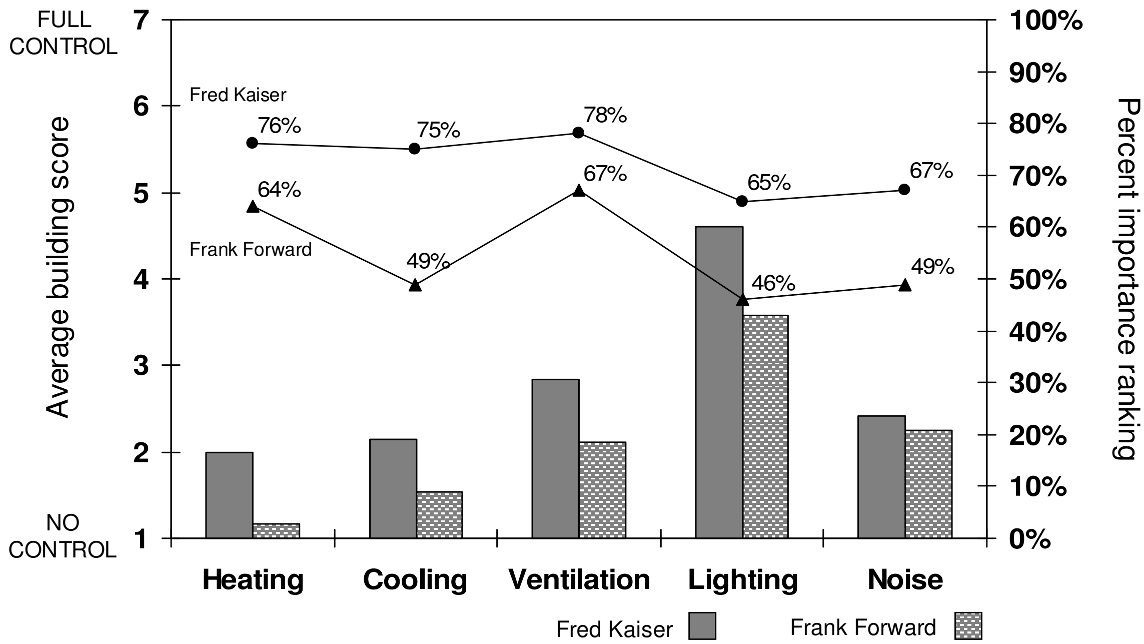

Figure 2.13 Occupant ranking of the amount and importance of different types of personal control in Fred Kaiser and Frank Forward

Interestingly, ventilation was ranked the highest in both buildings in terms of importance of personal control (78% said ventilation control was important to them in Fred Kaiser, and 67% in Frank Forward), with heating a close second (76% Fred Kaiser, 64% Frank Forward), and in cooling a close third (75% Fred Kaiser). Cooling was less important in Frank Forward (49%) and on par with lighting (46%) and noise (49%). In general, occupants in Frank Forward said personal control was less important to them than in Fred Kaiser. Consistent with the higher amount and importance of control perceived in Fred Kaiser compared with Frank Forward, occupants also used controls more frequently in Fred Kaiser (significant difference, $p<0.01 \times 10^{-4}$). A total of 26% of respondents said they used personal controls once a day or more, 15% said several times a week, and 11% said once a week. A total of 33% of respondents in Fred Kaiser never used personal controls compared with 41% in Frank Forward (Figure 2.14).

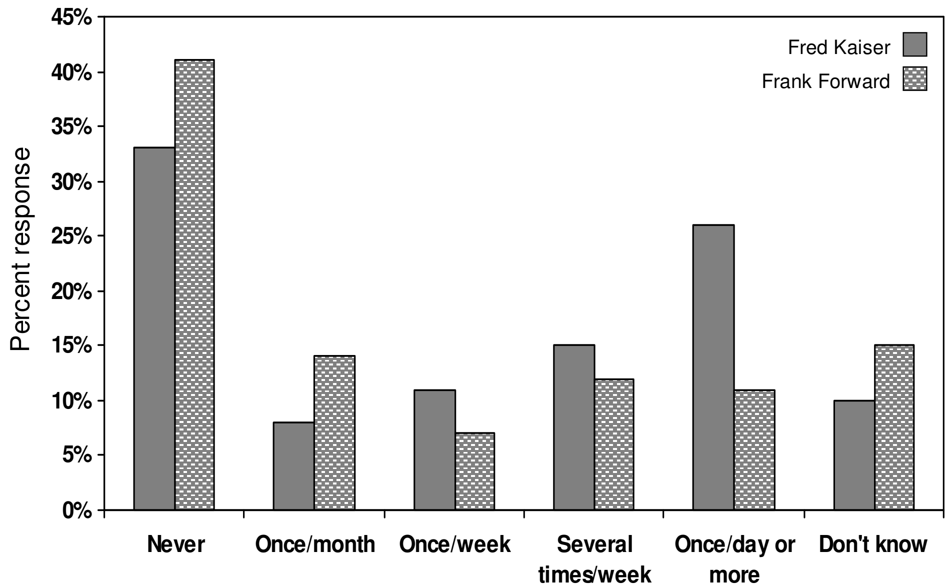

Figure 2.14 Average use of personal controls in Fred Kaiser and Frank Forward

For controls used once a week or more, users were asked to rate their accessibility, usability, and responsiveness. Average scores for accessibility and usability were similar (somewhat conveniently located, and somewhat easy to understand) for both buildings, but average responsiveness of controls in Fred Kaiser was perceived to be significantly slower and less effective than in Frank Forward ($p<0.05$) (Table 2.2). Since lighting controls in Fred Kaiser are on/off switches, it can be assumed that the perception of slow responsiveness relates to thermostats which control the in-slab radiant heating system. By nature, radiant slab systems take longer to respond to changes in set point temperature, and the lag time before they heat or cool air adequately in an adjacent space can be hours to days. A sample of comments suggests that occupants have little understanding of how the heating system works, and the role of the thermostat as a control device:

- ‘Heating controls do nothing. You can set them high or low and absolutely nothing changes.’
- ‘There is a little control box in our lab, however it is mystery what it controls. It looks like the heat however the little slider on it has never seemed to change anything.’
- ‘Regarding heating, although my office is one of the few with a “thermostat” in it, we’ve all heard the rumor that it doesn’t directly do anything. We can set it to a certain

temperature. This set point is then averaged with the set points from the other "thermostats" but on an infrequent basis. Then, the overall average is used to control some sort of large slab?'

	Accessibility (Average score, 1 – not at all conveniently located to 5 – very conveniently located)	**Usability** (Average score, 1 – very hard to understand to 5 – very easy to understand)	**Responsiveness** (Average score, 1 – slow and ineffective to 5 – fast and effective)
Fred Kaiser	3.29	3.52	**2.79**
Frank Forward	2.94	3.63	**3.2**

Table 2.2 Occupant rating of accessibility, usability, and responsiveness of controls they used once a week or more in Fred Kaiser and Frank Forward. Note: Significant differences are shown in bold

When asked to explain why they did not use personal controls, the highest reason given in both buildings (after 'controls don't exist') was 'I don't know where they are' (Fred Kaiser 25%, Frank Forward 22%), followed by 'I don't know how to use them' (Fred Kaiser 11%, Frank Forward 10%) (Figure 2.15). Very few occupants answered that they did not use personal controls because they did not have time (Fred Kaiser 3%, Frank Forward 0%).

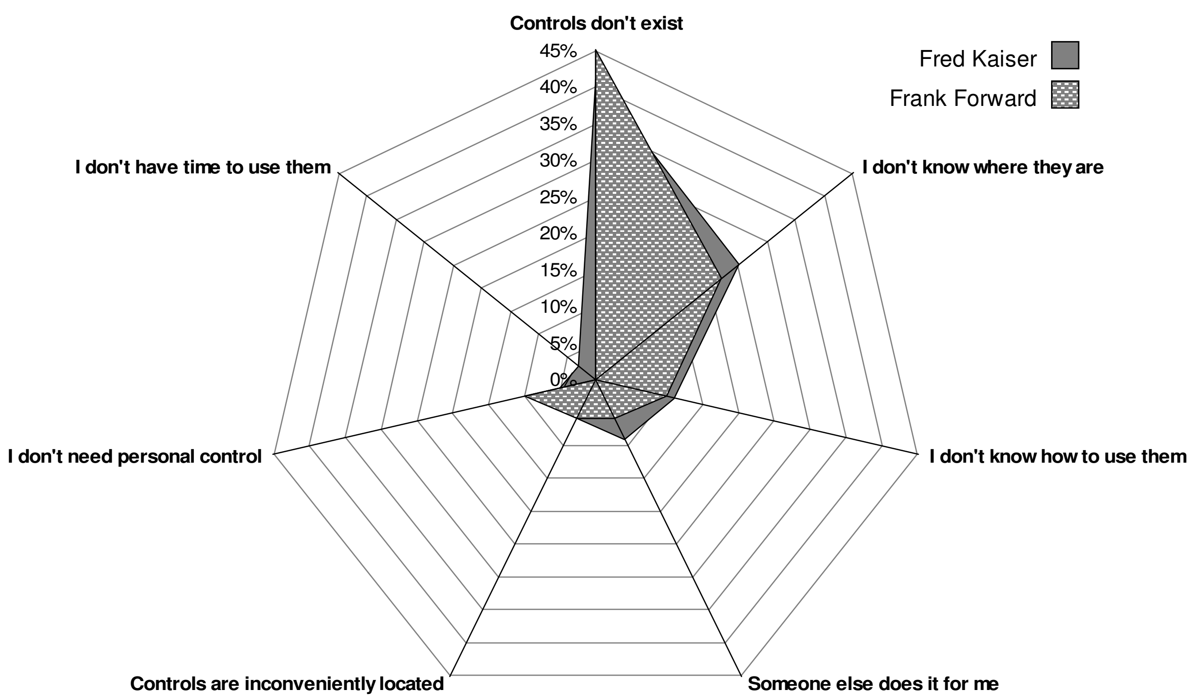

Figure 2.15 Per cent response to reasons for not using personal controls in Fred Kaiser and Frank Forward

2.5.4. *Modifications*

Inhabitants of Fred Kaiser used on average a significantly higher number of personal 'modifications' (e.g., fans, heaters, plug-in lamps, ear plugs/headphones) than in Frank Forward ($p<0.05$), even though management regimes regarding what users were permitted to bring into the building were the same for both buildings (no restrictions). This is an important observation since modifications not only can lead to higher energy consumption in the building, but also can serve as a strong indicator that inhabitants may be uncomfortable in the building, to the degree they have taken their own actions to render the indoor conditions to an acceptable level (for example, see Figure 2.16). A total of 42% of Fred Kaiser respondents reported having made requests for changes to heating, cooling, lighting or ventilation. Of this percentage, 54% were dissatisfied with the speed of response, and 56% with the effectiveness of response. This sentiment is also reflected in the comments:

- 'Communicated, several times, our group's need for better air flow and temperature control. The issue was taken by our facility manager but despite his best efforts could not be solved.'
- 'Have complained about low temperatures in winter. Someone came to check if the sensors were working properly. They were. Nothing changed.'
- 'I wrote Plant Operations emails, as have my colleagues. (Action from administration has not been forthcoming thus far.)'


Figure 2.16 Personal modifications in Fred Kaiser

The issue of personal modification raises the question as to whether users' perception of comfort and satisfaction in the building refer to the modified indoor environment (with use of fans, heaters, extra lights etc.) or to the pre-modified environment. For example, if overall comfort is reportedly high, but a large fraction of respondents are also using personal heaters in the winter, how does this impact the interpretation of results? The findings point to the importance of including of behavioural variables in post-occupancy evaluations, not only as an additional satisfaction indicator, but because of the impact behaviour may have on how overall comfort is perceived. (A potentially more reliable measure of the prevalence of behavioural modifications would be through conducting a thorough energy assessment, e.g. CIBSE TM22.)

2.5.5. Expectations and comfort

In addition to personal modification, it is also important to look at the role that expectations may play in shaping users' experience of comfort and indoor environmental behaviour. The issue of expectations has received considerable attention in the marketing literature, particularly with respect to customer satisfaction and service quality, where 'perceived service quality' is understood as the difference between expected quality of a service and perceived performance of quality of service (Parasuraman *et al.*, 1985). In the context of green building performance, 'perceived comfort' can similarly be thought of as the difference between expected indoor environmental quality and perceived performance of indoor environmental quality. Further, it is useful to distinguish between 'ideal' expectations, that is, how inhabitants wish the building would perform, and 'normative' expectations, that is, how they think the building should or ought to perform (Teas, 1993).

One way to evaluate the influence of 'ideal' expectations is to consider occupants level of 'forgiveness', or the amount of tolerance they have for the building and chronic faults. As has been suggested:

> if people understand how things are supposed to work and what they are for – window controls, perhaps, or thermostats – they tend to be more tolerant if things do not turn out quite as well as they should. (Leaman and Bordass, 2007, p. 665)

Forgiveness is derived by comparing mean values for comfort overall with mean values for specific comfort variables (e.g., lighting, noise, temperature and air quality) (see Equation 2.1). Values are normally in the range of 0.8–1.2, with values greater than 1.0 indicating more forgiveness.

$$\text{Forgiveness} = \frac{\begin{matrix}\text{Comfort Overall}\\ \text{Mean Score}\end{matrix}}{\dfrac{\left(\begin{matrix}\text{TWOverall}\\ \text{Mean Score}\end{matrix} + \begin{matrix}\text{TSOverall}\\ \text{Mean Score}\end{matrix} + \begin{matrix}\text{AirWOverall}\\ \text{Mean Score}\end{matrix} + \begin{matrix}\text{AirSOverall}\\ \text{Mean Score}\end{matrix} + \begin{matrix}\text{LtOverall}\\ \text{Mean Score}\end{matrix} + \begin{matrix}\text{NseOverall}\\ \text{Mean Score}\end{matrix}\right)}{6}}$$

Equation 2.1 Forgiveness, the mean overall comfort score value compared with mean values for specific comfort variables (Usable Buildings Trust, 2008). Note: TW Overall = satisfaction with temperature in winter; TS Overall = satisfaction with temperature in summer; AirW Overall = satisfaction with air in winter; AirS Overall = satisfaction with air in summer; Lt Overall = satisfaction with lighting; Nse Overall = satisfaction with noise

In their study comparing conventional and green buildings from a data set of 177, Leaman and Bordass (2007) conclude that occupants may be more tolerant of green than conventional buildings. In particular, they found that people were more likely to tolerate otherwise excessively uncomfortable conditions (higher forgiveness scores) in buildings that had natural ventilation. Table 2.3 would suggest similar findings for Fred Kaiser and Frank Forward. Although individual comfort variables received similar scores in both buildings, overall comfort was rated significantly higher in Fred Kaiser than in Frank Forward, translating into a higher forgiveness factor (1.08 versus 0.89).

Building	**Mean Scores**							**Forgiveness**
	Comfort Overall	Temp Winter	Temp Summer	Air Winter	Air Summer	Lighting Overall	Noise Overall	
Frank Forward	3.38	3.63	3.58	3.41	3.56	4.69	3.90	**0.89**
Fred Kaiser (overall)	4.1	3.58	3.41	3.56	3.42	5.47	4.02	**1.05**
Fred Kaiser (fifth floor)	5.25	4.22	3.94	4.28	4.00	6.18	4.35	**1.17**
Fred Kaiser (all but fifth floor)	3.90	3.44	3.28	3.41	3.27	5.47	3.99	**1.02**

Table 2.3 Forgiveness values for Frank Forward and Fred Kaiser, overall and by floor. Note: Bold values signify overall forgiveness score

A breakdown of comfort and forgiveness by location in Fred Kaiser produces somewhat contradictory results to Leaman and Bordass (2007). Satisfaction with overall comfort was found to be significantly higher on the fifth floor than in the rest of the building ($p<0.005$). With other individual comfort variables rated similarly between floors, this translated into a higher forgiveness factor on the fifth floor (air-conditioned) than in the rest of the building (in-slab radiant cooling plus naturally ventilated), 1.17 versus 1.02, respectively. In other words, people were more likely to tolerate otherwise excessively uncomfortable conditions in the mechanically conditioned part of the building compared with the passively conditioned floors.

In terms of 'normative' expectations, the research was interested in users' perceptions of how green buildings ought to perform versus conventionally designed and, in particular, two possible influences of normative expectations on comfort and comfort-related behaviour:

- High performance expectations, met with varied perceived performance of green buildings, leading to inhabitants' tolerance of 'growing pains' in exchange for benefits they receive in terms of fresh air or natural lighting (related to 'forgiveness').

- High performance expectations, met with low perceived performance of green buildings, leading to inhabitants that are more likely to complain or take matters into their own hands when things do not turn out the way they would like.

To investigate these influences, users were asked for their perception of the degree of 'greenness' of the building. In Fred Kaiser, 31% of respondents thought the building was a green building, 33% did not think it was a green building, and 36% did not know whether or not it was green (Figure 2.17). Those who responded 'Yes' compared the building with other less green buildings, referred to visible green features and strategies they had personally observed, and referred to specific things they had heard about the building. Sample responses were as follows:

- 'I think the building is energy efficient, not the best one, but really above the UBC average building.'
- 'I understand it is LEED certified (Silver or Gold I think?) That is enough for me.'
- 'Low-flow/water-free washrooms. Energy efficient lighting. Something resembling solar panels on the atrium roof. Rumors of supposedly "natural" airflow.'
- 'Solar panels, glass, recycled materials.'

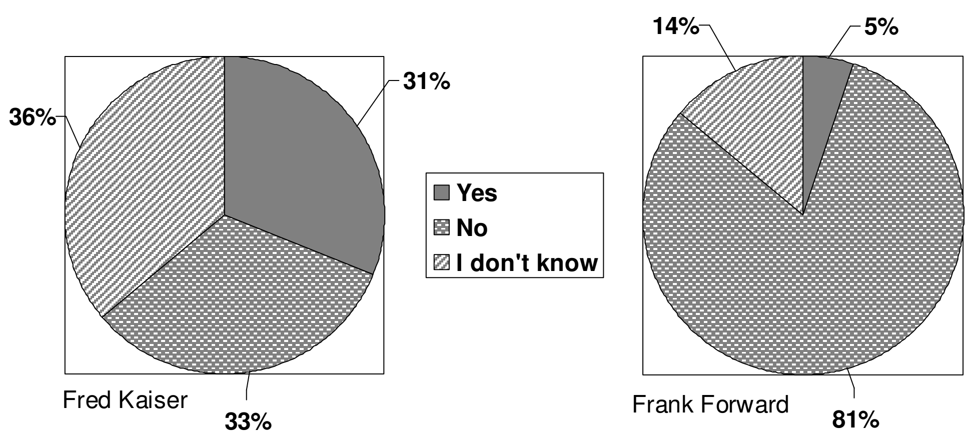

Figure 2.17 Occupant responses to the question 'Would you consider this building to be a green building?'

Those who responded 'No' had their own very specific definitions of what they considered to be green. They pointed to wasted energy or materials in the building, and observed changes to the original building design for reasons the building wasn't green. Sample responses were as follows:

- '"Green" building is a building that does not take away from the comfort of your day to day work.'
- 'I wonder about LEED standards. Putting in light sensors is a start but why do I need to use a heater and fan? Why do I need to block off a glass wall? If this is a green building, then it must be a very light shade of green.'
- 'Some green functions had to be replaced (low-flow toilets); others still do not work correctly (atrium cooling functions). Failure of automatic light function means people leave lights on.'

As expected in Frank Forward, the majority of respondents (81%) did not think the building was green, pointing to thermal comfort and ventilation issues, wasted energy and resources (e.g., heat leaking through windows) and comparing the building with where it could be (in an ideal world). Results suggest that both forms of normative expectations of green building performance may be operating in Fred Kaiser, with many occupants demonstrating a high level of forgiveness, but a few who have clearly been frustrated about the building's failure to deliver on human factors particularly given its celebrated 'green' designation. Further work is needed to understand the degree and direction (positive or negative) to which expectations influence users' perception of comfort, and the role that knowledge may play in shaping their expectations.

2.5.6. Occupant knowledge versus expert baseline

Users were asked to rate their knowledge of how the building performs and comfort is provided. Response profiles were similar for both Fred Kaiser and Frank Forward (Figure 2.18) with an average knowledge score in Fred Kaiser of 2.35 on a scale of 1.00– 5.00, compared with 2.43 in Frank Forward (no significant difference). Occupants were then asked about how they thought heating, fresh air, cooling, and lighting were provided in terms of mechanical, electrical or natural/passive systems. Responses were compared with the expert baseline for each building (Figure 2.19).

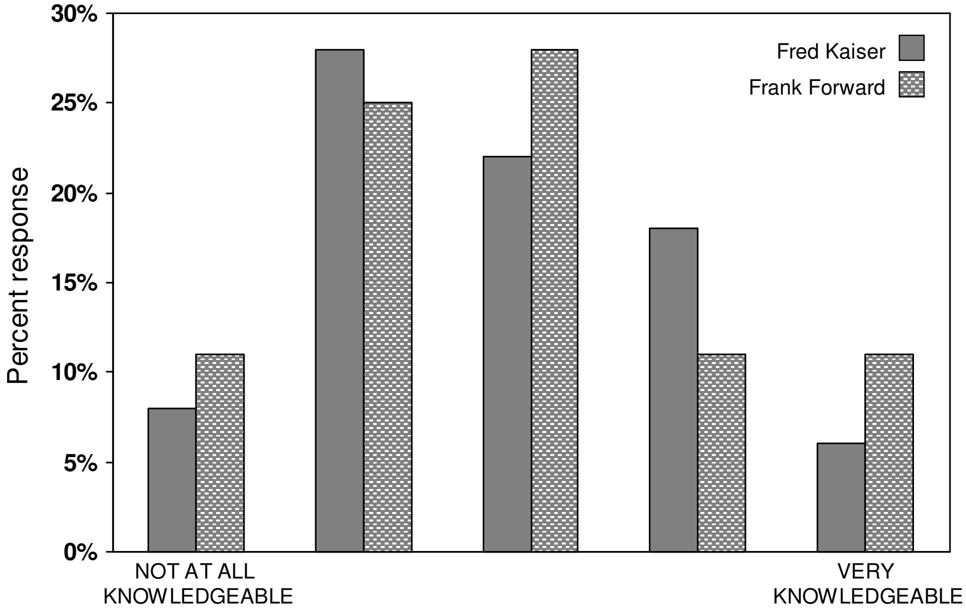

Figure 2.18 Occupant self-rated knowledge of 'how the building performs and comfort is provided'

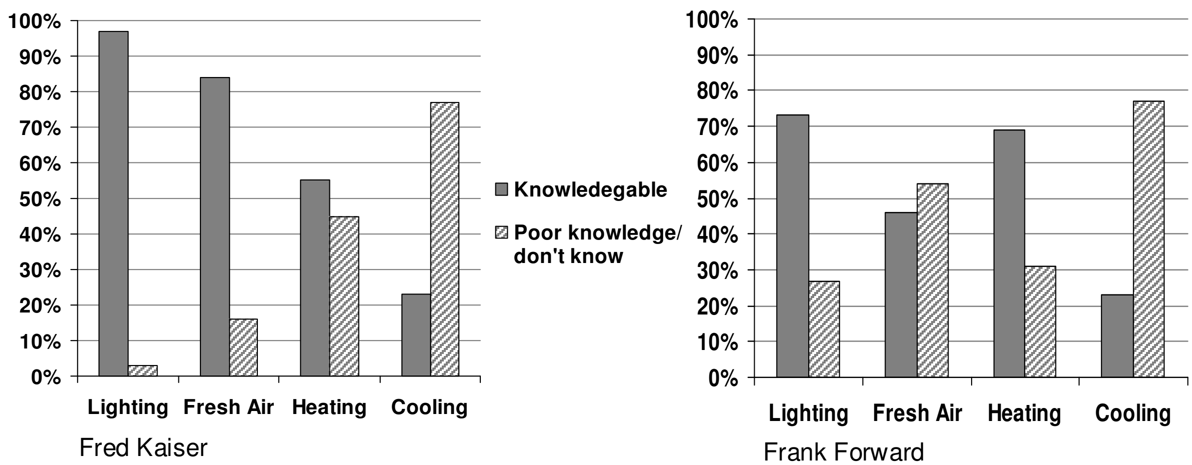

Figure 2.19 Occupant knowledge about specific environmental control systems compared with expert baseline for Fred Kaiser and Frank Forward

Respondents in Fred Kaiser were the most knowledgeable about lighting and fresh air provision, two comfort variables that are both familiar in terms of control (switching lights on and off), and tangible in terms of performance (sensing fresh air). Respondents were less knowledgeable about heating and cooling (Table 2.4). The building expert response for heating provision (mechanical heating combined with natural/passive) was submitted by 30% and 25% of respondents, respectively. However, 11% thought that heating was provided by an electrical system and 34% did not know how heating was provided. The building expert response for cooling provision (mechanical cooling) was submitted by 23% of respondents, while 43% thought that cooling was natural/passive and 35% did not know how cooling was provided.

	Heating	**Cooling**	**Fresh air**	**Lighting**
Mechanical (%)	30	23	34	
Electrical (%)	*11*			61
Natural/passive (%)	25	*43*	50	36
I don't know (%)	*34*	*35*	*16*	*3*
Knowledgeable (%)	**55**	**23**	**84**	**97**

Table 2.4 Fred Kaiser's occupant knowledge of comfort-related building systems compared with expert baseline. Note: Numbers indicate responses that were consistent with the building expert; those in italics are responses that differed from the building expert

In Frank Forward, respondents were the most knowledgeable about lighting and heating provision, and less knowledgeable about fresh air and cooling (Table 2.5). A total of 73% of respondents thought that lighting was provided by an electrical system, which was consistent with the building expert response. However, 23% of respondents also thought lighting was provided through natural/passive means which the building expert did not include in his response. The majority (69%) of respondents thought that heating was provided through a mechanical system, which was consistent with the building expert response. The building expert response for fresh air (mechanical ventilation) was submitted respectively by 46% of respondents. However, a further 29% of respondents thought that fresh air was provided by natural/passive means (e.g., operable windows), which the building expert did not include in his response. Finally, the building expert response for cooling provision (natural/passive) was submitted by 23% of respondents, while 31% thought that cooling was mechanical (i.e. air-conditioning) and 46% did not know how cooling was provided.

	Heating	**Cooling**	**Fresh air**	**Lighting**
Mechanical (%)	69	*31*	46	
Electrical (%)	*9*			73
Natural/passive (%)	0	23	*39*	*23*
I don't know (%)	*23*	*46*	*15*	*5*
Knowledgeable (%)	**69**	**23**	**46**	**73**

Table 2.5 Frank Forward's occupant knowledge of comfort-related building systems compared with expert baseline. Note: Numbers indicate responses that were consistent with the building expert; those in italics are responses that differed from the building expert

Results from the knowledge section of the questionnaire suggest that the method used to assess inhabitants' understanding of building environmental control systems relative to expert baseline was perhaps less accurate than hoped, in that the building expert's perception of comfort provision was equally as subjective as the inhabitant's perception. For example, to the inhabitant, the window was perceived as a source of both fresh air and cooling, whereas to the building expert, the window was seen as a form of comfort control rather than comfort provision. Findings point to the important role that tacit knowledge might play in terms of how individuals understand and interact with buildings, and also reiterates the fact that the exact wording used in questionnaire design can be extremely important in terms of how people respond.

2.5.7. Knowledge, comfort and behaviour

A central aim of the research was to evaluate the relationship between knowledge, behaviour, and overall comfort. Using data on self-rated knowledge of the building, frequency of control use, and overall comfort ranking, a correlation analysis was run for paired independent variables within each building, using Pearson's R as the correlation coefficient. In Frank Forward, correlations between knowledge and comfort and frequency of control use and comfort were positive but not significantly so. There was virtually no correlation between knowledge and frequency of control use in Frank Forward (Table 2.6). In Fred Kaiser, the correlation between frequency of control use and comfort was negative, but also not significant. While there was no correlation between knowledge and comfort in Fred Kaiser, a significant correlation was found between knowledge and frequency of control use ($r = 0.23$, $p<0.05$) (Table 2.7).

	Knowledge	**Use of controls**	**Comfort**
Knowledge	1		
Use of controls	-0.065	1	
Comfort	0.113	0.138	1

Table 2.6 Correlations between knowledge, use of controls, and comfort in Frank Forward

	Knowledge	**Use of controls**	**Comfort**
Knowledge	1		
Use of controls	**0.233**	1	
Comfort	-0.069	-0.170	1

Table 2.7 Correlations between knowledge, use of controls and comfort in Fred Kaiser. Note: Significant correlations are given in bold

Correlations between knowledge, comfort, and behaviour in Frank Forward were too weak support for a justification of the findings. In Fred Kaiser, it would appear that the less comfortable inhabitants are, the more they use personal controls available to them, and the more information they seek about building performance to improve their knowledge. However, possibly due to slow and ineffective controls and the lack of meaningful and effective feedback on the consequences of their actions, users become frustrated and their comfort decreases. This counter-effect of personal control provision and use challenges design assumptions regarding the impact of personal control on comfort, and suggests that there may be more complex factors at play in terms of knowledge and feedback on user actions taken. Findings are supported by the earlier discussion on ‘forgiveness’, which was found to be lower for Fred Kaiser’s passively conditioned floors (in-slab radiant heating and cooling with slow responsiveness), than for the one mechanically conditioned floor (mechanical air-conditioning).

Inhabitants were asked whether they would like to learn more about their building given the opportunity. A total of 59% of respondents in Fred Kaiser said they were interested in learning more, compared with 47% in Frank Forward. Reasons included personal interest or plain curiosity, feeling a sense of responsibility for building performance (‘If learning helps to make the building more “green”, I would be happy to learn’), and reference to an underlying environmental ethic (‘I am very concerned about the environment and would like to know if this building is doing what it reasonably can to help’). A total of 30% of respondents in Fred Kaiser did not want to learn more about the building, and 12% were unsure about whether or not they wanted to learn. Reasons given included being too busy, not having enough time, and – most strikingly – respondents were unsure about what difference learning would make. Sample comments include the following:

- ‘What is there to learn? Should I learn why I should be satisfied with the noise levels?’
- ‘What difference does it make if it is not providing the very basic human conditions? I just need fresh air, modest temperature, and proper ventilation. If the building is not providing these three basics then whether it is green or not is irrelevant.’

Respondents who wanted to learn more about their building in Frank Forward gave reasons relating to the large amount of time they spent in the building. Those who did not want to learn more (35%) or were unsure (18%) gave reasons such as not having enough time, and not feeling a sense of responsibility for building performance. For example:

- ‘As far as I know there is little that I can do to affect the way the building works. If there were effective controls I could use in my area, I would want to know about them.’

