The impacts of occupant behaviours on energy consumption in New Zealand office buildings

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Abstract

The building and construction sector consumes 36% of the global energy and produces 39% of energy-related CO_2 emissions. Building energy consumption is influenced by various factors, including climate, building-related characteristics, building services, and occupant behaviours. In return, occupant behaviours significantly impact building energy consumption, with the difference between simulated and actual energy use due to how occupants behave and interact within the building. Numerous direct and indirect factors may influence occupant energy behaviours, with physical environmental, contextual, and social-psychological factors being the most widely recognised categories. Research on occupant behaviour in buildings is expanding, but only about 7% of those studies explore the determinants of behavioural change. Also, behavioural models and tools are becoming more complex to represent the human component better. As such, there is a need for further research on energy conservation approaches and drivers of occupant behaviour change in commercial buildings, especially in the New Zealand context, and a need for models that consider both subjective and objective aspects and an ontology that explicitly addresses the subjective aspects. Thus, this research focuses on creating an ontology that specifies occupant behaviour-related data monitoring and collection to optimise the energy performance of New Zealand office buildings. This research followed a narrative and systematic literature review, a preliminary study, and two primary data collection rounds to fill the above research gap and achieve the research aim. The research used a mixed methods approach consisting of grounded theory, survey, and qualitative and quantitative data collection and analysis techniques, with critical realism philosophy and an abductive approach as the underlying theoretical framework.

The narrative and systematic literature reviews focused on identifying the prevalent occupant energy behaviours and the significant drivers that influence these behaviours in the New Zealand and international contexts. The narrative review of academic articles defines occupant behaviours and highlights the importance of considering indoor environmental quality (IEQ) parameters and other factors influencing occupant behaviours. Also, it identifies the main factors influencing occupant behaviours. The narrative review further suggests that energy research practices based purely on objective factors of occupant behaviours may not highlight valuable insights from subjective aspects. Therefore, a systematic review of research articles on the social-psychological drivers of occupant

behaviours is conducted to determine previous research patterns and trends and identify gaps for future investigation. The systematic review highlights the influence of social-psychological theories and constructs on occupant energy behaviours and discusses the application of theories in different occupant behaviours and future research trends and implications. In the following stages of the research, these identified prevalent occupant energy behaviours and the significant drivers that influence these behaviours are preliminarily and primarily investigated in the New Zealand context.

Accordingly, the preliminary research investigates the attitudes and approaches of building managers towards occupant energy behaviours in New Zealand tertiary education office buildings and how organisational energy culture affects their strategies for addressing occupant preferences. The research used grounded theory analysis, with 25 participants from a university being interviewed through semi-structured interviews with facilities managers, sustainability managers, and building occupants. The study found that building managers often oversimplify the complex relationship between discomfort, energy consumption, and the influence of social-psychological factors on occupant behaviour. To improve the organisational energy culture, the study suggests increasing occupant knowledge and awareness of energy consumption, providing energy feedback, and giving occupants more responsibility to meet energy targets. The preliminary study also evaluates the relationship between occupant energy behaviours, IEQ satisfaction, user control, and social-psychological factors. The study collected data from 52 occupants in five office spaces at a university in Auckland, New Zealand, and analysed using descriptive and binary logistic regression analysis. The study found that thermal and air quality conditions are the primary sources of IEQ discomfort, and occupant satisfaction is linked to their comfort preferences. The preliminary study showcases how organisations rationalise occupant energy behaviours and comfort preferences in New Zealand office buildings while highlighting the importance of considering occupant comfort and behaviours when implementing energy-saving measures and preparing occupant-centred energy policies.

Subsequently, the primary data of the research focuses on evaluating how occupants perceive decision-making regarding their energy behaviours in New Zealand office buildings to enable informed decisions for building managers. The primary research explores the influence of social-psychological factors on occupant energy behaviours in office environments. It utilises a combination of questionnaires distributed to 294 office occupants

in New Zealand and PLS-SEM analysis to assess the impact of motivation, opportunity, and ability on these behaviours. The results indicate that improving energy-saving opportunities through subjective norms, organisational support, behavioural interventions, and individual control capability leads to increased perceived behavioural control and knowledge, motivating occupants to engage in energy-saving behaviours. As the subjective factors are clearly identified, the research next investigates the influence of subjective and objective factors on occupant behaviours in New Zealand office buildings. The study collected data on indoor environmental comfort, control availability, and social-psychological factors through online surveys of 99 occupants and analysed the data using machine learning techniques. The study found that the availability of user controls is the main predictor of most occupant behaviours, followed by social-psychological factors and indoor environmental parameters. Demographic factors such as gender, work duration, and workspace permanence are also important. These primary research findings then contributed to developing an ontology for effectively monitoring and collecting occupant energy behaviour-related data to optimise the energy performances of New Zealand office buildings.

The proposed ontology effectively describes and captures the complex interplay of drivers affecting occupant energy behaviours in offices, including environmental factors, user control, social-psychological factors, and demographic information. The subject matter experts agreed that the ontology provides a comprehensive and structured representation of occupant energy behaviours and could be helpful in building performance simulation and energy management systems. They also emphasised the importance of considering occupant behaviour-related data in building energy management strategies and audits. Accordingly, this study provides a new approach to assessing the combined impact of comfort preferences, energy behaviour, and various environmental, building, and social-psychological factors for modelling occupant energy behaviours in office buildings. The study provides a practical and valuable contribution to building energy efficiency, supporting the integration of occupant energy behaviours into building performance simulation, energy management, and sustainability strategies.

I dedicate this thesis to

my husband, who encourages and pushes me towards dreams and goals,

my father, who selflessly sacrifices his needs for our wants, and

my mother, who inspires me in love and life.

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"Life takes you to unexpected places. Love brings you home."

- *Melissa McClone, Mistletoe Magic*

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Abbreviations and acronyms

AHU – Air handling unit

ANN – Artificial neural networks

ANOVA – One-way analysis of variance

ARM – Association rule mining

AVE – Average variance extracted

BEMS – Building energy management system

BMS – Building management systems

BPS – Building performance simulation

CART – Classification and regression trees

CDD – Cooling degree-day

CHAID – Chi-squared automatic interaction detection

CI – Confidence interval

CMB – Common method bias

CMV – Common methods variance

CR – Composite reliability

EECA – Energy efficiency and conservation authority

EPBD – European directive on the energy performance of buildings

EPV – Events per variable

EUI – Energy use intensity

FCU – Fan coil unit

FM – Facilities managers

GDP – Gross domestic product

GFA – Gross floor areas

GHG – Greenhouse gas

HDD – Heating degree-day

HTMT – Heterotrait–Monotrait

HVAC – Heating, ventilation, and air-conditioning

IAQ – Indoor air quality

IEA – International energy agency

IEQ – Indoor environmental quality

IPCC – Intergovernmental panel on climate change

IWBI – International WELL building institute

MBIE – Ministry of business, innovation & employment

MOA – Motivation-opportunity-ability framework
NABERSNZ – National Australian built environment rating system
NAM – Norm activation model
NIWA – National Institute of Water and Atmospheric Research
NZD – New Zealand dollar
NZEECS – New Zealand energy efficiency and conservation strategy
OATD – Open access theses and dissertations
OCC – Occupant centric controller
OECD – Organisation for economic cooperation and development
OR – Odds ratio
PBC – Perceived behaviour control
PCT – Perceptual control theory
PLS-SEM – Partial least squares structural equation modelling
PMV – Predicted Mean Vote
PRISMA – Preferred reporting items for systematic reviews and the meta-analysis
QUEST – Quick, unbiased, efficient statistical trees
SCT – Social cognitive theory
SD – Standard deviation
SM – Sustainability managers
SME – Subject matter experts
SNT – Social network theory
SPSS – Statistical package for social sciences
SPT – Social practice theory
SVM – Support vector machines
TE – Trading Economics
TPB – Theory of planned behaviour
UFA – Usable floor area
UK – United Kingdom
UNDP – United nations development programme
UNEP – United nations environment programme
UNFCCC - United nations framework convention on climate change
USA – United States of America
VBN – Value belief norm theory
VIF – Variance inflation factor

List of peer-reviewed publications

Journal articles (Published)

[1] Weerasinghe, A. S., Rotimi, J. O. B., & Rasheed, E. O. (2023). Modelling of underlying social psychological effects on occupant energy-related behaviours [Article]. *Building and Environment*, 231, 110055. https://doi.org/https://doi.org/10.1016/j.buildenv.2023.110055

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[3] Weerasinghe, A.S., Rasheed, E.O., & Rotimi, J.O.B. (2022), Environmental and socio-psychological drivers of building users' behaviours: A case study of tertiary institutional offices in Auckland, Journal of Facilities Management [Article]. EarlyCite, https://doi.org/10.1108/JFM-01-2022-0011

[4] Weerasinghe, A.S., Rasheed, E.O., & Rotimi, J.O.B. (2022), A Facilities Management Approach to Rationalising Occupants' Energy Behaviours [Article]. Facilities, 40(11/12), https://doi.org/10.1108/F-02-2022-0025

Journal articles (Under review)

[5] Weerasinghe, A.S., Rotimi, J.O.B., & Rasheed, E.O. (2023). Understanding social-psychological influences on occupant energy behaviours: A systematic review based on bibliometric and thematic analyses.

[6] Weerasinghe, A.S., Rotimi, J.O.B., & Rasheed, E.O. (2023). Validation of the occupant energy behaviour-ontology for energy performance improvement in New Zealand office buildings.

Conference papers

[7] Weerasinghe, A.S., Rasheed, E.O. and Rotimi, J.O.B. (2022). Self-rated Motivational Drivers for Occupant Behaviours: A Case Study of Tertiary Office Buildings. In S. Perera & M. Hardie (Eds.) Proceedings of the 45th Australasian Universities Building Education Association (AUBEA) Conference (pp. 995-1004), Western Sydney University.

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the 38th Annual ARCOM Conference (pp. 751-760). Association of Researchers in Construction Management.

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[11] Weerasinghe, A.S., Rasheed, E.O. and Rotimi, J.O.B. (2021). A Dilemma Between Building Indoor Environment Preferences and Occupant Energy Behaviours. In: L. Scott & C. J. Neilson (Eds.) Proceedings of the 37th Annual ARCOM Conference (pp. 794-803), Association of Researchers in Construction Management.

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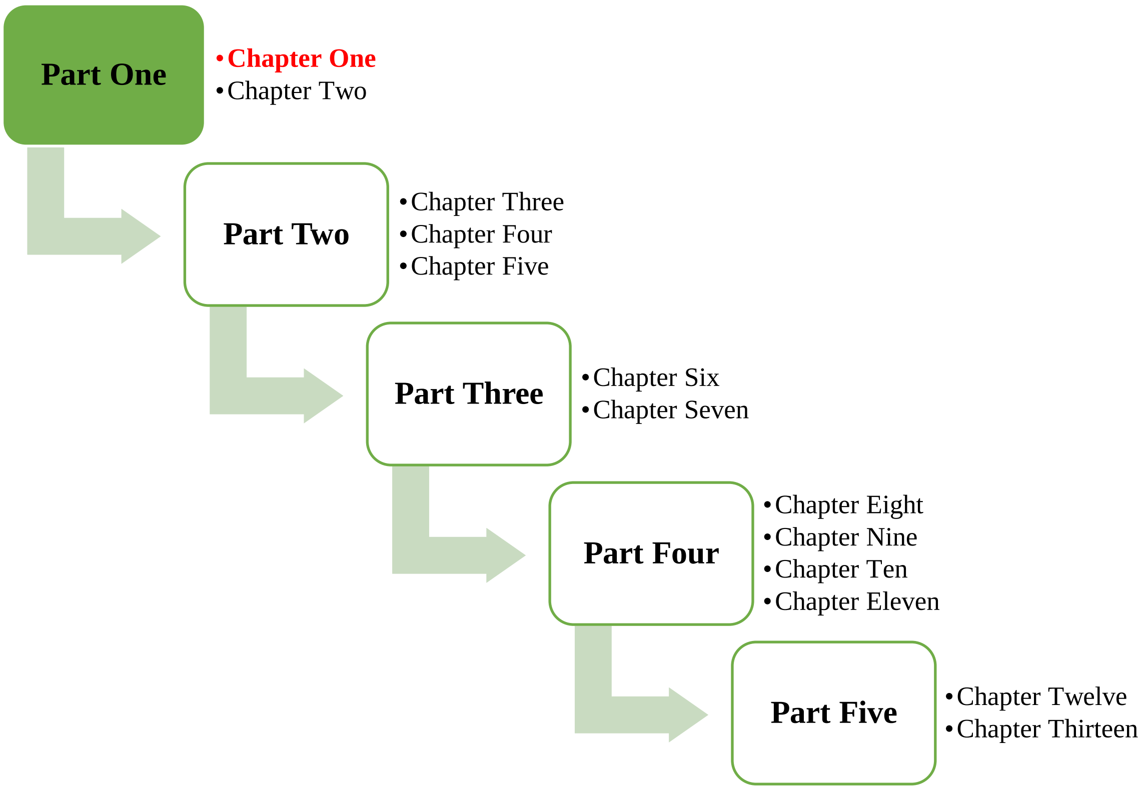
PART 1 – OVERVIEW

Prologue

The first part of this thesis introduces the study and explains the research methodology in depth. Reviewing previous empirical studies, the first chapter sets the background of the thesis and identifies the research gap. The chapter defines the problem and explains the study's rationale for local and international contexts according to the identified research gap. Next, it outlines the research aim, objectives, scope, ethical considerations, and structure. A snapshot of the relationship between research objectives, questions, and specific chapters of the thesis is provided at the end of the first chapter. The second chapter discusses the research methodology, including research design, conceptualisation using the existing literature, research philosophy, theory development approach, methodology selection, research strategies, data collection and analysis techniques, and considerations for validity and reliability. A research design flowchart is provided at the beginning of the second chapter to explain the methodical flow of the study in each chapter and how it connects to the research objectives. The first part of the chapter does not link to any objectives, and it mainly introduces the research and explains how the research is designed around the specific topic.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1.0 Research introduction

1.1 Background

Significant climate changes have been forecast due to the increasing greenhouse gas (GHG) atmospheric concentrations (UNEP, 2019). The changes have increased climate risks and hazards such as global warming, radiative forcing, rising sea level, and extreme weather events such as flash floods, tropical cyclones, and heat and cold waves (IPCC, 2019; UNEP, 2019). Regardless of human presence and action on the earth, climate change will continue at the current concentration of GHGs without further emissions or any future change (IPCC, 2014; UNEP, 2019).

Building construction and operations as end-use sectors are estimated to consume about 36% of final global energy and produce 39% of energy and process-related CO_2 emissions in 2018 (IEA and the UNEP, 2019). This includes the energy used by residential and non-residential building sectors and construction industries that manufacture building construction materials: steel, cement, and glass. The second highest energy use is by other industries, such as agriculture, fishing, manufacturing, and services contributing 32%, while transport contributes 28%, and other sectors, such as non-specified and non-energy use, contribute 4% (IEA and the UNEP, 2019). On the other hand, buildings and construction sectors related emissions include direct and indirect emissions from residential and non-residential buildings and the construction industry. These indirect emissions are due to the power generation for electricity and commercial heat. Further, the other industries, such as agriculture, fishing, manufacturing, and services, emit 31%, while the emissions due to transport are 23% and other non-specified are 7% (IEA and the UNEP, 2019). Therefore, in line with the net zero carbon goal to limit climate change introduced by the United Nations framework convention on climate change (UNFCCC) in 2015, the targets are set to achieve 100% net zero carbon buildings by 2050 (IPCC, 2019). Thus, the global building and construction sector is responsible for increasing energy use and emissions. Research and industry inputs are necessary to reduce emissions and provide a sustainable low-carbon building environment.

Many factors influence the ever-increasing building energy demand, and most previous studies are dedicated to analysing those influencing energy consumption factors (Yoshino et al., 2017). For example, residential building energy consumption is affected by climate, physical characteristics of the building, characteristics of services, energy systems and appliances in the household, occupants' activities and behaviours, and the interactions among them (Widén & Wäckelgård, 2010). Building energy consumption is also influenced by factors such as the construction and technical details and occupants' behaviours and activities towards energy utilisation (Chen et al., 2015). Therefore, in the context of building energy consumption, occupant behaviour has been identified as a significant and influential factor (De Silva & Sandanayake, 2012).

Over the past three decades, researchers realised that occupant behaviours highly influenced the increase of building energy demand. Their contributions are incredibly significant as the difference between simulated and actual energy use is mainly due to the way that occupants behave, their presence, and occupancy levels in buildings (Blight & Coley, 2013; Gaetani et al., 2016; Langevin et al., 2015; Nguyen & Aiello, 2013). For example, Hoes et al. (2009) showed that occupant behaviour is an essential input parameter influencing the whole building energy simulations. Similarly, a few studies highlighted that the reliability of simulation results depends on the quality of assessment of occupants' influence on buildings (Royapoor & Roskilly, 2015; Yu et al., 2011). Therefore, uncertainty in occupant behaviours in buildings could significantly affect energy prediction accuracies, eventually leading to higher energy consumption during the building operation stage.

Not all occupants use building services with similar intensities. Hong et al. (2017) categorised occupant behaviours on building energy use and comfort as adaptive and non-adaptive actions. According to their study, adaptive behaviours include occupants' actions 1) to adapt the environment to their needs or preferences and 2) to adapt themselves to the environment. The first category of adaptive behaviours includes opening/closing windows, lowering blinds, adjusting thermostats, turning lighting on/off, and operating plug-ins (personal heaters, fans, and electrical systems for space heating/cooling). Window opening behaviour might significantly affect the building's Energy Use Intensity (EUI). This variation equals a factor of four in commercial buildings in the United States of America (USA) and three in identical apartments in Denmark (Fabi et al., 2012). The second category includes adjusting clothing levels, drinking hot/cold beverages, and moving through spaces. Non-adaptive behaviours include occupant presence, plug-ins and electrical equipment operation, reporting discomfort, and inaction (Hong et al., 2017). Furthermore, the effects of occupant behaviour could be categorised as the number of occupants, occupancy schedules, and behaviour pattern groups (Diao et al., 2017). Identifying, monitoring, and evaluating such diverse occupant behaviours and their effects on energy are timely needed.

Occupant behaviours have numerous direct and indirect factors that may influence how occupants consume energy. Researchers in this field classified factors influencing occupant energy behaviours into various categories. One of the vastly recognised classifications consists of physical environmental, contextual, psychological, physiological, and social factors (Fabi et al., 2012). Another classification based on occupant behaviours in residential buildings is environmentally-related, time-related, and random factors (Peng et al., 2012). In another study, O'Brien and Gunay (2014) introduced contextual factors to consist of: the availability of personal control, accessibility of personal control, complexity and transparency of automation systems, presence of mechanical/electrical systems providing alternative means of comfort, view, and connection to the outdoors, interior design, experiences, and foreseeable future conditions, visibility of energy use, and occupancy patterns and social constraints. Furthermore, Yoshino et al. (2017) explained internal and external driving forces of occupant energy behaviours. Internal driving forces arise from the interaction between biological and psychological aspects, while external driving forces act on the individual to stimulate their reaction and comprise three factors: building and building equipment properties, physical environment, and time. Although there are a few other classifications based on different research, all of these classifications identify similar factors.

Furthermore, another set of empirical studies pointed out that the energy consumption of buildings with similar physical features also differs due to the comfort preferences of occupants, their interaction with building systems, occupancy patterns, and lifestyle of occupants (Andersen et al., 2009; Lindén et al., 2006; Maier et al., 2009). These comfort preferences are the factors that influence occupant energy behaviours. These factors were categorised into adaptive triggers, non-adaptive triggers, and contextual factors by Schweiker et al. (2018). These have been proven to stimulate occupant action in response to a thermal, olfactory, visual, and aural stimulus to voluntarily modify the surrounding built environment to restore or improve comfort. Occupants are exposed to multi-domain sources of discomfort inside buildings that continually affect them (Heydarian et al., 2020) and investigating occupant behaviours based on multi-domain comfort evaluates occupants' indoor environmental preferences and needs (Day et al., 2020). Specifically, this helps to model occupant behaviours for building performance simulations (BPS) (Carlucci et al., 2020).

On the other hand, the influence of social-psychological concerns is critical when understanding occupants' impact on building performance and energy (Day & O'Brien, 2017). Social-psychological drivers refer to the factors or influences that arise from the interplay between social and psychological aspects, shaping individuals' attitudes, behaviours, and decision-making (Heydarian et al., 2020). These drivers are particularly relevant in understanding how people behave in social settings, including within buildings or indoor environments (Hess et al., 2018). In the context of building energy consumption, D'Oca et al. (2017) conducted an online survey across 14 universities and research centres in the USA, Europe, China, and Australia. The occupants' response to interacting with building control systems and intention to share controls were considered. D'Oca et al. (2017) found that the influential factors include motivational drivers, group behaviour, ease and knowledge, and satisfaction with productivity. Most recently, Bavaresco et al. (2020) extracted the environmental, contextual, and personal factors from the relevant groups, and all other factors such as attitude: behavioural beliefs, normative beliefs, subjective norms: motivational drivers, and perceived behaviour control (PBC): knowledge controls, ease to share, perceived comfort were categorised as subjective aspects. For example, the positive attitude of occupants motivates them to perform more energy-related behaviours (Li et al., 2019). These studies further suggest that energy research practices based purely on objective factors of occupant behaviours may not highlight valuable insights from subjective aspects.

Researchers have recently given more attention to studying the impacts of social-psychological factors that significantly improve occupant energy behaviour modelling for BPS (Ding et al., 2018). Past studies adapted social science theories like the theory of planned behaviour (TPB) (Shi et al., 2017), social cognitive theory (SCT) (D'Oca et al., 2017), and the motivation-opportunity-ability framework (MOA) (Li et al., 2019) to study the effect of social-psychological aspects on occupant energy behaviours. Hence, along with objective aspects like environmental, contextual, and time-related factors, the occupants' comfort preferences and subjective aspects are also meaningful in this field.

There is a significant influence of occupant behaviours on building energy consumption. Furthermore, it is determined that the dynamic nature of occupant behaviours, occupant presence, and occupancy levels in buildings highly influences the difference between predicted and actual energy use in buildings. At the early design of the buildings, identifying the dynamic nature of occupants and the key factors that influence the energy-related behaviour of building occupants is contemporary to assess those impacts on energy. Researchers worldwide emphasise the importance of evaluating building occupants' comfort preferences and needs, integrating environmental, contextual, social-psychological, and other factors, and addressing the energy impacts caused by occupant behaviours. Hence, there is a need to identify and evaluate the occupant behaviours and their drivers that significantly impact on energy consumption of buildings. This research addresses the impacts of occupant behaviours on energy consumption in New Zealand buildings.

1.2 Research problem

Numerous studies have identified occupant behaviour as having a significant impact on building energy consumption (D'Oca, Hong, et al., 2018; Hong et al., 2017; Malik et al., 2022; Tam et al., 2018; von Grabe, 2019). Occupant behaviour is as important as technological innovations and physical conditions in building energy use (Franceschini & Neves, 2022; Stazi & Naspi, 2018; Y. Zhang et al., 2018). As such, quantifying energy consumption changes due to specific intervention techniques (Hong et al., 2016; Kosonen & Kim, 2017) is essential to the energy performance of buildings. However, the significant discrepancies between the predicted and actual building energy performance were observed to be a result of using standard occupant data (Guerra-Santin & Silvester, 2017). Likewise, the previous studies oversimplified or ignored adaptive and non-adaptive occupant behaviours throughout the whole building operation process (Hong et al., 2016).

While research on occupant behaviour in buildings has been expanding, only approximately 7% of the research explores the determinants of behavioural change (Y. Zhang et al., 2018). For example, occupant behaviours are primarily identified as a function of environmental factors (Haldi & Robinson, 2011; Richardson et al., 2008). However, empirical evidence of factors influencing occupant energy behaviours identified factors not associated with the environment that plays a crucial role in using building systems, such as contextual factors and the occupants' routines and habits (Stazi et al., 2017). As a result, behavioural models and tools are becoming more complex and essential to better represent the human component in buildings' energy performance. Similarly, Delzendeh et al. (2017), reviewing 75 published articles on the impact of occupant behaviours on energy consumption, concluded that occupant energy behaviours are complex and dynamic, influenced by various internal and external, individual and contextual factors. Similarly, Paone and Bacher (2018) established that the inner dynamic nature of occupant energy behaviours represents a challenge, and multi-disciplinary approaches are needed to provide new insights into the domain. Although recent research focuses on the interrelations between multi-domain comfort preferences with occupant behaviours in buildings (Bavaresco et al., 2021), the research focus has been limited to specific behaviours like windows, blinds/shades, heating, ventilation, air-conditioning (HVAC), and lighting (Harputlugil & de Wilde, 2021).

Similarly, occupant behaviour-related frameworks like Drivers, Needs, Actions, and Systems (DNAS) (Bavaresco et al., 2021; D'Oca, Pisello, et al., 2018) and MOA (Li et al., 2019) developed based on social-psychological theories and constructs are not evaluated comprehensively for their applicability in different contexts. Occupant behaviour-related research in different contexts, cultures, climates, and socio-economic backgrounds is recommended (D'Oca et al., 2019; Rupp et al., 2021). In New Zealand, the Energy Culture Framework (ECF) is an approach that recognises the social and cultural factors that influence energy consumption. It seeks to shift the focus from energy efficiency measures solely relying on technology to a more holistic approach incorporating occupant behaviour towards energy. The framework includes various dimensions that shape energy use, such as knowledge, values, norms, habits, and infrastructures (Stephenson et al., 2015; Stephenson et al., 2010). Therefore, when achieving energy targets in New Zealand, further research is expected to justify the performance of such frameworks (Li et al., 2019; Tverskoi et al., 2021).

Although significant interest has been given to investigating IEQ satisfaction, availability of controls and multi-domain comfort preferences on occupant behaviours, many potential drivers have not yet been fully identified (Bavaresco et al., 2021; Yan et al., 2017). When the occupant behaviour-related subjective data are limited, energy performance models and occupant behaviour tools are often deployed with preliminary observations (Yan et al., 2017). Specifically, the occupant behaviour modelling tools that integrate with energy performance simulation and modelling must consider subjective aspects, such as occupants' comfort preferences and social-psychological thinking, in addition to the commonly considered environmental, contextual, physiological, and time-related parameters (Yan et al., 2017).

Furthermore, a simpler model comprising such parameters enables efficient and reliable decision-making at the initial design stage (Yan et al., 2017). For example, Mahdavi and Taheri (2017) introduced an ontology for building monitoring of occupant behaviours and performance data. An ontology consists of concepts or categories and their properties or relationships in a subject area relevant to modelling a particular domain (Liu & Özsu, 2009). However, the subjective aspects are not explicitly and comprehensively addressed in the proposed ontology by Mahdavi and Taheri (2017).

Most previous studies in this field have focused on energy conservation in residential buildings (Fu et al., 2021; Kim et al., 2022; Liu et al., 2020; Xuan Liu et al., 2021; Y. Zhang et al., 2018). Less research has been conducted on energy use in commercial buildings. Occupant behaviour in residential buildings has been proven to significantly impact energy consumption for HVAC, lighting and appliances, and building controls (Page et al., 2008), while research on occupant behaviour in commercial buildings is still in its infancy. That said, recent work analysing thermal comfort and energy consumption patterns in an office building during a typical working day showed that thermal comfort depends on occupant behaviours (Pivac et al., 2018). Energy savings from occupant behaviour could constitute 10% (Pothitou et al., 2016) to 20% (Frankel et al., 2013) for residential buildings and 5% to 30% (Hong & Lin, 2013) for commercial buildings. In New Zealand, office buildings account for between 20% and 40% of commercial building floor area and represent a significant proportion of commercial building stock (Isaacs et al., 2010). As such, Pivac et al. (2018) noted a need for further research on energy conservation approaches and drivers of occupant behaviour change in commercial buildings.

Few occupant behaviour-related research has been conducted in the New Zealand context. These empirical researches evaluated the occupant behaviours like adjusting thermostats and opening/closing windows to cope with thermal discomfort in green and conventional buildings (Azizi et al., 2015a) and adjusting computers behaviour among office building occupants (Azizi et al., 2015b). But then, these studies were limited to thermal comfort behaviours and occupants' computer usage behaviour from a case study and did not represent the entire office building population in New Zealand.

Occupant behaviour-related models and tools can provide essential feedback to optimise the energy performance of buildings and the respective simulation and modelling. However, the potentials are not yet fully realised due to the models' lack of occupant behaviour-related data. The dynamic and diverse nature of occupant behaviours can create vagueness in building energy simulations, thus, the discrepancies between predicted and operational energy consumption. The existing occupant behaviour frameworks and ontologies do not fully integrate subjective aspects, such as occupants' comfort preferences, social-psychological thinking, and environmental, contextual, physiological, and time-related parameters. However, developing such an ontology focused on specific subjective and objective occupant behaviour drivers could enhance occupant behaviour-related data monitoring and collection to optimise the operational performance of existing buildings and to improve the future designs of buildings. Specifically, in New Zealand, the lack of research on occupant energy behaviours limits the potential energy savings in commercial office buildings. The previous studies emphasised that multi-disciplinary approaches enabling perspectives of building managers (i.e., facilities managers, sustainability managers, building occupants, etc.) play a significant role when preparing occupant-centred energy policies for achieving net zero carbon goals (Delzendeh et al., 2017; Paone & Bacher, 2018; Tam et al., 2018). Accordingly, this research pays particular attention to the impacts of occupant behaviours and related factors on energy consumption in New Zealand buildings. The research further attempts to provide recommendations that promote occupant-centric energy cultures giving due consideration to the occupants' subjective perspectives influencing occupant energy behaviours.

1.3 Research rationale

New Zealand uses about 1% more energy annually, and energy savings are still possible through different avenues (EECA, 2020). For example, energy savings are possible through using more renewable resources in the commercial, residential, and transportation sectors (see Figure 1.1). All sectors share responsibility for New Zealand's environment regarding energy use, air and GHG emissions, waste generation, and water withdrawals (Trading Economics, 2020). The service sector in New Zealand particularly dominates the national economy with a share of the gross domestic product (GDP) approximately 60% of the total GDP, and this is followed by the government, education and health, manufacturing, and primary sectors, which are also significant sources of revenue (Trading Economics, 2020). The service industry relies on the consumption of energy, raw materials, and products from the primary sector. Most services are based on commercial buildings, where occupants spend

8-10 hours daily or five days weekly, interacting with the indoor environment and buildings' systems and appliances.