Respondents were further asked to identify any means by which they had learned about how the building performs and comfort is provided. Although Fred Kaiser had a user orientation session upon move-in, and currently hosts a building monitoring display in the lobby showing real-time electricity generation from the photovoltaic cells, survey responses indicate that the majority of learning happened by word of month and personal experience. Occupants did not find the orientation session to be relevant to their everyday experience in the building and wished they could have learned more about topics important to them such as how to adjust heat and ventilation. Similarly, in Frank Forward, the learning was primarily by observation, as well as some respondents having spent a number of years in the building.

2.6. DISCUSSION

The premise of this paper has been to explore the influence that ‘knowledge’ may have on occupant behaviour and comfort, and the nature of the gap between assumed and actual comfort and behaviour in green buildings and conventional buildings. The primary vehicle for establishing this was to add separate knowledge and behavioural components to the BUS satisfaction survey, and compare responses across green and conventionally designed buildings. Results suggest that while the availability and use of personal controls were higher in the green building, the quality of personal control in terms of responsiveness, the absence of immediate and relevant feedback, and poor user comprehension may have led to suboptimal indoor environmental conditions. This was evidenced in the fact that Fred Kaiser inhabitants used significantly more personal modifications (heaters, fans, plug-in lamps) than in Frank Forward.

The issue of comprehension and feedback is particularly important in green buildings because of the nature of passive/natural systems employed which are much more closely linked to variations in outdoor conditions, and can have slower response times. Examples in Fred Kaiser include: fan-assisted natural ventilation controlled by a CO_2 sensor with no occupant override of fans, unlike traditional ventilation and cooling systems where users may have control over air speed and temperature; in-slab radiant heating system with thermostat control, which has a much longer lag time than perimeter radiant systems or electrical baseboard heating; and free cooling from operable windows, which serve as an integral part of the cooling and ventilation system.

Building environmental systems that were found to be most intuitive for users to understand and operate were lighting and ventilation. Heating and cooling systems appear to be less well understood in both Fred Kaiser and Frank Forward, which suggests that more attention needs to be paid in designing and communicating thermal comfort systems in buildings over other types of environmental control. The primary reasons given for not using personal controls in the buildings were not knowing where controls were, not knowing how to operate them, and assuming that someone else operated them on behalf of the users. The findings suggest a desire on the part of users to learn more about how buildings work and comfort is provided, with a higher interest level in the green building over the conventionally designed.

The relationship between knowledge, personal control use, and comfort appears to be more complex than what is often assumed in design. In Fred Kaiser, while knowledge was positively related to frequency of control use, this did not necessarily translate into a more comfortable population. Results point to the notion that 'perceived comfort' can dually serve as a trigger for a change in user behaviour (discomfort leads to action), as well as an outcome generated by changes in user behaviour (action leads to improved or diminished comfort). User expectations, related to how they wish the building would perform and how they think the building should perform, may play a role in shaping the direction and magnitude of influence.

The study reported here has attempted to understand and characterize better the 'active inhabitant', and to examine the design strategies and feedback needed to support the transition of occupants to new types of indoor environments. Results from Fred Kaiser hint at the influence of prior knowledge on human interaction with buildings, in particular engagement with personal controls. However, the work reported here also suggests that in order for the human–building interaction to be bidirectional and ongoing, the building must offer immediate and relevant feedback or risk a deterioration of comfort, particularly with respect to new technologies and environmental systems. Feedback on the consequences of exerting environmental control should be directly observable, inherently legible, and deal explicitly with the inhabitants' experience. Increases in knowledge through add-ons such as orientation sessions, signage, lobby displays etc.

may not be adequate or effective. Finally, there is an identified need for a broadening of current post-occupancy evaluation methods to include a wider range of behavioural, situational, and socio-psychological measures which can have real impacts not only on building energy performance, but also on comfort and satisfaction with indoor environmental conditions.

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3. FEEDBACK AND ADAPTIVE BEHAVIOUR IN GREEN BUILDINGS[10]

3.1. INTRODUCTION

Understanding occupant adaptive behavior in buildings has gained significance and attention in the literature in recent years, particularly in the context of climate change and the experience gained from green building design and performance assessment (Chappells and Shove, 2005; Wener and Carmalt, 2006; Roaf, 2006; Holmes and Hacker, 2007). The suggestion that we know very little about user perception and behavioural responses in buildings has implications for building design, energy and environmental performance, as well as occupant comfort, well-being and productivity. Occupant behaviour can become a hidden barrier to exploiting passive strategies in practice (Steemers, 2003), while occupant expectations of building performance can influence how comfort is experienced and achieved (Brown and Cole, 2009).

The successful design of environmentally sustainable, adaptive buildings requires a heightened level of intelligence both in terms of building form, system integration, operation and management, as well as in terms of building occupants themselves. Central to this objective is a tension around where control and intelligence reside (Cole and Brown, 2009). On the one hand, buildings are being embedded with technologies and control strategies designed to perform tasks more reliably and effectively than people. On the other hand, there is a belief that building occupants can be much more adaptive than automated control systems, modifying their environment when needed and reducing the overall footprint of the building and its services. Building performance in the former case relies on trust on the part of occupants, whereas the latter requires knowledge and a heightened level of occupant engagement and responsibility.

In the context of sustainable design, a growing number of buildings are being designed to explicitly enable users to adjust the comfort conditions in their workplace, e.g. through opening and closing windows and blinds, adjusting thermostats, and the flexible use of space. Several recent studies attempt to understand how and why occupants behave adaptively in buildings (Brager *et al.*, 2004; Barlow and Fiala, 2007; Leaman and Bordass, 2007; Yun *et al.*, 2008;

[10] A version of this chapter has been published. Brown, Z., H. Dowlatabadi, and R. Cole (2009) Feedback and adaptive behavior in green buildings. *Intelligent Buildings International*, 1:296–315

Brown and Cole, 2009). In particular, with relevance to this paper, it is important to understand not only *how* occupants behave, but *how they learn* to behave in buildings, and which forms of feedback are the most appropriate and effective at communicating the consequences of their actions.

'Feedback', in buildings, can be defined as the process of "learning from what you are doing, or from what you and others have done, to understand where you are, and to inform and improve what you are about to do" (Bordass *et al.*, 2006). In contrast to the residential energy demand literature, where feedback tends to be viewed as "information about recent consumption… provided after the act" (Lutzenhiser, 1993, p.254) [11], feedback in this paper is considered as acting on a number of different timescales through a variety of processes. Occupants' needs and desires can inform both the building design and management process, while the design team and building *itself* can inform users of design intention and the environmental consequences of their actions. This paper examines how occupants learn, and the extent to which effective feedback is provided through a case-study evaluation of two green office buildings located in Vancouver and Sidney, British Columbia.

3.2. RELATED WORK

The drivers of building energy use have been intensely studied for almost four decades, with economic, social, behavioral, climatologic and technical factors all well documented. A philosophical divide has emerged between those who believe occupants should be kept comfortable with minimal engagement, and those who believe that only through active engagement of occupants can we approach the limits of energy efficiency. There have been no systematic experiments to test the validity of either position. Both approaches rely on feedback, the former favoring simple, responsive controls, the latter advocating an extensive feedback process beginning before the building is designed and carried through implementation and occupancy. This divide has parallels in the ambient intelligence literature, where a distinction has been made between "systems-oriented smartness" and "people-oriented smartness", and the

[11] The authors acknowledge the growing use of instantaneous metering systems in residential buildings (e.g. B.C.'s Smart Meter program), providing *real-time* feedback on energy use, with implications both for managing comfort, consumption as well as evaluating investments in energy efficient capital.

successful operation of both forms of intelligence relies on appropriate and sufficient information from users (Streitz *et al*., 2005; Röcker *et al*., 2005).

How occupants learn to behave in buildings, both passively and actively, has also been explored in a number of different contexts. The coupling of the human learning process with information and incentives has long been a focus of the residential energy demand literature (Kempton and Neiman, 1987; Lutzenhiser, 1993; Wilhite *et al.,* 2000; Darby, 2006; Fischer, 2008). Significant changes in consumption and behaviour reported in many studies suggest that appropriately delivered information might be an important source of energy efficiency gains, particularly when the feedback provided is timely, interpretable and can be addressed through a practical response (Lutzenhiser, 1993). In the commercial sector, Brown and Cole (2009) examined design strategies and feedback needed to actively support the transition of occupants to new types of indoor environments in green buildings. Their findings point to the importance of user comprehension of controls, responsiveness of controls (particularly with regards to passive/natural conditioning systems), and the explicit relevance of feedback to occupant comfort rather than showing how much energy is being used/conserved.

Buildings themselves can play a role in teaching occupants about energy and behaviour. Architecture as "pedagogy" describes the notion that the curriculum embedded in any building instructs its occupants on environmental priorities and that conventional building design teaches that locality is unimportant, energy is cheap and abundant, and disconnectedness is normal (Orr, 1997). Conversely, Orr argues, contemporary green buildings should reflect locality, teach how they are cooled, heated and lighted, the origins of the materials used to build it, and broader lessons of upstream and downstream ecological consequences. Strategies to convey such building information to end-users tend to take the form of either passive or active instruction, where passive instruction is embodied in the building form (e.g. atria, shading devices, reduced material use), and active instruction occurs in the spaces provided by the building (e.g. signage, control interfaces, real-time monitoring and display). Passive instruction conveys to occupants that energy efficiency is taken care of through the building design and form, whereas active instruction is a more explicit attempt to engage occupants in environmentally responsible behaviour. Both can be considered feedback, acting through different processes, with implications for legibility of information, length of time to convey knowledge, and continuity of knowledge over the building's lifetime.

Legibility is often recognized as an important factor in the design of control interfaces, as emphasized in the Building Controls Industry Associate guide "Control for End Users" (Bordass *et al*., 2007). "Occupants," the authors argue, "want to make adjustments as quickly and simply as possible to obtain an environment that suits their needs." In contrast to the notion of buildings as pedagogy, they go on to write "[occupants] are not interested in the technology, only the results" (p. 4). This guide suggests that in order for control devices to be operated as intended, they should be: easy to understand and preferably intuitively obvious, easy to use and effective (otherwise people may choose a more convenient route), give rapid and tangible feedback to show both that the device has been operated and the intended effect has occurred, not need to be used too often, and be located as close to the point of need as possible.

Finally, several recent efforts have been made to extend the concept of feedback in buildings to broader spatial and temporal scales. The Building Performance Evaluation framework (Preiser and Vischer, 2005) is proposed as a way of ensuring that feedback is systematically provided on the building's ability to fulfill the functions of its intended use, through the life of a building, from planning, design and construction, to occupancy, to adaptive reuse or recycling. The framework draws on a model of "continuous quality improvement, to encompass the design and technical performance of buildings and to contribute to knowledge-building in the design and construction industry" (p.16). The "Soft Landings" process (BSRIA and UBT, 2008) similarly focuses on continuous feedback and follow-through by the design and construction team, emphasizing a delivery at the individual building level. Soft Landing components include: constructive dialogue, setting expectations and performance targets at the inception and briefing stage; establishing a building readiness program, training operations staff and users on key interfaces and systems at the pre-handover stage; and providing professional aftercare to help operators get the best out of the building through onsite presence, review meetings and focus groups, review of system performance, occupant satisfaction survey.

In both the above described approaches, feedback is considered to be continuous and multidirectional – between design team, operations staff, users and building itself, and intended to generate knowledge that can guide future decision-making and behaviour. This concept of feedback is particularly important in the context of sustainable design where building systems and indoor environmental control may be new to designers, operators and users, and matching technological and management sophistication is crucial (Cohen *et al.,*1999).

3.3. METHODS

This paper explores how feedback is provided in practice in the design and delivery of two green office buildings, and how this in turn shapes and influences occupant knowledge and adaptive behaviour. The primary means for examining feedback and adaptive behaviour is a post-occupancy evaluation survey of end-users, combined with the interview of the project architect and facilities manager, conducted over the course of an in-depth building site visit.

Two office buildings are examined – the Fred Kaiser building, located in Vancouver, B.C. and the Gulf Islands Operations Centre, located in Sidney, BC - both completed construction in the same year (2005), designed with sustainable principles in mind, and used similar types of systems to provide of heating, cooling and ventilation. While there are a host of variables which may influence occupants' learning and behaviour in a workspace (e.g. building ownership, size, institutional context, workplace culture, number and type of occupants, turnover) for the purposes of the analysis, the focus is on the range and extent of uptake of occupant engagement and feedback strategies employed in the two buildings. The Gulf Islands Operations Centre and Fred Kaiser buildings are examined side-by-side as two buildings representative of a wide spectrum of green-designated buildings wherein feedback processes can vary dramatically over the buildings' lifespan.

In describing the case-study buildings, it is useful to distinguish three phases of sustainable building design and delivery that incur/permit feedback. Throughout the paper, the phases serve as a framework for the assessment of type and level of feedback provided, and the interpretation of survey responses related to occupant knowledge and behaviour.

- *Phase One - Briefing and Design*: The design team conducts pre-design research related to user requirements and needs through program review supplemented with user meetings and interviews. Feedback flows in multiple directions and can vary in terms of the type of information provided and form of exchange, who represents user needs, and over what time frame users are involved. This work is carried out with in a regulatory and technical context for design, shaped by formal and informal standards around how energy efficiency and comfort should be delivered.

- *Phase Two - Implementation*: The design team works with building operators and users to explain how the building operates. This can include a range of training operations and maintenance staff, conducting a building information session, developing a building use manual, and conducting building tours, each of which must be accompanied by a willingness of users and staff to engage/learn in order to be effective. In this phase, metering may also be installed to monitor building energy and system performance for ongoing feedback during the use phase.
- *Phase Three - Use*: Feedback occurs through passive and active learning by occupants about how the building works, through personal control and the response of the indoor environment to this control, users providing feedback to building operators through complaints (and the subsequent response to these complaints), and real-time feedback on the building energy and system performance through metering installed during the implementation phase.

3.3.1. Case-study buildings

Gulf Islands Operations Centre

The Gulf Islands Operations Centre (Figure 3.1) is a 1 045m^2, 3-storey facility designed to accommodate the Gulf Islands National Park Reserve operations and administrative staff. Key sustainability features include: extensive natural lighting, operable windows, an ocean-based geo-exchange heat pump system providing all heating and hot water needs, photovoltaic panels installed on the roof supplying 20% of the building's electricity needs, a CO_2 sensor-activated ventilation system providing 100% outdoor air, and low-emission finishes and material in the interior of the building. The Gulf Islands Operations Centre was the first building to receive the LEED-NC v 1.0 Platinum designation in Canada.

Figure 3.1 Gulf Islands Operations Centre

The design of the Gulf Islands Operations Centre incorporated high levels of user engagement and feedback in the early stages of design (*Phase One*). For example, the architect conducted interviews with each Park staff member to understand their workplace needs and aspirations for the building. The staff members were invited to attend a green building workshop and a concepts development/planning workshop to learn about their ideas and vision for the building. A core user team was formed with representatives from the client, owner, architect, engineer and contractor, who attended an energy performance workshop during design development and continued to meet throughout construction and building implementation.

As part of the building implementation (*Phase Two*), an architect's information session was conducted for all staff several months after move-in, which involved an explanation of building systems, green concepts and personal controls available. The architect designed web-content and two different brochures on the building for educational purposes, and drafted a script for staff to use in conducting building tours for visitors and members of the public. Training of the operations staff occurred at the highest level since the commissioning agent who had conducted technical review of the mechanical, electrical, building envelope and architectural systems became the facilities manager for the building. There was no user manual developed on the operations and management of the building.

During the use phase (*Phase 3*) a "lessons learned" process was initiated by the building owner intended to document and evaluate successes and challenges with the design process, as well as a post-occupancy evaluation of system performance and occupant satisfaction. Metering equipment that had initially been cut from the budget is now being installed post-construction to monitor the performance of the various (separate) electrical circuits as well as the photovoltaic panels. Staff members have access to personal control over thermostats, operable windows, and manual override of photo-sensor controlled lighting. Finally, occupants provide ongoing feedback by way of complaints to the building administrator who feeds requests on to the facility management team. Since building completion and move-in, the Gulf Islands Operations has had 2 staff members retire and 1 staff member leave, representing a turnover rate of 7%.

Fred Kaiser Building

The Fred Kaiser building (Figure 3.2) is located at the University of British Columbia and home to the Electrical and Computer Engineering Department as well as the Dean's Office of Applied Science. At 5 stories high, with a gross floor area of 9 026m^2, key sustainability features include: in-slab radiant heating and cooling, fan-assisted natural ventilation, operable windows, water saving features, and photovoltaic panels providing DC power for emergency lighting. Designed to LEED-Gold standard, the Fred Kaiser building recognized by the UBC Sustainability Office is one of six recent green buildings on campus, representing significant improvements in energy and resource efficiency over the average campus building.

Figure 3.2 Fred Kaiser building

The design of the Fred Kaiser building was less focused on user engagement during the briefing and design stages (*Phase One*) than the Gulf Islands building, relying instead on a comprehensive program guide detailing user needs and requirements with respect to their workplace. A steering committee was formed comprising engineering Department Heads listed to move into the building, and this group attended several meetings through pre-design, schematic design and design development.

The design team provided a number of building tours during building implementation (*Phase Two*) to university planning officials, the steering group, and others outside of the project. As part of the building fit-out, users were invited to participate in furniture demonstration / selection and were briefed on personal control of workspaces, including power, data and security. An architect's information session was conducted at the time of building handover for students and staff, focusing on the building's environmental features and systems. A complete set of maintenance manuals were submitted to UBC Plant Operations and mechanical engineers spent additional time with Plant Operations explaining the operations protocols for the building. Finally, a programmable monitor was installed at the front entrance of the building to display weather, energy consumption, energy generation (from solar panels) and other building system information.

During the use phase (*Phase 3*), a photovoltaic array located in the building's main skylight serves as an 'exposed' building system, and several display boards in the front entrance depict the building's green features. The building took part in a campus Sustainability Office pilot study to display real-time energy consumption as a form of web-based feedback aimed at influencing behaviour change. Staff and students have access to personal control over thermostats, cooling controls (5th floor only), operable windows, and manual override of motion controlled lighting. Finally, occupants provide feedback by complaining to the building Director of Operations who submits requests for changes to Plant Operations; complaints are logged in a campus-wide database and monitored for response taken. Since building completion and move-in, the Fred Kaiser building has experienced a turnover rate of around 40% (mainly graduate students upon completing their program; staff and faculty are more stable).

Table 3.1 below summarizes types of feedback provided in the Gulf Islands Operations Centre and Fred Kaiser through briefing and design, implementation and use phases.

Table 3.1 Feedback through briefing and design, implementation and use phases for the Gulf Islands Operations Centre and Fred Kaiser. Single and double check marks indicate lower and higher degrees of user engagement and feedback

Types and Stages of Feedback	**Gulf Islands Operations Centre (GIOC)**	**Fred Kaiser (FK)**	**Comments**
Phase One: Briefing and Design			
Site and existing facility analysis	✓	✓	Lot area, topography, climate, vegetation, geotechnical aspects, existing infrastructure, surrounding neighborhood.
Needs analysis of functional program	✓	✓✓	GIOC design team felt functional program guide was incomplete. FK design team relied heavily on functional program guide written by trusted external consultant.
Interviews with individual users	✓✓		GIOC architect conducted interviews with each Park staff member to learn about needs and desires.
Green building workshop with users	✓		GIOC design team presented range of possible sustainable design strategies to staff.
Concepts development and planning workshop with users	✓		GIOC design team worked with staff to develop concepts and learn about their ideas and vision for the building.
Regular meetings between design team and steering committee	✓✓	✓	GIOC steering committee included representatives from client, owner, staff (users), engineer and contractor. FK steering committee included engineering Department Heads (users).
Energy performance workshop with steering committee	✓✓		GIOC design team conducted "live modeling" of life-cycle energy analysis with steering committee input to help set the building design.
Phase Two: Implementation			
Architect's information session	✓	✓	GIOC info session covered building systems, green concepts and personal controls available. FK info session focused on architectural strategies and environmental features.
Building tours to owner, steering group and public	✓✓	✓	In GIOC, tours regular conducted during implementation and use phases. In FK, regular tours conducted during implementation phase.
Building tours to users	✓		GIOC design team conducted tours for Parks staff.
Tour script developed for users to offer ongoing tours to visitors and public	✓		GIOC architect developed script for tours.
User participation in tenant fit-out		✓	FK users participated in furniture selection and briefed on how workstations were equipped for personal control, power, data and security.
Information pamphlet and brochure developed on building sustainable design	✓		Content provided by GIOC architect.
Website developed on building sustainable design	✓		Content provided by GIOC architect.

Types and Stages of Feedback	Gulf Islands Operations Centre (GIOC)	Fred Kaiser (FK)	Comments
Phase Two: Implementation			
Maintenance manual developed for operations staff		✓	Complete set of building maintenance manuals submitted to UBC plant operations.
Training of operations staff	✓✓	✓	GIOC commissioning agent became building facility manager. FK operations and mechanical engineers spent time with UBC plant operations explaining building design and operations protocols.
Sub-metering capacity installed	✓		Electric circuits and photovoltaic cells separately metered in GIOC.
Programmable monitor installed for display of system and energy information		✓	FK monitor has capacity to display weather, energy consumption, energy generation (photovoltaic cells), and building management system information.
Phase Three: Use			
Documentation and evaluation of design process	✓✓		GIOC owner conducted a "lessons learned" process to evaluate successes and failures of design process.
Display board on buildings' green features	✓	✓	Lobby displays in both GIOC and FK.
Exposed green building features	✓	✓	Roof-top photovoltaic cells on both GIOC and FK.
Experiential green building features			
Personal control over heating	✓	✓	GIOC: Thermostats within set points - 1 per person (office), 1 per 15 people (open-plan). FK: thermostats within set points - 1 per 4 people (office), 1 per 20 people (laboratory).
Personal control over cooling		✓	FK cooling controls on 5th floor only.
Personal control over operable windows	✓✓	✓	GIOC: 77% users sit next to an operable window. FK 51% users sit next to an operable window.
Personal control over lighting	✓	✓	GIOC: Automated with manual override - 1 per person (office), 1 per 10 people (open-plan). FK: Motion-controlled with manual override - 1 per person (office), 1 per 10 people (laboratory).
User requests for changes managed by building administrator	✓		Building administrator forwards requests for changes to facility manager.
User requests for changes to managed by plant operations (database system)		✓	Building operator forwards requests for changes to UBC Plant Operations. Requests logged in database management system and tracked for response.
Monitoring of building energy and system performance	✓		GIOC building energy and system performance are continually monitored and evaluated by design team and owner
POE review of occupant satisfaction	✓		GIOC owner commissioned a post-occupancy evaluation of occupant comfort and satisfaction

3.3.2. Survey process and response rates

Building users were surveyed in the spring and fall of 2008 using the Building Use Studies (BUS) occupant questionnaire (UBT, 2008 version). The BUS survey gives respondents an opportunity to rate and comment on building design, work requirements, comfort (temperature, air quality, noise and lighting), health and productivity. Widely used in post-occupancy evaluations around the world, the BUS survey has led to the development of national and international building performance benchmarks. For the purposes of analysis, the 2008 BUS International Benchmark was used comprising of 66 buildings (many explicitly designed to high environmental standards) from 16 countries around the world. The survey was modified to include questions addressing occupants' knowledge of the building, how they learned, perceptions of greenness and building energy efficiency, and engagement with control opportunities available to them. The survey was conducted via a Web-based version and ran for approximately one week in each building.

Response rates for the survey were 78% for the Gulf Islands Operations Centre (32 responses, confidence interval = 0.08) and 56% for Fred Kaiser (108 responses, confidence interval = 0.06). In both buildings, the majority of respondents had worked in the building for one year or more. Gulf Islands Operations Centre respondents were older (97% aged 30 or more) and majority female (62%), while Fred Kaiser respondents were younger (46% under the age of 30) and majority male (67%).

In addition to surveying end-users, the project architect of each building was interviewed by the research team to better understand the user engagement and feedback involved in the design, handover and operation of the building. This was complemented with a building walk-through with administration / operations staff, and a meeting with the facilities manager focusing on building environmental features and systems and personal controls available.

3.4. RESULTS

The survey results allow for assessment of: occupant comfort, knowledge, perceptions of building performance, feedback and adaptive behaviour.

3.4.1. Occupant comfort

a. Occupant satisfaction with indoor environmental quality

Occupant satisfaction with comfort conditions in the Gulf Island Operations Centre and Fred Kaiser are shown in Figure 3.3. Satisfaction with overall temperature and air quality were rated within range or statistically higher than the BUS benchmark in the Gulf Islands Operations Centre (mean response: 4.34 and 4.63, respectively), and statistically lower than benchmark in Fred Kaiser (mean response: 3.50 and 3.49 respectively). In both buildings, satisfaction with lighting was rated higher than benchmark (mean response: 5.36 for Gulf Islands and 3.47 for Fred Kaiser) and noise was rated lower than benchmark, significantly so in the Gulf Island Operations Centre (mean response: 2.97 for Gulf Islands and 4.02 for Fred Kaiser). Overall comfort in the Gulf Islands Operations Centre was above benchmark and significantly higher than overall comfort in the Fred Kaiser building ($p<0.05$).

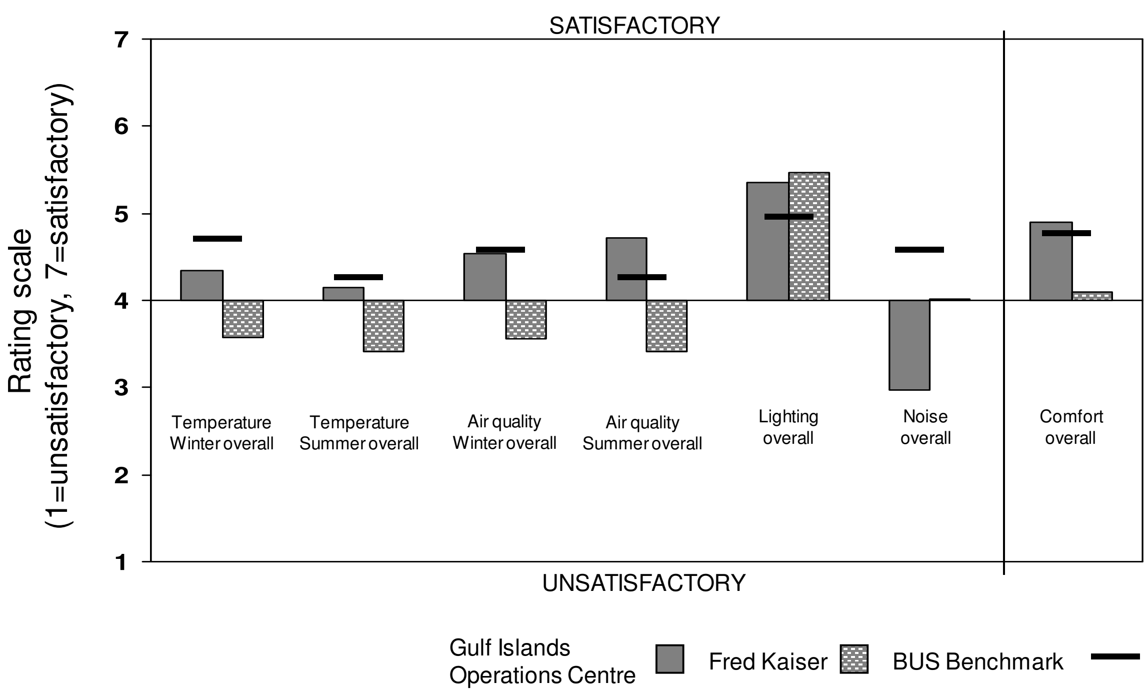

Figure 3.3 Occupant comfort in Gulf Islands Operations Centre and Fred Kaiser compared to BUS benchmark

3.4.2. Knowledge, learning and feedback

a. Level of knowledge on how the building performs and comfort is provided

i. Aggregated population results

Occupants in the Gulf Islands Operations Centre rated their knowledge significantly higher than in the Fred Kaiser building ($p<0.05$). Average self-rated knowledge was 3.38 for the Operations Centre where 19% of respondents described themselves as "very knowledgeable", compared to 2.82 for Fred Kaiser where 8% described themselves as "very knowledgeable" and 10% described themselves as "not at all knowledgeable" (Figure 3.4).

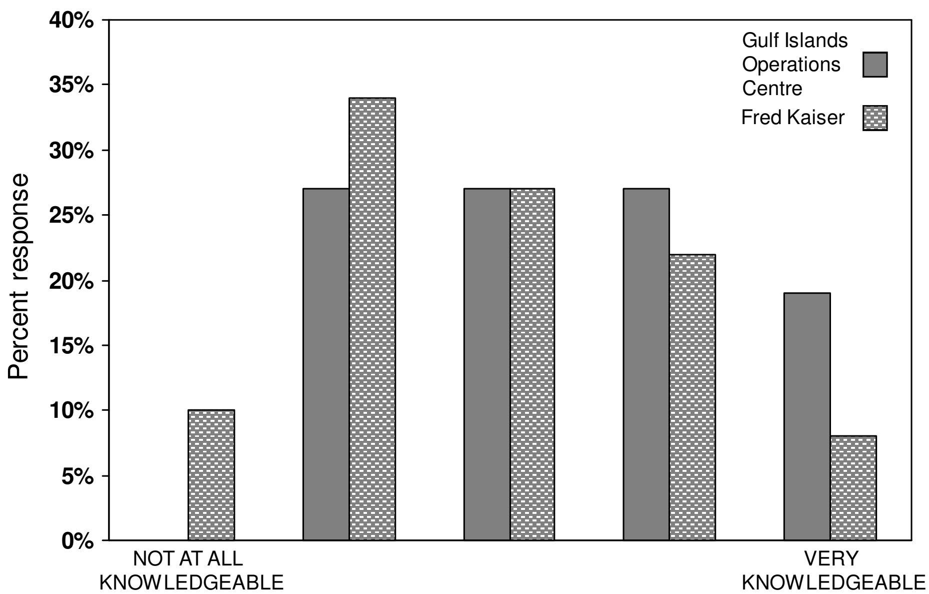

Figure 3.4 Occupants' self-rated knowledge of how the building performs and comfort is provided for Gulf Islands Operations Centre and Fred Kaiser

ii. Disaggregated population results

Based on respondents' descriptions of the work they carried out, Gulf Islands Operations Centre staff was assumed to have a fairly uniform level of understanding of building and control systems across the population. However, the Fred Kaiser population was disaggregated by work type to examine for differences in knowledge between administrative staff and engineering students/faculty. Somewhat surprisingly, there was no significant difference found between mean responses in knowledge for these two groups (mean response: 2.75 administration, and 2.84

engineers)[12]. Normally, one would expect engineers to have a superior knowledge of building operations and controls than the average population. We hypothesized that feedback received in response to their attempted control of comfort was key determinant of self-reported knowledge.

b. Means by which occupants had learned about how the building performed and comfort was provided

Gulf Islands Operations Centre inhabitants described having learned about the building through making use of various forms of information available (e.g. orientation session, pamphlets, signage, tours), as well as through their use of personal controls and talking to others. In the Fred Kaiser building, some respondents learned through bulletin boards and the information session provided by the architect, but in general they lamented the fact that there was little feedback available on user experience (e.g. comfort, personal control etc.) The majority of respondents learned through personal observation, as well as through incurring problems in the building and discussions that ensued either with other occupants or with operations/maintenance. This supports the hypothesis that an absence of effective feedback from building controls led the users to conclude that they did not understand the building.

c. Interest in learning more about how the building performs and how comfort is provided if given the opportunity

Seventy-three (73%) of respondents in the Gulf Islands Operations Centre indicated they were interested in learning more about the building, compared to 59% in Fred Kaiser ($p=0.22$). Reasons in the Operations Centre included a strong desire to know how the building was actually performing compared to predictions, and a personal responsibility to make the building work better and to be able to communicate knowledgeably to the public. Respondents in Fred Kaiser were interested in learning about the building out of personal interest/curiosity, in order to improve their current situation, and to help UBC to learn from past mistakes. Thirty per cent (30%) of respondents in Fred Kaiser did not want to learn more about the building, compared to 19% in the Gulf Islands Operations Centre, and 12% were unsure as to whether they wanted to learn or not, compared to 7% in the Gulf Islands Operations Centre. The only reason provided for not wanting to learn in the Operations Centre was being too busy. In the Fred Kaiser

[12] One limitation of the survey design was that it was not possible to control for individuals' interpretation of the response scale. For example, a computer engineering student may have had much more demanding expectations of what they would consider to be "very knowledgeable" than a non-technical staff person. This could have been addressed by asking respondents to qualify the scale end-points around their response.

building, occupants didn't feel it was necessary for them to have this information, and some didn't understand what difference learning would make to improve their current situation – further confirming their disappointment in having little effective control over their immediate environment.