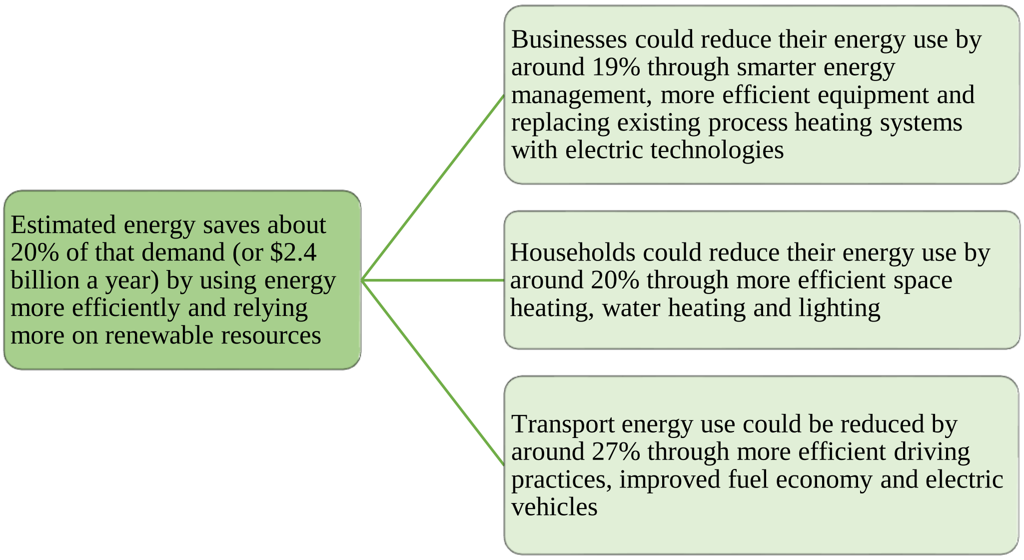


Figure 1.1 Energy impacts in New Zealand

Adapted from EECA (2020)

On the other hand, international agreements such as the Paris agreement, Kyoto Protocol, European Emissions Trading Scheme, and European Directive on the Energy Performance of Buildings (EPBD) showed the prominence of climate change (D'Oca, Hong, et al., 2018; Delzendeh et al., 2017; Rupp et al., 2021). Accordingly, through the Paris Agreement introduced by UNFCCC, many countries agreed "to limit the rise in the world's average surface temperatures to "well below" 2°C above pre-industrial times this century, while "pursuing efforts" for 1.5°C. It also sets a target of eliminating global GHG emissions (i.e., anthropogenic (manmade), natural GHGs by the second half of the century or at least compensating any residual emissions through, for example, forest growth" (UNDP, 2019, p. 10). With this initiation, many countries decided not to reduce carbon emissions but to stop further emissions and limit warming to 1.5ºC by setting goals for Net Zero Carbon emissions by 2050 (any emissions are balanced by absorbing an equivalent amount from the atmosphere) (IPCC, 2019). To reduce emissions and switch to renewables, New Zealand set a net zero emissions target by 2050 and implemented the New Zealand Energy Efficiency and Conservation Strategy (NZEECS 2017-2022) (MBIE, 2020).

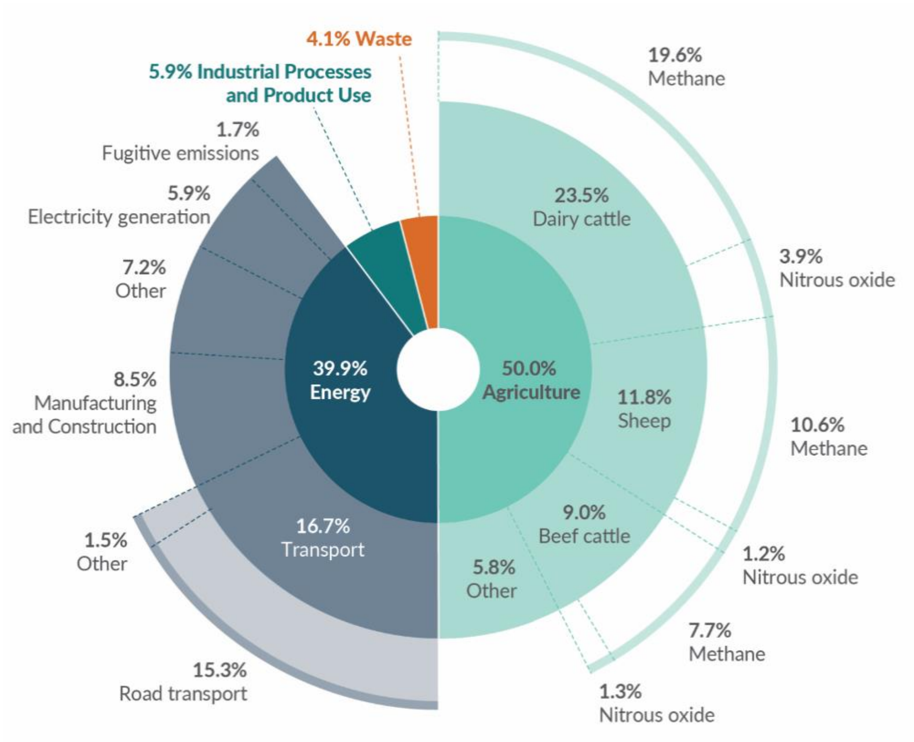


Figure 1.2 New Zealand's Greenhouse Gas Inventory 1990-2020
Source: Ministry for the Environment (2022)

As shown in Figure 1.2 energy use in transport, manufacturing and construction, electricity generation, and fugitive emissions makes up 40% of New Zealand's total GHG emissions (MfE, 2022). New Zealand has a lower energy productivity improvement (MBIE, 2017) compared to other Organisation for Economic Cooperation and Development (OECD) countries (Australia, the United Kingdom (UK), and the USA) (Conti et al., 2016). Therefore, energy use and emissions in New Zealand are significant in raising energy productivity, reducing emissions, and switching to renewables. For example, raising energy productivity helps reduce business costs, transform, manage risk, and optimise systems (EECA, 2020). Therefore, government, businesses, and broader society must significantly reduce energy from the early design and construction stages to post-occupancy.

However, the proposed technical solutions alone do not guarantee the estimated energy savings. The building occupants have a vital role in using energy more efficiently and reducing individual consumption, and the building management must recognise the occupants' role in achieving energy targets. Organisations must welcome occupants to the energy culture and implement occupant-centric strategies and technologies for energy efficiency. Accordingly, this research has spoken for the impacts of occupant behaviours on energy consumption in New Zealand buildings.

Theoretically, the study addresses the need to review the relationship between occupant energy behaviours, IEQ, and influential factors. It also addresses the need to review the relationship between occupant energy behaviours and social-psychological factors. Conceptually, the study addresses the need to identify the dilemma between building indoor environment preferences and occupant energy behaviours, the building managers' approach to rationalising occupant energy behaviours, and the environmental and social-psychological influence on occupant energy behaviours. On a practical note, the study addresses the need to evaluate and model social-psychological effects on occupant energy-related behaviours and identify and evaluate occupants' decision-making regarding their behaviours in office environments based on self-rated drivers. Also, the study addresses the need to develop an ontology for occupant behaviour monitoring and validate such an ontology for its applicability in New Zealand office buildings.

Theoretically, the study aims to address the relationship between occupant energy behaviours, IEQ, and other influential factors. It also seeks to explore the connection between occupant energy behaviours and social-psychological factors. Conceptually, the study delves into the dilemma arising from the interplay between building indoor environment preferences and occupant energy behaviours. Furthermore, it examines building managers' approaches to rationalising occupant energy behaviours, as well as the environmental and social-psychological influences on such behaviours. On a practical note, the study strives to evaluate and model the social-psychological effects on occupant energy-related behaviours. It seeks to identify and assess occupants' decision-making processes regarding their behaviours within office environments, with a focus on self-rated drivers. Additionally, the study aims to develop an ontology for monitoring occupant behaviour and validate its applicability in New Zealand office buildings.

1.4 Aim and objectives

The research aims to develop an occupant energy behaviour-related ontology that enhances data monitoring and collection to optimise the energy performance of New Zealand office buildings. The following objectives were formulated to achieve this aim of the research.

1. To identify the prevalent occupant energy behaviours and the significant drivers that influence these behaviours in the New Zealand and international contexts
    1.1. To identify the occupant energy behaviours and drivers influencing occupant behaviours based on IEQ parameters
    1.2. To identify the social-psychological drivers influencing occupant energy behaviours
    1.3. To explore the relationship between prevalent occupant energy behaviours and the occupants' comfort preferences in New Zealand office buildings
2. To analyse how organisations rationalise occupants' energy behaviours and comfort preferences in New Zealand office buildings
    2.1. To investigate building managers' approach and organisational energy culture towards occupants' behaviours and preferences in New Zealand office buildings
    2.2. To examine the interrelationships among occupant energy behaviours, IEQ satisfaction, user-centred control, and social-psychological aspects in New Zealand office buildings
3. To evaluate how occupants perceive decision-making regarding their energy behaviours in New Zealand office buildings
    3.1. To model underlying relationships between social-psychological drivers and occupant energy behaviours from the perspective of behavioural theories
    3.2. To evaluate the influence of occupants' perceived indoor environmental comfort, the availability of control, and the social-psychological impacts on individual behaviours in New Zealand office buildings
4. To develop an ontology for the effective monitoring and collection of occupant energy behaviour-related data to optimise the energy performances of New Zealand office buildings
    4.1. To validate the developed ontology using Subject Matter Experts (SMEs) in New Zealand
    4.2. To propose recommendations to optimise the energy performances of New Zealand office buildings based on the occupant energy behaviour ontology

Accordingly, **Objective 1** was achieved by conducting a literature review on occupant behaviours, drivers influencing those behaviours, and conceptualizing preliminary findings on occupant energy behaviours and comfort preferences in New Zealand office buildings. This objective is crucial for defining the research problem and developing a conceptual model. Subsequently, **Objective 2** was attained by analysing building managers' perspectives on occupant energy behaviours and comfort preferences, along with the occupants' viewpoints on their behaviours, IEQ satisfaction, user-cantered control, and social-psychological aspects in New Zealand office buildings. **Objective 3** was accomplished by examining the social-psychological influences on occupant energy behaviours in New Zealand office buildings, based solely on occupants' perspectives and self-ratings of subjective and objective factors related to occupant behaviours. Finally, **Objective 4** was achieved by developing an ontology for effectively monitoring and collecting occupant energy behaviour-related data and validating the ontology using SMEs in New Zealand. Real-time monitoring of occupant energy behaviour identifies immediate energy-saving opportunities and potential wasteful practices, while collecting occupant energy behaviour-related data involves in-depth analysis over time, enabling a better understanding of occupant motivations and preferences for developing effective, long-term energy optimisation strategies in office buildings. This led to proposed recommendations for energy consumption in New Zealand office buildings. Additionally, achieving these objectives addresses the research questions outlined in Table 1.1 in section 1.7, which further explains the connections between research objectives, research questions, and research stages.

- RQ1. What are the dominant occupant energy behaviours and the main factors influencing occupant energy behaviours in New Zealand office buildings?
- RQ2. How to reduce the energy consumption of office buildings based on occupant energy behaviours and factors influencing occupant energy behaviours in New Zealand office buildings?
- RQ3. How do integrate factors influencing occupant energy behaviours to reduce energy consumption in New Zealand office buildings?
- RQ4. What parameters are required to develop an ontology for monitoring and collecting occupant energy behaviour-related data in New Zealand office buildings, and how can it be validated?

1.5 Research scope

This thesis focuses on the impacts of occupant behaviours on energy consumption in New Zealand buildings. In New Zealand, specific opportunities are available to reduce energy consumption in the commercial, residential, and transportation sectors. While there is limited research on occupant behaviours in the New Zealand context, the research in the international context highlights the importance of focusing on office buildings. Mainly, focusing on occupant behaviour is essential for improving the performance and sustainability of office buildings. Building managers can implement measures to reduce energy waste, improve IEQ, and enhance productivity and comfort levels by understanding how occupants use and interact with the space. Hence, the research only covers office buildings, their occupants, and building managers within the built environment in New Zealand.

Furthermore, the data were primarily collected from Auckland, Manawatu-Whanganui, Waikato, Wellington, and Canterbury regions in New Zealand, and the occupants who work full-time and part-time in any office spaces were considered. These regions were selected as they are highly populated and include the country's highest number of office buildings. This research notably considered the tertiary institutional buildings in selected cases at the preliminary stage and part of the primary data collection because these buildings consist of a significant share of office spaces. Another part of primary data collection focused on social-psychological drivers of occupants considered general office occupants across the selected regions. The focus on social-psychological drivers is vital as the existing research lacks valuable insights from subjective aspects while they are primarily based on objective factors of occupant behaviours.

Considering the scope of the investigation, this research considered occupant energy behaviours, drivers influencing behaviours, building managers' and organisational approach to occupants' behaviours and preferences, social-psychological drivers, occupants' decision-making on energy behaviours, and impacts on energy consumption in New Zealand office buildings. The primary unit of analysis of the study is building occupants, while the study also considered the observations from facilities managers and sustainability managers in office buildings as they play a crucial role in promoting sustainable and energy-efficient occupant behaviours. The research adopted a mixed method design using a grounded theory approach in the preliminary stage and a survey approach for primary data collection. Accordingly, data collection techniques such as interviews and questionnaires were used to achieve the research objectives of the study. More information on the methodology and data collection is provided in chapter 2.

1.6 Ethical considerations

As this research involves human participants, ethics approval is required to ensure that the research project is conducted ethically and that the rights and welfare of all participants are protected. This research has been evaluated by peer review and considered low-risk by Massey University Human Ethics Committee. The ethics notification (4000022597) of this research has been valid for three years since 15th May 2020. The peer review of the research was conducted with the primary supervisor, who reviewed the research for ethical issues such as the anonymity of participants and organisations, participants' consent, the confidentiality of information collected and the conflict of interest. Precautions were taken throughout the research to manage the participants' sensitive information. The researcher is responsible for the ethical conduct of this research. The risks that were considered are:

- The anonymity of participants: Only the personal views of study participants were collected. Identifying information such as name, organisation, and business was not collected on either person or organisation, and that information did not appear in any part of the research.
- Participants' consent: Information on the study was presented to the participants, and their consent was duly obtained on paper or online before they could participate. Participants could withdraw their participation at any time during and after the study.
- Confidentiality of information: All responses are kept in line with Massey Ethics Regulations, which the supervisors and researcher can only access within the stipulated time frame.
- Conflict of interest: The research is generic, and no conflict of interest is engaged with any party or organisation involved in data collection. Additionally, author rights are followed for including the published articles in the thesis. Massey's statement of contribution for each publication/manuscript was filled and signed by both the researcher and primary supervisor and included in the Appendixes.

1.7 Thesis outline

This thesis consists of five major parts: Part 1 – Overview, Part 2 – Problem definition and conceptual modelling, Part 3 – Problem analysis: preliminary findings, Part 4 – Problem analysis: primary research findings, and Part 5 – Solutions. Each part contains specific chapters of the thesis. The thesis consists of 13 chapters. This research followed Massey University's thesis by publication guidelines. Accordingly, ten chapters contain journal and conference papers that have either been accepted, published, or submitted to a journal or conference, and the title of each paper forms a chapter heading. The other three chapters include the research introduction, methodology, and conclusion. The four research objectives are represented in Part 2 to Part 4, while each research question is answered with one objective. This thesis analysed the relationship between occupant energy behaviours and specific factors that drive these behaviours. Based on the analysis, the study presents occupant energy behaviour-related ontology. The research output enhances occupant energy behaviour data monitoring and collection to identify the impacts on energy and optimise the energy performance in New Zealand office buildings. The thesis is outlined as follows;

Chapter 1 establishes the research context, defines the research problem, and establishes the rationale based on the research background and identified problem. The chapter also provides the research aim, objectives, scope, ethical considerations, and outline.

Chapter 2 provides an overview of the research methodology, including research philosophy, approach to theory development, methodological choice, strategies, data collection and analysis techniques, and how the researcher addressed the validity and reliability.

Chapter 3 conceptualises the importance of incorporating IEQ parameters and other influential factors to recognise the dynamic nature of occupant energy behaviours presenting a narrative literature review of 50 theses. This chapter highlights the link between IEQ parameters: thermal, indoor air, visual, and acoustic, and occupant energy behaviours. Also, it identifies and classifies the factors influencing occupant behaviours into physical environmental, contextual, time-related, social, psychological, and physiological factors.

Chapter 4 determines the patterns or trends of previous research on social-psychological drivers of occupant behaviours, understands the depth of existing knowledge, and reveals research gaps for further investigation. In this chapter, 79 journal articles that apply social-psychological theories to occupant energy behaviours have been systematically reviewed and analysed using bibliometric and thematic analyses. The chapter highlights the social-psychological theories, the influence of social-psychological drivers, and the application of theories in different occupant behaviours.

Chapter 5 conceptualises the relationships among indoor environmental conditions, comfort preferences, and occupant behaviours to improve future energy modelling works on occupant behaviour in buildings. The study investigated the perceptions of 46 occupants from five tertiary office buildings in New Zealand. Indoor environmental conditions in the study are explored based on occupants' satisfaction with IEQ, user-centred designs, and furniture arrangements.

Chapter 6 investigates building managers' approach towards occupant energy behaviours and rationalises organisational energy culture concerning their strategy to address occupants' preferences in New Zealand tertiary education office buildings. The chapter presents a grounded theory analysis by interviewing 25 participants from a university, including facilities managers, sustainability managers, and building occupants. A set of theoretical perspectives outlines the comfort-related aspects, factors influencing occupant behaviour, behaviour impacts on energy, and occupant-centric energy culture

Chapter 7 presents an extended analysis of Chapter 5, which evaluates the interrelationships among occupant energy behaviours, IEQ satisfaction, user control, and social-psychological factors influencing occupant behaviours in New Zealand offices further to identifying occupant behaviour patterns based on multi-domain comfort preferences. Social-psychological factors are preliminarily applied following the MOA framework. A sample of 52 occupants (including the 46 mentioned in Chapter 5) was used for the study analysis.

Chapter 8 investigates the social-psychological insights into energy-saving behaviours based on the general occupancy survey data collected from 294 office occupants in New Zealand. This chapter presents social-psychological insights relating to occupant energy behaviours following a modified MOA framework giving due consideration to the demographic factors: age, gender, ethnicity, and region. The results highlight increased social-psychological effects such as attitude, personal norms, and actual and perceived knowledge to save energy. At the same time, there was a lack of organisational support and behavioural intervention to save energy.

Chapter 9 explores underlying relationships between social-psychological drivers and occupant energy behaviours from the perspective of behavioural theories adopting a modified MOA approach. While Chapter 8 only presents an overview of the social-psychological perceptions, this chapter analyses the direct, indirect, and mediated causal relationships between social-psychological constructs and adaptive and non-adaptive behaviours using statistical modelling of 294 office occupants in New Zealand.

Chapter 10 presents findings from a case study of occupants' perceived environmental beliefs, individual control, and multi-domain reasons for their behaviours, considering the seasonal variance and time-related factors in a New Zealand tertiary office building. The case study used 99 data points to highlight the relationships between the study variables.

Chapter 11 models the influence of occupants' perceived indoor environmental comfort, the availability of control, and the social-psychological impacts on occupant behaviours of 14 individual behaviours. The analysis used 99 office occupants from the New Zealand tertiary office building case. A machine learning technique was applied to identify the critical factors influencing the decision-making of occupant behaviours.

Chapter 12 validates an occupant energy behaviour ontology developed for effective monitoring and collecting occupant energy behaviour-related data using SMEs. Twelve SMEs were selected for the validation and conducted semi-structured interviews. The collected data were analysed using frequency analysis and content analysis.

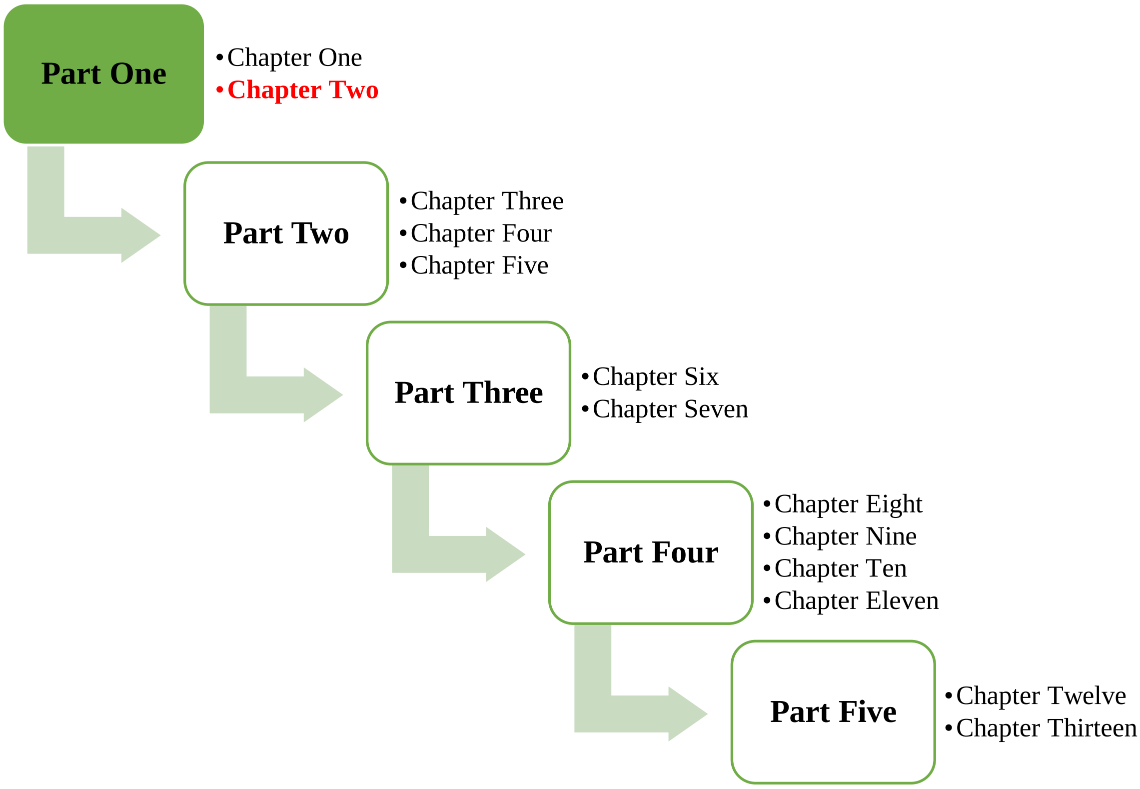
Chapter 13 presents the research conclusion and summary of findings according to each objective, highlighting the impacts of occupant behaviours on the energy consumption of buildings and the significant factors influencing these behaviours. The chapter also provides the theoretical and practical contributions of the study, recommendations for different stakeholders, limitations, and suggestions for future research.

Table 1.1. provides a snapshot of the relationship between research objectives, questions, and specific chapters of the thesis.

Table 1.1 Thesis outline

Objectives	Research Questions	Research Sub Questions	Chapter
[1] To identify the prevalent occupant energy behaviours and the significant drivers that influence these behaviours in the New Zealand and international contexts	**RQ1.** What are the dominant occupant energy behaviours and the main factors influencing occupant energy behaviours in New Zealand office buildings?	**1)** What is the relationship between occupant energy behaviours and the IEQ?	**Chapter 3:** Occupant energy behaviours – A review of indoor environmental quality (IEQ) and influential factors (Published conference paper)
		2) What social-psychological theories drive or underpin occupant behaviours? **3)** Which theories are more frequent in each behaviour? **4)** What are the future research trends and implications?	**Chapter 4:** Understanding social-psychological influences on occupant energy behaviours: A systematic review based on bibliometric and thematic analyses (Submitted journal article)
		5) What occupants' indoor environment preferences and energy behaviours are related?	**Chapter 5:** A dilemma between building indoor environment preferences and occupant energy behaviours (Published conference paper)
[2] To analyse how organisations rationalise occupants' energy behaviours and comfort preferences in New Zealand office buildings	**RQ2.** How to reduce the energy consumption of office buildings based on occupant energy behaviours and factors influencing occupant energy behaviours in New Zealand office buildings?	**1)** What are building occupants' preferences compared to their prevailing comfort conditions? **2)** How do building managers perceive the impacts of occupant energy behaviours on energy use? **3)** How do building managers address the impact of occupant energy behaviours on energy use in their buildings?	**Chapter 6:** A facilities management approach to rationalising occupants' energy behaviours (Published journal article)
		4) What factors have the most significant influence on occupants' energy behaviours?	**Chapter 7:** Environmental and socio-psychological drivers of building users' behaviours: A case study of tertiary institutional offices in Auckland (Published journal article)

[3] To evaluate how occupants perceive decision-making regarding their energy behaviours in New Zealand office buildings	**RQ3.** How do integrate factors influencing occupant energy behaviours to reduce energy consumption in New Zealand office buildings?	**1)** How do occupants' social-psychological insights on occupant energy behaviours differ based on socio-demographic characteristics?	**Chapter 8:** Social-psychological insights into energy-saving behaviours: An occupant survey in New Zealand (Published conference paper)
		2) What are the significant social-psychological factors affecting occupant energy behaviours? **3)** How do these social-psychological factors shape the occupants' energy behaviours?	**Chapter 9:** Modelling of underlying social-psychological effects on occupant energy-related behaviours (Published journal article)
		4) What are the multi-domain reasons/comfort preferences that drive specific occupant behaviours? **5)** How do occupant behaviours differ at different time instants in a typical day?	**Chapter 10:** Self-rated motivational drivers for occupant behaviours: A case study of tertiary office buildings (Published conference paper)
		6) What do occupants perceive about their indoor environment and the availability of control? **7)** What triggers the specific occupant behaviours?	**Chapter 11:** Occupants' decision-making of their energy behaviours in office environments: A case of New Zealand (Published journal article)
[4] To develop an ontology for the effective monitoring and collection of occupant energy behaviour-related data to optimise the energy performances of New Zealand office buildings	**RQ4.** What parameters are required to develop an ontology for monitoring and collecting occupant energy behaviour-related data in New Zealand office buildings, and how can it be validated?		**Chapter 12:** Validation of the occupant energy behaviour-ontology for energy saving in New Zealand office buildings (Submitted journal article)


Part One
•Chapter One
•Chapter Two
Part Two
•Chapter Three
•Chapter Four
•Chapter Five
Part Three
•Chapter Six
•Chapter Seven
Part Four
•Chapter Eight
•Chapter Nine
•Chapter Ten
•Chapter Eleven
Part Five
•Chapter Twelve
•Chapter Thirteen

2.0 Research methodology

This chapter discusses the methodological framework used to address the research objectives identified in the first chapter. Initially, the research purpose was explained, and the research process was discussed in detail. Research 'onion' introduced by Saunders et al. (2019) explicates the research design in six layers. This is illustrated in Figure 2.1 below. The six layers are philosophies, approaches, methodological choices, strategies, time horizons, and techniques. The process of this research consists of these layers.

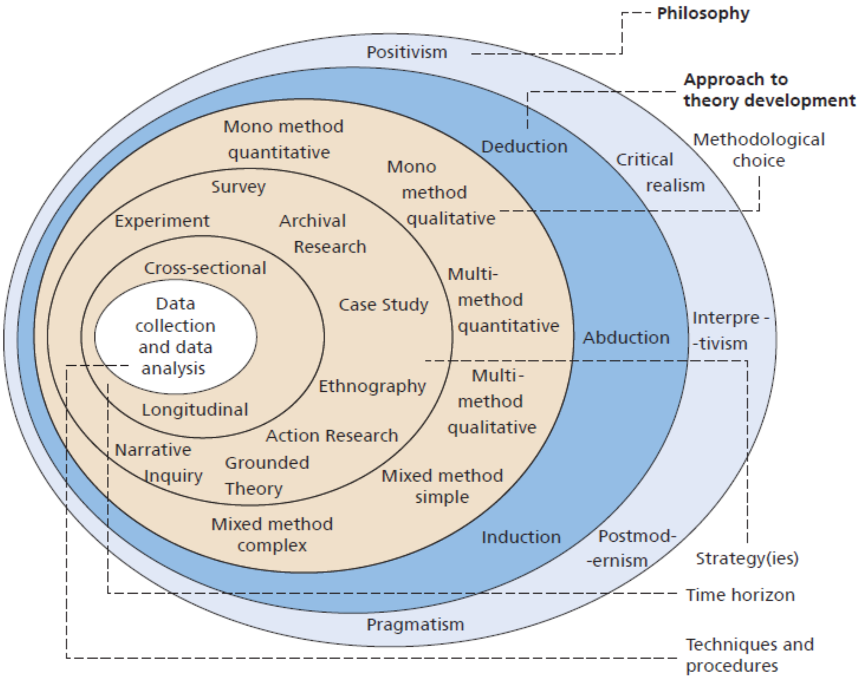


Figure 2.1 Research 'Onion'

Source: Saunders et al. (2019)

2.1 The Research Purpose

This study aims to develop an occupant energy behaviour-related ontology that enhances data monitoring and collection to optimise the energy performance of New Zealand office buildings. According to Saunders et al. (2019), research studies could be categorised as; exploratory, descriptive, and explanatory studies according to the underlying purpose or type of answer the research intends to find out. Exploratory studies are conducted to find out what is happening in a given scenario, ask questions, or assess a phenomenon in a different setup. As described by Yin (2009), exploratory studies are carried out to develop appropriate hypotheses and propositions for further inquiry. Descriptive research aims to profile happenings, people, or situations accurately. Descriptive, explanatory and exploratory studies can coexist in one research project, where they might extend one another. In contrast, explanatory studies try to explain causal relationships among variables (Saunders et al., 2019).

This research first explores the prevalent occupant energy behaviours and the significant drivers that influence them, how organisations rationalise occupants' energy behaviours and comfort preferences and then evaluates how occupants perceive decision-making regarding their energy behaviours to develop the occupant energy behaviour ontology using explanatory methods. The study aims to achieve several objectives, including identifying the prevalent occupant energy behaviours and the significant drivers that influence these behaviours in the New Zealand and international contexts, analysing how organisations rationalise occupants' energy behaviours and comfort preferences in New Zealand office buildings, evaluating how occupants perceive decision-making regarding their energy behaviours in New Zealand office buildings, and developing an ontology for the effective monitoring and collection of occupant energy behaviour-related data to optimise the energy performances of New Zealand office buildings. These objectives suggest a need to understand causal relationships among variables. Explanatory research is well-suited to explore and explain such causal relationships between variables. By seeking to explain the drivers and factors influencing occupant energy behaviours, the study aligns with the purpose of explanatory research. Explanatory research allows the researchers to examine these relationships in depth, explore the factors influencing energy behaviours, and identify cause-and-effect connections. However, to achieve the research objectives, both qualitative and quantitative data will be collected and analysed. The qualitative data collection aims to explore the phenomenon in-depth, while the quantitative data analysis is used to explain and understand causal relationships. This aligns with the process of explanatory research, where initial qualitative exploration can lead to the development of hypotheses and propositions, followed by quantitative analysis to test and explain those hypotheses.