3.4.3. Feedback and perception of building performance

a. Did occupants consider their building to be green

A significantly higher percentage of respondents in the Gulf Islands Operations Centre considered their building to be 'green' (87%) than in Fred Kaiser (31%) ($p<1x10^{-6}$). Justification of responses for the Gulf Islands Operations Centre included familiarity with the LEED rating system and features in the building that led to the achievement of the Platinum standard, as well as a personal appreciation of environmental features, and a collective sense of pride for the building among staff. Respondents rated the building as 'green' despite identifying certain deficiencies in its performance. In the Fred Kaiser building, respondents who considered the building to be 'green' referred to visible strategies they had observed, and compared its performance to other buildings on UBC campus. Those who did not consider the building to be 'green' referred to the modification or removal of environmental features, to the malfunction of specific aspects of design, and to their observance of wasted energy in the building. Some respondents offered a list of features they would need to see in order to consider the building 'green', and a number stated the requirement for a 'green' building to also deliver a comfortable space.

b. How well did occupants think their building was performing in terms of energy efficiency

Significantly more respondents in the Gulf Islands Operations Centre thought their building was more energy efficient than respondents in the Fred Kaiser (mean response: 4.5 and 2.9 respectively, $p<1x10^{-5}$). However, a higher percentage of respondents in the Gulf Islands Operations Centre also answered "don't know" for energy efficiency compared to in Fred Kaiser (56% and 29% respectively) (Figure 3.5). Open-ended comments from the Gulf Islands building suggested a strong desire on the part of users to learn more about how the building was performing compared to design expectations.

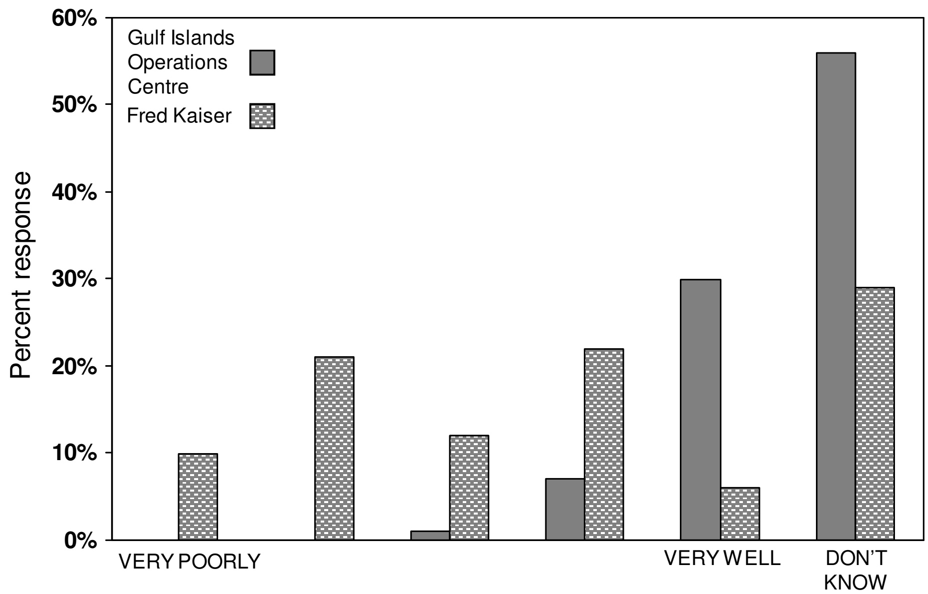

Figure 3.5 Occupants' perception of building energy efficiency in the Gulf Islands Operations Centre and Fred Kaiser

c. Actual building energy performance

Based on data for the period July 2006-2007, the Gulf Island Operations Centre consumed 162.5 kWh/m^2/year. This number includes all energy use for the building: regulated & unregulated loads, lighting, and incidental electricity use outside of the building for the marine support area. Site-generated kWh (photovoltaic panels) is also included. The number represents a 58% reduction in energy use in the Gulf Islands Operations Centre over a typical office building in the same geographic region (Hepting, 2007). The design team is currently working on addressing discrepancies between projected and actual consumption, and will eventually communicate energy information to users via a real-time monitoring system. In the Fred Kaiser building, although a metering feedback system had been set up during the building design, energy data was unavailable at the time of writing due to a number of data connectivity issues, representing in the context of this paper a broken feedback loop between building, operations staff and end-users.

3.4.4. Adaptive behaviour: Use of controls and complaints

Analysis of 'adaptive behaviour' included occupants' use of personal controls (such as windows, thermostats, switches, blinds) as well as their requests to operations staff for changes to be made.

Open-ended responses suggested the two behaviours were often interrelated, with control and complaints viewed by respondents as either complementary or alternative adaptive measures.

a. Frequency with which occupants took an action that influenced heating, cooling, ventilation, lighting, or noise

In both buildings, use of personal control was bi-modal, with users taking actions either frequently (several times/week, once/day or more) or not at all (never). The highest overall level of control was over lighting followed by ventilation, and then cooling. Noise and heating were the least frequently controlled in both buildings (Figure 3.6, Figure 3.7).

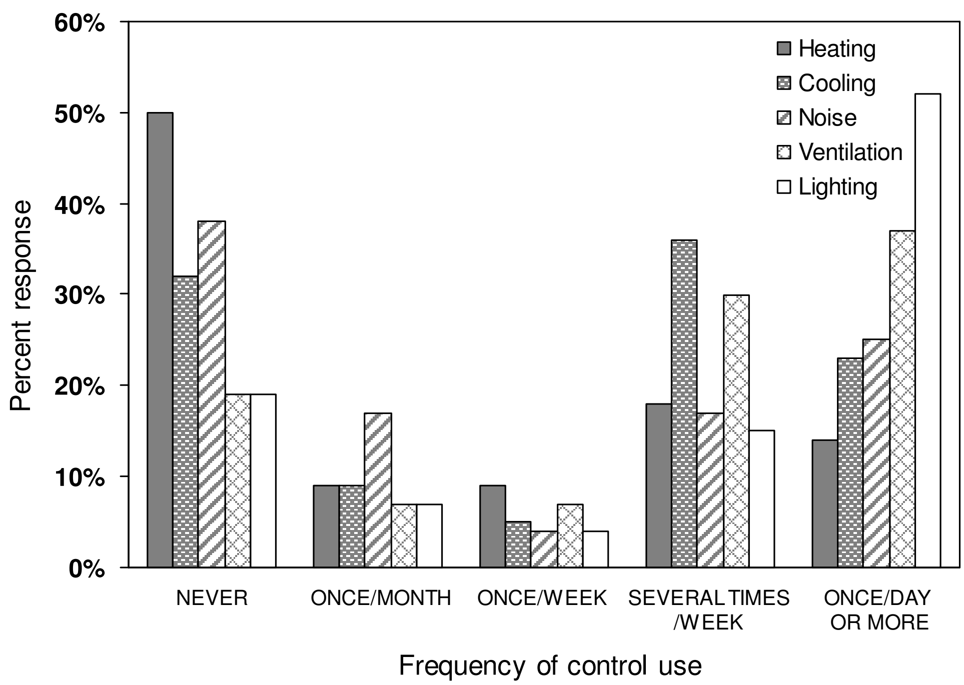

Figure 3.6 Frequency of personal control in Gulf Islands Operations Centre

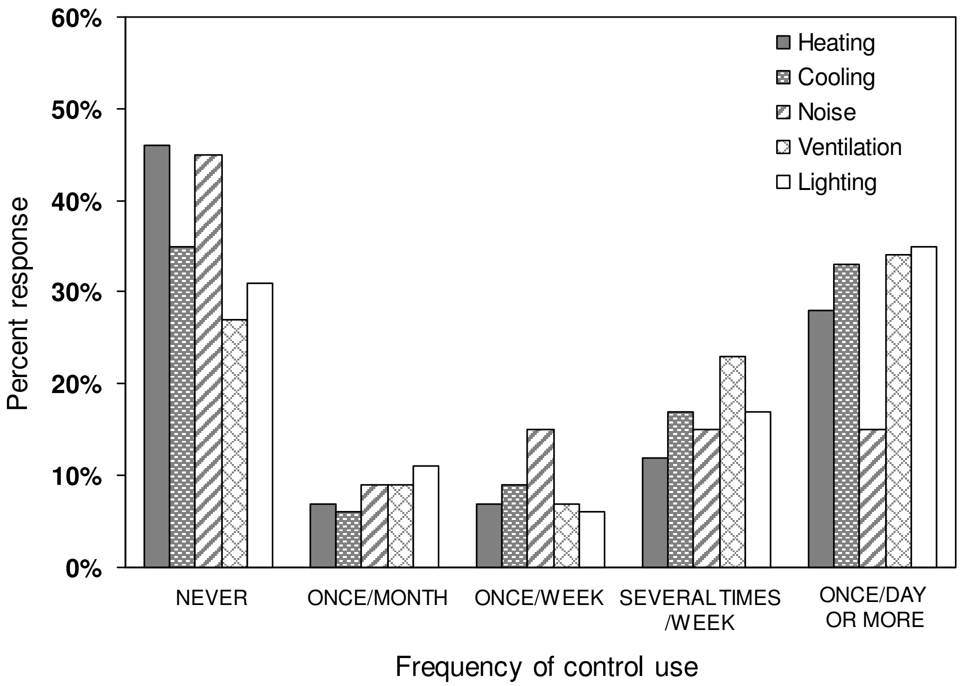

Figure 3.7 Frequency of personal control in Fred Kaiser

Personal control use was related to occupants' satisfaction level with each environmental variable, as well as amount of control available to modify variables. These influences were unpacked by examining personal control use for lighting conditions – with which occupants were highly satisfied in both buildings, and acoustic conditions – with which occupants in the Gulf Islands Operations Centre were particularly dissatisfied. Scatter-plot analysis suggested the use of lighting controls in both buildings was related to the availability of control over lighting more so than occupants' satisfaction levels, and the use of acoustic controls in the Gulf Islands Operations Centre was related to occupants' satisfaction levels more so than the availability of control over noise (which was generally low). Thus frequency of personal control is sometimes but not always an indicator of occupant satisfaction; the availability of controls and effectiveness of feedback received from attempted control also play a role.

b. Ranking of accessibility, usability and responsiveness of personal controls they used

Controls responsiveness was ranked the lowest of the three categories of feedback quality in both the Gulf Islands Operations Centre and Fred Kaiser (Table 3.2). This was not surprising given the longer lag time of passive systems (e.g. radiant heating/cooling, natural ventilation) to respond (Brown and Cole, in press).

	Controls accessibility (Average, scale 1-5, 1=not at all conveniently located, 5=very conveniently located)	Controls usability (Average, scale 1-5, 1=very hard to understand, 5=very easy to understand)	Controls responsiveness (Average, scale 1-5, 1=slow and ineffective, 5=fast and effective)
Gulf Islands Operations Centre	3.4	3.4	3.3
Fred Kaiser	3.3	3.5	2.8

Table 3.2 Average rating of controls' accessibility, usability and responsiveness in Gulf Islands Operations Centre and Fred Kaiser. No significant differences

c. Frequency of requests for changes to heating, lighting, ventilation, or air-conditioning/cooling, and satisfaction with the speed and effectiveness of response

In the Gulf Islands Operations Centre, 56% of respondents had made a request for change, and 44% had not. Complaints in the Operations Centre mainly had to do with the lighting control systems, and thermal comfort and ventilation in the summer. In the Fred Kaiser building 42% of respondents had made a request for change, and 58% hadn't[13]. Complaints in Fred Kaiser generally had to do with operational issues related to the heating system, design issues related to airflow and temperature (which were often not resolvable), and lack of responsiveness from the operation/maintenance team. Satisfaction with speed and effectiveness of responses to complaints were similar in both buildings, with higher overall satisfaction with speed of response than effectiveness of response (Table 3.3). A number of respondents in Fred Kaiser ranked the speed and effectiveness of response to complaints even though they had never made a request for change, evidence of the social nature of feedback in this building, particularly in shared spaces.

	Satisfaction with speed of response (Average, scale 1-7, 1=unsatisfactory, 7=satisfactory)	Satisfaction with effectiveness of response (Average, scale 1-7, 1=unsatisfactory, 7=satisfactory)
Gulf Islands Operations Centre 56% complained, 44% didn't	2.8	2.3
Fred Kaiser 41% complained, 58% didn't	3.2	2.4

[13] Given the greater amount of shared space in the Fred Kaiser building than in the Gulf Islands Operations Centre (e.g. lab space shared by 20 graduate students), one complaint logged may have actually represented a number of occupants' uncomfortable situation. Sample comment: "Communicated, several times, our group's need for better air flow and temperature control. The issue was taken by our facility manager but despite his best efforts could not be solved." The percentage of complaints reported should therefore be interpreted as a measure of uncomfortable space, rather than a measure of uncomfortable occupants.

Table 3.3 Average satisfaction with speed and effectiveness of response to complaints in Gulf Islands Operations Centre and Fred Kaiser. No significant differences

3.4.5. Knowledge, perceptions of building performance and comfort

Statistical analysis was performed to examine how occupants' engagement with personal controls and complaints related to their knowledge of the building, comfort and perception of building performance. Correlation analysis was run with paired independent variables for each building to determine the strength and direction of relationships between variables. Complete correlation matrices are provided in Table 3.4 and Table 3.5, with significant correlations identified in bold and similarities and differences between buildings highlighted. Key findings are summarized in Table 3.6.

	Knowledge	Greenness	Energy efficiency	Comfort	Perception of control	Use of controls	Complaints
Knowledge	1						
Greenness	0.268	1					
Energy efficiency	0.511	-0.184	1				
Comfort	**0.433**	0.280	0.191	1			
Perception of control	0.136	0.111	-0.052	0.041	1		
Use of controls	-0.030	0.219	0.258	0.124	0.496	1	
Complaints	-0.075	-0.267	-0.064	**-0.428**	0.037	-0.097	1

Table 3.4 Relationship between knowledge, perceived building 'greenness', perceived building energy efficiency, comfort, personal control, and complaints in the Gulf Islands Operations Centre. Significant correlations are in bold. Key similarities with the Fred Kaiser building are highlighted with a black oval; key differences with a black rectangle

	Knowledge	Greenness	Energy efficiency	Comfort	Perception of control	Use of controls	Complaints
Knowledge	1						
Greenness	-0.036	1					
Energy efficiency	-0.107	**0.726**	1				
Comfort	-0.069	**0.681**	**0.725**	1			
Perception of control	**0.250**	0.167	0.104	**0.235**	1		
Use of controls	**0.275**	-0.088	-0.227	-0.112	**0.413**	1	
Complaints	0.104	**-0.291**	**-0.369**	**-0.306**	0.170	**0.312**	1

Table 3.5 Relationship between knowledge, perceived building 'greenness', perceived building energy efficiency, comfort, personal control, and complaints in Fred Kaiser. Significant correlations are in bold. Key similarities with the Gulf Islands Operations Centre are highlighted with a black oval; key differences with a black rectangle

	Gulf Island Operations Centre	Fred Kaiser
Knowledge ⟷ Comfort	+	No correlation
Energy efficiency ⟷ Comfort	No correlation	+
Greenness ⟷ Comfort	No correlation	+
Energy efficiency ⟷ Greenness	No correlation	+
Personal control availability ⟷ Personal control use	+	+
Comfort ⟷ Complaints	–	–
Personal control use ⟷ Complaints	-	+

Table 3.6 Summary of key correlations between knowledge, comfort, perceived energy efficiency, perceived 'greenness', personal control, and complaints. Positive correlations are represented by plus signs; negative correlations represented by minus signs. Largest plus and minus signs represent correlations between 0.6-0.79, medium signs represent correlations between 0.4-0.59, small signs represent correlations between 0.2-0.39, and very small signs represent correlations < 0.2

Knowledge and comfort were positively correlated ($r=0.43$, $p<0.05$) in the Gulf Islands Operations Centre, possibly suggesting that improved knowledge of building systems and comfort provisioning, through various means of feedback described by respondents, led to improved overall comfort in this building. No such correlation was found in the Fred Kaiser, despite self-rated knowledge having a similar distribution in both buildings (higher on average in

Gulf Islands Operations Centre). Rather, comfort in Fred Kaiser was strongly positively correlated to perceived building energy efficiency ($r=0.73$, $p<0.01$) and perceived greenness ($r=0.69$, $p<0.01$). The strength of the correlations was both in the positive and negative quadrants. In other words, respondents who were more comfortable overall also perceived the building to be meeting expectations of greenness and energy efficiency, whereas respondents who were less comfortable overall perceived the building to be failing on many fronts, including greenness and energy efficiency. Moreover, in Fred Kaiser occupants positively correlated building greenness and energy efficiency. These types of correlations were not found in the Gulf Islands Operations Centre, where respondents appeared to be better able to separate out the notion of comfort from green, as well as green from energy efficient.

In both buildings, perception of personal control and use of personal control were positively correlated, and comfort and complaints negatively correlated. However, in the Gulf Islands Operations Centre, a negative correlation was found between personal control use and complaints, while this correlation was positive and significantly so ($r=0.31$, $p<0.05$) in the Fred Kaiser building. One possible explanation for this finding is that in the Gulf Island Operations Centre, controls and complaints are seen as alternative forms of adaptive behaviour, whereas in Fred Kaiser, they are viewed as complementary: occupants who use personal control also tend to complain to management, and vice versa, occupants who don't use personal control choose not to complain to management either. Evidence for this was found in the open-ended comments, with some respondents in Kaiser having "given up" on both controlling and complaining about indoor environmental conditions.

3.5. CONCLUSION

The aim of this study was to evaluate how occupants learned about their buildings and the extent to which user engagement and effective feedback influenced their knowledge, perceptions and adaptive behaviour. Feedback was considered in the broader sense as information flow through a number of processes and scales over the lifetime of a building. This concept of feedback is particularly important in the context of sustainable design where building systems and indoor environmental control are likely to be new to both operators and users, and matching technological and management sophistication is crucial.

The two buildings studied employed a range of feedback mechanisms through building briefing and design phase to implementation and use phase. This had to do with a number of factors including the scale of the project, architect's approach and mandate, the nature of the client and institutional processes in place, as well as the characteristics and culture of the building end-users.

Gulf Island Operations Centre occupants reported a high level of satisfaction with a building that met their comfort needs (with the exception of acoustics), and reinforced a sense of pride in their work and organization. Staff, many of whom were involved in a part of the design process, perceived the building to be green in terms of environmental systems, and wanted to learn whether it was actually saving energy as well. They had personal control, made requests for changes when necessary, and were able to provide feedback for Phase 1 (Briefing and Design) of the next Parks Canada green building. In contrast, Fred Kaiser building occupants reported a building that wasn't meeting their comfort needs, therefore wasn't considered by respondents to be particularly green or energy efficient. The benefit of feedback from Kaiser was to communicate their experience to designers to improve Phase 1 of the next generation of UBC green buildings. Since gains from feedback to current occupants were perceived to be low, their desire to learn about the building was also reduced.

Self-reported knowledge of the building was influenced not only by user engagement and feedback during building design and handover (evidenced in the Gulf Islands Operations Centre), but also through feedback occupants received in response to their attempted control of the indoor environment during the use phase. In Fred Kaiser, absence of effective feedback from building controls may have led users to conclude that they didn't understand the building as well as they thought. Furthermore, slow and ineffective response to complaints to management led some users to abandon engaging with the building altogether. The notion of 'learning to behave' in Fred Kaiser reflected learning not to complain, not to adjust controls, in other words to be passive rather than active occupants. Given the challenges described in this paper of how to interpret subjective statements of comfort, knowledge, and engagement, it is impossible to know whether occupant adaptive behaviour in Fred Kaiser was shaped by their satisfaction levels, or by a general feeling of despondence. This can only be assessed through longer interviews and understanding that complaints logged with central facility services can take weeks to resolve.

A growing number of sustainable buildings are being designed to explicitly enable users to adjust the comfort conditions in their workplace through personal control or other means. This is driven by evidence that the provision of personal control can lead to improved occupant comfort, and the belief held by some that only by actively engaging occupants in the buildings they inhabit can we begin to approach the limits of energy efficiency. Feedback is a central component of occupant engagement acting on a number of different time scales/processes. This paper raises the question of what happens when feedback fails and occupants learn to be passive rather than active participants? The implications for comfort, energy use, and user acceptance of green buildings are potentially huge. Further research is needed to better understand how to balance intelligence and engagement in the context of green building.

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4. EVALUATING USER EXPERIENCE IN GREEN BUILDINGS IN RELATION TO WORKPLACE CULTURE AND CONTEXT[14]

4.1. INTRODUCTION

The benefits of green building[15] to the organizations and individuals who inhabit them are the subject of increasing attention and research. Green building strategies have been linked to gains in occupant comfort, health and productivity, as well as to organizational success through improved quality of work life, enhanced relationships with stakeholders, enhanced community livability, and the ability to market to pro-environmental consumers (Heerwagen, 2000). Green buildings also have the potential to shape and reinforce organizational culture, through imbuing values and beliefs around the human connection to nature and sustainable patterns of living, offering greater personal control and responsibility to occupants to shape their immediate environment, and fostering a collective sense of responsibility and pride for the organization and building (Cole *et al*., 2008).

Much of the evidence on the performance of green building in-use stems from early adopter projects where the notion of 'green' was considered to be front-and-centre in the design and operation priorities. With green building moving into mainstream, office buildings are now incorporating 'green' into the workplace in much more subtle and integrated ways. The contemporary workplace is expected to provide a whole host of benefits including a reassuring atmosphere, compensation for the abstraction of work, protection of workers from stress, unification of the organization, expression of organizational values, motivation and mobilization of staff, promotion of sociability and cooperation, and reflection of a company's desired image (Collard and DeHerde, 2001). Changes in the 21st century including new business processes, new philosophies of spatial organization, and advances in computing and telecommunication,

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[14] A version of this chapter is in print. Brown, Z., R. Cole, J. Robinson and H. Dowlatabadi (2010) Evaluating user experience in green buildings in relation to workplace culture and context. *Facilities,* 28(3/4).

[15] The term "green building" is defined and interpreted in many different ways, primarily related to the range of performance issues addressed, but all green buildings typically strive for a reduction in resource use, reduction in emissions and waste, and the improvement of occupant comfort and health. The definition of green building used in this paper relates to the scope, emphasis and performance targets currently incorporated in voluntary green building rating systems such as Leadership in Energy and Environmental Design (LEED®).

have led to a shift in viewing the workspace as a backdrop for work to an active support for getting work done (Vischer, 2008).

Current trends in workplace design include: a greater emphasis on flexibility, both in work schedules and organization of space, as the assumption of permanent individual ownership of workstations is replaced by increasingly mobile workers (Worthington, 2006); success measured more commonly in terms of the attraction and retention of staff rather than absolute efficiency (Tanis and Duffy, 1999); and building design and internal arrangement of workspace reflecting an increasing effort to take into account a firm's operation and corporate culture (Goodrich, 1986; Haworth, 2000). Each of these factors can fundamentally shape how individuals, groups and the organization operate, and the resulting potential gains in workplace satisfaction and productivity can be difficult to disentangle from those due to green building factors.

The two agendas of workplace design and green building design have for the most part progressed along separate paths. As Heerwagen *et al.* (1998) suggest, "emerging interests in workplace productivity, the workplace of the future and energy efficiency are all proceeding with little connection or common goals". And yet, organizational and green building factors are highly interrelated, some would even argue dependant on one another for success, in the sense that the benefits of both are more likely to occur when the building and organization are treated as an integrated system from the outset (Heerwagen, 2000). By encompassing both environmental and social considerations, such integration may be thought of as a form of 'sustainable' (as opposed to 'green') building design process.

This paper explores this important new area of research, linking workplace design, organizational culture and green building in evaluating user experience in buildings. It centers around a Canadian company's move to a new headquarter building explicitly designed to both shift organizational culture and to meet environmental objectives. Post-occupancy evaluations (POEs) conducted pre and post-move allowed for the unique opportunity to assess physical, organizational and cultural changes that occurred as a result of the move, and how they relate to gains observed in comfort and productivity of staff. The findings have relevance for building designers, owners, operators and end users striving to realize the combined benefits of green and workplace design.

4.2. STUDY DESCRIPTION

The two headquarter office buildings, both located in Toronto, Ontario, are designated in the paper as HQ1 (old building) and HQ2 (new building). HQ1 is a conventionally designed building leased from a property management company and characterized by closed offices and cubicles, while HQ2 is a 'green' designed, custom-built facility characterized by an extensive open plan office layout. Table 4.1 **Comparison of building attributes and properties for HQ1 and HQ2** compares key building attributes and properties for HQ1 and HQ2.

The company is family owned and staff feel strong levels of personal attachment to the brand, the organization and to other members of the staff[16]. It moved from HQ1 to HQ2 in the Fall of 2008, and the research reported below was conducted 6 months prior to and 5 months after the move.

Building Properties	**HQ1**	**HQ2**
Size	16,300 m^2	9,300 m^2
No. of floors	6	2
Year of completion	1974	2008
Tenancy	Leased facility	Custom-built facility
No. of occupants	382	216
Green design	n/a	LEED-Silver standard
Workplace design	Closed offices and cubicles	Open plan layout

Table 4.1 Comparison of building attributes and properties for HQ1 and HQ2

4.2.1. Old facility: HQ1

HQ1 is a 16 300m^2, 6-story traditional office building, located along a busy road in a suburb north of Toronto (Figure 4.1). Built in 1974, the building is concrete construction with sealed, reflective-glazed windows, and conditioned through a central forced air ventilation and cooling system, and radiant perimeter heating. The building has been regularly upgraded by the property management company to incorporate energy efficient fixtures and system upgrades. The property management company is also responsible for building operation and maintenance, complaints resolution, renovations, and exterior landscaping.

[16] For the purposes privacy, the company's identity and several aspects of its organizational structure, culture and operations have been omitted in this paper.

Figure 4.1 Old headquarter building prior to the move

Home to 382 employees, HQ1 served as the central location for company operations, information technology, real estate, marketing, human resources, finance, and accounting. Organizational culture in HQ1 centered on the value and responsibility of the individual staff member in helping the company achieve success, exemplified through the company slogan “The difference is you”. The interior workplace design consisted of a combination of cubicle desks in the building core (8ft high partitions, 3-4 sides closure), and closed offices along the perimeter typically occupied by higher level managers. Staff members’ workstations were organized by department in terms of floor number and seating arrangement. Board rooms were centrally located and closed off to the rest of the staff to maximize privacy. Overall, the workplace design and culture embodied by HQ1 could be characterized as private, hierarchical, low-interaction and individually focussed.

4.2.2. New facility: HQ2

HQ2 is a 9 300m^2**,** 2-story green office building, located along a major highway approximately the same distance from the downtown core as HQ1 (Figure 4.2). Although accessible by public transit, most employees at HQ2 drive to work, as with the previous building. Completed in 2008, the building was designed to LEED-NC Silver standard, with key sustainability features including: extensive natural lighting, views to the outdoors for 90% of spaces, daylight and occupancy sensors, high efficiency lighting fixtures, CO_2 monitoring, low-emission materials and finishes, water efficient fixtures, and native vegetation landscaping. While custom designed and built, the building remains leased from the development company who are also responsible for facilities management.

Figure 4.2 New headquarter building after the move

The building was designed to accommodate the same staff and departmental groups as in HQ1, with the exception of the IT department which was re-located to an off-site facility at the time of the move. However, significant cuts to the company operating budget meant that roughly 25% of the headquarters staff was made redundant shortly after the move to HQ2, leaving a remainder of 316 employees in the building.

With the move to HQ2, the company used the opportunity to promote a new organizational culture centered on the collective rather than the individual, along with the introduction of new company slogan “everyone is special”. The building front entrance expresses a warm and welcoming feeling, with sliding doors opening onto a large closet for visitors’ coats, and bright colours contrasting with subdued beiges and greys in the interior design. A waterfall located in the atrium provides visual and acoustic benefits, and a self-serve coffee bar offers free beverages to employees throughout the day. The building also houses a 24-hour gym and fitness facility, offering a variety of exercise classes to staff and providing day-lockers and showers.

The most striking difference between HQ2 and HQ1 is the workplace design, now characterized as one large open plan office. The majority of staff members (80%) sit at workstations on the ground floor, arranged in inter-connected desks (5-12 people per hub) with below eye-level partitions. There is no differentiation in workstation size or location based on hierarchy; the executive team sit with the rest of the staff. Meeting rooms located along the south perimeter have glass walls to maximize transparency. There are a number of collaborative workstations interspersed among the desk hubs, as well as quiet spaces for concentrated work. Sound masking is provided by white noise generators combined with background radio playing throughout the building. Overall the workplace design and organizational culture embodied by HQ2 may be characterized as transparent, egalitarian, high interaction, and collective focussed, a significant shift from the culture of HQ1.

4.3. METHODS

Building users were surveyed in the spring of 2008 (HQ1) and 2009 (HQ2) using the Building Use Studies (BUS) occupant questionnaire (UBT, 2008 version). The BUS survey gives respondents an opportunity to rate and comment on building design, work requirements, comfort (temperature, air quality, noise and lighting), health and productivity. Widely used in post-occupancy evaluations around the world, the BUS survey has led to the development of national and international building performance benchmarks, which can be used to situate the building performance within a broader context. The survey was modified to include questions regarding occupants' knowledge of the building, engagement with personal control, and perceptions of organizational culture[17].

The survey was conducted via a Web-based version and ran for approximately one week in each building. Response rates for the survey were 37% for the HQ1 (145 responses, confidence

[17] Sample questions from the BUS occupant questionnaire (modified) are as follows. (1) All things considered, how would you rate the building design overall? (2) All things considered, how to you rate the overall comfort of the built environment? (3) In the building as a whole, do the facilities meet your needs? (4) Specifically, for the work that you carry out, how well do the facilities meet your needs? Please give examples of things which can hinder effective working?… and examples of things which usually work well? (4) Please estimate how you think your productivity at work is decreased or increased by the environmental conditions in the building? (5) Do you feel more or less healthy when you are in the building? (6) How would you describe your overall sense of wellbeing at work?… stress while at work?… level of personal attachment to this organization?

interval = 0.06) and 48% for HQ2 (104 responses, confidence interval = 0.07). In both buildings, the majority of respondents were aged 30 or over (76% in HQ1, 87% in HQ2) and female (60% in HQ1, 56% in HQ2). In HQ1, 58% of respondents had worked in the building for one year or more while 42% had worked there for under a year, while in HQ2 all respondents had worked in the building for less than a year. Since the survey was completed anonymously, it was unknown how many and which respondents of the HQ2 survey had also completed the HQ1 survey.

Due to limited resources, it was not possible to conduct a full assessment of corporate culture (e.g. as per Goodrich, 1986) however, the human resources manager, who had held this post in both HQ1 and HQ2, was interviewed to gain insight into strategic aspects of the organizational culture and workplace environment. In addition, company publications (e.g. brochures, and tour scripts for the new building) were reviewed for identification of recurring themes and important values and beliefs, and the workplace environment was observed directly through a guided building walk-through and two days spent working in each building.

4.4. RESULTS

Results from post-occupancy evaluations conducted both pre (HQ1) and post move (HQ2) buildings allowed for the assessment of human and environmental performance in terms of occupant satisfaction with workplace design, comfort, productivity, health and well-being, and overall performance compared to benchmark[18]. In addition occupants' perceptions of how organizational culture influenced their behaviour and expectations of the workplace were examined.

4.4.1. Overall satisfaction with building

Occupants in HQ2 were highly satisfied with the building in terms of its overall design, ability to meet needs, image, facilities and furnishings (Figure 4.3). Satisfaction ratings for these variables were significantly higher than had been reported in HQ1, and exceeded the BUS benchmark.

[18] Throughout the results section, "benchmarked dataset" and "benchmarked buildings" refer to the 2008 BUS International Benchmark comprising 66 buildings from 16 different countries, the majority of which are new buildings and 'green' designed.

Open-ended comments suggested occupants appreciated the aesthetic quality of the architecture and interior design of the new building, the brightness, openness and views to outside and the availability of meeting rooms. Some respondents complained about the lack of printers, and not having enough storage at their desk for files and personal items. (The latter may have related to the introduction of a "Clean Desk" policy in HQ2, designating a central storage area for staff to keep personal items such as coats, boots, umbrellas, while requiring they maintain their desk areas clear of clutter). Overall, satisfaction with the building design of HQ2 ranked in the 83rd percentile of benchmarked buildings, and related to both workplace design (workstation layout, meeting rooms, storage) as well as green aspects (daylighting, views to outside).

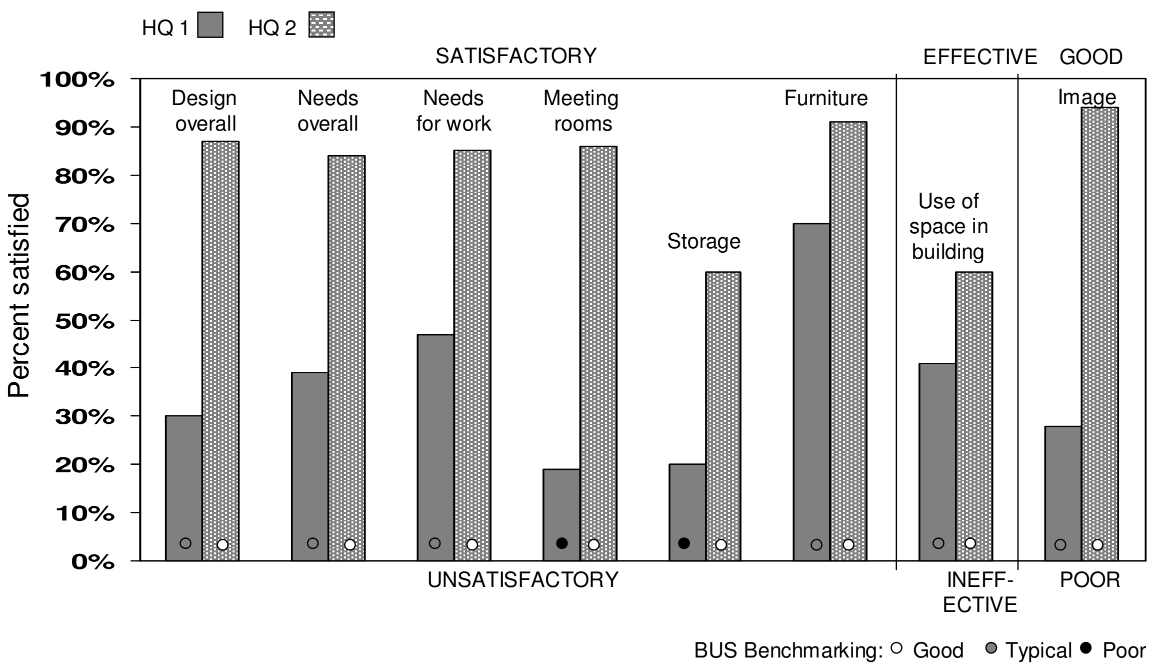

Figure 4.3 Occupant satisfaction with workplace design in HQ1 and HQ2. "Good" signifies that the study building is significantly better than BUS benchmark, "typical" is neither better nor worse than benchmark, and "poor" is significantly worse than benchmark.

4.4.2. *Comfort*

Overall comfort was on average 36% higher in HQ2 compared to HQ1 (Figure 4.4). The greatest gains in comfort were with respect to lighting (70% satisfied) and air quality (48% satisfied) with numerous comments referring to the clean, fresh air and exceptional lighting conditions. Forty-four percent (44%) were satisfied with noise in HQ2 (slight improvement over HQ1) and only

36% satisfied with thermal comfort (slight decline in satisfaction from HQ1). Comments suggested that some found the background music and occasional loud conversations to be distracting in HQ2, with 46% reporting too much indoor noise generally, and 42% reporting too much noise from other colleagues specifically. With respect to thermal comfort, the majority of respondents in HQ2 found the temperatures to be too cold in the winter (69%). Since winter temperatures in Toronto did not differ significantly between 2008 and 2009 (Environment Canada, 2009), this may have been due to HVAC set-points in the building set too low, to accommodate a higher density of occupants than actually materialized (as a result of layoffs). Summer thermal comfort data was unable to be collected, since respondents in HQ2 had not spent a full year in the building at the time of survey.

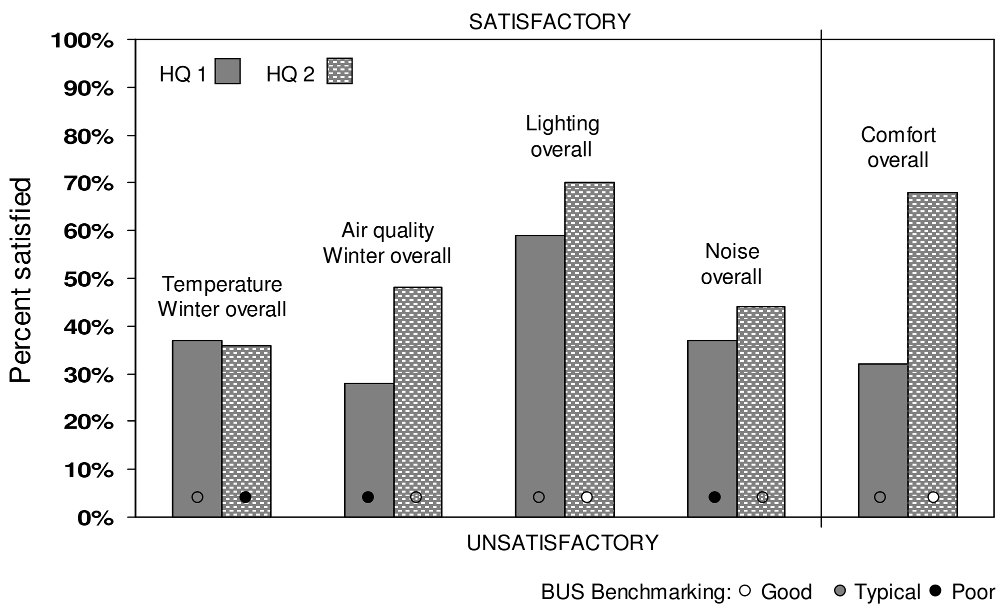

Figure 4.4 Occupant comfort in HQ1 and HQ2 compared to BUS benchmark. “Good” signifies that the study building is significantly better than BUS benchmark, “typical” is neither better nor worse than benchmark, and “poor” is significantly worse than benchmark.

Satisfaction with overall comfort in HQ2 ranked in the 68th percentile of benchmarked buildings, and related to aspects of both workplace design (open plan concept, acoustics) and green design (fresh air, daylighting). Gains in overall comfort from HQ1 to HQ2 were greater than gains in satisfaction with individual comfort variables. This finding may be expressed as a higher level of ‘forgiveness’ of occupants in HQ2 compared to HQ1 (1.21 and 1.08 respectively). Forgiveness is a measure of the amount of tolerance for chronic faults, derived by comparing mean values for overall comfort with mean values for specific comfort variables (UBT, 2008). The value for forgiveness resulting from occupant responses in HQ2 ranked the building in the 95th percentile of benchmarked buildings, and suggests that occupants were willing to tolerate more discrepancies in comfort in HQ2 than in HQ1 for the benefits they perceived in the building overall.

4.4.3. Health and wellbeing

Respondents were asked whether they felt more or less healthy when in the building compared to their experience of using buildings in general. Overall, respondents felt more healthy (41% healthier on average) and rated their overall sense of wellbeing higher (24% improved on average) in HQ2 than in HQ1 (Figure 4.5). Reasons given included better air quality, improved physical health from use of the gym, improved moods from access to sunlight and the waterfall, and a general ‘feeling’ that health and wellness are more of a priority in the new building. Occupants’ perceived health in HQ2 ranked the building in the 80th percentile of all benchmark dataset buildings. It is unclear whether, at the time of the HQ1 survey, staff anticipated that there would be substantial lay-offs occurring within the year. If so, this may also have contributed to the difference in sense of wellbeing between buildings. Thus, while reported improvements to health and wellbeing in HQ2 were in part a reaction to green design features and improved indoor environmental quality, confounding factors resulting from the move, including psychological impacts of staff layoffs, may also have influenced the post-occupancy findings.

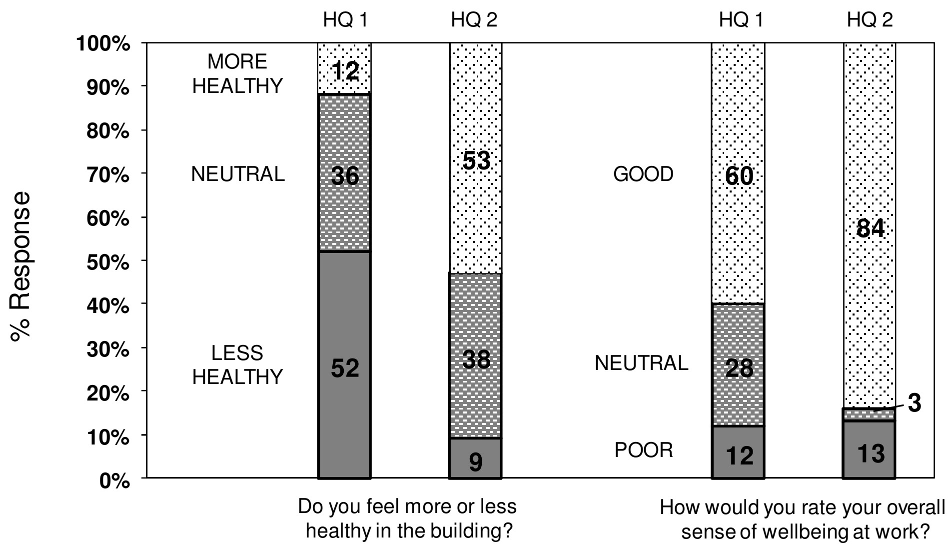

Figure 4.5 Occupants' perceived health and wellbeing in HQ1 and HQ2

4.4.4. Perceived productivity

Respondents were asked to estimate how their productivity at work was increased or decreased by the environmental conditions in the building, compared to their experience of using buildings in general[19]. Three quarters (73%) of respondents in HQ2 rated the building as having a neutral or positive effect on their productivity compared to 39% in HQ1 (Figure 4.6). On average, respondents felt their productivity increased by 5% due to environmental conditions in HQ2, representing a 12% gain in productivity from HQ1, where the average perceived affect on productivity was -7%. Respondents attributed gains in productivity to indoor environmental conditions (natural light, clean air), tidiness of the workspace (in part due to the "Clean Desk policy"), ease of access to colleagues, and improved ability to communicate and collaborate from the open plan concept. It is possible that the major loss of perhaps the less effective colleagues also had an impact on reported productivity.

[19] Perceived productivity, asking occupants to self-assess their productivity at work, is one of many approaches used to evaluate the impact of the indoor environment on work output. Perceived productivity, as defined in the BUS questionnaire, relies on the ability of respondents to compare their own building with "buildings in general", which introduces a degree of bias into the results. Other more accurate measures of productivity include the use of performance metrics such as speed, accuracy and quality of work (where applicable), and the evaluation of absenteeism and churn.

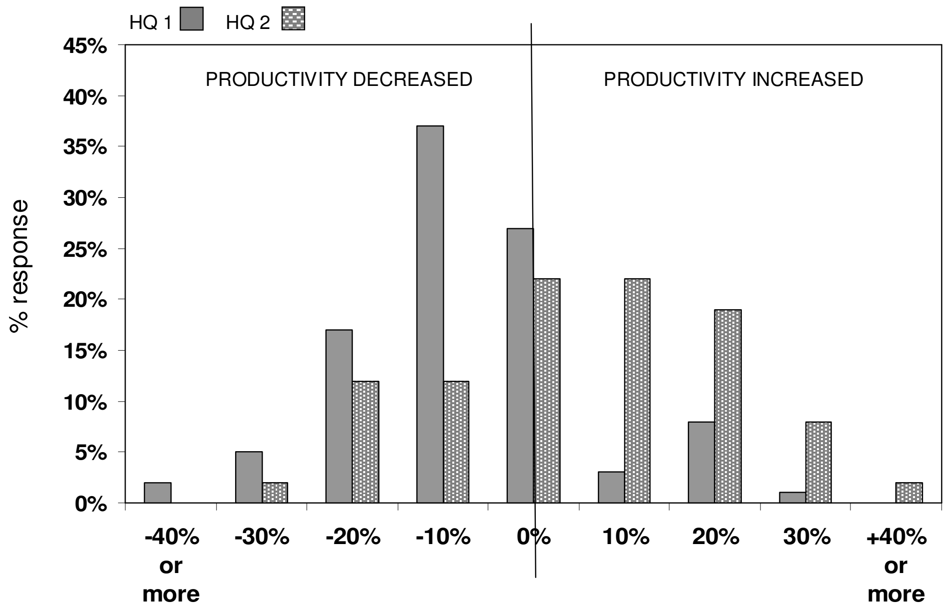

Figure 4.6 Occupants' perceived productivity decrease and increase in HQ1 and HQ2

4.4.5. Workgroup size and personal control

Results for perceived productivity gains in the open plan office of HQ2 are in contrast to Leaman and Bordass (1999) and others who argue that workplace productivity improves when workgroups are smaller and more integrated and individuals have personal control over their immediate environment as typically provided by cellular offices. Occupants in HQ2 reported sharing their office or workstation on average with “4 to 5 others”, which was significantly higher compared to HQ1 ($p<0.05$), and yet surprising given the open plan concept devoid of any noticeable subdivisions. This suggests that the company structure and organization, in terms of working group size (by department, brand etc.) and reporting hierarchy, shaped occupant perception of the extent of their workspace more so than the open plan office itself.

In contrast, the availability of personal control over indoor environmental variables was rated low in both HQ1 and HQ2 (average response “no control” to “low control”), ranking in the bottom 2-8% by variable of benchmarked buildings. The frequency with which occupants took an action to influence their immediate environment was also reportedly low in both buildings (average response “never” to “once/month”). This is not surprising given that in HQ1, lighting switches were one of the few forms of available personal control, while in HQ2 control over heating, cooling, lighting, ventilation and acoustics were all designed to be automated and programmed with no manual override except during non-peak hours.

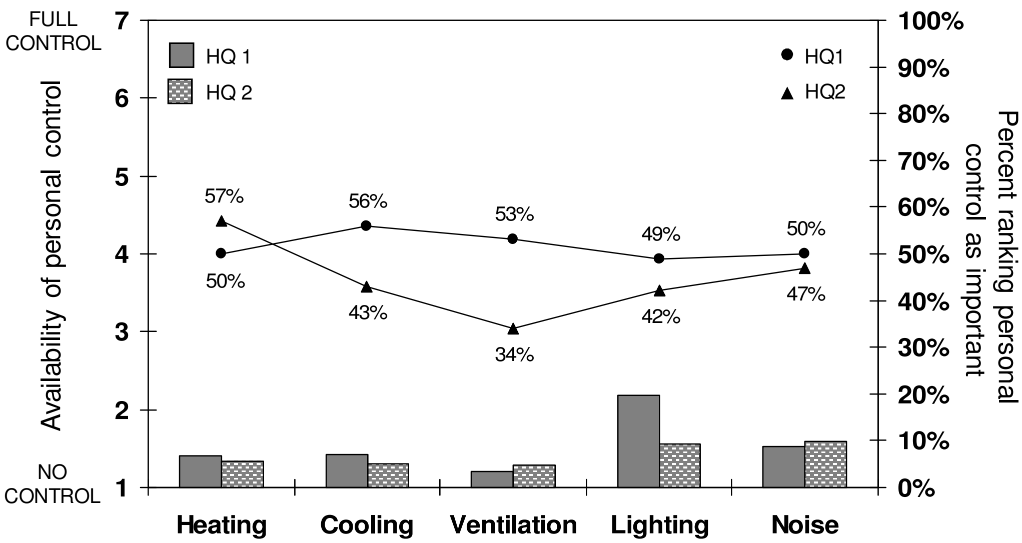

Figure 4.7 Availability and importance of personal controls in HQ1 and HQ2

Environmental control – and users' perception of control – is thought to affect workers both in the physical/mechanical sense as well as the psychological sense through empowerment (Vischer, 2005). While half of the respondents in HQ1 rated personal control over indoor environmental quality as being important to them, this fraction declined in HQ2, particularly for those variables with which occupants' satisfaction had improved, *i*.e. lighting, cooling and air quality (Figure 4.7). Leaman (2003) compares personal control to other design strategies for managing indoor environmental quality including "fit and forget" (systems operating in the background normally without intervention) and "make habitual" (policy, ethics and value systems that implement and internalize control). Findings suggest that the automation of control had, to a great extent, become habitual to occupants of HQ1 allowing for a relatively easy transition into the open plan office of HQ2 when coupled with policy and culture validating this approach. However, when indoor conditions caused discomfort (e.g. winter thermal comfort in HQ2), occupants would like to have been able to do something about it.

4.4.6. Organizational culture

Respondents were asked their opinions regarding how the organization's implicit and explicit workplace "rules" guided their behaviour. There was no significant difference between the number of days and hours worked in HQ1 and HQ2 (average 4.7 days/week, 9 hours/day for both buildings), nor in the flexibility of arrival time at work (average response "somewhat to very flexible" for both buildings). Flexibility of dress code was rated significantly higher in HQ1 compared to HQ2 ($p<0.05$), possibly related to the open plan concept and sharing of workstation with more people in HQ2, including senior management. Overall levels of stress at work were the same across both buildings (average response "somewhat stressful"), and there was no significant difference between occupants' level of attachment to the organization (average response "somewhat to very attached"). It is possible that offsetting effects relating to the staff layoffs and shift in organizational culture contributed to occupants' responses. For example: the stress from moving to a new building and accommodating to the pressures of a reduced staff may have been offset by relief and validation of worth from personal retention in the company; and decline in attachment to the organization due to the constant shifting of culture and slogans may have been compensated for by the appreciation of features and amenities in the new building.

4.4.7. Attribution of performance improvements

Performance improvements in HQ2 over HQ1 were documented in the areas of comfort, health, wellbeing and productivity. Results from the post-occupancy evaluation suggest that these were in part related to workplace design and organizational culture aspects (e.g. open plan concept, high interaction, transparent, egalitarian values, and a greater emphasis on health and wellbeing) and in part related to green building aspects (e.g. daylighting, views to outdoors, improved ventilation, biophillic features). However, a number of other influential factors may also have played a role, complicating the attribution of gains. These included:

- A high level of engagement of company managers in the building design, fit-out and handover, exemplified by:
    - An open plan concept trial set up on the 4th floor of HQ1 pre- move, intended to acclimatize staff to the anticipated workplace design of HQ2.

    - A staged move in to the new building, requiring all staff to engage in learning sessions focussing on the workplace design and new office protocols.
- A concerted effort by the company to convey the new organizational culture, in terms of values, beliefs and identity, through:
    - A tour guide script used to transition occupants into from HQ1 to HQ2 emphasized features such as the calming effect of the waterfall, wellness aspects of the fitness centre, a quiet room intended for moments of personal reflection, as well as considerations for wellbeing and safety embedded in design strategies throughout the building.
    - The building design expressing organizational culture through explicit means (e.g. signage incorporating the new slogan and words such as "comfort", "green building") and implicit means (e.g. high transparency, high interaction, people oriented).
    - Implementation and enforcement of new in-house policies such as the Clean Desk Policy, uniform background music and combined with white noise, and greater automation of control of indoor environmental quality.
- Significant restructuring of up to 25% of the workforce shortly after moving to HQ2, impacting:
    - Perceived wellbeing and levels of stress, relating to the possible anticipation of layoffs pre-move and relief/validation of worth from retention in the organization post-move.
    - Perceived productivity, relating to pressures associated with working with a reduced staff in HQ2 but potentially offset by the loss of perhaps less effective colleagues.
    - Perceived workplace cultural aspects, including level of attachment to the organization amidst layoffs and willingness to adopt new company values and slogans.

As Leaman and Bordass suggest, "buildings are complex systems made up of physical and human elements and their many associations, interactions, interfaces and feedbacks. Because of interdependencies, it is often fruitless to try and separate out different variables and treat them as 'independent'" (1999, p.5). The realization of organizational benefits in HQ2, in terms of gains in occupant comfort, health, wellbeing and productivity, were related to the combined implementation of workplace design and green building design strategies. These strategies were deployed against the backdrop of a company highly committed to the successful transition into a new headquarter building and way of working, while at the same time faced with having to cut the workforce. The outcome was overwhelmingly positive for HQ2, but the lessons learned are difficult to extrapolate beyond the case study. More research is needed combining pre and post-occupancy evaluation with contextual and cultural analysis to better understand the relative contribution of influential factors.

4.5. DISCUSSION

This paper provides a demonstration of the complex nature of user experience in buildings, shaped in part by the characteristics and quality of the space, but also influenced by a host of other factors. Gains in occupant comfort, productivity, health and wellbeing documented in a company's move to a new headquarter building coincided with a shift in workplace design and culture and an emphasis on green building, suggesting that when these aspects work together in synergistic ways the benefits can be considerable. However, workplace design and green building strategies can also interact in antagonistic ways, compromising the potential building performance. Indoor environmental quality in green buildings has been known to cause occupant discomfort in key workplace attributes such as acoustics, lighting conditions and glare, leading to modifications to be made that clash with initial design intentions. Conversely, workplace design can compromise green building performance by failing to take into account the operation of environmental systems and access to control points when programming the use of space and arranging partitions, carpet and furniture. In addition, there are many other factors relating to organizational culture and context which may play a role, some of which have been addressed here, some of which need to be taken into consideration in future studies.

The findings reported raise a number of important considerations for organizational and workspace research, and post-occupancy evaluation of green building:

- How much of the performance improvements attributed to green building are actually green building related, versus those due to organizational culture / workplace design?
- Are certain organizational culture / workplace models more suited to green building design than others?
- What are the potential performance gains to be made from better integrating green building design with workplace design and organizational culture at the outset of design?
- What kinds of demands will this integration place on owners, designers, facilities managers and users in future office buildings?
- What changes are necessary in post-occupancy evaluation to explicitly take into consideration cultural and contextual factors?

This paper begins to articulate some of the key issues arising from the mainstreaming and merging of green building design with workplace design practice. It explores the role of organizational culture in shaping and design and operation decisions, and highlights the need for further research into realizing the combined opportunities from integrating green and workplace goals in the context of building design.

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5. CONCLUSION

5.1. SUMMARY OF THESIS OBJECTIVES

The goal of this thesis was to assess, from an interdisciplinary perspective, the behavioural, socio-psychological and contextual factors influencing occupant comfort and engagement in green buildings. The research was motivated by the identification of gaps in the related literature, specifically in: (1) the role of knowledge and expectations of green buildings in shaping occupant comfort; (2) the role of feedback incorporated into the design and delivery of green buildings in shaping occupant behaviour; and (3) how broader contextual factors relating to workplace and organizational culture influence user experience in green buildings.

In Chapter 2, occupants' knowledge of how their building performs and comfort is provided was compared to an expert baseline in a green and a conventionally designed building. The role of expectations in shaping occupant comfort was examined, as well as the relationship between knowledge, comfort and use of controls. In Chapter 3, the incorporation of feedback into the design, implementation and use phases of buildings was compared for two green buildings. The influence of feedback on occupants' self-rated knowledge of the building, their perception of building performance, their use of controls and complaints was assessed. In Chapter 4, a move from a conventionally designed to a new green building was examined through the lens of cultural and contextual factors shaping design and operation decisions of the latter. User experience was compared in the new and old building in relation to the shifts in workplace, green design and organizational culture that occurred during the move. Throughout the chapters, consideration was given to the implications of findings for the building design process, in particular how comfort and comfort-related behaviour are supported, and to the limitations of current post-occupancy evaluation methods.

5.2. KEY FINDINGS

Collectively, the chapters presented in this thesis support the premise that optimizing green building performance is not only a technical and economic challenge, but equally importantly a human one, and that behavioural, socio-psychological and contextual factors play a larger role in shaping user experience than previously acknowledged. The following summarize four key findings of the research:

1) Occupants' knowledge of a building can significantly influence their comfort levels, when knowledge is gained primarily through involvement. When knowledge is gained primarily through personal observation/experience, occupants' comfort levels correlate to perceived building performance.
2) Both knowledge and perceived 'greenness' of a building are shaped by feedback received by users on building performance (or lack thereof); this feedback influences the degree to which occupants actively engage with the building.
3) Cultural and contextual factors relating to a building's design and operation may play an equally important role in shaping occupant comfort as the quality and characteristics of a space itself.
4) Current post-occupancy evaluation methods are limited in their ability to capture significant socio-cultural determinants of user experience in buildings.

Based on results obtained in Chapter 2, the relationship between occupants' knowledge of a building and their comfort was initially thought to be weak. However, further analysis in Chapter 3 suggested a dependency of the relationship between knowledge and comfort on how the knowledge is formed. In the Gulf Islands Operations Centre, occupants learned about the building through early involvement in its design, orientation sessions and tours, pamphlets and signage, as well as through their direct use of personal controls. An appreciation and subsequent understanding of the building's green design led occupants to better calibrate their expectations of green building performance. This was evidenced by significant positive correlation in the Gulf Islands Operations Centre between occupant knowledge and comfort, and the ability of occupants to make clear distinctions between comfort and perceived building greenness and energy efficiency (Chapter 3).

In contrast, Fred Kaiser building, a "knowledge gap" (Brown and Cole, 2008) was observed relating to the difference between occupants' desire to learn, and the quality, accessibility and relevance of information available to them (Chapter 2). Orientation sessions focused on technical aspects of building design rather than the user experience (comfort, control etc.) and occupants learned about the building primarily through personal observation/experience (trial and error) and word of mouth. Only one-third of respondents consider their building to be ‘green’ (even though it was design to LEED®-Gold standard). Occupants’ comfort did not correlate to their knowledge of the building, but correlated significantly to how green they perceived the building to be. Those who were more comfortable also perceived the building to be greener, while those who were less comfortable also perceived the building to be failing on many fronts including green design (Chapter 3).

Findings underline the importance of engaging users in building design, implementation and use in order to help occupants better understand the building systems and controls with which they are expected to interact (or not interact). Knowledge thus gained can lead to improved comfort levels and occupants’ tolerance of a wider range of indoor environmental conditions and deficiencies. Results also suggest that occupants may have *a priori* expectations around green building performance, which when coupled with informed knowledge of the building design and comfort provision, can lead to gains in comfort and forgiveness, but when coupled with limited knowledge and low perceived building performance, can lead to exacerbation of discomfort. Hence, building performance expectations amplify perceived comfort/discomfort.

Occupant use of personal control and complaints was examined in all three chapters in relation to comfort, knowledge and workplace context. Feedback received by users in response to their attempted control of indoor environmental conditions was found to be a key determinant of occupants’ behaviour and self-reported knowledge of the building (Chapter 3). Particularly, in the Fred Kaiser building, absence of effective feedback from building controls may have led users to conclude they didn’t understand the building as well as they thought, while slow and ineffective response to complaints to management led some users to abandon engaging with the building altogether. Personal control use and complaints were viewed by occupants as either complementary or alternative forms of adaptive behaviour. If controls and complaints both provided effective feedback, occupants were likely to continue to actively engage with the building, whereas if neither controls nor complaints led to the desired outcome, occupants were more likely to tend towards passivity.

These findings have implications not only for the subjective nature of ‘knowledge’ of a building, but also for occupant comfort in relation to overall building performance. The risk of providing controls and complaints outlets that don’t function effectively is either that occupants will make greater use of personal modifications (plug in lamps, heaters and fans) (Chapter 2), or that occupants will learn to suffer discomfort passively (Chapter 3); both of these outcomes have implications for building efficiency and utility. The research thus supports the notion that the quality of feedback in buildings matters more than its provision alone, particularly in green buildings where systems and technologies may be new to users and operators, and accessibility, usability, effectiveness and responsiveness of controls are essential requirements if occupant engagement is to be pursued successfully.