In summary, the study's objectives and the research design demonstrate a clear alignment with the characteristics of explanatory research. By seeking to explain causal relationships among variables related to occupant energy behaviours in New Zealand office buildings, the study follows an explanatory approach to develop a conceptual model and ontology for optimising energy performance.

2.2 Research design

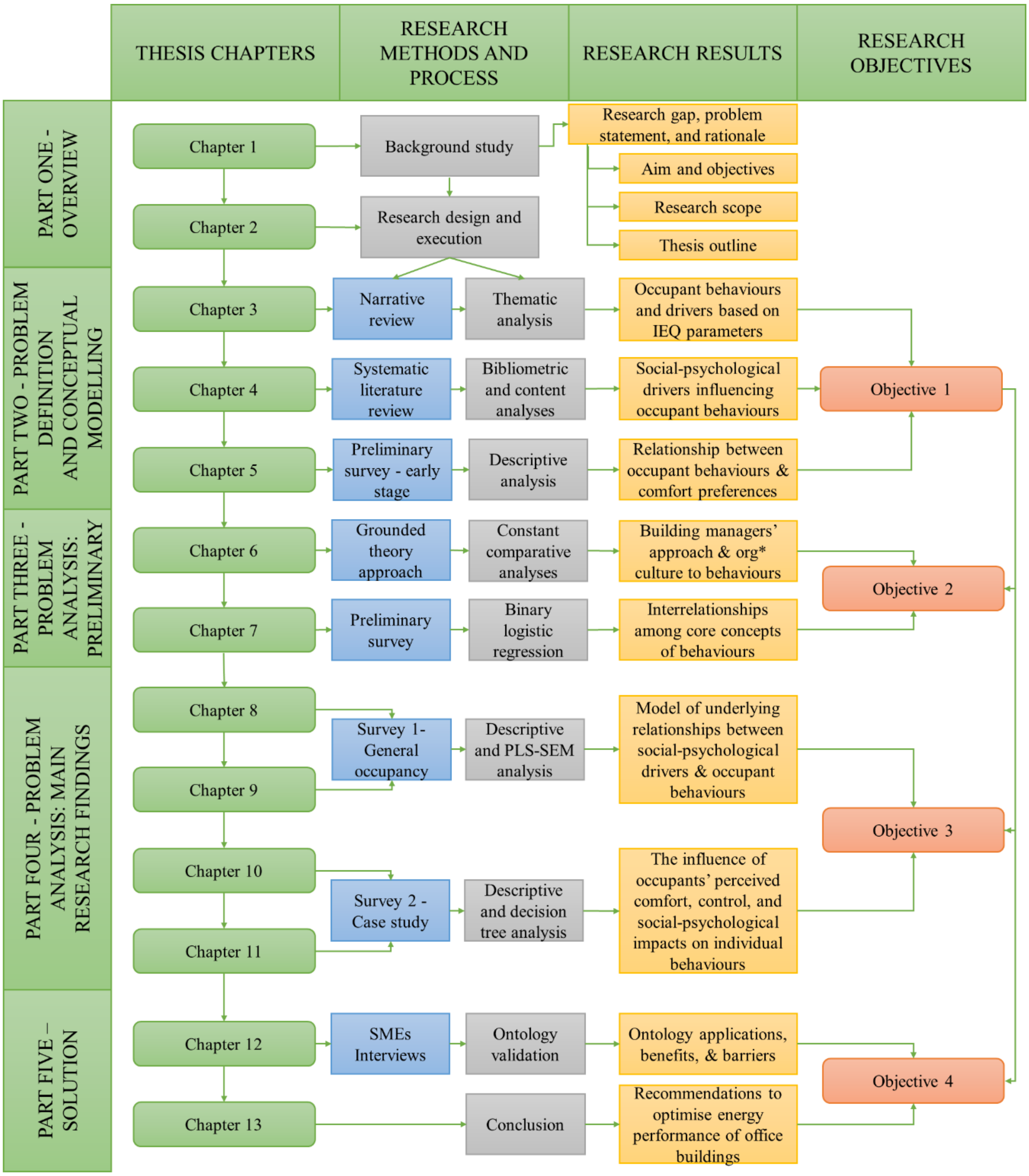


Figure 2.2. Research design flowchart

Figure 2.2 illustrates the research design flowchart explaining the relationship between research chapters, research methods, research process, research deliverables, and achievement of research objectives. This research flowchart further expands the thesis outline provided in Table.1.1. Followed by the research flowchart, this chapter explains the different philosophical stances, research approaches, methodological choices, strategies, techniques and procedures. It provides the reasoning for the selected research methodological framework to achieve the current research objectives.

2.3 Conceptualisation

Initially, a background study was carried out within the identified research area, which mainly focused on occupant energy behaviour research, factors affecting occupant behaviours, and the significance of occupant energy behaviour-related research in New Zealand. The background study referred to journal articles, conference articles, books, reports, and published theses and dissertations. The background study helped identify the research gap and define the research problem, rationale, aim, objectives, and scope. Afterwards, the literature review was done by going through different sources to identify the most significant occupant behaviours that lead to changes in energy consumption of buildings and influential factors of the dynamic nature of occupant behaviour in buildings.

A literature review was conducted to achieve two purposes. First, the importance of incorporating IEQ parameters and other influential factors to recognise the dynamic nature of occupant energy behaviours was reviewed. Specifically, the study narratively reviewed 50 theses to identify the research area that has not yet been explored (see chapter 3).

Next, a systematic review was conducted using 79 articles that applied social-psychological theories to occupant energy behaviours and analysed using bibliometric and thematic analyses. Social-psychological theories, the influence of social-psychological drivers, the application of theories in different building settings/contexts, and the energy-saving potentials of occupant behaviours were the review's main focus (see Chapter 4). As such, this research contributes to theoretical progress by discovering occupant behaviour-related future research avenues for reducing the energy consumption of buildings. The literature review of the research contributes to answering RQ1 and achieving Objective 1.

By conducting both narrative and systematic reviews, the researchers were able to combine the strengths of both approaches. The narrative review provided a broad perspective on the research area, encompassing occupant energy behaviours, IEQ parameters, and other influential factors, while the systematic review offered a more detailed and data-driven analysis of specific aspects of occupant energy behaviours and the application of social-psychological theories. This comprehensive approach allowed the researchers to fulfil Objective 1 by gaining a deeper understanding of the research landscape, identifying gaps, and exploring the potential for energy-saving interventions based on occupant behaviours and social-psychological drivers in various building contexts.

2.3.1 Narrative literature review

A narrative literature review critically evaluates existing research, provides a comprehensive overview, and develops the theoretical context in the field of interest (Byrne, 2016; Juntunen & Lehenkari, 2021). It provides a foundation for the researcher to position their new research by identifying gaps or discrepancies (Rother, 2007). This non-systematic review broadly concludes the field of interest without following pre-defined guidelines. Therefore, the quality and clarity of narrative review are improved when applying systematic review principles (Baker, 2016; Ferrari, 2015). A well-defined selection criterion is essential to improve the quality of the conclusions derived through narrative review. Accordingly, chapter 3 explains more information on study identification and selection for this review.

2.3.2 Systematic literature review

A systematic review is a literature review that identifies, evaluates, and creates relevant research to address a specific research question (Boland et al., 2017; Rasoolimanesh et al., 2020), widely used to identify emerging trends and what is known about several aspects of a topic. Unlike a narrative review, a systematic review uses the best available evidence in the field and underpins the theoretical and practical recommendations for further research (Rother, 2007). Before conducting the systematic review, the researcher should follow a clearly defined protocol and criteria. The systematic review of this research was guided following the preferred reporting items for systematic reviews and the meta-analysis (PRISMA) 2020 statement by Page et al. (2021). The PRISMA methodology considers four main phases: (1) identification, (2) screening, (3) eligibility, and (4) inclusion of studies. chapter 4 of this thesis includes the step-by-step approach for conducting the systematic literature review.

2.4 Research philosophy

Research philosophy refers to a system of assumptions about the development of knowledge. Further, according to Saunders et al. (2019), these philosophical assumptions include ontological: assumptions about the realities you encounter in your research, epistemological: assumptions about human knowledge, and axiological: assumptions about the extent and ways your values influence your research process. A well-organised set of assumptions reflects a reliable philosophy with methodological choice, research strategy, data collection techniques and analysis procedures to design a coherent research project.

Ontology is about how or in what way the world operates (Saunders et al., 2019), or it is the nature of reality (Kulatunga et al., 2008). According to Saunders et al. (2019), the two extremes of ontology are explained through Objectivism and Subjectivism. Objectivism is that reality exists independently of the social actors. In contrast, subjectivism is that no reality exists independent of the social actors, and reality is created through their perceptions and consequent actions.

Epistemology is how knowledge is acquired and accepted (Kulatunga et al., 2008). In another study, epistemology elaborated by questioning the relationship between the researcher and what is being researched (Creswell & Poth, 2016). Saunders et al. (2019) argue that the two extremes of epistemology include sufficient knowledge to be acquired through objective measurement of the phenomenon or by subjective means of knowledge acquisition with thick descriptions and narrations.

Axiology is the third type of philosophical assumption about how much value the researcher places on the study or throughout the research process. The amount of value the researcher places increases more towards subjectivism along the objectivist-subjectivist continuum. More value input is called value-laden, and lesser value input is considered value-free (Kulatunga et al., 2008).

Based on these assumptions, researchers bring in several types of philosophical positions. Saunders et al. (2009) identify four major research philosophies; Positivism, Realism, Interpretivism, and Pragmatism. Creswell (2009) named them research paradigms or worldviews, indicating four types; Positivist Worldview, Social Constructivist Worldview (Interpretivism), Advocacy and Participatory Worldview, and Pragmatic Worldview. Positivism, Critical Realism, Interpretivism, and Pragmatism are discussed in detail.

Positivism in management research is apparent when the ontological assumptions include external, objective, and independent social actors; epistemological assumptions focus on causality with high generalisability and reducing phenomena to simple elements; and axiological assumptions carry a value-free way from the researcher. This paradigm governs quantitative means of knowledge creation (Saunders et al., 2019). Creswell (2009) explains that positivism argues for a single reality impractical for studies on behaviours and human actions. Thus, post-positivism now governs the research arena with some concerns about multiple perspectives from participants.

Critical realism philosophy, a form of post-positivism, explains what we see and experience regarding the fundamental realities that underlie observed occurrences. For critical realists, the reality is the essential philosophical factor, and an organised, multi-layered ontology is fundamental (Fleetwood, 2005). Critical realists believe that reality is independent and external but cannot be directly observed or known. Epistemological relativism, a somewhat subjectivist approach to knowledge, is accepted by critical realists (Reed, 2005). Epistemological relativism acknowledges that social facts are social creations that humans have agreed upon rather than existing on their own and that knowledge is historically contextual (Bhaskar, 2013). The axiological viewpoint of critical realism acknowledges that societal factors influence our comprehension of reality and cannot be comprehended solely from an individual's perspective. It recognises the significance of social actors in shaping our understanding of reality. The post-positivist also contends that all observations are theoretically predicated and that scientists are naturally prejudiced due to their upbringing, worldview, and other factors.

Interpretivism holds the ontological assumption that reality is socially constructed and multiple. Thus, it leads to the epistemological assumptions of creating subjective meanings with qualitative research mechanisms. The axiology of the paradigm is value-laden, with difficulty separating the researcher and what is being researched (Saunders et al., 2019).

The research philosophy-pragmatism governs when a researcher believes the determinant of ontology, epistemology, and axiology is the research question. If a given research question does not hold the perfect match to interpretivism or positivism where the research approach, quantitative or qualitative solely, would not serve the purpose (however, the mixed method approach is the one that suits), it is the research pragmatism that governs (Saunders et al., 2019).

Having reviewed these four types of philosophical stances, the researcher holds a critical realist's philosophical stance and believes that there is a reality independent of our thinking. However, it recognises that all observations are fallible and have an error and that all theories are revisable. In other words, the critical realist is critical of our ability to know reality with certainty. Where the positivist believed that the goal of science was to uncover the truth, the post-positivist critical realist believes that the goal of science is to hold steadfastly to the goal of getting it right about reality, even though we can never achieve that goal. Because all measurement is fallible, the post-positivist emphasizes the importance of multiple measures and observations, each of which may possess different types of error, and the need to use triangulation across these multiple errorful sources to get a better bead on what is happening in reality. Therefore, the current research considers occupant energy behaviours and factors influencing occupant energy behaviours as external and independent, historically situated and socially constructed. The researcher is value-laden, where the researcher acknowledges but tries to minimise bias and errors and to be as objective as possible.

2.5 Approach to theory development

Deductive and inductive reasoning are the two fundamental approaches to logical thinking used to reach conclusions or make inferences, as shown in Figure 2.3. The deductive approach involves developing a theory that is then rigorously tested through a series of hypotheses. It emphasises structure, quantification, generalisability, and testable hypotheses, typically aligning with the positivist research philosophy (Saunders et al., 2019). On the other hand, the inductive approach formulates a theory, often expressed as a conceptual framework, to establish cause-effect links between variables without necessarily understanding how humans interpret their social world. Researchers in this tradition often study small samples, work with qualitative data, and use various methods to explore different perspectives on phenomena. The inductive approach is usually informed by the interpretivism philosophy (Saunders et al., 2019).

The researcher chose an abductive approach as it offers a flexible and nuanced way to move back and forth between deduction and induction (Suddaby, 2006). Unlike the traditional linear paths of deduction and induction, the abductive approach allows researchers to combine both reasoning processes. This flexibility allows researchers from various research philosophies to use the abductive approach effectively. Abduction is commonly associated with pragmatism, postmodernism, and critical realism (Saunders et al., 2019).

The use of an abductive approach in this research is justified due to the context-specific nature of the study. In this research context, there is a substantial amount of information on occupant behaviours and influential factors internationally, but limited data in the specific context of office buildings in New Zealand. The abductive approach, under the critical realism philosophy, suits this research to modify existing theories and develop a conceptual model based on inductive reasoning. Additionally, the critical realism philosophy aligns well with the abductive approach, as it emphasises understanding the underlying mechanisms and structures while acknowledging the complexity of the social world (Saunders et al., 2019). The researcher initially explored building managers' approach and organisational energy culture towards occupants' behaviours and preferences in New Zealand office buildings through qualitative methods (inductive). Subsequently, the researcher collected data to refine the conceptual model using quantitative methods (deductive). This approach allows for a comprehensive investigation of the research problem, considering both theory and empirical data to develop a conceptual model tailored to the New Zealand office buildings' energy behaviour context.

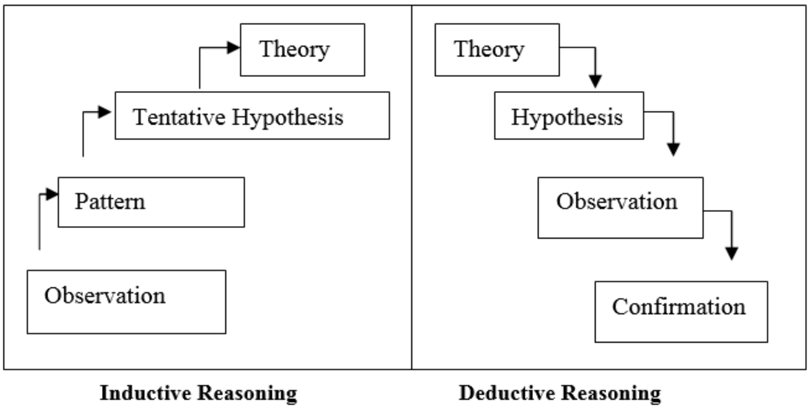


Figure 2.3 Deductive and inductive reasoning

Source: Saunders et al. (2019)

2.6 Methodological choice

As discussed in the study by Saunders et al. (2019), research methods can be categorised as mono-method or multi-method choices. In mono-method, the researcher employs a single data collection technique with corresponding analysis procedures to answer the research question. On the other hand, multi-method involves using more than one data collection technique and analysis procedures, but within the confines of either a quantitative or qualitative worldview (Tashakkori & Teddlie, 2003). The term "mixed-methods" encompasses both quantitative and qualitative data collection techniques and analysis procedures used in research design. Mixed-method research involves using both quantitative and qualitative data collection techniques and analysis procedures either simultaneously (parallel) or sequentially, but without combining them (Saunders et al., 2019).

However, the researcher in this study adopted a mixed-model approach, which goes beyond using both quantitative and qualitative data collection techniques and analysis procedures. In mixed-model research, the researcher also employs both quantitative and qualitative approaches at various phases of the research, such as research question generation. This comprehensive approach allows for a more thorough investigation and understanding of the research problem (Saunders et al., 2019).

In this specific study, the researcher used an "explanatory sequential" mixed-method design, which is practical when developing and testing a new instrument, as proposed by Creswell (2009). The design involved a sequential process of data collection, starting with qualitative data, followed by quantitative data, and then concluding with qualitative data again. This three-step approach allowed the researcher to gain a comprehensive understanding of the research problem and develop a robust ontology.

In the first phase of the study, qualitative data was collected to explore and understand the building managers' approach and organisational energy culture towards occupants' behaviours and preferences in New Zealand office buildings. Interviews were employed to gather rich and detailed insights into the subject. Subsequently, in the second phase, the researcher collected quantitative data to examine the interrelationships among occupant energy behaviours, IEQ satisfaction, user-centred control, and social-psychological aspects in New Zealand office buildings, to model underlying relationships between social-psychological drivers and occupant energy behaviours from the perspective of behavioural theories, and to evaluate the influence of occupants' perceived indoor environmental comfort, the availability of control, and the social-psychological impacts on individual behaviours in New Zealand office buildings. These further analyse and quantify the relationships between variables related to occupant energy behaviours. This step involved using surveys to gather numerical data and test hypotheses generated from the qualitative findings. Finally, in the third phase, the researcher conducted another round of qualitative data collection to validate the developed ontology using SMEs in New Zealand and to propose recommendations to optimise the energy performances of New Zealand office buildings based on the occupant energy behaviour ontology. By using qualitative methods again, the researcher was able to explore the intricacies and nuances of occupants' perceptions and experiences, providing additional context to refine the conceptual model.

The use of an explanatory sequential mixed-method design with a qualitative → quantitative → qualitative data collection sequence allowed the researcher to build upon the strengths of both qualitative and quantitative methods. The initial qualitative phase provided a foundation for the research, guiding the development of hypotheses and propositions for further exploration. The quantitative phase enabled the researcher to test these hypotheses and establish causal relationships between variables, adding empirical evidence to support the conceptual model. Finally, the subsequent qualitative phase enriched the understanding of the research topic, allowing for a more nuanced and comprehensive interpretation of the quantitative findings.

In conclusion, the researcher's choice of an explanatory sequential mixed-method design with a qualitative → quantitative → qualitative data collection sequence was well-suited for the objectives of the study, enabling the development and refinement of a conceptual model (ontology) to optimise the energy performances of New Zealand office buildings based on a comprehensive exploration of occupant energy behaviours. Furthermore, the choice of an abductive approach in this research also complements the explanatory sequential mixed-method design. Abduction involves moving back and forth between deduction and induction, combining both reasoning processes (Saunders et al., 2019). The researcher chose an explanatory sequential mixed-method design under an abductive approach to effectively address the research question and achieve the study's objectives. This combination of design and approach allows for a comprehensive investigation, enabling the development of a ontology that is both empirically grounded and theoretically informed.

2.7 Research strategies

Eight research strategies are highlighted by Saunders et al. (2019), which can be divided into qualitative and quantitative research strategies. Experiment, survey, and archival research are mainly highlighted under quantitative strategies, where there are five main types of qualitative research strategies; narrative studies, phenomenology, grounded theory, ethnography, and case studies (Creswell, 2009).

Narrative studies were best fit for capturing an individual's life experiences and stories or a small number of individuals. Narrative researchers refrained from building objective knowledge about individuals (Josselson, 2006). Thus, different narrative researchers interpreted and theorised their understandings differently. In contrast, phenomenology explains the lived experience of several individuals about a given concept or phenomenon (Creswell, 2007). For example, lived experience of women who had undergone a breast biopsy could be analysed using a phenomenological study (Byrne, 2001). Ethnography involves describing people's lives as they lived and experienced (Ingold, 2017). According to Creswell (2007), ethnography explores and describes a cultural group's beliefs, language, behaviours and power issues. However, this was mostly done through participant observation. It was used when there was a dearth of literature on how a specific group works. The grounded theory included theory building from scratch by entering the field as soon as possible the area of research was identified, without much guidance from literature, following an inductive, iterative, and interactional process of data collection, analysis, and interpretation (Douglas, 2003). Creswell (2009) explained the case study as a study of an issue through the bounded case(s) system. These boundaries included constraints in terms of time, events, and processes.

An experiment aims to study causal links, whether a change in one independent variable produces a change in another dependent variable (Hakim, 2000). The most straightforward experiments concern whether there is a link between two variables. More complex experiments also consider the size of the change and the relative importance of two or more independent variables. Experiments, therefore, tend to be used in exploratory and explanatory research to answer 'how' and 'why' questions (Saunders et al., 2019). The survey strategy is usually associated with the deductive approach. It is a popular and common strategy in business and management research. It has often been used to answer questions seeking who, what, where, how much, and how many. It, therefore, tends to be used for exploratory and descriptive research. Surveys are popular as they allow the collection of a large amount of data from a sizeable population in a highly economical way. Often obtained using a questionnaire administered to a sample, these data are standardised, allowing easy comparison (Saunders et al., 2019). Archival research uses administrative records and documents as the principal data source. Although the term archival has historical connotations, it can refer to recent and historical documents (Bryman, 2003). All research that uses data contained in administrative records is inevitably secondary data analysis. However, when these data are used in an archival research strategy, they are analysed because they are a product of day-to-day activities (Hakim, 2000). They are, therefore, part of the reality being studied rather than having been collected originally as data for research purposes.

Having introduced each type of research strategy, it could be argued that grounded theory and survey strategies are the choices for this research. For instance, grounded theory is concerned with building up a theory without or with very little guidance of literature for the empirical study and developing a conceptual model (Douglas, 2003), while the survey approach can be used to refine the conceptual model.

2.7.1 Grounded theory research design

Grounded theory has two main methodological genres: traditional grounded theory associated with Glaser and evolved grounded theory associated with Strauss (Birks & Mills, 2015). The first of these genres is known as traditional or classic grounded theory. The goal of traditional grounded theory is to generate a conceptual theory that accounts for a pattern of behaviour that is relevant and problematic for those involved (Glaser, 1978). The second genre, "evolved grounded theory", is founded on symbolic interactionism and stems from work associated with Strauss. Symbolic interactionism addresses the subjective meaning people place on objects, behaviours, or events based on what they believe is true (Corbin & Strauss, 2014). While there are commonalities across the two genres of grounded theory, there are factors that distinguish differences between the approaches, including the philosophical position of the researcher; the use of literature; and the approach to coding, analysis, and theory development. For instance, grounded theory is a set of integrated conceptual hypotheses systematically generated to produce an inductive theory about a substantive area (Holton, 2008). Corbin and Strauss (2014) define grounded theory as a theory derived from data systematically gathered and analysed through the research process. The researcher begins with an area of study and allows the theory to emerge from the data. Table 2.1 summarises the significant differences between Glaser and Strauss approaches.

The Strauss approach to grounded theory rejects the existence of a pre-existing reality, emphasises that it is not possible to be completely free of bias, enables an analysis of data and a reconstruction of theory, engages proactively with the literature from the beginning of the research process, and uses complex coding methods as strategies to examine the interface between structure and process. Primarily, in this approach to grounded theory, the literature can provide examples of similar phenomena that can stimulate our thinking about properties or dimensions we can use to examine the data in front of us (Corbin & Strauss, 2014).

Table 2.1 Glaser vs Strauss

Criteria	Glaser	Strauss
Theory development	• Purely inductive approach • Detailed coding process leading to theory saturation • A set of integrated conceptual hypotheses organised around a core category	• Purely descriptive approach • Rigorous coding leading to verification • The ability to generalise beyond the immediate study
The emergence of the research question and use of literature	• The researcher should come to the study without preconceptions and detailed research questions • The literature is not studied beforehand • The researcher should be neutral and allow the topic to emerge	• The researcher should be encouraged to use prior experience and knowledge • The literature will be a good source of ideas and data
Use of procedures	• A set of procedures must be followed during data analysis and coding	• Use of procedures is optional
Coding	• Open coding is being used with as many categories as possible until the core category emerges	• More attempts to "force" coding
How to use GT	• GT is research design, not just a technique • Uses a systematically applied set of methods to generate an inductive theory about a substantive area	• A research technique systematically followed • Uses a systematic set of procedures to develop an inductive theory about a phenomenon

Source: (Gurd, 2008)

Initial purposive sampling directs the collection and generation of data (Charmaz & Bryant, 2011), where researchers purposively select participants and data sources that can answer the research question. Concurrent data generation, collection, and analysis are fundamental to grounded theory research design (Birks & Mills, 2015). This initial data serves as a foundation for the subsequent steps of the study. The researcher collects, codes and analyses this initial data before further data collection/generation is undertaken. Purposeful sampling provides the initial data that the researcher analyses. Theoretical sampling follows the codes and categories developed from the first data set. This iterative process allows the researcher to build and refine the emerging theory.

Therefore, current research considers the Strauss approach to grounded theory, and a part of the pilot study data collection was conducted based on the grounded theory to answer RQ2 and achieve part of Objective 2. The grounded theory approach, particularly the Strauss approach, provides a robust foundation for the study's qualitative component, where the researcher explores and analyses the building managers' approach and organisational energy culture towards occupants' behaviours and preferences in New Zealand office buildings. The qualitative data obtained through grounded theory methods are then used to develop a conceptual model based on the initial qualitative findings. Following the qualitative phase, the study progresses to the quantitative data collection and analysis stage. The researcher collects and analyses quantitative data to test and quantify the relationships between variables related to occupant energy behaviours. This phase involves survey approach to gather numerical data for testing hypotheses generated from the qualitative findings.

In summary, the Strauss approach to grounded theory informs the research process, allowing for systematic theory development based on the data collected from participants. This approach provides continuity in the methods employed throughout the study, linking the initial qualitative phase, quantitative phase, and final qualitative phase cohesively. The use of grounded theory serves as a powerful tool for developing a conceptual model that is grounded in the data and aligned with the research objectives.

2.7.2 Survey research design

The survey approach is highly appropriate where there is an involvement of analysing numerical data to conduct an objective study and construct algebraic models to identify causal relationships between variables abstracted through hypothesis or research questions developed (Yin, 2009). Moreover, surveys can accurately document the norm, identify extreme outcomes, and delineate associations between variables in a sample (Gable, 1994).

Sampling is a means of selecting a subset of units from a population to collect information from those units to draw interpretations about the population as a whole. Building occupants are this study's target data source and constitute the population. It was impractical to collect data from all the occupants in New Zealand office buildings as it is an enormous sample, so sampling was necessary because of time and cost constraints (Fowler Jr, 2013). Saunders et al. (2009) identified two types of sampling: probability and non-probability.

Non-probability sampling involves the choice of subjects who are well-equipped with information that will be relevant to the researcher's focus. This sampling technique is employed when the desired population for the study is uncommon or very difficult to locate and employ. Therefore, this technique is proper when a limited number or category of people have the information sought by the researcher—usually associated with case study research design and qualitative research (Taherdoost, 2016). A non-probability sampling includes quota, snowball, purposive, judgmental, and convenience sampling. Saunders et al. (2009) explained that with probability samples, the chance, or probability, of each case being selected from the population is known and is usually equal for all cases. Furthermore, a study by the Ministry of Industry of Canada (2010) affirmed that probability sampling is a method that allows interpretations to be made about the population based on observations of a sample. Also, probability sampling is often associated with survey and experimental research strategies. According to Saunders et al. (2009), probability sampling includes simple random, systematic, stratified random, and cluster sampling techniques.

For the current study, stratified random sampling is identified as suitable. The current study's population consists of all the building occupants in New Zealand office buildings. However, this population is geographically concentrated into 16 regions, and the sampling frame has relevant strata. Therefore, stratified random sampling can be used in the current study. Stratified random sampling is a modification of random sampling in which the researcher divides the population into two or more relevant and significant strata based on one or several attributes. In effect, the sampling frame is divided into several subsets. A random sample is drawn from each stratum (Taherdoost, 2016). However, the sampling frame should be the complete list of all employee names of occupants working in office buildings in New Zealand. Furthermore, a few regions could be selected out of 16 regions. This technique is ineffective due to the time and complexity of employing a realistic sample size (Day & Gunderson, 2015). Also, one single list of all office building occupants does not exist. Therefore, the sampling method shifted to purposive sampling.

A purposive sample can be selected based on the expert judgment of researchers (Teddlie & Tashakkori, 2003). In quantitative studies, purposive sampling proved successful when establishing credibility with building representatives through expert suggestions or personal contacts, and the building owners would more likely agree to participate in the survey (Day & Gunderson, 2015). Accordingly, the office building representatives (i.e., facilities, sustainability, and energy managers) were contacted through personal contacts, experts, and online searches and then approached building occupants in the sample. Regarding external validity, purposive sampling is not robust compared to probability sampling. However, it is frequently used in qualitative and mixed-methods research, generating in-depth knowledge within a specific population (Teddlie & Tashakkori, 2003).

Considering the total population in New Zealand, which is around 5 million currently, the population of office building occupants is less than 5 million. However, a minimum sample size of 384, given a 95% confidence level for 5% margins of error, is suggested by Saunders et al. (2009) for a population between 1 to 10 million. In different stages of the study, the researcher considered different sample sizes, and the specific details are given in the respective chapters (see Chapters 6, 7, 9, and 11). In the preliminary study a sample size of 52 was considered, and the main survey in two stages included a sample size of 294 and a sample size of 99. Accordingly, a survey approach was used to answer RQ3 and to achieve Objectives 2 and 3.

2.8 Preliminary study

A Strauss grounded theory design and a survey approach were selected for the preliminary study to investigate building managers' approach towards occupant energy behaviours and occupants' preferences and to evaluate the interrelationships among occupant energy behaviours, IEQ satisfaction, user control, and social-psychological factors influencing occupant behaviours in New Zealand offices. The preliminary study also aims to evaluate the efficacy of the data collection methods.

The essential elements in the grounded theory included theoretical sampling, constant comparative technique, coding and categorising, and memo writing, which generated data that constructed insight into the building managers' approach and organisational energy culture towards occupant energy behaviours. As the study employed theoretical sampling, a purposive sample of five building professionals engaged in facilities and sustainability management and 20 building occupants was selected and interviewed face-to-face using a semi-structured interview guideline. The survey considered 52 occupants from five tertiary office buildings in a university case. Building occupants were subjected to a self-administered questionnaire survey conducted online.