With respect to the subjective nature of ‘knowledge’, the assessment in Chapter 2 of occupant versus expert knowledge led to the realization that expert knowledge of building systems and comfort provision may be as biased as occupant knowledge. Expert knowledge tended to be engineering-based whereas occupant knowledge tended to be more tacit in nature, impacting the interpretation of results and reliance on expert knowledge as a ‘baseline’. For example, the building expert viewed operable windows as a form of comfort control rather than comfort provision, while occupants considered the window to be an important aspect of comfort provision in terms of fresh air and cooling. Because of the limitations of this approach, occupants’ self-rated knowledge of their building (rather than comparative knowledge) was used in statistical analyses performed. However, even self-rated knowledge was found to be subjective in the sense that it was not possible to control for individuals’ interpretation of the response scale end-points (i.e. 1 = not at all knowledgeable, 5 = very knowledgeable). These findings have significant implications for how ‘knowledge’ is used in future post-occupancy survey research, as well as for the way in which building performance information is conveyed to end-users, highlighting the need to take into consideration how occupants view comfort provision in relation to their every day experience, rather than designing educational materials from the designer/engineers point-of-view.

In addition to knowledge, this thesis has highlighted a number of challenges related to interpreting occupants’ subjective statements in post-occupancy evaluations about comfort and engagement with a building. Chapter 2 raised the question of whether occupants’ perception of comfort and satisfaction in the building referred to the modified indoor environment (with use of fans, heaters, extra lights) or to the pre-modified environment. Chapter 3 observed that the frequency of personal control use is sometimes, but not always, an indicator of occupant satisfaction. In the buildings surveyed, control use over IEQ variables with which occupants were satisfied was shaped more so by the availability of the controls. By contrast, control use over IEQ variables with which occupants were dissatisfied was shaped more so by their level of satisfaction with the variable. The frequency of logged complaints was also observed to be a complex indicator of occupant satisfaction, subject to influence from social dynamics, workplace rules, or learned occupant passivity. Chapter 4 demonstrated that there are many other influential cultural and contextual factors which may play a role in augmenting or diminishing occupants' experience of a workspace which can be difficult to disentangle from building design-related factors. These include organizational values and workplace culture, socio-psychological dynamics around the restructuring of a workforce, and other relevant factors encountered in a company's move to a new building, but not captured in post-occupancy surveys typically used to evaluate such moves. The findings identify a need for broadening current post-occupancy evaluation methods to include a wider range of behavioural, socio-psychological and contextual factors, which are demonstrated in this work to have real impacts on occupant comfort and satisfaction as well as building energy performance.

5.3. RESEARCH IMPLICATIONS AND CONTRIBUTION

This thesis provides evidence and further support for expanding the scope of comfort provision and evaluation in green buildings to encompass a wider range of behavioural, socio-psychological and contextual aspects. It builds on previous work, extending the physiological and psychological dimensions of thermal comfort to take into consideration different influences at play in naturally ventilated versus mechanical buildings (e.g. Humphreys and Nicol, 1998; Brager and de Dear, 2000)[20], and broadens the way and extent to which personal control and other adaptive mechanisms are seen to shape occupants' experience and interaction with building systems and indoor environments. The research acknowledges that comfort is fluid and dynamic,

[20] The work of de Dear and Brager (2000) led to the amendment of ASHRAE Standard 55 on *Thermal Environmental Conditions for Human Occupancy* (2004) to include a wider ranging, 'adaptive' thermal comfort standard for occupants of naturally ventilated buildings. Similar efforts are currently under way with the European Standard EN 15251 on *Indoor Environmental Parameters for the Design and Assessment of Energy Performance in Buildings* (CEN, 2007).

shaped by socio-technical systems and the normalization of habits and practices, particularly within organizations. Finally, it supports the development of a new context for comfort provision in green buildings, informed by feedback, experience on real user interactions with buildings, and the recognition that informed occupants and operators are critical to the successful performance of buildings.

New contributions to the literature from this research relate to the evidence provided herein that:

- Educating occupants on design decisions, comfort provision and the building environmental consequences of their actions, may play a valuable role in improving comfort and calibrating green building expectations.
- Feedback may have greater significance in terms of shaping how occupants understand and interact with a building and as a result experience comfort than previously acknowledged, not only in the building in-use phase, but through building design and implementation
- Personal control and complaints can be viewed as complementary and equally important forms of occupant adaptive behaviour, with the speed and effectiveness of response to both influencing occupants' self-rated knowledge of a building, and whether they choose to be active or passive participants in improving its performance.
- Within the context of commercial buildings, the balance between optimizing human, environmental and economic factors in the successful delivery of green buildings needs to be set within the broader context of cultural and situational drivers that influence workplace design and decisions

This research has implications for the design community in that it supports the existence of a much larger potential variability of user experience in buildings than typically acknowledged, with consequence for how the users' perspective is incorporated into the design process as well as how occupant comfort and behaviour are supported in the building in use. With regards to green buildings in particular, the findings suggest that it is not enough to provide personal control (as credit is currently awarded in LEED-NC (v2.2) green building rating system), but that the goal should shift to one of ensuring adequate and timely feedback, whether personal control or automated strategies are pursued, in the provision of comfort conditions. Feedback is necessary throughout a building's lifetime, from design to implementation and use. Occupants need to be made aware of the design intent of their building's features and systems, and control opportunities available to them; operators need to be able to understand how the building management system works and respond to requests for changes in a timely and effective manner; and designers need to follow projects through into operation so they can gain and pass on knowledge and not repeat the same mistakes (Bordass, 2008).

Advanced feedback is beginning to be provided in buildings with the emergence of real-time building energy monitoring tools such as PulseEnergy Energy Management Software and Northwrite EnergyWorksite being adopted by commercial entities and utilities to better understand how buildings use energy in practice. Green building rating systems are seen to be shifting towards performance-based evaluation (Jarvis, in press). For example, LEED Canada-NC (v1.0) incorporates a Measurement and Verification credit, intended to track and evaluate actual compared to predicted building performance (CaGBC, 2004). LEED Canada-EB (v1.0) includes credits for energy monitoring, sub-metering and continuous commissioning to ensure building performs as intended (CaGBC, 2009). Design firms are also starting to develop and incorporate their own routine post-occupancy evaluation methods (Gonchar, 2008). Comprehensive methods such as Soft Landings (BSRIA and Usable Buildings Trust, 2008) encompass feedback through all stages of building design and use. The extent to which feedback of the types described above becomes routine practice remains to be seen.

Support provided by the research findings for the expansion of comfort definitions beyond the standardized physiological approach to encompass factors influencing occupants' actual comfort experience in practice, is also starting to find traction in industry. Credits are now available in LEED® green building rating systems for conducting post-occupancy satisfaction surveys (USGBC, 2005) and educating end-users and the public on green aspects of design. Comfort performance is increasingly recognized as an important component to building performance in the UK's implementation of the European Energy Performance Buildings Directive (EPBD), with efforts to introduce comfort certificates for buildings alongside energy certificates that compare building performance to baseline. However, with regards to post-occupancy evaluation, current methods remain limited in their ability to capture the complexities of user experience. As Vischer (in press) points out, “what people like and dislike in a given environment depends on a variety of influences, many of which are not always related to the built environment or to the decisions that created it”. Further, she argues for the development of a more diverse, sensitive and wide-ranging measures to evaluate a built environment’s effectiveness, including functional comfort and task support, sense of belonging and community, stress management, and territoriality.

Such measures are difficult to capture using available tools, and require the incorporation into post-occupancy evaluation methods of more extensive means of understanding human factors such as interviews, focus groups etc. However, POE has long been marred by barriers to market uptake including time commitment and financing (who pays), lack of authoritative methods, lack of formal training, and difficulties in obtaining/managing data, which a more extensive POE process would only exacerbate. In order to take advantage of the emerging interest of building practitioners in “evidence-based design”, basing design decisions on empirical research results (Vischer, in press), POE methodology will need to evolve in a way that allows building performance feedback to be accessible and usable by design professionals, easy to implement in terms of collection and analysis of data (e.g. web-based), standardized to allow for cross-comparison between buildings, and at the same time mindful of dynamic nature of (and wide range of factors influencing) user experience in buildings.

5.4. STRENGTHS AND LIMITATIONS

The strengths and limitations of the work fall into three main areas:

1. *A multiple-buildings study.*
    - Recruitment and post-occupancy evaluation of six Canadian office buildings for this study generated a rich data set representing many potential avenues of inquiry. Since much of the existing research evaluating occupants’ comfort and engagement with buildings stems from the U.S. and the U.K. and the majority of research on drivers of building energy use has been directed towards the residential energy sector, this thesis

represented a unique opportunity to examine human factors of green building performance in a Canadian setting for the commercial sector.

- On the counter side, a limitation of the research was that only six buildings were included in the overall study, making it difficult to extrapolate findings beyond the case studies. Each building had its own characteristics (e.g. age, size, construction), dynamics, ownership structure, management style, occupants and culture. While the initial research approach had been to compare the post-occupancy performance of the three green buildings to the three conventionally designed, as well as compare data across workplace cultures, in practice there were too many conflating variables (many of which only became apparent once on-site and gathering data) that prevented the pursuit of such a strategy. Even the evaluation of paired case-study buildings was not without caveats (Chapters 2 and 3).
- The research was also compromised by the difficulties encountered in recruiting buildings to begin with, which resulted in a set of case-study buildings that were accessible rather than necessarily ideal candidates (Chapter 1). Ultimately, it was decided that Whistler Municipal Hall was too dissimilar to the other buildings to include in the research analysis, due to the fact that it had initially been constructed for another end-use, and had undergone several stages of renovations in order to adjust to evolving demands as an office building. However, this serves as a valuable example of the challenges of conducting post-occupancy evaluation research in practice, where study design, timing of the study, constraints around implementation, and expectations of study outcomes, are all factors that can shape the data collection and analysis of findings.

2. *License and use of a standard post-occupancy evaluation survey tool (BUS Survey), allowing for access to a benchmark.*
   - The BUS benchmark provided a valuable opportunity to situate results within a broader context of building performance, which would otherwise not have been possible. The inclusion of six Canadian buildings into the BUS database contribute to and build the North American component of the international buildings dataset for use in future research.

- The BUS benchmark itself is admittedly biased. The international dataset comprises mostly green buildings from the UK and Australia, many of which would have self-selected for participation in post-occupancy evaluation studies (possibly to justify investments made in green building design). The three conventionally designed buildings included in this research's dataset, which ranked poorly according to the BUS benchmark, would be expected to rank closer to the normal distribution of a Canadian benchmark that include older and conventionally designed buildings.
- With any post-occupancy survey there can be self-selection of respondents which may bias results. Moreover, the timing of surveys conducted in each of the six buildings did not allow for occupants' in situ reflection of their year-round experience. This was mitigated by surveying occupants in the spring and fall months to avoid extreme indoor and outdoor conditions.
- The BUS method does not require standardized physical measurements of indoor building environmental conditions. Although measurements were made as part of the research, allowing for spot comparison of indoor microclimate to relevant workplace standards and criteria, the data was not representative enough (spatially or temporally) to be included in substantive analysis. This would have necessitated year-round monitoring and data logging to generate an objective dataset as a meaningful comparison to survey responses.

3. *Incorporation of customized questions.*
    - The customized questions expanded the scope of post-occupancy evaluation by capturing occupants' knowledge of how the building worked and comfort was provided, perceived building environmental performance, awareness and engagement with adaptive opportunities, and perceived workplace and organizational culture, aspects typically not included in POE surveys.
    - The incorporation of additional questions was constrained by the length of the survey (standard BUS questionnaire is already 2-pages long) and the ability to retain the attention and interest of respondents. In some cases the additional questions could have been tested on additional subjects before being implemented (e.g. knowledge in Chapter 2 and 3), and others were perhaps too narrow in scope (e.g. organizational culture and context in Chapter 4).

5.5. AVENUES FOR FUTURE RESEARCH

This thesis has examined individuals' knowledge, perceptions, and behaviour in relation to their experienced comfort in buildings. Further research in the area of social dynamics of comfort and comfort-related behaviour represents a new and exciting area of inquiry. Social aspects addressed in this work are limited to acknowledging the role of workplace and organizational culture in providing a common set of rules to guide occupant behaviour. Future work could apply an evolving understanding of how occupants learn about buildings (in particular through personal experience and interaction with others) towards designing effective educational and feedback mechanisms. For example, a valuable question to ask would be not only how occupants learn about buildings in shared settings, but also how *many* occupants need to be knowledgeable in a shared space for its effective engagement? How does knowledge of how comfortable others are in the building impact occupants' own comfort experience? Software tools could be developed that combine display of real-time indoor environmental conditions with means for occupants to submit requests for changes (e.g. to temperature, ventilation), perhaps displaying where/when in the building complaints have already been made, or even further, allowing users to promote or demote others' complaints.[21] Similarly, much could be learned from asking occupants to vote for where they would like to be seated in a building if they had the choice and why. The social dimensions of comfort represent an exciting new frontier of research particularly for commercial, green-designed buildings, where technologies are new and users share the space they can control with a greater number of people.

Real-time mechanisms themselves, such as kiosk or web-based displays designed to communicate environmental features, real-time energy and resource consumption, and control opportunities available to occupants (e.g. Building Dashboard®, Quality Attributes Software, PulseEnergy) represent a topical and growing area of research. While many such tools originated in an academic/institutional setting, their application is becoming more widespread in commercial buildings, with potential benefits and implications for occupant knowledge, comfort

[21] Norms Evolving in Response to Dilemmas (NERD) is an example of a survey platform designed around the assumption that how respondents answer questions may change based on their knowledge level of the topic, expert advice sought, and the influence of social dynamics (Ahmad *et al*., 2006).

and environmental behaviour. A number of pertinent questions can be asked of relevance/extension to this thesis: 1) Do real-time feedback tools lead to occupants' improved understanding of the building? 2) Does an improved understanding of the building lead to behavioural change? 3) Does behavioural change lead to gains in comfort and building energy efficiency? Exploring these and related questions requires a controlled "laboratory" setting with adequate sub-metering in place to assess energy and resource consumption and comfort conditions by zone, such as the Intelligent Workplace in Pittsburgh, PA, or that proposed in the Centre for Interactive Research in Sustainability in Vancouver, B.C. (Brown *et al.*, 2009).

Finally, given the combined contexts of climate change, improved access to reliable building performance data, and the rise of pervasive computing and 'smart environments', the scenario of ubiquitous building energy monitoring is becoming increasingly likely. As the measurement of buildings becomes more commonplace, the potential for learning about occupant behaviour and other dynamics from large databases of building energy information is significant. Important lines of inquiry include examining trends and patterns in building energy data to determine whether observed energy anomalies derive from design error, technical error (e.g. the BMS system), or human error (e.g. building manager or building occupants), and developing the capacity to predict common energy discrepancies before they become a problem. At the individual building scale, 'smart environments' introduce a host of new factors of relevance to the inhabitant experience, including decisions around which tasks to intelligently support and which to leave to users, and how, when and where to communicated pervasive building information; matching the complexity of the system to the expertise and involvement of the user; and integrating 'smart' functions within existing tools and systems rather than reinventing the wheel (Velikov and Bartram, 2009). The tension between system-oriented smartness and people-oriented smartness in intelligent buildings represents an important area of research with implications for green building design.

5.6. SIGNIFICANCE OF WORK

The research presented here will be of interest to academics/educators, researchers, practitioners, clients/building users, and policy makers involved in the planning, design construction occupancy and use, and evaluation of the built environment. Findings contribute the literature by expanding the scope of current post-occupancy evaluation to encompass perception and values, feedback, and a range of contextual factors into the discussion of user experience. The manuscripts included in this thesis have or will be published in significant journals in the area, and results presented at key conferences and workshops. Data on the post-occupancy evaluation of the six buildings reported here now form part of the BUS International Benchmark.

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Appendix A: BEHAVIOURAL RESEARCH ETHICS BOARD CERTIFICATES OF APPROVAL

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - FULL BOARD

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
Raymond J. Cole	UBC/Applied Science/School of Architecture and Landscape Architecture	H07-01607

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
Office buildings in the Vancouver area (pending recruitment to the study).

CO-INVESTIGATOR(S):

Zosia Bornik
Hadi Dowlatabadi
John B. Robinson

SPONSORING AGENCIES:
N/A

PROJECT TITLE:
Green building performance: knowledge, communication and feedback.

REB MEETING DATE:	CERTIFICATE EXPIRY DATE:
April 10, 2008	**April 10, 2009**

DOCUMENTS INCLUDED IN THIS APPROVAL: **DATE APPROVED: April 21, 2008**

Document Name	Version	Date
Consent Forms:		
Study Consent Form: UBC	2	April 17, 2008
Main Study Consent Form	2	April 17, 2008
Questionnaire, Questionnaire Cover Letter, Tests:		
Main survey	N/A	March 13, 2008
Follow-up Survey	2	April 17, 2008
Letter of Initial Contact:		
Main Cover Letter	N/A	March 13, 2008
UBC Cover Letter: Feedback	N/A	March 13, 2008
UBC Cover Letter: Follow-up survey	N/A	March 13, 2008

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board and signed electronically by one of the following:

Dr. M. Judith Lynam, Chair
Dr. Ken Craig, Chair
Dr. Jim Rupert, Associate Chair
Dr. Laurie Ford, Associate Chair
Dr. Daniel Salhani, Associate Chair
Dr. Anita Ho, Associate Chair

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - AMENDMENT & RENEWAL

PRINCIPAL INVESTIGATOR:	DEPARTMENT:	UBC BREB NUMBER:
Raymond J. Cole	UBC/Applied Science/School of Architecture and Landscape Architecture	H07-01607

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
Office buildings in Vancouver, Whistler, Sidney and Toronto.

CO-INVESTIGATOR(S):

Zosia Bornik
Hadi Dowlatabadi
John B. Robinson

SPONSORING AGENCIES:

N/A

PROJECT TITLE:
Green building performance: knowledge, communication and feedback.

CERTIFICATE EXPIRY DATE: March 9, 2010

AMENDMENT(S):	RENEWAL AND AMENDMENT APPROVAL DATE: March 9, 2009

Document Name	Version	Date
Consent Forms:		
Interview consent form	1	March 3, 2009
Questionnaire, Questionnaire Cover Letter, Tests:		
Interview script	1	March 3, 2009
Letter of Initial Contact:		
Interview cover letter	1	March 3, 2009

The application for continuing ethical review and the amendment(s) for the above-named project have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board and signed electronically by one of the following:

Dr. M. Judith Lynam, Chair
Dr. Ken Craig, Chair
Dr. Jim Rupert, Associate Chair
Dr. Laurie Ford, Associate Chair
Dr. Anita Ho, Associate Chair

Appendix B: SAMPLE SURVEYPACK (ISSUED TO STUDY PARTICIPANTS)

Thank-you for your interest in the UBC Research Project: Engaging Occupants in Green Building Performance. This document contains detailed information on the survey process (including roles and responsibilities, timeline, confidentiality etc). Please review these materials, and contact us at your earliest convenience if and when you are ready to proceed.

You may reach us by email at zbrown@ires.ubc.ca, or by phone at (604)-657-4624.

Survey Implementation Guide

Step 1

Obtain approval from your organization to participate in the research study. A one-page executive summary is available to circulate if you feel this would be helpful. This describes the nature of the study, who is conducting the research, what the research entails, and the benefits to participating.

Step 2

Complete the building information sheet. This includes the name and address of the building(s), approx number of occupants, and contact information of the person who will act as a liaison between the researchers (UBC) and the building occupants.

We also ask you to recommend an individual who may be considered the resident 'expert' on the building. This person could be yourself, a property manager, a facilities manager, an operations staff or other appropriate personnel. The expert's responses to the survey will be used to generate a knowledge baseline against which to compare all other occupants' responses.

Step 3

Agree on a tentative schedule for the survey start/end date. Note: we prefer a minimum of 6 months and preferably 1 year after move-in to a new building or major renovation.

Step 4

Prepare for survey implementation:

- Once you have provided us with the building information, we will customize our web-based survey and provide you with the survey URL.
- Review the survey and notify the researchers of any discrepancies or questions you may have.
- Prepare a copy of the building floor plans (.pdf format). These are needed to assist with our preparation of the indoor physical measurements, and should be provided at least 2 weeks before the commencement of the survey.
- Decide on how you will inform occupants about the survey, *i.e.* by email, link to a website.

- Prepare introductory message for the survey. Note: an invitation that is sent from an individual who is well known and respected within the organization will convey a message of support and can have significant effect on the response rate.

Sample invitation:

Dear Employee/Staff:

Researchers at the University of British Columbia are using web-based survey to evaluate your satisfaction with our building, and knowledge about how energy is used and comfort provided.

Your participation in this survey is very important. Please visit the following link by [date]:

[insert survey URL]

This survey will give you an opportunity to comment on your satisfaction with the building overall, your workspace, thermal comfort, air quality, noise, lighting, and personal control. The survey takes around 15 minutes to complete. Results will be confidential and anonymous.

If you have any questions regarding this study, you may contact Ms. Zosia Brown (Co-Investigator) at 604-822-0067, or Dr. Ray Cole (Principal Investigator) at-604 822-2857.

Thank-you in advance for your participation.

Step 5

Send invitation to respondents on the morning of the survey start date. The survey will typically be available for a time period of 2 weeks.

Step 6

While the survey is running…

- Assign a knowledgeable person (this could be yourself) to accompany the Co-Investigator (Ms. Zosia Brown) on a walk-through of the facility
- Facilitate building access for the Co-Investigator to conduct basic indoor microclimate measurements (temp., humidity, CO_2, light levels and acoustics). These are spot measurements and can take place over the course of a typical working day.

Step 7

Receive individual building report after completion of survey.

Informed Consent

The welcome page is the first page respondents will see when the click the URL, and explains who is conducting the survey, the purpose of the research, how long it will take, *etc*. The welcome page also serves as the consent form to participate in the study.

You may wish to tailor the text to suit the needs of your organization. If so, please let us know at least one week prior to activating the survey.

Sample welcome page:

> *Building Use Study*
>
> *Welcome! Thank-you for agreeing to fill out this survey.*
>
> *The purpose of our study is to evaluate your satisfaction with this building and to understand how you think about energy use and comfort.*
>
> *Your answers will help us to make this facility work better for you, and inform the design better of buildings in the future. Results will be shared with the building's owners, managers, and maintenance team.*
>
> *This survey should take 15 minutes to complete (longer if you add comments). All of your answers will be kept strictly confidential, and used only in preparation of statistical reports in which neither you nor your answers will be identifiable. If you have any questions about the study, you may contact Zosia Brown at 604-822-0067, or Dr. Ray Cole at-604 822-2857*
>
> *Consent: I am over 19 years of age. I understand that my participation in this study is entirely voluntary and that I may refuse to participate or withdraw from the study at any time. By completing questions in the survey, I give the research team consent to use my responses for the purposes stated above.*
>
> *When you are ready to begin the survey, click Next below:*

Scope of Work

Building evaluation survey

The Building Use Study (BUS) Ltd. occupant survey has been licensed by the research team to capture background data, satisfaction with the building and workplace, comfort and personal control for the building included in this study. The BUS survey was developed by a U.K. consortium (including Building Use Studies and William Bordass Associates) as part of the *PROBE* series carried out from 1995-2000. The survey is now widely used in post-occupancy evaluations around the world, with over 350 buildings comprising the BUS performance benchmark, and a separate international benchmark for green buildings.

To accompany the BUS occupant survey, the research team at the University of British Columbia has developed an additional module that evaluates occupants' knowledge of building environmental features and systems, and awareness and engagement with control opportunities available to them.

The complete survey is administered online, and has been pilot-tested and refined by the research team. The survey takes 15 minutes to complete, or longer if respondents choose to fill in the comments boxes.

Notes about the implementation process

Maximizing response rate

For large commercial buildings, we suggest aiming for a sample of at least 125 respondents. This sample size is recommended by BUS survey researchers based on a wealth of experience in evaluation occupant satisfaction, and is required for consistency in the development of their benchmark. For smaller buildings, the more staff that can be sampled the better.

The research team will keep track of how many people have responded, and notify sponsor whether it is necessary to send out a reminder email and/or extend the survey end-date. Typical response rates for web-based occupant satisfaction surveys are around 50%.

It may be useful to provide a participation incentive such as a prize to encourage participation. If you choose to do this, the research team will collect entries via the survey website, and after the survey is closed randomly select a winner. Your organization is responsible for supplying and administrating the prize to winners.

Data analysis and results

Once the survey end-date is reached, the research team will deactivate the survey. From this point on, all web browsers directed to the survey site will receive a notification that the survey has now been closed.

The research team will cleanse the data as necessary, and begin analysis. You will receive an individual building report approximately 1 month after completion of the survey. This will include statistical analysis on a range of quantitative and qualitative data carried out by Building Use Study Ltd., complete with benchmark plots and graphics.

Data storage and access

Survey responses are gathered over the Internet and stored in a secure SQL database maintained by SurveyMonkey.com. SurveyMonkey employs multiple layers of security to ensure that account and data remains private and secure. This includes third-party daily audits of security and the latest in firewall and intrusion prevention technology. The UBC research team owns all data collected or uploaded into the survey. The Principal and Co-investigators listed at the bottom of this document will have access to the data.

Data collected using the BUS Ltd. occupant survey questionnaire will be filed directly to Building Use Studies subject to full confidentiality in secure computer file format. Building Use Studies Ltd. will be responsible for long-term maintenance and administration of the data as it relates to the development and refinement of the BUS performance benchmark. This benchmark helps to facilitate BUS's research by allowing for the analysis of a large set of building use study results.

The list of building characteristics you provide, and all other electronic data files related to this study (including floor plans), will be password protected and stored only on the Co-Investigator's computer at the University of British Columbia. Information about each building will be used to group buildings by type, and used for comparison and analysis. Results from analysis will be presented in aggregate form and building characteristics will not be made publically available unless specifically requested.

Physical microclimate measurements

A well designed post-occupancy evaluation will include objective measurements of indoor environmental quality to complement subjective occupant satisfaction data. Leaning on expertise from UBC's School of Occupational and Environmental Health and Mechanical Engineering Departments, the research team has developed a physical microclimate measurement protocol to allow us to capture this data.

Data that we typically gather includes:

Method	*Parameter*
Spot measurement	Temperature • Air temperature • Radiant temperature
	Humidity
	Light levels
	Noise levels • Background • Total
	CO_2

All measurements and data logging will be conducted by the Co-Investigator (Ms. Zosia Brown), and done in a manner so as to minimize disruption of the occupants. It is helpful if the person serving as the liaison can help to facilitate building access, permissions *etc*. for the measurements to be taken.

Contact Information

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Co-Investigators

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Appendix C: BUILDING USE STUDIES OCCUPANT QUESTIONNAIRE LICENSE AGREEMENT

Definitions

Questionnaire: The work produced by the Licensor

Territory: Canada

Period: Two years

Term: The full term of copyright and all renewals and extensions.

Rights: The non-exclusive right by licence, to utilise the questionnaire in the agreed material format for the purposes defined.

Study building: The building to which the licence applies, normally named in Further Details below.

Further details:

For use in PhD survey of 6-8 office buildings in Canada.

Bus code: 898

Invoices: If invoices apply they should be raised and paid to:
Building Use Studies Ltd.,
c/o Sprunt,
The Quadrangle,
180 Wardour Street,
London W1F 8FY
UK

Licence agreement

11/2/08

This is a questionnaire licence agreement between:

Adrian Leaman, Building Use Studies — *The Licensor*

and:

Zosia Brown, University of British Columbia — *The Licensee*

concerning the method/s:

Building Use Studies 2-page occupant questionnaire 2008 Probe or Workplace version

The licensors as owners of the copyright of the title agree to grant the rights to the licensee subject to these terms and conditions.

1. The licensor as beneficial owner grants the licensee rights throughout the territory for the period.
2. The licensor warrants that they are the sole owners of the rights and have full power to enter the agreement.
3. The licensee undertakes that the following copyright notice is prominently displayed on all pages of the questionnaire and prominently in the report of survey, especially within data tables:

© Copyright: Building Use Studies Ltd 2008 Used under licence.

4. If a survey is undertaken, the licensee undertakes to lodge the data file of the survey with Building Use Studies subject to full confidentiality in agreed computer file format..
5. If a survey is undertaken. and data are supplied as in 4., Building Use Studies undertakes to supply the licensee with data analysis in the current formats.
6. If a survey is undertaken, the licensee undertakes to conduct the survey using agreed ethical principles such as those of the Market Research Society.
7. The licensee undertakes not to change any questionnaire or other formats without prior agreement of Building Use Studies.
8. The licensee undertakes not to publish or circulate details of questionnaires or benchmarks without prior agreement of Building Use Studies.
9. The licensor undertakes never to reveal details of individuals or to release details of building names without prior agreement of the licensee.
10. The licensor undertakes not to grant more than one licence for a particular study building during a defined period.
11. If a translation is undertaken, the licensee undertakes to carry out the translation under supervision from the licensor and to release the resulting translation file to Building Use Studies.

More details are available of the approach on:
www.usablebuildings.co.uk/WebGuideOSM/index.html

Signed: Adrian Leaman

Digitally signed by Adrian Leaman
DN: cn=Adrian Leaman, o=Building Use Studies, ou, email=adrianleaman@usablebuildings.co.uk, c=GB
Date: 2008.02.11 16:09:44 Z

Adrian Leaman, Building Use Studies

Signed: February 18, 2008

Zosia Brown, University of British Columbia

VAT number: (GB) 371 1084 78		Company number 1497266
Account Name:	Building Use Studies Limited	
Account No:	20207543	
Bank Address:	Barclays Bank, Barclays Business Centre, P O Box 32016, London NW1 2ZH	
Bank Sort Code:	20-03-53	Swift code: BARCGB22

Appendix D: BUILDING USE SURVEY, ONLINE VERSION

1. Building Use Study

Welcome! Thank-you for agreeing to fill out this survey.

The purpose of our study is to evaluate your satisfaction with this building and to understand how you think about energy use and comfort conditions. Your answers will help to make this facility work better for you, and inform the design of better buildings in the future.

The research is also being conducted as part of Ms. Zosia Brown's doctoral thesis. Results will be summarized and shared with the building's owners, managers, and maintenance team. All individual responses will be confidential.

This survey should take 15 minutes to complete (longer if you add comments).

All of your answers will be kept in a secure database, and used only in preparation of statistical reports in which neither you nor your answers will be identifiable. If you have any questions about the study, you may contact Zosia Brown at 604-822-7725, or Dr. Ray Cole at 604-822-2857. If you have concerns about your rights or treatment as a research subject, you may contact the UBC Office of Research Services at 604-822-8598.

Consent: I am over 19 years of age. I understand that my participation in this study is entirely voluntary and that I may refuse to participate or withdraw from the study at any time. By completing questions in the survey, I give the research team consent to use my responses for the purposes stated above.

When you are ready to begin the survey, click Next below:

2. Background

Please note: We ask about age and sex because these are both relevant to people's needs in buildings.

What is your age?

- ◯ Under 30
- ◯ 30 or over

... and your sex?

- ◯ Male
- ◯ Female

... and your Department?

____

Is this building your normal base?

- ◯ Yes
- ◯ No

If not, which is?

____

Please tick if you are an outside contractor

- ◯ Contractor

Where is your floorspace located in this building?
("Perimeter" is within 5 meters of an exterior wall)

- ◯ Core
- ◯ Perimeter (North)
- ◯ Perimeter (East)
- ◯ Perimeter (South)
- ◯ Perimeter (West)

Floor number:

- ◯ Ground floor
- ◯ Main floor
- ◯ Mezzanine

Is your office or work area...?

- ◯ Normally occupied by you alone
- ◯ Shared with 1 other
- ◯ Shared with 2-4 others
- ◯ Shared with 5-8 others
- ◯ Shared with more than 8 others

Do you sit next to a window at your normal workspace?

- ◯ Yes
- ◯ No

How long have you worked in this building?

- ◯ Less than a year
- ◯ A year or more

How long have you worked in your present work area?

- ◯ Less than a year
- ◯ A year or more

How many days do you spend in the building in a normal working week?

How many hours per day do you spend in the building on a normal working day?

How many hours per day do you spend at your desk or normal work area on a normal working day?

How many hours per day do you normally spend working with a computer screen?

3. The building overall

All things considered, how would you rate the building design overall?

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

Comments about design overall

In the building as a whole, do the facilities meet your needs?

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

Comments about needs overall

In the building as a whole, do you think that space is used...?

Ineffectively overall 1	2	3	4	5	6	Effectively overall 7
○	○	○	○	○	○	○

How do you rate the image that the building as a whole presents to visitors...?

Poor 1	2	3	4	5	6	Good 7
○	○	○	○	○	○	○

How do you rate your personal safety in and around the building...?

Poor 1	2	3	4	5	6	Good 7
○	○	○	○	○	○	○

How do you rate the cleaning...?

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

How do you rate the availability of meeting rooms?

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

Comments about meeting rooms

How do you rate the suitability of storage arrangements?

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
◯	◯	◯	◯	◯	◯	◯

Comments about storage

4. Your work requirements

Please briefly describe the work that you carry out in the building...?

Specifically, for the work that you carry out, how well do the facilities meet your needs...?

Very poorly 1	2	3	4	5	6	Very well 7
○	○	○	○	○	○	○

Please give examples of things which can hinder effective working...?

... and examples of things which usually work well?

How do you rate the usability of the furniture provided at your desk or normal work area...?

Very poor 1	2	3	4	5	6	Very good 7
○	○	○	○	○	○	○

Do you have enough space at your desk or normal work area...?

Too little 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Comments about your desk or work area

5. Comfort (Winter)

This section asks how comfortable you find the building in the winter.

How would you describe typical working conditions in your normals work area in WINTER?
(If you have not worked here in winter, please leave these questions blank and just complete the questions on Temperature in Summer - next page)

Temperature in winter:

Uncomfortable 1	2	3	4	5	6	Comfortable 7
○	○	○	○	○	○	○

Too hot 1	2	3	4	5	6	Too cold 7
○	○	○	○	○	○	○

Stable 1	2	3	4	5	6	Varies during the day 7
○	○	○	○	○	○	○

Air in winter:

Still 1	2	3	4	5	6	Draughty 7
○	○	○	○	○	○	○

Dry 1	2	3	4	5	6	Humid 7
○	○	○	○	○	○	○

Fresh 1	2	3	4	5	6	Stuffy 7
○	○	○	○	○	○	○

Odourless 1	2	3	4	5	6	Smelly 7
○	○	○	○	○	○	○

Conditions in winter overall:

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

6. Comfort (Summer)

This section asks how comfortable you find the building in the summer.

How would you describe typical working conditions in your normal work area in SUMMER?
(If you have not worked here in summer, please leave these questions blank and just complete the questions on Temperature in Winter - previous page)

Temperature in summer:

Uncomfortable 1	2	3	4	5	6	Comfortable 7
○	○	○	○	○	○	○

Too hot 1	2	3	4	5	6	Too cold 7
○	○	○	○	○	○	○

Stable 1	2	3	4	5	6	Varies during the day 7
○	○	○	○	○	○	○

Air in summer:

Still 1	2	3	4	5	6	Draughty 7
○	○	○	○	○	○	○

Dry 1	2	3	4	5	6	Humid 7
○	○	○	○	○	○	○

Fresh 1	2	3	4	5	6	Stuffy 7
○	○	○	○	○	○	○

Odourless 1	2	3	4	5	6	Smelly 7
○	○	○	○	○	○	○

Conditions in summer overall:

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

7. Noise

This question refers to conditions all year round.

How would you describe noise overall in your normal work area?

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

Noise from colleagues:

Too little 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Noise from other people:

Too little 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Other noise from inside:

Too little 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Noise from outside:

Too little 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Please estimate how often you are affected by unwanted interruptions...?

Not at all 1	2	3	4	5	6	Very frequently 7
○	○	○	○	○	○	○

Comments about noise and its sources

8. Lighting

This question refers to conditions all year round.

How would you describe the quality of lighting overall in your normal work area?

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

Natural light:

Too little 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Glare from sun and sky:

None 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Artificial light:

Too little 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Glare from lights:

None 1	2	3	4	5	6	Too much 7
○	○	○	○	○	○	○

Comments about lighting conditions

9. Overall experience

All things considered, how do you rate the overall comfort of the building environment?

Unsatisfactory 1	2	3	4	5	6	Satisfactory 7
○	○	○	○	○	○	○

Comments about comfort

All things considered, please estimate how you think your productivity at work is decreased or increased by the environmental conditions in the building?
(Please try to evaluate this building with respect to your experience of using buildings in general)

Productivity decreased by -40% or less 1	-30% 2	-20% 3	-10% 4	0% 5	+10% 6	+20% 7	+30% 8	Productivity increased by +40% or more 9
○	○	○	○	○	○	○	○	○

Comments about productivity

Do you feel more or less healthy when you are in the building?
(Please try to evaluate this building with respect to your experience of using buildings in general)

Less healthy 1	2	3	4	5	6	More healthy 7
○	○	○	○	○	○	○

Comments about health

10. Personal control

How much control do you personally have over the following aspects of your working environment...?

	No control 1	2	3	4	5	6	Full control 7
Heating	◯	◯	◯	◯	◯	◯	◯
Cooling	◯	◯	◯	◯	◯	◯	◯
Ventilation	◯	◯	◯	◯	◯	◯	◯
Lighting	◯	◯	◯	◯	◯	◯	◯
Noise	◯	◯	◯	◯	◯	◯	◯

Please tick if important to you

Heating	◯
Cooling	◯
Ventilation	◯
Lighting	◯
Noise	◯

How often do you take an action that influences...?

	Never	Once/month	Once/week	Several times/week	Once/day or more	Don't know
Heating	◯	◯	◯	◯	◯	◯
Cooling	◯	◯	◯	◯	◯	◯
Ventilation	◯	◯	◯	◯	◯	◯
Lighting	◯	◯	◯	◯	◯	◯
Noise	◯	◯	◯	◯	◯	◯

Note: Consider that some actions can influence more than one aspect of the indoor environment, eg. opening a window

For actions you take which involve building controls, on average how would you rate their...

	Not at all conveniently located 1	2	3	4	Very conveniently located 5	Don't know 6
Accessibility:	◯	◯	◯	◯	◯	◯

	Very hard to understand 1	2	3	4	Very easy to understand 5	Don't know 6
Usability:	○	○	○	○	○	○

	Slow and ineffective 1	2	3	4	Fast and effective 5	Don't know 6
Responsiveness:	○	○	○	○	○	○

For building controls you never use, what is the reason? (Please tick all that apply.)

- ☐ Controls don't exist
- ☐ I don't have time to use them
- ☐ Controls are inconveniently located
- ☐ Someone else does it for me
- ☐ I don't know where they are
- ☐ I don't need personal control
- ☐ I don't know how to use them
- ☐ I don't know

Comments about personal control

Do you supplement your personal control with any of the following devices?

- ☐ Personal heater
- ☐ Personal fan
- ☐ Plug-in lamp

Other (please specify)

11. Workplace environment

Please note that the scale for these questions has changed, with 6 now representing "I don't know".

How would you describe your overall sense of wellbeing at work?

Very poor 1	2	3	4	Very good 5	Don't know 6
○	○	○	○	○	○

How would you describe your overall level of stress while at work?

Very stressful 1	2	3	4	Not at all stressful 5	Don't know 6
○	○	○	○	○	○

How would you describe your level of personal attachment to this organization?

Not at all attached 1	2	3	4	Very attached 5	Don't know 6
○	○	○	○	○	○

How flexible is the...

	Very strict 1	2	3	4	Very flexible 5	Don't know 6
Time you arrive at work?	○	○	○	○	○	○
Dress code at work?	○	○	○	○	○	○

How satisfied are you with your ability to alter physical conditions at your workspace?

Very unsatisfied 1	2	3	4	Very satisfied 5	Don't know 6
○	○	○	○	○	○

12. Knowledge

This section asks about your knowledge and perception of how the building performs and comfort is provided.

Would you consider this building to be a "green" building?

- [ ] Yes
- [ ] No
- [ ] I don't know

Please explain

How well do you think this building is performing in terms of energy efficiency?

Very poorly 1	2	3	4	Very well 5	Don't know 6
○	○	○	○	○	○

How would you describe your level of knowledge about how the building performs and comfort is provided?

Not at all knowledgeable 1	2	3	4	Very knowledgeable 5	Don't know 6
○	○	○	○	○	○

Would you like to learn more?

- [ ] Yes
- [ ] No
- [ ] I don't know

Why or why not?

To the best of your knowledge... (select all that apply)

How is HEATING provided in your workspace?

- [ ] Mechanical system (eg. forced air, radiator system)
- [ ] Electrical system (eg. baseboard heaters)
- [ ] Natural/passive system (eg. passive solar)
- [ ] I don't know

Who is responsible for controlling HEATING in your workspace?

- [ ] Automated system (sensor activated)
- [ ] Building operator (scheduled)
- [ ] Occupants
- [ ] I don't know

How is COOLING provided in your workspace?

- [ ] Mechanical system (eg. air conditioning)
- [ ] Natural/passive system (eg. slab cooling, shading)
- [ ] I don't know

Who is responsible for controlling COOLING in your workspace?

- [ ] Automated system (sensor activated)
- [ ] Building operator (scheduled)
- [ ] Occupants
- [ ] I don't know

How is FRESH AIR provided in your workspace?

- [ ] Mechanical ventilation
- [ ] Natural ventilation (eg. windows)
- [ ] I don't know

Who is responsible for controlling FRESH AIR in your workspace?

- [ ] Automated system (sensor activated)
- [ ] Building operator (scheduled)
- [ ] Occupants
- [ ] I don't know

How is LIGHTING provided in your workspace?

- [ ] Electrical system
- [ ] Natural system (eg. daylighting)
- [ ] I don't know

Who is responsible for controlling LIGHTING in your workspace?

- [ ] Automated system (sensor activated)
- [ ] Building operator (scheduled)
- [ ] Occupants
- [ ] I don't know

Please identify any means by which you have learned about how the building performs and comfort is provided?

13. Response to problems

Have you ever made requests for changes to the heating, lighting, ventilation, or air-conditioning/cooling (if you have it)...?

☐ Yes

☐ No

Please give brief details

If yes, how satisfied in general were you with the...?

	Unsatisfactory overall 1	2	3	4	5	6	Satisfactory overall 7
Speed of response	○	○	○	○	○	○	○

	Unsatisfactory overall 1	2	3	4	5	6	Satisfactory overall 7
Effectiveness of response	○	○	○	○	○	○	○

14. Thank-you!

Thank-you for your participation!

If you would like to be included in the draw prize, please enter your email address below.

Email

Appendix E: SAMPLE SIZE CALCULATIONS

The sample population for the study included all permanent occupants in recruited buildings. In the case of academic office buildings, 'permanent' referred to full time graduate students and staff. Initial contact with potential subjects was done through an email invitation, with names and addresses provided by building administrators, and those who agreed to participate were then given the option to complete the online survey.

Sample size calculations with a finite population correction were used to establish target response rates (Equation I).

$$n = \begin{array}{c}\text{finite}\\\text{population}\\\text{correction}\end{array} * \frac{\text{probability level * variance}}{\text{confidence interval}} = \left(1 - \frac{n}{N}\right) * \frac{t^2\ (p*q)}{d^2}$$

Equation I Sample size calculation for a finite population

Where:

n = The sample size or number of completed surveys

N = The size of the eligible population

t^2 = The squared value of the standard deviation score that refers to the area under a normal distribution of values

p = The percentage category for which we are computing the sample size

q = 1-p

d^2 = The squared value of one half the precision interval around the sample estimate

Czaja and Blair (1996)

Response rates were 56% for Fred Kaiser (confidence interval (C) = 0.06), 37% for Frank Forward (C = 0.12), 54% for Whistler Municipal Hall (C = 0.11), 78% for Gulf Islands Operations Centre (C = 0.08), 38% for Cara Airport Road (C = 0.06) and 48% for Cara Four Valley Drive (C = 0.07) (Table I). The Usable Buildings Trust recommend aiming for the largest sample size that is 'reasonably available'; in larger buildings they aim for 125 respondents. Average response rates for the BUS questionnaire are around 80% however this refers to hand-delivered paper-based surveys. Response rates for web-based surveys are typically lower. CBE reports response rates ranging from 27% - 88%, with the majority of response rates between 45% and 65% and the mean at just over 50% (Zagreus *et al.,* 2004).

Building	Sample Size Assuming Large Population	Actual Population at Time of Survey	Sample Size with Finite Population Correction	Number of Responses	Response Rate	Confidence Interval
Fred Kaiser	384	192	128	108	56%	0.06
Frank Forward	384	123	93	43	37%	0.12
Whistler Municipal Hall	384	70	59	38	54%	0.11
Gulf Islands Operations Centre	384	41	37	32	78%	0.08
Headquarter Building 1	384	382	192	145	38%	0.06
Headquarter Building 2	384	216	138	104	48%	0.07

Table 1. Sample size calculations and confidence intervals for six buildings

REFERENCES

Czaja, R.&J. Blair (1996) Designing Surveys: A Gude to Decisions and Procedures, Thousand Oaks, CA, Pine Forge Press.

Zagreus, L., C. Huizenga, E. Arens and D. Lehrer (2004) Listening to the occupants: a Web-based indoor environmental quality survey. Indoor Air, 14(8):65-74.

Appendix F: ARCHITECT'S INTERVIEW GUIDE

THE UNIVERSITY OF BRITISH COLUMBIA
Institute for Resources, Environment and Sustainability
AERL 413, 2202 Main Mall
Vancouver, BC Canada V6T 1Z3

Architect Interview Guide

1. Can you describe any pre-design research relating to user requirements and needs that was conducted for this project?

2. Who represented user needs in the design process?
   a. What kind of information did they provide and in what format?
   b. Over what time frame were potential users involved with the process?
   c. Did the users/representatives change throughout this process?

3. Was there an architect's information session at the time of building handover?
   a. Who attended this session?
   b. What was presented?
   c. How many of the people who attended are still working in the building?

4. Were there any building tours conducted at the time of handover? If so, who by and for whom?

5. Were any manuals generated on the design/operation of the building?

6. Was there an effort to train management staff on the design/operation of the building?

7. What kind of metering equipment was installed in the building to monitor energy and system performance?

8. Are there any features in the building you would describe as 'exposed' or 'experiential' that were explicitly designed to educate users on how the building works and comfort is provided?

9. Is there any other signage or educational material you would identify in the building that aims to educate users on how the building works and comfort is provided?

10. In your opinion, how do you think occupants learn about how the building works and how comfort is provided?

11. In your opinion, whose mandate is it to educate end-users on how the building works and comfort is provided?

12. Are you aware of any effort (outside of this study) to gather post-occupancy feedback from the occupants of the building?

Appendix G: IEQ DATA COLLECTION SHEET

IEQ Data Logging Sheet

Context

Date	
Building	
Location in building	
Time of day	AM PM
Weather	
No. of occupants	
Contextual factors	Doors Windows Lights Equipment Events/Noise
Picture Y/N?	

WBGT

Location in room	
Time of reading	
Dry bulb temp	
Wet bulb temp	
Globe temp	
WBGT	

Q-TRACK

Location in room				
Test name				
Test time				
CO2				
CO				
Temp				
RH				

Noise Meter

Location in room	
Time of reading	
Memory location	
Total dB (1 min)	

Light Meter

Location in room				
Time of reading				
Light level				
Lights on/ off (ratio)				

Building Walk-Through

	Thermal/Air quality	**Visual**	**Acoustic**	**Spatial/Amenities**
Physical	Diffuser/return air density	Panel height	Panel thickness	Workstation size
	Dedicated exhaust?	Light fixture density	Sides of closure	Storage
	Pollution source management	Computer screen type	Density of workstations	Local kitchen/ break/coffee area
			Ceiling/ floor quality	
Individual/Social	Temp and airflow control (*core*)	Ambient light control	HVAC noise	Privacy
	Temp and airflow control (*perimeter*)	Task light density	Distributed noise (equipment, break areas, mtng rooms, circulation)	Ergonomic support
	Ease of window management	% and quality of view to outdoors		Plants/ green space
		Daylighting controls		
Behavioral	Space heaters/ fans	Extra task lights	Ear plugs/ headphones	Workstation reconfiguration
	Clothing	…	…	…

Appendix H: LIST OF INDOOR ENVIRONMENTAL QUALITY (IEQ) INSTRUMENTS

QUESTemp 34 Thermal Environmental Monitor

- Dry bulb (ºC) and globe temperature (ºC)
- Direct digital read

TSI Q-Track Plus Indoor Air Quality (IAQ) Monitor

- Carbon dioxide (ppm), carbon monoxide (ppm) and relative humidity (%)
- Data logged and averaged over a 60s period

RION NA-29E Sound-Level Meter

- Ambient noise levels (dBA)
- Equivalent continuous sound-pressure level (Leq) measured over 60s intervals in octave bands from 31.5 to 8000 Hz

UEI Digital Light Meter (DLM2)

- Light levels (lux)
- Direct digital read

Appendix I: SAMPLE POST-OCCUPANCY EVALUATION REPORT

Gulf Islands National Park Reserve Operation Centre
Post-Occupancy Evaluation Report

Prepared for Terry Arnett, Public Works and Government Services Canada

Friday, February 13, 2009

Zosia Brown, Institute for Resources Environment and Sustainability, UBC
4th Floor AERL Building – 2202 Main Mall, Vancouver B.C. V6T 1Z3

Executive Summary

This report contains the results of a post-occupancy evaluation of the Gulf Islands National Park Reserve Operations Centre, carried out in November 2008 by Zosia Brown, PhD student at the University of British Columbia. The purpose of the study was to evaluate occupant comfort, health and productivity in the Operations Centre, as part of a larger follow-up research effort by the owner and design team documenting lessons learned. An underlying goal was to explore possible connections between the 'green' integrated design of the building and human performance. Study results indicate that lighting and air quality were both found to be highly satisfactory by occupants, having a positive impact over their health and productivity. Thermal comfort was also found to be satisfactory (although possibly too hot in the summer and cold in the winter) and did not appear to directly impact occupant productivity. Acoustics were an area of concern for the building with three-quarters of occupants unsatisfied, and noise, interruptions and lack of privacy often cited in terms of their impact in decreasing productivity and concentration at work. Perceived health in the building was significantly above average, and personal wellbeing was also highly rated. On balance, the Gulf Islands Operations Centre ranked in the 80th percentile of the BUS Satisfaction Index (top 20% of all buildings) for the combination of occupant satisfaction, productivity and health at work. Recommendations are made for suggested improvements to acoustics, air quality, glare and lighting controls in order to promote and provide high levels of occupant comfort and satisfaction into the future.

1.0 Introduction

1.1 Study Background

This report pertains to a post-occupancy evaluation of the Gulf Islands National Park Reserve Operations Centre, carried out in November, 2008 by Zosia Brown, PhD student at the University of British Columbia. The study was commissioned by Terry Arnett, Regional Manager, Conservation, Public Works and Government Services Canada, and as part of Ms. Brown's doctoral thesis. The purpose of the study was to evaluate occupant comfort, health and productivity in the Operations Centre, as part of a larger follow-up research effort by the owner and design team documenting lessons learned.

In what follows, we present a summary of results from the BUS occupant survey. We begin by describing the Operations Centre design and features, and the post occupancy evaluation method used. We present a summary of findings for occupant satisfaction with the building overall, as well as for individual indoor environmental quality (IEQ) variables, including thermal comfort, air quality, lighting and noise. Each set of results includes a bar graph of responses with percentages satisfied and dissatisfied, colored symbols showing how the study building compares to the benchmark dataset buildings, and representative open-ended comments relating to the variable. Also included are summaries of findings from the physical microclimate measurements compared to relevant standards and criteria. The report then describes results for personal control importance and availability, as well as self-assessed productivity, health and wellbeing. Finally, a number of recommendations are made with the aim to promote and provide high levels of building performance and occupant satisfaction into the future.

1.2 Gulf Islands Operations Centre

The Gulf Islands Operations Center, located on the waterfront in Sidney, B.C., was the first building to receive the LEED-NC v 1.0 Platinum designation in Canada. Completed in 2005, the 11,250 sf., 3-storey facility was designed to accommodate the Gulf Islands National Park Reserve operations and administrative staff, while explicitly expressing the National Park's core values of environmental stewardship. Three key principles guided the Operation Centre's sustainable design philosophy: 1) Respect for the site and surrounding area; 2) Incorporate natural energy and resource systems occurring at the site; and 3) Integrate sustainable components into the fabric of the building. Key sustainability features include an ocean-based geothermal system providing all heating and hot water needs, a 30,000 litre rainwater storage tank used for dual flush toilets and wash water needs in the marine operations area, photovoltaic panels installed on the roof providing 20% of the building's energy needs, and recycled building materials to t he order of 27% of total material cost.

The design of the Operations Centre was a highly integrated process, involving Park personnel every step of the way. Larry McFarlane architects and associates interviewed each Park staff member about their workplace needs and desires, and invited representatives to participate in green design charettes and planning phases. A Core user team was formed which included the client, owner, architect, engineer and contractor. Users expressed a strong desire for a workplace that had both natural light and fresh air. A central goal of the facility design was the provision of high levels of indoor environmental quality, which would result in improved health, wellbeing and productivity of the staff. Key IEQ features include extensive levels of natural lighting, operable windows, a CO_2 sensor-activated ventilation system providing 100% outdoor air, and low-emission finishes and material use in the interior of the building.

Staff working in the Operations Centre were provided with the following environmental control systems: sliding thermostats (within set points) zoned at 1 per person (office) and 1 per floor (open plan); operable windows at every office and workstation; and photo sensor-controlled overhead lighting with manual override, zoned at 1 per person (office) and 1 per 6 people (open plan). In addition to the environmental system design features, the interior fit-out was also intended to enhance staff wellbeing and productivity through increased communication and collaboration between workstations. The interior of the Operation Centre is based on an open plan concept, with high ceilings, unobstructed views across and between floors, and the only enclosed spaces being formal meeting rooms and a handful of offices (*e.g.* superintendant). Staff members have access to bike racks, showers, a locker room, a communal kitchen and dining area, a large deck leading onto a marina, and a heritage house and ornamental garden which were preserved from the original site. Following completion of construction, the architect made a design presentation to occupants as part of the hand-over process.

Figure 1. Exterior view of the Gulf Islands Operations Centre

Figure 2. Interior view of the Gulf Islands Operations Centre

2.0 Methodology

2.1 BUS Occupant Questionnaire

Building occupants were surveyed in November, 2008 using the Building Use Studies occupant questionnaire (UBT, 2008 version), modified to include questions addressing occupants' knowledge and engagement with control opportunities available to them. The BUS survey was developed by and for a U.K. consortium (including Building Use Studies Ltd. and William Bordass Associates) as part of the PROBE series carried out from 1995-2000. The survey is now widely used in post-occupancy evaluations around the world, and has led to the development of national and international building performance benchmarks. For the purposes of this report, we refer to the 2008 BUS International Benchmark, comprising of 66 buildings from 16 countries around the world.

2.2 Sampling and Descriptive Statistics

The survey was conducted via the Web, and ran online for approximately one week. Initial contact was done through an email invitation sent out by the building administrator; those who agreed to participate were then given the option to complete the online survey. The sample population included all full-time and part-time staff in the Gulf Islands Operations Centre. A total of 32 employees participated in the survey, representing a response rate of 78% (confidence interval = 0.08), which exceeds the typical range for web-based post-occupancy surveys (45-65%) (1).

The gender of respondents was 62% female and 38% male, with the vast majority (97%) aged thirty or older. In terms of location in the building, half of the survey respondents (53%) had workstations on the main floor, while 43% were on the second floor and 3% in the basement. Fifty-five per cent (55%) of respondents were located along the north perimeter, 24% along the south perimeter, and 21% in the building core, which is roughly what would be expected given the distribution o f workspaces in the building. The average time survey respondents spent in the building was 7.7 hours/day, 4.4 days/week, with 6.9 hours/day spent at the desk and 6.3 hours/day in front of a computer screen.

2.3 Physical IEQ Measurements

Physical microclimate measurements were conducted during the time of the administration of the survey, so as to maximize the intersection of subjective occupant responses and objective measures of indoor environmental quality. Dry bulb temperature, humidity, globe temperature, carbon dioxide, carbon monoxide, ambient noise and lighting were measured at six representative locations within the Gulf Islands Operations Centre. Spot measurements were taken in the morning (9-11 am) and repeated at the same locations in the afternoon (2-4 pm). All measurements were taken at desk level simulating the occupants' experience, and during regular working hours. Ranges and averaged measurements were evaluated against known performance standards for each variable.

3.0 Summary of Results

3.1 Building Overall

Based on survey results, as shown in Figure 3, occupants of the Gulf Islands Operations Centre are highly satisfied with the building overall in terms of its design, image, and ability to meet their needs. Satisfaction ratings for these variables ranged from 84 – 97% and (with the exception of needs being met) were significantly higher than the BUS International Benchmark. [1]

Occupant satisfaction with the effective use of space in the building and the usability of furniture provided in work areas was also fairly high (around 75%), with satisfaction with use of space significantly higher than benchmark, and satisfaction with furniture within the 'typical' range for dataset buildings. The ability of facilities to meet needs for work, the availability of meeting rooms, and suitability of storage arrangements were rated lower (around 40-60% satisfaction) and were statistically no different from the benchmark. Twenty per cent (20%) of occupants were satisfied with the amount of space at their desk, while 45% felt they had too much space and 34% felt they had too little.

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[1] While occupant satisfaction the ability of facilities to meet their needs was high (84%), so was the averaged score for this variable in the benchmark dataset, which accounts for the "typical" (yellow) rating.

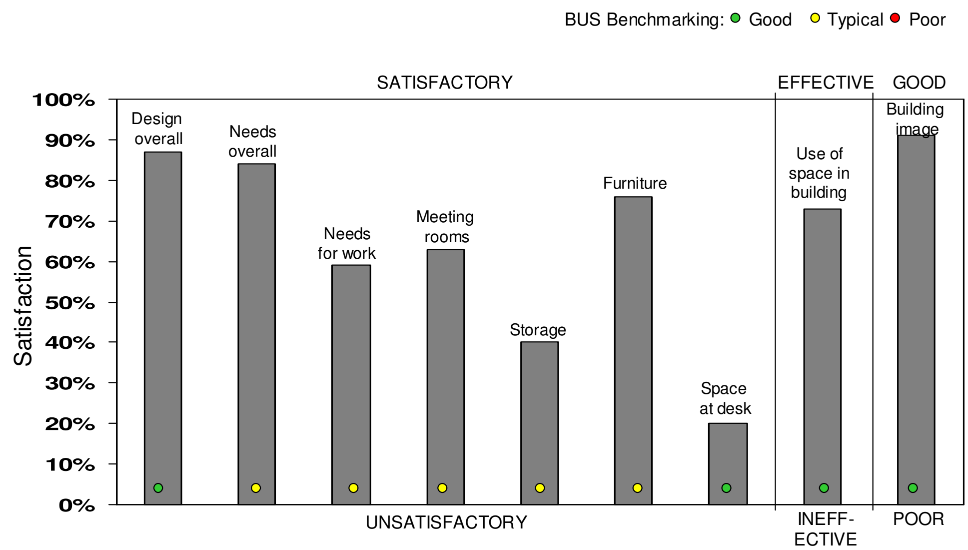

Figure 3. Occupant satisfaction with building overall. Green symbols indicate a higher than average score, yellow is average and red is below average according to the 2008 BUS International Benchmark

Comments regarding meeting rooms pertained to ventilation and thermal comfort in the rooms, lack of availability (in part due to the use of one boardroom as an office), and noise transmission between boardrooms and adjoining areas. Sample comments:

- *Air flow in small meeting room is poor, stuffy.*
- *The main floor, large boardroom is always cold, and therefore, uncomfortable.*
- *Only one large and two small rooms available. All are booked out. One has just been made into an office.*
- *Usually available for all needs. Confidentiality of information discussed in rooms is low because you can hear the rooms discussion between meeting rooms and in some adjoining areas.*

Comments regarding space and storage at desk pertained to somewhat crowded workstations, the need for more shelving and under-desk storage, storage for archival files and communication / promotional materials, and the need for coat racks. Lockers and storage for operational equipment were generally positively reviewed, although respondents felt they would be further improved when the fit-out of this space was completed. Sample comments:

- *Not enough at-desk storage*
- *I could use a bookshelf to organize books and printed material, without cluttering my desk surface with magazine boxes.*
- *No dedicated storage space for communications materials (posters, display panels etc).*
- *An area to hang coats for staff and guests would be great.*
- *There is still work to do to complete the storage areas. When they are completed I think things will be great.*

When evaluating the performance of the Gulf Islands Operations Centre in the broader context of the BUS International Benchmark, the building ranked in the 80th percentile (top 20% of all buildings) in terms of occupant satisfaction (Figure 4). This result is based on the BUS Satisfaction Index, which combines occupant satisfaction with overall building design and meeting occupants' needs, with productivity and health at work (see Sections 3.4-3.5).