2.9 Data collection

Participant observations, interviews, questionnaires, and document surveys can be applied as data collection techniques in research (Saunders et al., 2009). This study used semi-structured interviews at the preliminary and validation stages, and questionnaires were used as the primary data collection technique. The authors also referred to the documents relating to the building characteristics to collect the relevant data on building demographics. The Following explains each selected data collection technique in detail.

2.9.1 Data triangulation

The need for triangulation arose from the ethical need to confirm the validity of the processes. Four (04) types of triangulation are identified: (a) Data source triangulation, when the researcher looked for the data to remain the same in different contexts; (b) Investigator triangulation, when several investigators examined the same phenomenon; (c) Theory triangulation, when investigators with different viewpoints interpreted the same results; and (d) Methodological triangulation, when one approach was followed by another, to increase confidence in the interpretation (Denzin, 2017). This research study used data source triangulation and methodological triangulation.

2.9.2 Semi-structured interviews

Interviews can be classified as structured, semi-structured, or unstructured interviews. This research considers the semi-structured interview method as ideal because it elicits more elaborate and purposeful answers from the responses to the research questions (Yin, 2009). Moreover, semi-structured interviews allow the researcher to ask additional questions to follow up on any satisfying or unexpected answers (Keraminiyage et al., 2005). Semi-structured interviews were used to interview the facilities managers and sustainability managers at the preliminary stage and SMEs at the validation stage to validate the occupant energy behaviour ontology developed for effective monitoring and collecting occupant energy behaviour-related data in New Zealand office buildings. Thus, the study used SMEs to answer RQ4 and to achieve Objective 4.

The participants were approached individually using their email addresses, and meetings were scheduled as per their consent and convenience. The data collection consists of digitally recorded single-participant semi-structured interviews for approximately 30 to 45 minutes. The electronic interviews were in a video or audio format, and the quality depends on the technical characteristics, such as the device used, the communication platform, and the internet connection (Morgan & Symon, 2004).

An adequate number of interview participants should be selected based on the saturation point of data and the participant's knowledge of the research problem, and 5 to 30 participants are usually recommended (Creswell & Poth, 2016). Accordingly, five building professionals were interviewed at the preliminary stage, while 12 SMEs were interviewed at the validation stage.

2.9.3 Questionnaire survey

The questionnaire is the most suitable data collection technique to be adopted when large amounts of information have to be collected from many people. A questionnaire allows the researcher to collect data quickly and cost-effectively, with limited effect on validity and reliability (Saunders et al., 2009). This study required a larger sample of building occupants to easily quantify and analyse with maximum objectivity to determine the impacts of occupant behaviours on energy consumption in New Zealand office buildings. Thus, a questionnaire was selected as a suitable data collection technique for this research.

The questionnaires were developed for the preliminary and primary data collection. In the preliminary stage, open-ended and close-ended questions were used to collect data from building occupants. However, close-ended questions were mainly employed throughout the primary data collection process. Closed-ended questions enable survey respondents to choose an answer from a pre-determined range of options. Since only pre-selected options are available, this structured data collection technique encourages uniformity among questionnaire respondents (Colosi, 2006). The precise response alternatives are included in the well-designed, carefully crafted, and well-worded closed-ended questions, which make the questionnaire self-explanatory (Wang et al., 2006). Pre-defined options must be carefully chosen to satisfy the primary goal of the research question; they must not have conceptually similar meanings and be simple to understand. The use of closed-ended questionnaire approaches is most common when it is necessary to quantify data, classify respondents, and collect and analyse a large number of data (Gouldthorpe & Israel, 2014).

Closed-ended questions matching the anticipated quantitative outcome of the research were designed considering the main sections focusing on the background, IEQ, occupant behaviours, occupant preferences, social-psychological factors, and other factors. All participants were provided with an invitation letter, information sheet, informed consent form and the purpose and significance of the study. The participants had to confirm their interest in the study before answering it. A Likert scale is an ordered scale from which respondents choose one option that best aligns with their view. Likert scales may meet the researcher's needs when they have attitude, belief, or behaviour items (McLeod, 2008). A Likert scale of 1-7 was used in the preliminary stage, and a Likert scale of 1-5 was used in the primary stage to estimate the relationship between dependent and independent variables.

A test run is necessary to show the methodological rigour of a survey (Munn & Drever, 1990). Before starting the survey, a test was conducted to evaluate the questionnaire's clarity and completeness. The main purpose of the test run is to identify any potential issues with the questionnaire, such as ambiguous or unclear questions, missing items, or difficulties in understanding certain aspects of the survey. The developed questionnaire was distributed among a few conveniently selected occupants in one of the selected office buildings within the Auckland region as a test run. Once the target sample was decided upon, the questionnaires were distributed to the potential respondents of the selected office buildings. Both in-person and online distribution were used depending on the preference and flexibility of the building management and occupants.

The test run allowed to make necessary modifications before distributing the questionnaire to the target sample. The modifications made during the test run involve revising and refining the questionnaire based on the feedback and observations gathered from the test participants. For instance, the questions that were found to be confusing or difficult to answer, were rephrased or clarified. Additionally, any missing items were added, and irrelevant items were removed to enhance the survey's overall quality and relevance. During the test run process, the researcher also gained insights into the logistics of distributing the questionnaire, such as the preferred distribution methods (in-person or online) based on the building management and occupants' flexibility.

2.9.4 Subject matter experts

SMEs possess deep and comprehensive knowledge based on their skills, knowledge and experience of a particular topic or subject (Hopkins & Unger, 2017; Lavin et al., 2007). SMEs are often used in research as they have a high level of expertise and understanding of the subject, which enables them to provide new and insightful details on that particular topic or subject (Ford & Wood, 1992; Truxillo et al., 2004). Characteristics of an SME include being an expert in the subject, having excellent competence, being able to think critically and analytically about the subject, and providing accurate information (Marshall, 1996; Tremblay, 2003).

The SMEs should have many years of experience or formal education in the subject matter and be willing and confident to respond to interview questions (Lavin et al., 2007; Marshall, 1996). The SME was chosen as the appropriate data collection approach because it allows participants to contribute ideas based on their experience. Utilising SMEs is a reasonable and economical way to complete qualitative research projects on time and within budget while fostering the emergence of fresh perspectives (Marshall, 1996).

In order to cover a variety of points of view and to provide essential and insightful details, the SMEs were chosen using the snowball sampling technique (Biernacki & Waldorf, 1981) to pick individuals with in-depth expertise of the subject matter from interdisciplinary backgrounds around New Zealand. Incorrect identification and selection of the SMEs could unintentionally influence their contributions, lead to hidden agendas regarding the subject, and result in inadequate response because of misconception and a lack of clear guidelines on what is expected from the SMEs (Lavin et al., 2007; Marshall, 1996). Before the investigation, a pilot study enables testing the data-gathering method and spotting any potential issues or flaws in the research methods (Hassan et al., 2006). First, a pilot research was conducted using two experts who satisfied the requirements for being chosen as SMEs. Thus, before the validation process started, the interview guideline was corrected based on the pilot study's recommendations.

2.10 Data Analysis

This research follows grounded theory analysis, content analysis, descriptive and statistical analysis, and machine learning techniques to analyse the collected data from interviews and questionnaires.

2.10.1 Grounded theory analysis

The constant comparative analysis is an analytical process used in grounded theory for coding and category development. This process commences with the first data generated or collected and pervades the research process. Incidents are identified in the data and coded. Douglas (2003) indicated three levels of coding; open coding, axial coding, and selective coding to be used in inductive theory generation. Open coding involves comparing and contrasting similar incidents and phenomena to be coded correspondingly. Such incidents and phenomena could be events, activities, functions, relationships, contexts, influences, and outcomes. Axial coding involves regrouping the open codes. Selective coding involves selecting the core codes out of the axial codes identified. Core codes were selective codes comprised of strongly related open codes. According to Douglas (2003), the rest of the selective codes could directly or indirectly relate to the identified core codes. In the context of the current study, the researcher conducted open coding on transcribed data, identifying 360 key phrases representing significant relationships, which were later categorised and sub-categorised to understand core categories like "indoor environmental discomfort" and "occupant behaviours" in the context of thermal discomfort and adapting to indoor conditions. Unrelated keywords were removed in the selective coding phase. This process is further explained under Section 6.3.4.

Memo writing is an ongoing practice integrated throughout the grounded theory research which is considered essential 'in ensuring quality in grounded theory'. Memos are the storehouse of ideas generated and documented through interacting with data. Memos provide detailed records of the researchers' thoughts, feelings, and intuitive contemplations (Douglas, 2003).

2.10.2 Content analysis

Content analysis is a technique for data analysis which involves codifying qualitative information into pre-defined categories to derive patterns in the presentation and reporting of information (Kumar, 2018). In content analysis, qualitative data are codified into pre-defined themes for presenting and reporting information (Krippendorff, 2018). On the other hand, the thematic analysis includes identifying, analysing, and reporting themes (patterns) within qualitative data (Braun & Clarke, 2006). This process involves many steps, such as identifying the main themes, assigning code to the central theme, classifying responses under the main themes, and integrating themes and responses into the text of the report. Content analysis was used in this research at the validation stage where the qualitative data obtained from open-ended questions were subjected to manual content analysis (see Section 12.4.1).

2.10.3 Descriptive and Inferential Statistics

Descriptive statistics summarise the information contained in a sample. This summary is achieved by condensing the information and presenting it in a tabular form (Jaccard &

Becker, 2021). Frequency distributions and graphical methods of summarising data include histograms, pie charts, bar charts, and scatter plots. Data also can be summarised by numerical values such as to describe the centre of a data set, the mean or median to describe variability, and the variance, standard deviation, or interquartile range can be used. Each numerical value is a single number computed from the data describing a specific sample characteristic. The secondary data may also be analysed using descriptive statistics (Jaccard & Becker, 2021). Descriptive statics were used at both preliminary and primary stages to analyse the collected data. Different software, such as Microsoft Excel and Statistical Package for Social Sciences (SPSS), was used to analyse the data. The current study used descriptive analysis to analyse the respondents' demographic information and for the frequency analysis and graphical illustrations of the study variables (see Chapters 7 to 11).

Inferential statistics, such as binary logistic regression, one-way analysis of variance (ANOVA), and partial least squares structural equation modelling (PLS-SEM) analysis, were used to analyse the collected data in different stages. Binary logistic regression analysis was carried out to evaluate the interrelationships among occupant energy behaviours, IEQ satisfaction, user control, and social-psychological factors influencing occupant behaviours in New Zealand offices (see Chapter 7). This analysis allows binary or dichotomous levels of measurement with only two categorical outcome variables for dependent variables (Kassambara, 2018). ANOVA, a statistical technique that is frequently employed in the social sciences (Rockcastle et al., 2017; Whitley et al., 2021), was used to examine the variation in social-psychological perspectives and occupant energy behaviours among various demographic groups (i.e., age, gender, ethnicity, and location) (see Chapter 8). The SPSS software was used to perform the above three analyses. The social-psychological theoretical framework and research hypotheses in Chapter 9 were tested via a PLS-SEM analysis. PLS-SEM is a nonparametric statistical technique that illustrates the correlations between manifest or observed and latent variables (Schumacker & Lomax, 2016).

2.10.4 Machine learning techniques

This study used a decision tree-based methodology to assess the indoor environment, building user control, social-psychological factors, and demographic factors as predictors of individual occupant behaviour in office buildings (see Chapter 11). It is a non-parametric supervised machine learning technique that classifies or predicts a dependent variable based on the values of independent variables (Lu & Ma, 2020; Rizvi et al., 2019). This characteristic is crucial in this study, where the target attribute (occupant behaviour) and predictor variables (indoor environment, building user control, social-psychological factors, and demographic factors) were collected as nominal and categorical variables. The decision tree develops several predetermined groups or categories based on the data set and provides a top-down branched graphical categorisation model or rule expressions (Ryu & Moon, 2016). Decision tree models offer very effective forecasting through faster computations and simple interpretations when compared to other machine learning models like artificial neural networks (ANN) and support vector machines (SVM) (Han et al., 2022; Lu & Ma, 2020). In this study, the ease of interpretation allows researchers to explain the decision-making process and causal relationships between variables clearly and understandably. The decision trees can also be identified as a classification technique that comes under data mining. Data mining is a powerful data analysis tool to discover patterns in a large amount of data. It has been demonstrated to be a promising approach to analysing numerous occupant-related data. Clustering, classification, association rule mining (ARM), and regression are four standard data mining techniques in analysing occupant-related data (Ren et al., 2019).

The decision trees are robust to outliers, making them suitable for this study's context, where data from various sources and occupant behaviours may vary. Additionally, the ability to handle missing values effectively makes decision trees a practical choice for analysing occupant-related data in real-world settings where data may not always be complete (Rizvi et al., 2019). Therefore, the decision tree approach aligns well with the research objective of assessing the predictors of individual occupant behaviour. By creating predetermined groups or categories based on the data set, decision trees allow for a systematic evaluation of the factors influencing occupant behaviour. Furthermore, the study's sample size is adequate for decision tree analysis, as previous research has shown that decision trees perform well even with small sample sizes (Lu & Ma, 2020).

Overall, the decision tree-based methodology employed in this study complements the research objective 3 and sub-objective 3.2 by offering an efficient, interpretable, and robust approach to assess predictors of individual occupant behaviour in office buildings. It allows for the exploration of complex relationships between variables and provides valuable insights into the factors influencing occupant behaviour, contributing to the understanding of occupant energy behaviours in real-world building settings.

2.11 Research validity and reliability

Validity is proof that an instrument measures what it intends, claims, or pretends to measure and that a description accurately captures the properties intended to describe, explain, or theorise (Winter, 2000). The significance of the research components is what validity is concerned with. Although knowing whether a measure is valid precisely is impossible, researchers can create compelling arguments for its validity (Bollen, 1989).

Reliability, or the accuracy of an instrument, is the second criterion for evaluating the quality of a study. Reliability is the degree to which measurements can be repeated when different people perform the measurements, on various days, under various circumstances, with purportedly different devices that measure the same thing. Overall, consistency of measurement, or stability of measurement under various settings where essentially the same results should be achieved, is what the term reliability means (Bollen, 1989; Nunnally, 1994).

The earlier researchers identified the measures that can be used to evaluate the validity and reliability of a study. Table 2.2 summarises these measures that are frequently considered in the previous studies. As the current study includes interviews and questionnaires for data collection, different validity and reliability measures were used in each data collection stage. The researcher used face validity, i.e., whether the questions appear to be measuring what they purport to measure. This is frequently used as a basis for validating conclusions (Cannell & Kahn, 1968).

Table 2.2 Validity and reliability measures

Validity measures		Reliability measures	
Construct validity	The measurement's conformance to accepted theory and comprehension of the concept being measured	Test-retest reliability	Whether the researcher consistently receives the same results when repeating a measurement over time
Content validity	The degree to which the notion being measured is fully covered by the measurement	Interrater reliability	Whether the researcher receives the same findings when conducting the same measurement with various raters or observers
Criterion validity	The degree to which a measure's outcome agrees with other reliable measurements of the same notion	Internal consistency	Whether several test components intended to measure the same thing get the same results

Sources: (Cohen et al., 2017; Drost, 2011; Heale & Twycross, 2015)

In the current study, two experts concluded that it appeared to be a reliable measure of reading ability after reviewing the interview instructions. However, due to the weakness of face validity (Drost, 2011), it is also recommended to minimise bias of the interviewer and interviewee (Cohen et al., 2017). To lessen study bias, the researcher employed a carefully structured interview with each respondent having the same structure, order of words, and questions (Silverman, 2015). The researcher also took care to avoid leading questions. Making assumptions about interviewees or inserting words into their lips is a leading question (Morrison, 1994). Reducing these biases also supports the interview's reliability (Cohen et al., 2017).