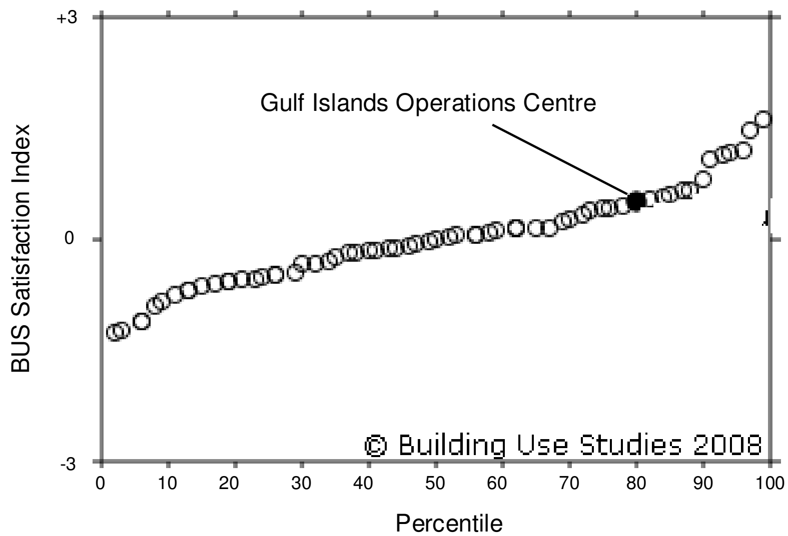

Figure 4. BUS Satisfaction Index for Gulf Islands Operations Centre with international dataset

3.2 Indoor Environmental Quality

3.2.1 Overall Satisfaction

Survey results indicate that air quality, lighting quality and comfort overall were rated highly in the Gulf Islands Operations Centre, with satisfaction levels ranging from 54 – 78% (Figure 5). Both lighting quality (78% satisfaction) and air quality in the summer (54% satisfaction) scored higher than BUS benchmark, while comfort overall (68% satisfaction) and air quality in the winter (45% satisfaction) fell within the 'typical' range for benchmarked buildings. Occupant satisfaction with temperature was lower than with other variables, at 47% satisfaction for winter temperature and 39% for summer temperature overall. Noise was poorly rated by occupants, with only 24% satisfied, while a majority of 64% was dissatisfied with noise overall in the work area.

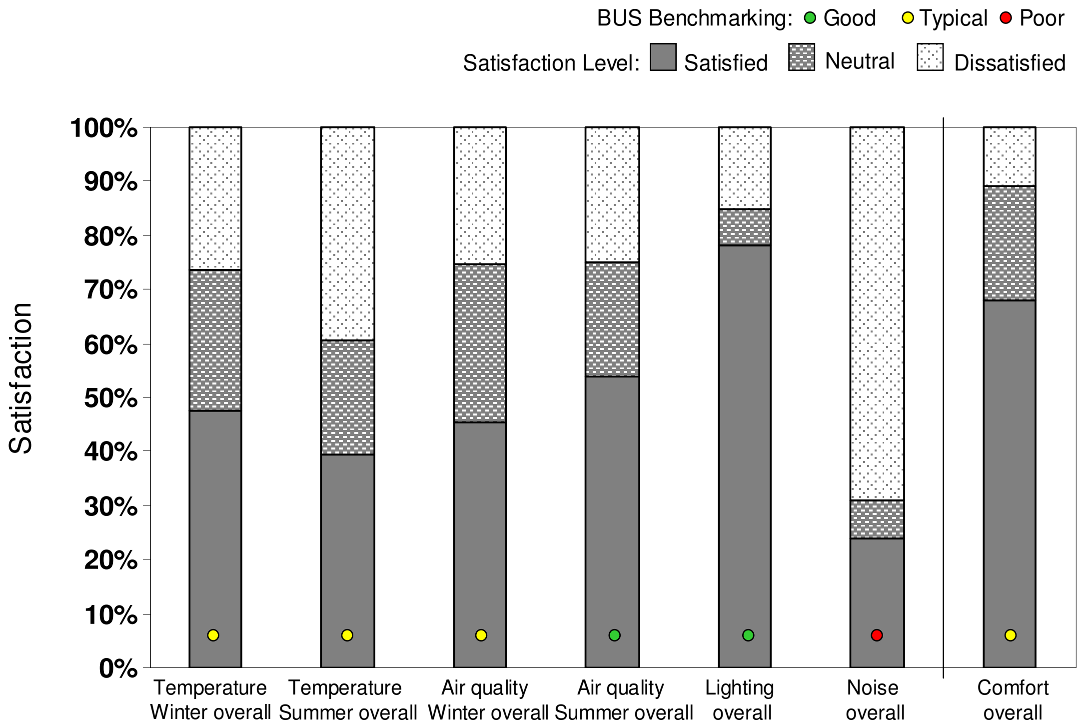

Figure 5. Occupant satisfaction with key aspects of IEQ

A closer look at individual comfort variables in the Gulf Islands Operations Centre provides insight into occupants' experience with specific environmental factors impacting their overall comfort, wellbeing and productivity in the workspace, and allows for more targeted recommendations to be made.

3.2.2 Thermal Comfort

Occupant satisfaction with overall thermal conditions was 43% averaged between winter and summer (Figure 6). Respondents reported indoor conditions as being too cold in the winter (30% of respondents, within 'typical' benchmark range), and too hot in the summer (52% of respondents, significantly worse than benchmark). Satisfaction with temperature variability was moderately better with 29% rating temperature in the winter as stable (within 'typical' benchmark range), and 34% rating temperature in the summer as stable (significantly better than benchmark).

Comments on thermal comfort mainly had to do poor understanding of occupant control over temperature, and the lag time associated with the geothermal system and. However, thermal comfort did not appear to have as great an impact on productivity as some of the other indoor environmental variables. Sample comments:

- *The building is great for the most part although the temperature can be quite uncomfortable in the summer during the hot days and cool in the winter.*
- *Comfort is an issue if the building systems break down as it takes a considerable amount of time for heat to stabilize.*

- *Transition days when the temperature outside varies, takes relatively long time for the system to switch to new outside temperature, would be very distressful in a colder climate.*

- *Have mentioned to other colleagues that the conditions are too hot and asked how to turn the heat down. No one in the building new how.*

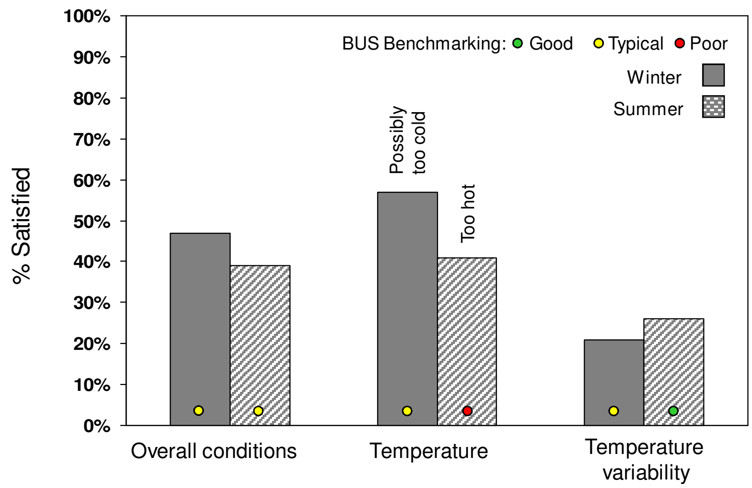

Figure 6. Occupant satisfaction with thermal comfort

Physical measurements of thermal comfort were carried out at three locations on each of the main and second floor of the Gulf Islands Operations Center. Measurements were compared to relevant criteria for occupant health and comfort (Figure 7). Summary of observations:

- Dry-bulb temperature was within the range of ASHRAE Standard 55-2004 winter standards (20-23.5°C) (2), with the exception of the NW corner office on the second floor, which was colder than standard. This office was unoccupied at the time of measurement, and would likely have been warmer had the staff member been present and managing the thermostat.
- Humidity was within the range of ASHRAE Standard 55-2004 winter standards (30-50%) across the 6 locations, with the average measured humidity at 37%.
- Wet-bulb globe temperature, which measures the net heat load to which occupants are exposed from the combination of air temperature, humidity, air movement and radiant heat exchange, was well below typical workplace screening criteria for heat stress (3).

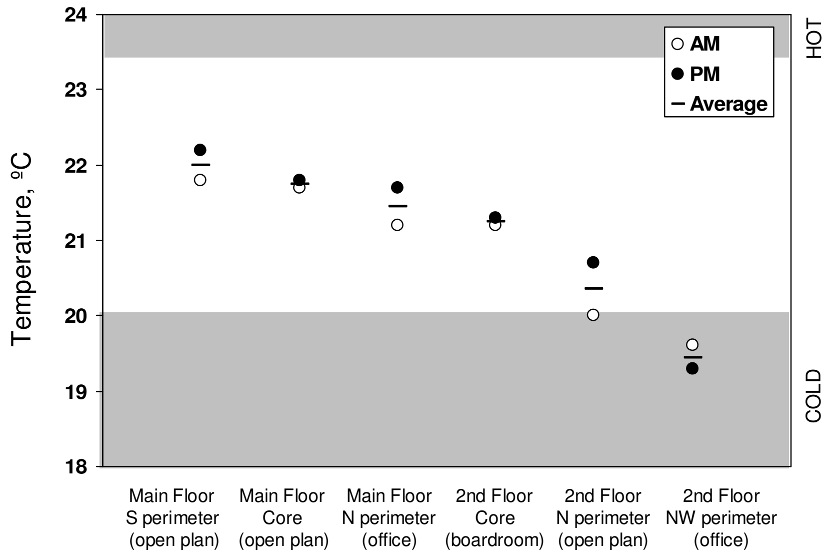

Figure 7. Dry-bulb temperature relative to standard

Overall, thermal comfort was average in the Gulf Islands Operations Center, based on both occupant perceptions and physical measurements. The exception was summer conditions which were found to be too hot, a seasonal effect that was not captured by physical microclimate measurements.

3.2.3 Air Quality

As shown in Figure 8, occupant satisfaction with overall air quality was around 50%, with higher satisfaction in the summer than the winter (54% and 45% respectively). Satisfaction with both air movement and freshness (*i.e.*'stuffiness') was significantly better than benchmark. Respondents found the quality of the air to be fresh year round, with good air movement – although at times too still in the summer. Satisfaction with humidity and odours both fell within the 'typical' benchmark range.

The main occupant comments on air quality pertained to lack of air movement in specific isolated areas of the building, and to fumes from the plumbing system which some occupant felt impacted their health and productivity. Sample comments:

- *If the fans aren't on and windows on both side of the building open, the second floor gets very stuffy and warm, even if the outside air temp is cool.*
- *The upstairs boardroom is airless. The fan does not work.*
- *[There is] a continuing issue with the sewer smell emanating from the sump in the basement. It has improved but is still noticeable and has not been completely fixed.*
- *We notice a smell associated with a type of gas - possibly sewage gas - that permeates the whole building when there is a low ceiling of fog. It affects people in different ways: eye irritation, headaches, nausea, breathing difficulties, allergies, multiple symptoms.*

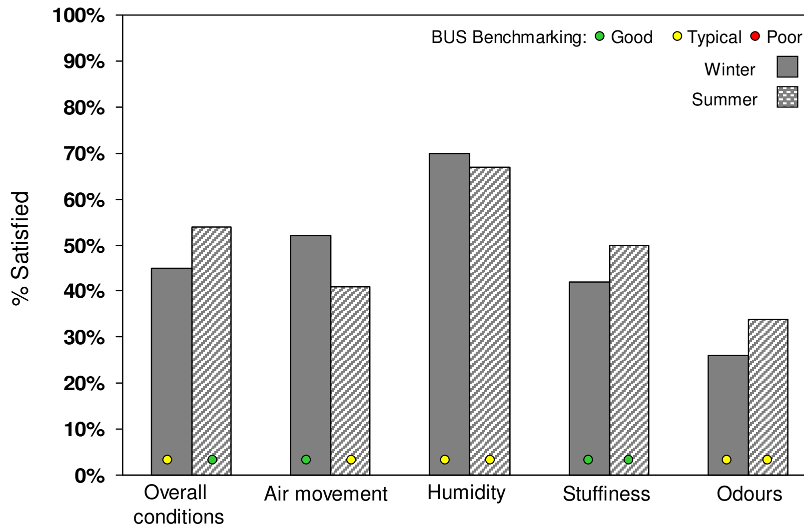

Figure 8. Occupant satisfaction with air quality

Physical measurements of air quality were carried out at the same six locations as thermal comfort on the main and second floors of the building. Measurements were compared to relevant criteria and standards (Figure 9). Summary of observations:

- CO_2 levels ranged from 450 – 490 ppm which is much lower than normally found in office buildings, and well below the Health Canada criterion of 1000 ppm (4), indicating that ventilation was adequate to provide fresh air and remove occupant odours.
- CO was detected in the building at very low concentrations (<1.2 ppm), and below the Health Canada criterion of 11pm over 8 hrs.

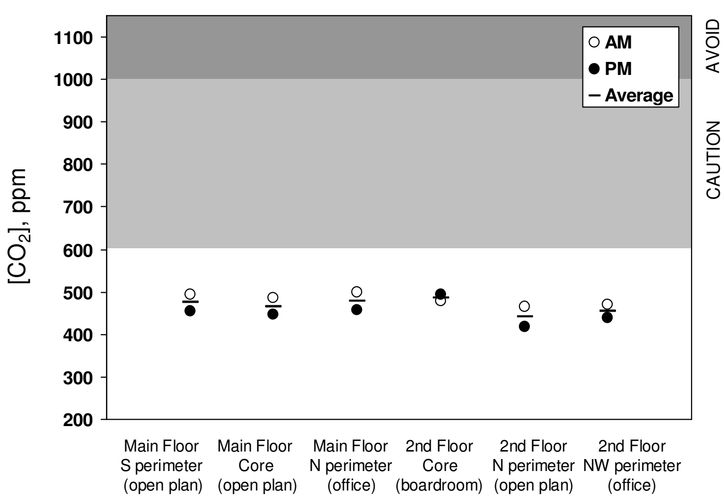

Figure 9. Carbon dioxide concentration relative to standard

Air quality was very good in the Gulf Islands Operations Center based on physical measurement and occupant perceptions. This finding can be attributed in part to the 100% fresh air ventilation system, the frequent use of operable windows, as well as low emissions materials and finishes in the building.

However, the issue of odours from the plumbing system appears to be persistent, raising some level of concern from occupants over their health and safety. This is true, even though the problem was identified during the early stages of occupancy and at the time was addressed by the facility management team.

3.2.4 Lighting

Occupant satisfaction with lighting was higher than any of the other indoor environmental variables, with 78% were satisfied with overall conditions (Figure 10). 70% of respondents were satisfied with the amount of natural light (neither too, much nor too little), 68% were satisfied with the amount of artificial light, and 50% were satisfied with the absence of glare from lights (only 15% experienced glare from lights). Each of these variables scored significantly higher than benchmark. The only lighting variable which fell within the 'typical' benchmark range was glare from sun and sky, with which 47% of respondents were dissatisfied (too much glare), 29% were neutral, and 25% satisfied.

Comments about lighting were generally very good. A few occupants noted issues with glare, as well as inefficiencies in the lighting control system, however on the whole the abundant natural lighting in the Operations Centre had a positive impact on productivity. Sample comments:

- *Lighting is good – both natural and artificial. Some light conditions result in outside glare from water and boat house – not that often and blinds are an easy fix. It's generally really good.*
- *The lights come on but rarely shut off when there is more than adequate light to work from, and the basement lights never go off unless they are turned off.*
- *Use of natural light is great, makes it a lot easier when working with computers all day.*
- *The building is well lit and ventilated which seems to help when working prolonged periods.*

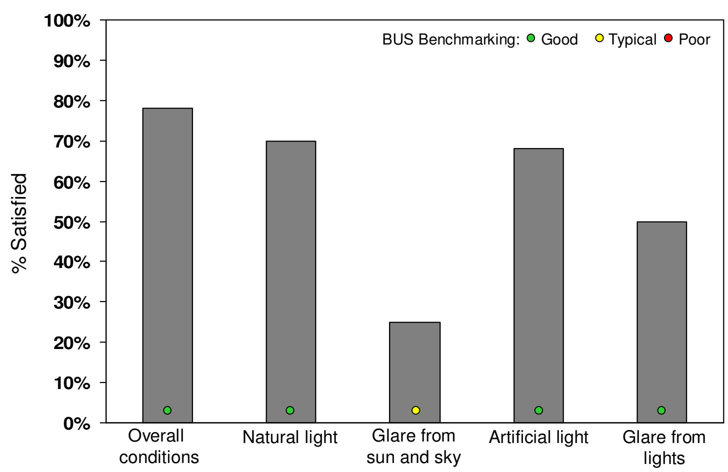

Figure 10. Occupant satisfaction with lighting

Physical assessment of lighting quality was based on horizontal illuminance at the desk level measured using a direct read digital light meter. These were taken alongside thermal and air quality measurements and at the same locations in the building, and measurements were compared to relevant criteria and standards (Figure 11). Summary of observations:

- Illuminance levels ranged widely from 120 to nearly 2000 lux depending on the location in the building. In general those offices on the North perimeter were more brightly illuminated than on the South perimeter or in the building core. This may be due to existence of shading fins on the south facade of the building as well as greater use of venetian blinds along this orientation.
- Illuminance levels were within the range of acceptable to good for office work throughout the building (5) with the exception of the 2nd floor small boardroom which was dark, although improved by about 400lux when all lights were switched on.

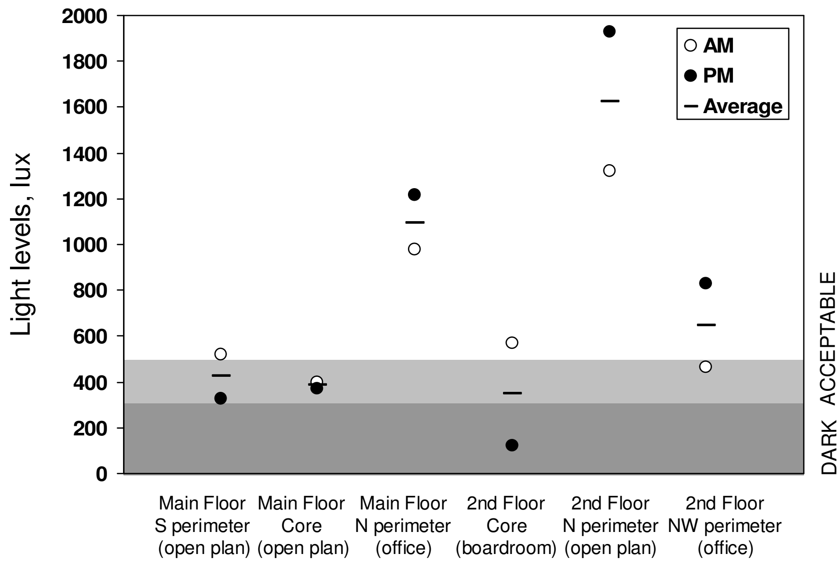

Figure 11. Illuminance levels relative to standard

Lighting quality was generally very good in the Gulf Islands Operations Center based on both physical measurements and occupant perceptions. This is a positive outcome, especially considering the early emphasis placed on providing high levels of natural lighting in the workspace to enhance occupant productivity.

3.2.5 Noise

Occupant satisfaction with acoustics in the Gulf Islands Operations centre were average to poor, and worse than BUS benchmark for severable variables (Figure 12). Satisfaction with noise overall was 24%, with respondents experiencing too much noise from colleagues (76% dissatisfaction) and noise from other people (72% dissatisfaction). 73% of respondents were frequently affected by unwanted interruptions at their workplace.

While a few occupants enjoyed the constant hum of activity in the Operations Centre, the majority of comments pointed to noise and interruptions as the largest combined issue in the building, having direct impacts on productivity. Sample comments:

- *For me, the sound of activity and people discussing things is pleasant white noise that encourages me to do more. If I find myself getting distracted, I use headphones.*
- *Very noisy work environment.*

- *Biggest problem is the transmission of high and low level noise throughout the building. Even whispers can transmit across the office from different work zones. Areas where people tend to congregate and generate noise are in work areas that require quiet.*

- *There is woefully inadequate sound-proofing in the enclosed office and washroom walls.*

- *I like the open design but some dampening methods would help reduce the volume from conversations in the common areas – fabric hangings maybe?*

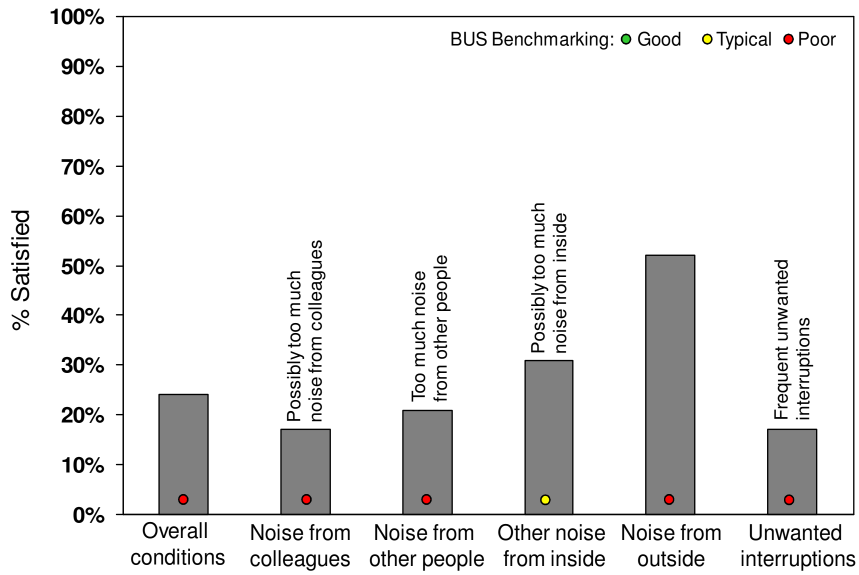

Figure 12. Occupant satisfaction with acoustics

Physical assessment of acoustic quality was based on measured ambient noise levels taken at the same time and locations as other indoor environmental variables. Balanced noise criteria (NCB), the most appropriate criteria for sound level measurements in occupied spaces, are recommended at 35-43 dB for workspaces, and 25-35 dB for meeting rooms (6). Summary of observations:

- Ambient noise levels in the Gulf Islands Operations Center ranged from 32-48 dB NCB
- Noise levels were within or above criteria levels (too loud), for all locations with the exception of the NW corner office on the second floor which was in the quiet range (Figure 13).

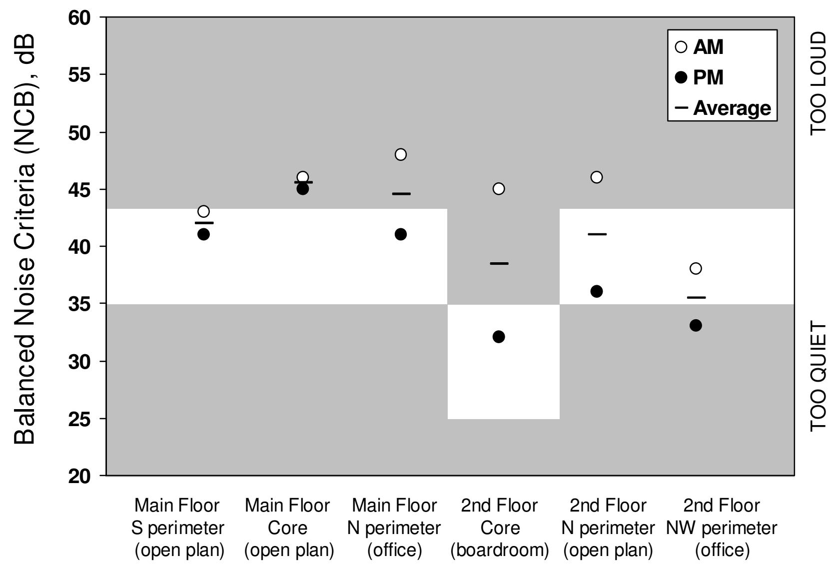

Figure 13. Ambient noise levels relative to standard

Acoustic conditions were average to poor in the Gulf Islands Operations Center based on both physical measurements and occupant perceptions. This is not an altogether surprising result as previous studies have shown noise to be one of the biggest sources of dissatisfaction in green buildings (7). Acoustic issues can be attributable to the combination of high ceilings and open-plan concepts, exposed floors, low material finish, and reduced background noise from fewer mechanical systems. This poses a challenge for designers who need to balance benefits from green design concepts with the potential for increased noise levels and reduced productivity of occupants. In the Gulf Islands Operations Centre, this balance of performance factors may need to be addressed as a priority area for improving occupant comfort and productivity in the building.

3.3 Personal Control

Occupants were asked to rate their perceived level of control over indoor environmental variables, as well as how important personal control was to them. Lighting and ventilation scored the highest on perceived control, and with ratings significantly higher than BUS benchmark (respectively 4.89 and 4.26, scale of 1-7) (Figure 14). Perceived control for cooling was within the typical range for benchmarked buildings, while perceived control over heating and noise were significantly lower than benchmark.

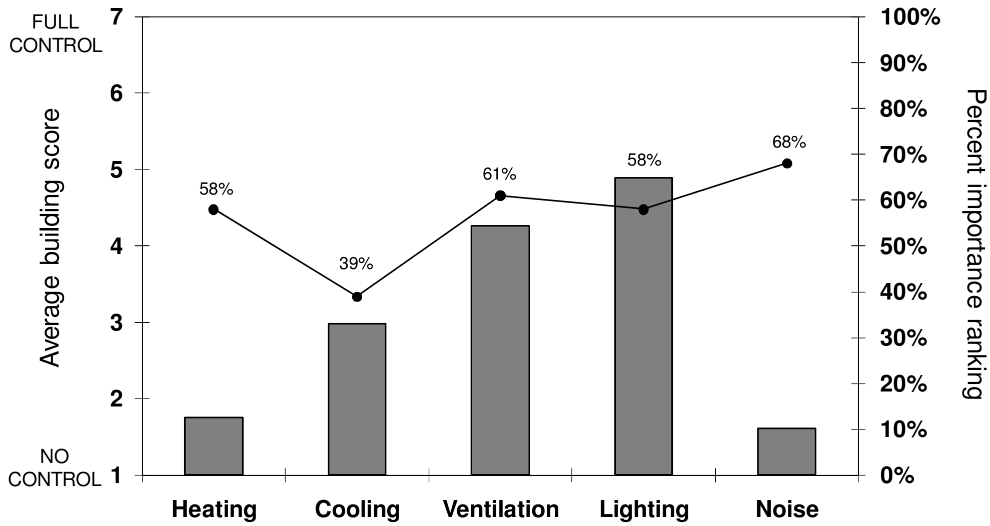

Figure 14. Perception and importance of personal control over key indoor environmental variables

Overall, noise was ranked highest in terms of importance of personal control (68%) followed by ventilation (61%), lighting and heating (58%), and then cooling (39%). The largest gaps between the importance and availability of personal control were for heating and noise. While the majority of respondents said personal control over these variables was important to them, the average rating of personal control over heating in the building was 1.75 and noise was 1.61 (scale of 1-7).

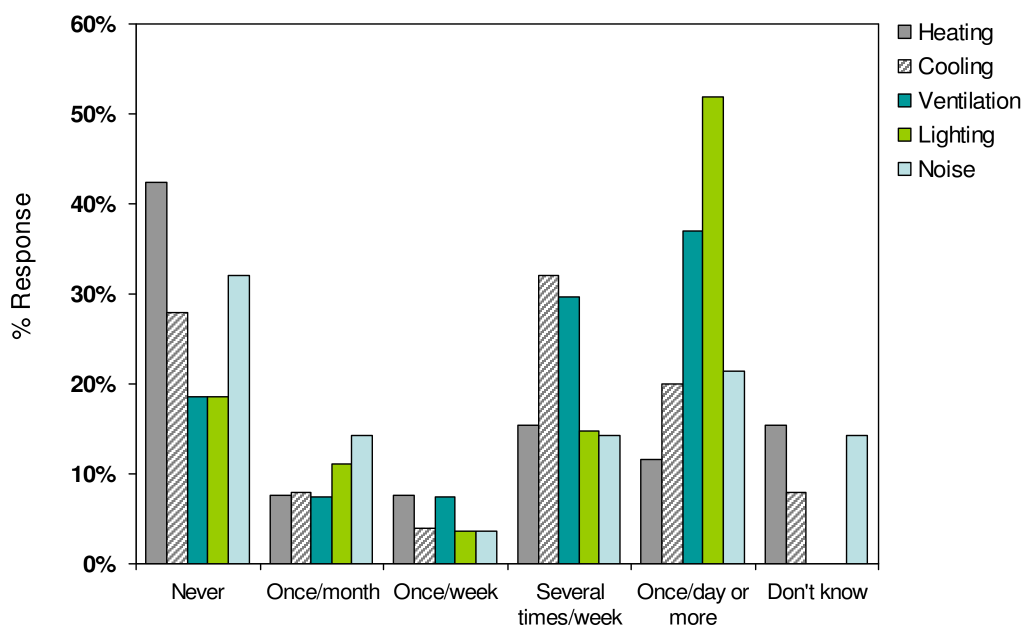

Figure 15. Frequency of control use for key indoor environmental variables

Consistent with the rankings of importance of personal control, 53% of respondents used lighting controls once/day or more, while 37% used ventilation controls with the same high frequency (Figure 15). Cooling controls were used less frequently, with 33% of respondents using cooling controls several times/week, and 28% never using cooling controls. Heating was the least frequently controlled variable with 42% indicating they never used heating controls. While 33% also indicating they never used noise controls, the distribution of responses for this variable was somewhat bimodal. 22% of respondents indicated they controlled noise in the workspace once/day or more, and 16% controlled noise several times/week.

The use of controls reflects in part the availability of personal controls in the Operations Centre, with higher amount of lighting and ventilation controls available (switches and windows) than for heating and cooling. However, occupants will often take personal control into their own hands if building controls aren't afforded to them. For heating there is a building-wide policy prohibiting the use of plug-in heather and fans, but for noise control, a number of occupants used earplugs or headphones at their desks and move out of the common work area for longer/louder conversations. Sample comments:

- *Open concept results in regular and sometimes near constant interruptions. A lot of people have resorted to wearing headphones*
- *People are generally considerate in leaving the area if they are going to have longer conversations, but they are also limited in their options of where to go without disrupting others*
- *Individuals need to be aware of how easily their voices carry and we try to discourage people talking over the cubical dividers, move to another area for a group discussion.*

3.4 Productivity

A key goal of the building design was to create a space that would enhance human health, wellbeing and productivity. The design team believed that the improved performance of occupants would have an impact of bottom line and should ultimately be incorporated into whole building economic analysis. Productivity was measured through a self-assessed rating as part of the BUS questionnaire. Respondents were asked to estimate whether their productivity at work was increased or decreased by the environmental conditions in the building. Occupant responses were fairly split on whether the impact of the building on their productivity, with 42% reporting an increase in productivity and 43% reporting a decrease in productivity (Figure 16). Overall, indoor environmental conditions in the Gulf Islands Operations Center led to an average increase in productivity of +1.07% across all respondents.

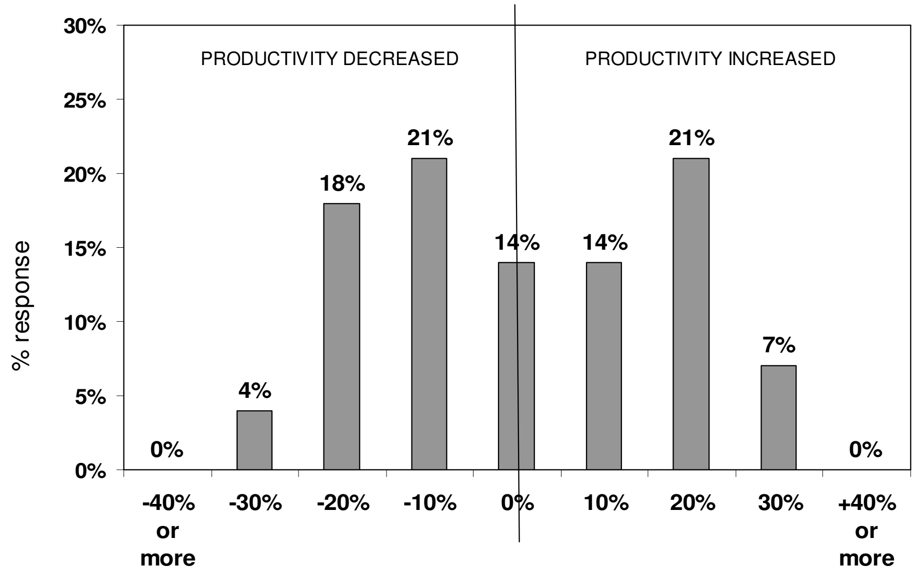

Figure 16. Perceived impact of indoor environmental conditions on productivity

Occupants who commented on their increased productivity due to environmental conditions in the building pointed to natural light, fresh air, open concept design allowing for improved collaboration and community, as well as access to shared spaces, the dock area and connection to nature in general. Sample comments:

- *I think the environment does improve productivity. I have worked in buildings with no windows, artificial lighting, stuffy air, too cold etc. I think that I was less productive in that environment.*
- *The approach of having staff from different functions work side by side rather than in 'silos' makes for increased integration/awareness in the work we do.*
- *I love the social benefits of shared space, especially the lunchroom and deck.*
- *Access to the docks is great. I also enjoy the open concept and integrated nature of the workspaces.*

Occupants who commented on their decreased productivity due to environmental conditions in the building frequently referred to the tradeoff of open concept design in terms of acoustics. Noise, interruptions and the lack of privacy were the top reasons given for a decline in productivity. Some occupants also pointed to glare on their computers and plumbing odours leading to sub-optimal working conditions. Sample comments:

- *I like the light open space, although it can be quite noisy by times.*
- *I really like the fact that we have windows to open but do find the open concept challenging sometimes as a result of excessive noise.*
- *Distraction from noise is the main cause of decline in productivity.*
- *The constant stream of traffic by my workstation combined with the need to travel upstairs when using fax/printer is a hindrance to my productivity.*

- *I wear sunglasses to work due to glare that comes off a wall and hits eyes looking at computer.*

- *Long-standing periodic noxious fumes from the plumbing.*

Results suggest that while many of the green design features do in fact lead to increased occupant productivity, acoustical conditions may in some cases outweigh the benefits of natural light, ventilation and open plan concept. Productivity in the Gulf Islands Operations centre could be significantly improved by addressing the acoustical issue.

3.5 Health and Well-being

Based on survey results, as shown in Figure 17, occupants of the Gulf Islands Operations Centre were healthy and experienced high levels of personal wellbeing. 67% of respondents felt more healthy in the Operations Centre compared to their experience in other buildings. This result was significantly better than benchmark, and placed the Gulf Islands Operations Center in the 88th percentile of all benchmarked buildings for health. Wellbeing was also highly rated by survey respondents, with 78% indicating high levels of satisfaction with their personal wellbeing.

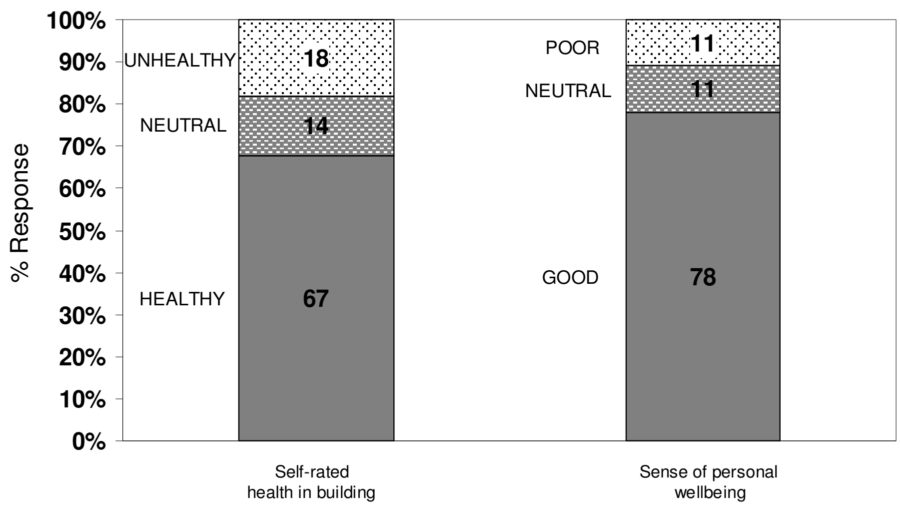

Figure 17. Occupants' perceived health and wellbeing

Comments regarding improved health in the Operations Centre were similar to those on increased productivity, and cited the beautiful design of the building, spaciousness, the abundant fresh air and natural lighting. A concern with regards to health in the building again had to do with air quality issues arising from the sewage system. One respondent did not thing that the continual use of earplugs was healthy. Sample comments:

- *Beautiful design. Spacious with lots of natural light and fresh air (opening windows). A healthy environment to spend my working hours.*

- *Fresh air and natural ventilation can't be beat, however the air circulation isn't good enough on the second floor if the windows are closed.*

- *I don't have headaches as I used to have while working in my previous building.*

- *I feel more healthy most of the time. However when the plumbing fumes are present I get dry itchy eyes, headaches, and generally feel unwell.*

- *People shouldn't have to wear ear plugs. It's not healthy.*

3.6 'Forgiveness'

Beyond physiological factors, a broad range of psychological, social and behavioral factors can have an impact on occupants' comfort in a building. One way to evaluate this influence is to consider their level of "forgiveness", or the amount of tolerance occupants have for the building and chronic faults. Forgiveness is derived by comparing mean values for comfort overall with mean values for specific comfort variables (lighting, noise, temperature and air quality). Values are normally in the range of 0.8-1.2, with values greater than 1 indicating more forgiveness.

	Mean Scores							
Building	Comfort Overall	Temp Winter	Temp Summer	Air Winter	Air Summer	Lighting Overall	Noise Overall	Forgiveness
Gulf Islands Operations Centre	4.89	4.35	4.14	4.54	4.71	5.36	2.97	**1.13**

Table 1. Forgiveness values for the Gulf Islands Operations centre

Overall forgiveness in the Gulf Islands Operations Centre was found to be high, with a score of 1.13. As outlined in Table 1, while satisfaction levels with specific comfort variables were rated lower by survey respondents (range of 2.97 – 4.71, scale of 1-7), overall comfort was rated higher than any of the individual variables themselves (4.89). This suggests that occupants were willing to tolerate a higher level of discomfort in the Operations Centre than one would expect given their satisfaction with different aspects of the indoor environment. The score places the Gulf Islands Operations Centre in the 85th percentile (top 15% of building) of the BUS International Benchmark for forgiveness.

4.0 Study Limitations

The main limitations of the study and analysis are as follows:

- Values presented for indoor physical climate are based on averaged data from spot measurements taken at six locations in the building over the course of a day. These values should not be taken to represent an accurate assessment of the building's indoor climate on the whole. A more comprehensive and accurate assessment would require higher spatial resolution of measurements, taken over longer periods of time and at varying times throughout the year.

- The 2008 BUS International Benchmark used in the analysis comprises primarily British and Australian buildings with only a limited number of Canadian buildings. As such the benchmark may be biased towards the UK and Australian building context. POE benchmarks naturally tend to be biased regardless of the context due to the self selection of buildings that choose to participate in this type of study. In addition, in the 2008 BUS benchmark, the majority of buildings are considered to be "green" designed therefore one would expect the average level of performance to be higher than if the benchmark included a full spectrum of buildings.

- As with any survey-based POE study, satisfaction findings reported here may also be biased (either positively or negatively) due to the self selection of respondents.

5.0 Conclusions and Recommendations

Gulf Islands Operations Centre occupants are highly satisfied with the **building overall** in terms of design, image and ability to meet their needs. The building ranked in the 80th percentile of the BUS Satisfaction Index (top 20% of all buildings) for the combination of occupant satisfaction, productivity and health at work. L**ighting quality** and **air quality** were the best rated indoor environmental variables by occupants, who frequently cited the natural light and fresh air as having a positive influence on their productivity and health compared to other buildings they had worked in previously. Illuminance levels were generally acceptable to high, and carbon dioxide levels were much better (lower) than normally found in office buildings. Occupant satisfaction with **thermal comfort** was lower than other variables (too hot in the summer, too cold in the winter), but did not appear to have a significant impact on perceived productivity according to comments provided. Temperature and humidity (measured in the fall season) were both within the range of standards, and radiant temperature was below typical criteria for heat stress. **Noise** was the most significant area of concern in the building with 76% of occupants dissatisfied overall, and ambient noise levels found to be within the average to above average range for recommended workplace levels. **Personal controls** were generally frequently used where provided, with the exception of heating controls. A number of occupants took personal actions to control noise in the building through the use of earplugs and headphones.

The average influence on **productivity** due to indoor environmental conditions was +1.07% across all respondents. Roughly the same number of respondents felt the indoor conditions increased their productivity as those who felt they decreased their productivity. Natural lighting and fresh air were the primary reasons given for increases in productivity while noise, interruptions and lack of privacy were primary reasons given for a decline in productivity. One aspect of the building design which both increased and decreased productivity was the open concept design, which led to improved collaboration and community among staff, but also led to significant productivity issues in terms of excessive noise, distraction and inability to concentrate on work.

Perceived **health** in the Operations Centre was significantly above average, placing the building in 88th percentile of the BUS Satisfaction Index (top 12% of all buildings) for this variable. Wellbeing was also highly rated, with over three quarters of respondents satisfied with their personal well-being. Respondents also demonstrated a high level of 'forgiveness' or tolerance for comfort conditions in the building, ranking in the 85th percentile of benchmark buildings (top 15%).

Recommendations to promote and provide high levels of occupant comfort and satisfaction into the future include the following:

- Noise issues may be addressed by installing acoustic panels, carpet (in select areas), and sound-absorbing material finishes on office furniture and partitions. White noise generators may also be considered to increase the level of background noise. Sound absorption in the workplace, and sound isolation from bathrooms and meeting rooms are considered priority areas.

- Designated break-out spaces could be provided for phone calls and conversations to take place without disrupting others. These could include offices designated as common rooms or mobile sound-proof booths.
- Outstanding air quality/odour issues related to the plumbing system need to be resolved, as they continue to be raised by occupants as problematic and posing a concern to health and safety.
- Lack of ventilation in the upstairs boardroom should be addressed, particularly if this space is being converted into an office.
- Glare issues may be addressed by reducing the source of glare (tin roof and walls of Boathouse on the North perimeter, exterior metal flashing on the South perimeter), and ensuring that when interior blinds are used to cut out glare, occupants have adequate means of illuminating their workspace, e.g. task lights.
- Lighting control issues could be address by changing the overhead lighting system default from on to off to reduce the number of hours lights are on during daylight hours. This would put the onus on occupants to turn on lights when needed rather than turn off lights when not needed and improve overall energy efficiency.
- Concerns regarding the need to walk up and downstairs for printing could be addressed by installing a secondary printer/fax machine area on the second floor.

6.0 References

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(5) IESNA (2004) *American National Standard Practice for Office Lighting*. Illuminating Engineering Society of North America, ANSI/IESNA-RP-1-04, New York.

(6) ANSI (1995) *American National Standard Criteria for Evaluating Room Noise*. ANSI/ASA S12.2-1995.

(7) Abbaszadeh, S., L. Zagreus, D. Lehrer, and C. Huizenga (2006) Occupant Satisfaction with Indoor Environmental Quality in Green Buildings. *Proceedings of Healthy Buildings 2006*, 3, 365-370, Lisbon.

Appendix

Complete list of open-ended comments from building evaluation survey

Comfort

- Comfort is an issue if the building systems break own as it takes a considerable amount of time for heat to stabilise. The ability to open or close my window allows me the flexibility to modify my local environment.
- If the fans aren't on and windows on both sides of the building open, the second floor gets very stuffy and warm, even if the outside air temp is cool.
- It is a new freshly constructed building and you do not expect to have conditions that affect your overall healthy well being. Everyone was excited about its construction, the sustainable design vision, leadership in energy principals, its impact on the environment, practicing our mandate, being an example for other facilities. So many of the design features for heating, water conservation, indoor environmental quality are all excellent we just need to measure/test to see if all these systems are working.
- Lots of fresh air, usually not too hot or too cold.
- The building is great for the most part although the temperature can be quite uncomfortable in the summer during the hot days and cool in the winter. It seems as though all of the glitches have yet to be worked out to the heating system.
- The lack of privacy when having a conversation is a bother. When conversing, unless in a closed office or boardroom, there will be anywhere from 1 to 10 people who can hear your conversation.
- There is often a lack of hot water in the shower.

Design

- Although this is a relatively functional office, the open office concept is a failed concept due to the transmission of noise throughout the building.
- Beautiful design. Spacious with lots of natural light and fresh air (opening windows). A healthy environment to spend my working hours.
- Beautiful....but not always functional.
- Great concept, good use of facilities, LEED rating system, used staff input for design implementation. Some basic needs - air quality, water quality and sewage removal are not adequate for a government or any work site.
- Hot Water Tank is not always functioning.
- I do not particularly like the industrial look inside of the building.
- I like it, but additional noise dampening methods are needed. Perhaps decorative fabric hangings?
- I like the light, open space, although it can be quite noisy by times.
- I really like the fact that we have windows that open but do find the open concept challenging some times as a result of excessive noise.
- Ideally, I would prefer to have an enclosed office but given that we are cannot, because we have to follow Treasury Board directives, I find the building design satisfactory.
- Modern with warmth.
- Our staff is growing fast, lack of space.
- Privacy is difficult sometime.
- There could be better sound insulation between workstations. The washrooms are not sound insulated at all either from the door side or the through the walls.
- Unique design, positive public profile with it being a LEED Platinum building; some issues with environmental controls aspects, and with plumbing; noise levels from primarily open concept are distracting; even 'closed in' offices are not soundproof.
- Very nice looking building but poor acoustics and poor temperature control, problems with offensive sewage smells.

Health

- Eye irritation, headaches, nausea, chest pain or all of the above.
- Fresh air and natural light can't be beat, however the air circulation isn't good enough on the second floor if the windows are closed.
- I don't have headaches as I use to have while working in my previous building.
- I feel more healthy most of the time. However, when the plumbing fumes are present, I get dry, itchy eyes, headaches and feel generally unwell. I have a poor sense of smell so often I only know that the situation has occurred again as a result of those symptoms. I think that the situation must be very bad by the time that I notice symptoms.
- I find the healthiest place to be is outside.
- Natural light loss, cold in winter, draughty in summer as all windows are open to control heat on very hot summer days.

- Open windows are a MUST... Re-circulated air, I have found in "closed window" offices, breed much more illness, etc..
- The one exception to this is a continuing issue with the sewer smell emanating from the sump in the basement. It has improved but is still noticeable and has not been completely fixed.

Hinder (things that hinder work)

- Ability to talk with colleagues without disturbing others, because of the amount of open space working environment; as a manager, having the capacity to speak privately with staff.
- Because of the open concept, at times it is difficult to concentrate because of the noise level.
- Biggest problem is the transmission of high and low level noise throughout the building. Even whispers can transmit across the office from different work zones. Areas where people tend to congregate and generate noise are in work areas that require quiet.
- Distractions, since I share the space with 2 other co-workers, and there is a lot of traffic going through my office space.
- Interruption and too large of an open concept. Three people is a room is way too much. Productivity is affected. People shouldn't have to wear ear plugs, it's not healthy.
- It would be useful to have a small workbench down in the basement. Also, there are a couple spaces that have not been completed - the laboratory and the secure storage. It will improve work when these are completed.
- Lack of desk space!!!!, lighting is hard on eyes.
- Lack of privacy, not enough office space, no free terminals for out of office staff.
- No space for meetings with the public, project teams, etc..
- Noise can sometimes be very load when a large majority of the staff are present.
- Noise from co-workers and interruptions from people in immediate work area.
- Noise levels can be distracting, but pls see below. Minor thing: monitors get a lot of glare from all the natural light, but this is a good problem to have.
- Noise, light.
- Noise, people talking in hallways and open spaces particularly near the entrance from the visitor reception area. It is important to have these discussion but I think folks forget others are trying to get work done.
- Noise, interruptions.
- Other than the problem with the air quality. I feel the facilities meet my needs (6) but the Air Quality-(1) it is a main concern with basic human needs that are required to be met. As an unknown entity we do not know what it is and have no idea if this is having long term affects on our bodies/health. Makes us edgy, symptoms are distracting affect the quality of work that you are capable of performing. Affects how you feel when you leave the work facility takes some time to recover after leaving the site. Is this gas/or what ever, always present and we only notice it when it is high and can smell something/when it really irritates are senses; or is it only present under those severe conditions. Consistent temperature in the building can be a problem - transition days when temperature outside varies, takes relatively long time for the system to switch to new outside temperatures would be very distressful in a colder climate.
- Poor acoustics, lack of privacy,.
- Poor storage for supplies, stock, etc... Ineffective fans in the washroom... one located adjacent to my workspace and large meeting room... not effective for either smell... or sound (echoes quite a bit...).
- Proper storage areas, noise in the workplace (distractions),.
- The lack of adequate space for all of the staff that I have working in the building. The safety issue arising from the long-standing, periodic noxious fumes from the plumbing.
- The printers and fax machine are located on the main level prompting the need to go up and down a staircase every time these actions are required.
- Very noisy work environment. Inadequate dedicated storage area.
- Work space could be a little bit bigger.

Lighting

- At certain times of day and year, there is glare off of the metal flashing outside and directly through the windows. I prefer having all the natural light, and I think the blinds do the best if not a perfect job at reducing glare. I would prefer a desk lamp to the overhead artificial light.
- Definitely found that there was some glare, bounce of light from sky and off water we were sad to ask for blinds because we liked the views but they made a huge difference.
- Generally, lighting in my work area is fine. Lots of natural light. No task lighting needed.
- I am happy about the lighting situation. Its just sometimes late in the day that I get glare from outside
- I do not use my artificial lights at all unless the natural light is very dim. Usually, natural light is all I require.
- I don't believe the lights work as intended as they come on but rarely shut off when there is more than adequate light to work from, the basement lights never go off unless they are turned off. The bathroom lights would be more

efficient if they just worked on an on/off switch as they come on when someone walks by and never go off unless turned off.
- I used the blinds provided to reduce the glare from the natural light.
- Its good -- but requires monitoring throughout day to adjust artificial light to what's happening outside.....
- Lighting is good - both natural and artificial. Some light conditions result in outside glare from water and boat house - not that often and blinds are an easy fix. Its difficult to complain about a water view! Its generally really good. If boat house is recapitalized, I recommend a low glare tin roof and walls.
- Lighting issues.. one light automatically shut itself on and off randomly for no reason, numerous times a day, finally after repeated attempts to fix, the light is permanently fixed to be on at all times.
- My desk faces a window, it's a bit hard since my computer is right in front of it.
- Sun comes through blinds. No overhead light at my desk.
- The stairwell to the basement has very little natural light, so when the artificial lights automatically turn off (after 4:30), it's quite dark on the stairs. Several of us work past this time, and the timer should be changed as daylight gets shorter during the winter.
- There are a lot of windows which allows a lot of natural light and this is very nice.
- Window light in minimal. have compensated with full spectrum.

Meeting rooms

- Air flow in small meeting rooms is poor, stuffy.
- Committing them for use as an office is less than ideal.
- I really like having access to the smaller board rooms.
- One meeting room is currently being use as office, this restrict meeting space.
- Only one large and two small rooms available. All are booked out. One has just been made into an office...
- Some good suggestions were made to incorporate the large meeting room and break out rooms for our facility saves time and money from renting facilities in the area on a regular basis. Usually available for all needs. Confidentiality of information discussed in rooms is low because your can hear the rooms discussion between meeting rooms and in some adjoining areas.
- Stuffy and dry air!!!!!!.
- The upstairs boardroom is airless. If you have to spend any time in the space it quickly becomes too hot and there is not circulation. The fan does not work and, although this has been noted before, it still does not work.
- The main floor, large boardroom is always cold and, therefore, uncomfortable.
- There are often conflicts when all the boardrooms are being used and there is no area to have a private meeting.
- There is often not enough office space, so people end up working in one of the boardrooms.
- Typically available when needed. Options available when one room is full.

Needs

- A protected and larger bike rack is necessary.
- Air Quality-we notice a smell associate with a type of gas-possibly sewage gas that permeates the whole building when there is a low ceiling of fog, overcast cooler temperature days. It affects people in different ways. Eye irritation, headaches, nausea, breathing difficulties, allergies, multiply symptoms. Plumbing may not have been implemented well into the design concept, the system may not be working because of unusual circumstances, contractor may not have install appropriately. This site may need a different venting system because of site specific environmental conditions. Water it is difficult to get any hot water in the building. continuous problems with toilets- use of water to flush, is it meeting the LEEDS rating system, need to flush and run water in the building so that the sewage fumes do not come out of the toilets causing concern under some weather conditions or when the system dries out and needs more water. Location of a Fuel Storage System- fumes that enter the building even when windows/door are closed while it is being loaded with fuel.
- Meets needs but: (1) have to wear sunglasses to work due to glare that comes off of wall and hits eyes looking at computer (2) Was a huge overheating problem as I have the only small closed office on the second floor. It was mitigated by installation of a fan/air conditioner. (3) Sounds travels along the aluminum windows so there is no confidentiality. (4) The open concept and central stairwell means that "chat spaces" on the main floor are central and so noise comes right up into the 2nd floor office areas,.
- More storage space for equipment in basement would be useful. Need space dividers.
- Once the lab is completed it will meet most of my needs.
- Open concept too open.
- Still need lab space in the basement.
- The building was originally designed as an operations building but a lot of the planned "messy" areas are not finished or have been taken over for admin purposes.
- The common copy area could definitely have [?] to be bigger. There isn't enough counter space to accommodate everything we need.

- The one major fault are the washrooms. They are either not well sound-proofed or too close to the offices. If you are close to the washrooms you can hear things and/or smell things which is not pleasant.
- Too many people currently housed in this building; privacy is an issue; meeting areas are at a premium.
- Window is for light, not viewing, which is okay, but not prime real estate.

Noise

- Already described above, outside noise is not a problem. Inside noise varies from loud co-workers in their workspace; people in hushed whispers (noise travels across the office); large groups of people congregated in entrance or at foot of stairs or other areas of congregation - very loud conversation; open office results in regular and sometimes near constant interruptions - you can't close the door in an open office! A lot of people have resorted to wearing headphones.
- I like the open design, but some noise dampening methods would help reduce the volume from conversations in the common areas. Fabric hangings, maybe?.
- It is an open concept building some days the volume on everybody is turned up. Occasionally individuals forget to use there inside voices. Generally speaking it is a happy working as normal hum. Individuals mostly need to be aware of how easily their voices carry and we try to discourage people talking over the cubical dividers, move to another area for a group discussion.
- It's a very open building. Everyone can hear everyone, all the time.
- My workstation is located between the gear area and the lunchroom. Traffic through this space is frequent and often includes interruptions in my work.
- No ability to communicate to others that you are not to be disturbed.
- Noise carries especially from people across and first floor.
- Noise is the biggest issue in the building, some days it can be fine other days it is a challenge, even co-workers phone calls can be distracting.
- Not an issue. Interruptions are the real work.
- Shared workspace means that people come in to talk to me or to my colleagues, which is distracting when you're trying to concentrate on your work. People are generally considerate in leaving the area if they are going to have longer conversations, but they are also limited in their options of where to go to continue the conversation without disrupting others. You can also overhear conversations in other workspaces that are adjacent to you.
- Sometimes affected, but its not the norm. Usually the disruption is from other people that are speaking or laughing very loud or from a sound from the street or harbour. But this doesn't happen that often.
- The open-concept of office does not work when I have to concentrate on some of my work. There is often noise from people talking around or some colleague walk in a room to talk with my room-mate.
- There is woefully inadequate sound-proofing in the enclosed office walls and in the washroom walls.
- Too open concept.

Perceived productivity

- Distraction due to noise from people is the main cause of decline in productivity.
- For me, the sound of activity and people discussing things is pleasant white noise that encourages me to do more. If I find myself getting distracted, I use headphones.
- I can step out on a bright sunny and warm summer day and not even know the outdoor conditions. I function best went connected to the outdoors by window views and natural light, and in quiet private settings. I am compensating with personal devices and coping mechanisms so I am productive. Without these my decreased productivity would be greater than 10%.
- I think the environment does improve productivity. I have worked in buildings with no windows, artificial lighting, stuffy air, too cold, etc.. I think that I was less productive in that environment.
- Lack of privacy impacts on effectiveness,.
- Sometimes the environmental quality gives you symptoms that distract from your work load. You may need to go outside for some fresh air, you may need to leave the site or you may need to take sick days that you normally would not take.
- The building is well light and ventilated, which seems to help when working prolonged periods of time.
- The constant stream of traffic by my workstation combined with the need to travel upstairs when using fax/printer is a hindrance to my productivity.
- This is highly variable but when I am trying to do focused work (writing or editing technical documents) I have great difficulty due to noise and interruptions.

Requests for changes

- Asked for lights to be manually switchable after 4:30. When we're still here, there are some lights we can't turn on manually once the system shuts them off.
- Draughty window frame.

- Have mentioned to other colleagues that the conditions are too hot and asked how to turn the heat down. No on in the building knew how.
- I have asked for more air circulation during the summer.
- Lights used to come on when not necessary..no one in the room.
- Made comments to Superintendent and Admin. person about the boardrooms.
- Upstairs boardroom ventilation.
- Ventilation, Questions about the air quality to my supervisor, building co-ordinator and my supervisor took to Gulf Islands superintendent & field unit superintendent. Asked questions about the heating and how it works, give feedback on when it is unreasonably cold and if it does not fluctuate after the system has a chance to adjust.
- We have asked for changes to the lighting system to make them more efficient, to have lights that come on automatically turned off (Closets, closed rooms in the basement, etc. but have been told they are all on one loop and could not be isolated with out changes to the wiring. Another issue which has yet to be solved is the hot water in the basement is not hot, luke warm at best and makes for a cold shower if you have biked to work, not to mention presents hygiene concerns for washing dishes.
- Yes, to ensure staff comfort as I'm the contact for the building maintenance contractor.

Space at desk

- As already mentioned, there is sufficient space but because operations areas are not complete, desk space is compromised for storage of equipment etc..
- As an ergonomics coach for the office we have found some design features that affect the set-up of work stations for individuals. Just some of the angles of the tables, square edge, work tray size although they look good can interfere with alignment for some individuals. Edges that do not interfere with computer work tray, easy change of height of work surface for different size of employee.
- Could use a door.
- Currently crowded, due to in-filling of workstations while we're waiting for renovations to be completed on the office space next door; width of desk makes it difficult to easily access the windows to open and close them.
- Ergonomically doesn't work... but as 4 other individuals have worked here in the past year (for an individual on education leave) I would imagine that it will be status quo for the next little while..
- Filing cabinets take up too much space.
- Fine. Could always use a little more.
- Had to self relocate to another area so that the ergonomics of new desk would accommodate my body shape.
- I could use a bookshelf to organize books and printed material, without cluttering my desk surface with magazine boxes.
- More enclosed under-desk storage is needed. More coat racks!.
- My work space is 1.5 square meter! and I had to wait for over 8 weeks to get a keyboard tray and pedestal.
- Some shelves are not reachable above my desk.
- Space is allocated based on specific criteria. Nothing can be done to increase that space. There is cramping when visitors are present, and limited access to meeting rooms. I take visitor outside on sunny days.
- The chairs are brutally uncomfortable and hard on the back.

Storage

- Always not enough storage.
- Generally speaking design took in the consideration provided by the design team from staff input. Definitely facility use specific.
- Lack of storage, need a bigger library.
- Not enough at-desk storage.
- Not enough storage, even for the basics.
- Not enough wall space to hang things.
- Not great storage for supplies....but then there is not much shelving, etc.... Also, the set-up for different areas such as stock, do not seem to have been thought out... that could be the built-ins... or just poor use of the space (or both).
- Not very much of it.
- Operational storage and work areas (see above "messy" areas) are compromised for administrative needs.
- The individual lockers are great. We've worked out pretty good storage for operational equipment. I think some people are lean on storage at their workspaces that have been added between others or in areas not originally designed as workstations.
- There is no formal storage for important archival files etc.. There is a collection of junk in the basement that if organized could lead to more storage space. Instead, the pile just grows larger. Organization of that space is needed for temporary storage and immediate safety reasons.
- There is no place to store wet bike clothes where they will dry well. There is no dedicated storage space for Communications materials (e.g. posters, display panels, etc..).

- There is plenty of storage space for kitchen storage but lacking in utility type/personal storage for workstations that are not in an office. An area to hang coats for staff and guests would be great.
- There is still work to do to complete the storage areas. When they are completed I think things will be quite good.
- There is very little storage in the Sidney Operations Centre.

Work well (things that help work)

- Access to the docks is great. I also enjoy the open concept and integrated nature of the work spaces.
- Availability of the boardrooms on both floors is key to directing potential hallway discussions so they are less disruptive on those trying to get focused work done.
- Communications.
- Everyone you need assistance with is under the same roof and easy to access.
- For the most part, people are doing their own work and not interrupting others. I think the layout works well for separating prep to go into the field (basement) from the main office component.
- Good lighting, reasonable air quality (after sewage problem was rectified); functional furniture (I had to replace my chair because the standard one was very uncomfortable). access to docks and boats is good; functional work areas in lower level are pretty good but not completed yet.
- Good private & quite office space.
- I love the social benefits of the shared spaces, especially the lunchroom and deck. I value the energy and materials efficiency of the building.
- Meeting room availability (although this will likely change when the upstairs meeting room converts to an office soon), lunch room, amenities, architectural design, washrooms, operational flexibility.
- My office is situated on the perimeter of the building, away for traffic and common areas. On balance, I think the open building design contributes to better communication.
- Open design,.
- Telephone systems work well, set up of space is fine, organization of tools photocopier, printers, supplies, kitchen, storage of files.
- The approach of having staff from different functions work side by side rather than in 'functional silos' makes for increased integration/awareness in the work we do.
- Use of natural light is great -- makes it a lot easier when working with computers all day..!... fresh air flow is good.. especially on first floor...
- Windows, fresh air.