The researcher assessed the questionnaire's content validity while proving that it fairly and thoroughly covers the topic or items it is meant to cover (Carmines & Zeller, 1979). Before the primary survey, the questionnaire was tested by conducting a test run, and relevant implications were identified, ensuring content validity. The criterion validity was tested using convergent validity and discriminant validity. When two related or comparable factors of a given construct are shown to be connected or similar to one another, it is said that the results have converged or are consistent (Cohen et al., 2017). To calculate the convergent validity, the standardised factor loadings and average variance extracted (AVE) were utilised (Hair & Alamer, 2022). Even if two or more unrelated items appear to be similar, discriminant validity demands that they be proven unrelated to or distinct from one another (Cohen et al., 2017). Discriminant validity can be assessed using Heterotrait-Monotrait (HTMT) ratio, Fornell-Larcker criterion, and cross-loadings representing discriminant validity (Fornell & Larcker, 1981; Henseler et al., 2015). Consequently, the construct validity was achieved through content validity and criterion validity. Additionally, using the same measurement tool or response strategy to measure independent and dependent variables within a single survey can lead to common method bias (CMB), which was measured using common methods variance (CMV) analysis (Jakobsen & Jensen, 2015; Podsakoff et al., 2012; Richardson et al., 2009) further confirming construct validity. In terms of reliability, the survey's internal consistency was examined using Cronbach's alpha (α) reliability analysis, which reveals how well the survey captures the study's intended outcomes. An alpha value of 0.70 or higher indicates internal consistency (Taber, 2018).

Epilogue

This first part of the thesis presents the research introduction and methodology chapters. The introduction chapter highlights that occupant behaviours play a crucial role in building energy consumption and must be considered in the early design stages. It outlines that evaluating comfort preferences, considering environmental, contextual, and social-psychological factors, and addressing the energy impacts caused by occupant behaviours are crucial to assess these consumptions accurately. The chapter establishes that current models and tools for evaluating the impact of occupant behaviours on building energy consumption are limited, and a lack of informed data on occupant behaviour makes it challenging to optimise building energy performance. Also, it explains that the proposed technical solutions for reducing building energy consumption may not be enough to achieve energy savings targets. It further highlights that building management and occupants must work together to create an energy-efficient environment, and occupant-centric strategies and technologies must be implemented. Thus, it proposes the need to understand the relationship between occupant behaviour, IEQ, and social-psychological factors, evaluate the decision-making process of occupants in office environments, and develop an ontology for monitoring occupant behaviour to improve energy efficiency in New Zealand office buildings. Four objectives are formulated to achieve the above aim, and the thesis outline in Chapter 01 highlights the link between Objectives, Research Questions, Research Sub Questions and Chapters

As such, the second chapter explains the research methodology with preferred choices to achieve the research aim and objectives. The research selects a critical realism philosophy, abductive approach, mixed-model research choice, grounded theory and survey strategies. Interviews and questionnaires were used for data collection and analysed using content analysis, descriptive and inferential statistics, and machine learning techniques. The next part of the thesis further establishes and defines the problem and develops the conceptual model during the preliminary stage of the research.

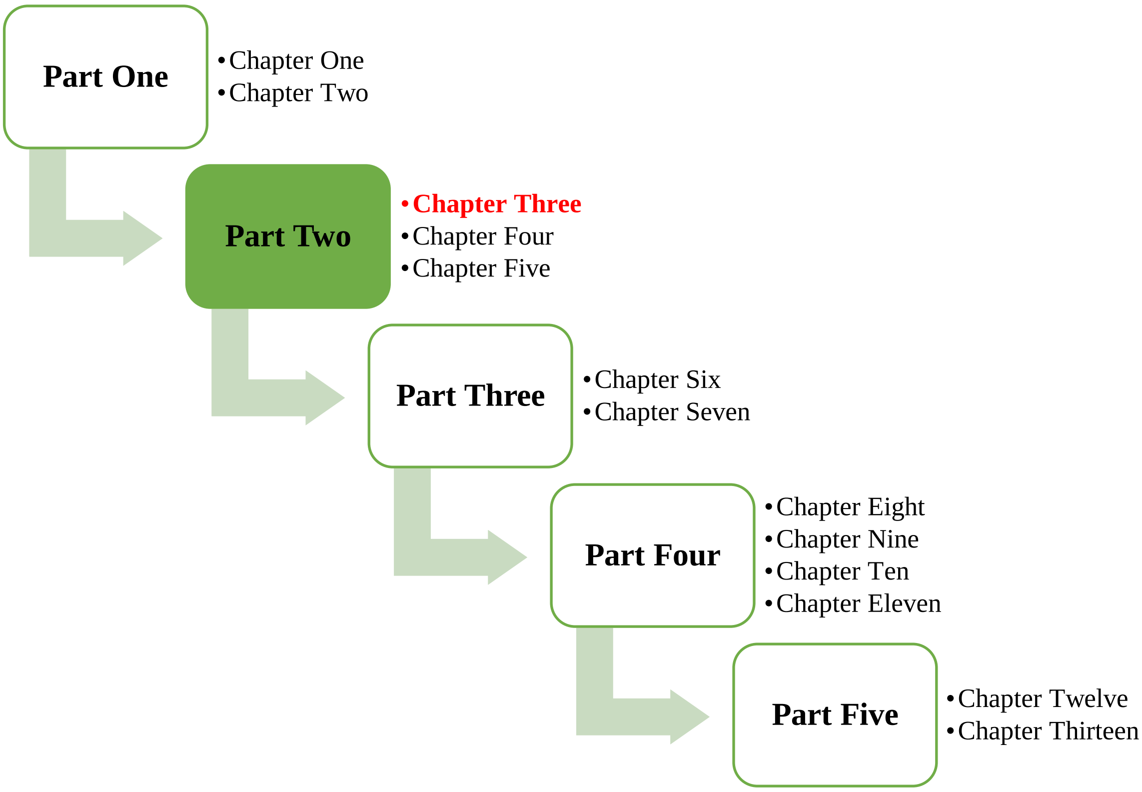
PART 2 – PROBLEM DEFINITION AND CONCEPTUAL MODELLING

Prologue

The three chapters in Part 2 comprise the study's problem definition and conceptual modelling. This part follows literature reviews and an analysis of the preliminary findings at an early stage. These chapters identify the prevalent occupant energy behaviours and the significant drivers that influence these behaviours in the New Zealand and international contexts and contribute to achieving Objective 1. The first chapter within this part (chapter 3) focuses on the occupant energy behaviours and drivers influencing occupant behaviours based on IEQ parameters. It presents a narrative review of journal articles and theses to define occupant behaviours and highlights the importance of considering IEQ parameters and other factors influencing occupant behaviours. The chapter identifies the main factors influencing occupant behaviours. These studies further suggest that energy research practices based purely on objective factors of occupant behaviours may not highlight valuable insights from subjective aspects. Thereby, chapter 3 contributes to achieving sub-objective 1.1. Thus, a systematic review of research articles on the social-psychological drivers of occupant behaviours is followed-up in chapter 4.

Chapter 4 determines patterns and trends in previous research and identifies gaps for future investigation. The chapter highlights the influence of social-psychological theories and constructs on occupant energy behaviours and discusses the application of theories in different behaviours and future research trends and implications. Chapter 4 contributes to achieving sub-objective 1.2.

After defining the problem in chapters 3 and 4, chapter 5 explores the relationship between indoor environmental conditions, comfort preferences, and occupant behaviours in the New Zealand context using a small sample to develop the conceptual model. The chapter examines the indoor environmental conditions based on occupants' satisfaction with IEQ, user-centred designs, and furniture arrangements across the three office types: private, shared, and open-plan offices. It tries to link occupant behaviours with comfort preferences and contributes to achieving sub-objective 1.3.



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3.0 Occupant energy behaviours – A review of indoor environmental quality (IEQ) and influential factors

Abstract

Occupants try to adjust or adapt to the indoor environment to improve the IEQ. However, the impact of these occupant behaviours is overlooked in building energy modelling. Furthermore, no general agreement exists on the factors that drive occupants' decisions and reflect their energy behaviour. A narrative literature review and a subsequent desk study of fifty (50) theses highlight the impact of occupant behaviours on the energy consumption of buildings based on the relationship to IEQ and influential factors. Accordingly, the most prominent behaviours that drive the energy consumption of buildings are the operation of plug-ins and equipment, opening/closing windows, turning lighting on/off, adjusting thermostats, lowering blinds, and occupant presence. Amongst, interaction with opening/closing windows to improve IEQ operation of plug-ins and adjusting thermostats as a response to thermal discomfort, turning lighting on/off, and lowering blinds to improve visual conditions directly affect the building's energy use. Also, indoor environmental conditions, climate, building characteristics, building systems and devices, user-centred design, and building elements are essential influencers. Overall, this study highlights the importance of incorporating occupant comfort-related parameters and significant influential factors to recognise the dynamic nature of occupant energy behaviours.[1]

[1] This chapter is based on the following published conference paper:

Weerasinghe, A. S., Rasheed, E., & Rotimi, J. O. B. (2020). Occupant energy behaviours – A review of indoor environmental quality (IEQ) and influential factors. In A. Ghaffarianhoseini et al. (Eds.) Proceedings of the 54th International Conference of Architectural Science Association (pp. 805 – 814), ANZAScA.

3.1 Introduction

Over the past three decades, researchers proved that occupant behaviours highly influence the increase in building energy demand (Hoes et al., 2009; Langevin et al., 2015). For example, it is identified that occupant behaviour is the main reason behind the discrepancy between simulated and actual energy (Langevin et al., 2015). Further, Hoes et al. (2009) showed that occupant behaviour is an essential input parameter influencing the whole building energy simulations. Therefore, uncertainty in occupant behaviours may significantly affect such predictions. Similarly, Lin and Hong (2013) demonstrated via computer simulations that the inefficient work style of occupants leads to double the energy. However, occupant behaviours are often simplified in building simulations of design and operation stages (D'Oca, Hong, et al., 2018).

Occupant energy behaviour refers to the unconscious and conscious actions of a human being to control the physical parameters of the surrounding built environment based on comparing the perceived environment with the sum of past experiences (Schweiker, 2010). Usually, these reactions of occupants are possible when they are in discomfort and trying to create a comfortable indoor environment (Nicol & Humphreys, 2002). According to Bluyssen (2019), building occupants influence the internal environment through their presence and modifying the building's systems and components. These activities aim to improve thermal, acoustic, visual, and indoor air quality (IAQ), ensuring buildings' IEQ.

Occupants driven by these adaptive IEQ triggers aim to achieve the desired personal comfort level using various strategies. They include building systems and elements such as openings, shading, lighting, HVAC systems, hot water, and electrical appliances (Delzendeh et al., 2017). Other strategies are the occupants' actions and inactions. As Hong et al. (2015) identified, occupants' actions include opening and closing windows, adjusting blinds, adjusting thermostat temperature, and turning the air conditioning on or off) and the inactions include moving to a different location dealing with some inconvenience.

Also, the behaviours differ from one building occupant to another due to physical, physiological, and psychological differences between occupants and related external factors such as economic and regulatory (energy regulation and compliance) (Bluyssen, 2019). Occupant behaviours such as occupant presence, window opening, light switching, adjusting blinds and clothing level adjustments, not limited, are a function of environmental factors such as indoor air temperature and daylight illuminance (Haldi & Robinson, 2011). Furthermore, another set of empirical studies added that the energy consumption of buildings having similar physical features differs due to the comfort preferences of occupants, their interaction with building systems, occupancy patterns, and the lifestyle of occupants (Andersen et al., 2009; Maier et al., 2009). Accordingly, the occupant energy behaviours driven by IEQ parameters (thermal, visual, aural, and IAQ) and influential factors (physical, physiological, psychological, contextual, and social) contribute to the discrepancy between expected and actual energy use. Therefore, this paper reviews the previous studies on occupant energy behaviours, IEQ parameters, and factors influencing occupant energy behaviours to highlight the impact of occupant behaviours on the energy consumption of buildings. To achieve the aim of this study, related literature was identified, referring to published journals, conference articles, and theses. Fifty (50) published theses were examined to highlight the significant energy-driven occupant behaviour and influential factors. The findings are discussed in the following sections.

3.2 Research methods

The study undertakes a narrative literature review based on the empirical findings of research theses and dissertations to explore occupant energy behaviours and the significant factors that influence occupant energy behaviours and determine the interrelationships of these behaviours and factors that challenge the energy consumption of buildings. The theses and dissertations stand for the originality of a work that has not been explored and produced into theses to fulfil an academic qualification previously. Like journal and conference articles, the theses and dissertations also offer relevant literature for researchers (Usman & Yahaya, 2017). Therefore, this review is limited to previous research theses and dissertations to determine the interrelationships between these behaviours and factors for better energy simulations to support future studies.

Theses and dissertations are identified using major Global databases: Networked Digital Library of Theses and Dissertations, Open Access Theses and Dissertations (OATD), and EBSCO Open Dissertations. The rationale for using these databases lies in their access to relevant thesis reports published by reputable universities worldwide for many years. EBSCO Open Dissertations has a firm number of theses from American universities. Other databases are also used, including ProQuest Dissertations and Theses and Google Scholar, to ensure the inclusion of other relevant theses and dissertations which might not be included in the above databases and increase the coverage. An extensive search is conducted using the keywords; “occupant behaviour”, “occupant”, “occupancy”, “energy consumption or energy use”, and “energy modelling or simulation” used to select any theses that match with the research area following a title, abstract and full-text analyses. The title and abstract analyses were considered where the keywords were mentioned in either/both the title and abstract. Subsequently, the full text of the theses was assessed to select the theses to be included in the narrative literature review. The review search also showed that most studies on the impact of occupant behaviour on building energy consumption were published in the most recent decade, from 2011 to 2020, highlighting increasing interest in occupant energy behaviours. Therefore, this review is limited to relevant studies published between 2011 to 2020 on the paradigm of occupant behaviour and building energy consumption. Fifty theses were included in the qualitative synthesis of the narrative literature review using thematic analysis. The thematic analysis includes identifying, analysing, and reporting themes (patterns) within qualitative data (Braun & Clarke, 2006).

3.3 Occupant energy behaviours

In a recent study, Hong et al. (2017) categorised occupant energy behaviours into two main clusters: adaptive and non-adaptive. According to the authors, adaptive behaviours include opening/closing windows, lowering blinds, adjusting thermostats, turning lighting on/off, and operating plug-ins (e.g. personal heaters, fans, and electrical systems for space heating/cooling) to adjust the environment to their conditions. Other actions include adjusting clothing levels, drinking hot/cold beverages, and moving through spaces to adapt themselves to their environment. On the other hand, non-adaptive behaviours are typically actions that do not involve direct control over the environment but rather indicate occupant presence, reporting complaints regarding discomfort, and the use of various plug-ins and electrical equipment (e.g. office and home appliances) without actively adapting to the environmental conditions. They can also be inactions like accepting the existing indoor environmental conditions without access, awareness, and choice to control comfort (O'Brien & Gunay, 2014). Thus, these occupant actions directly depend on the occupants’ comfort requirements and influence overall building performance in terms of building energy consumption and comfort (Wang et al., 2016). Of the 50 theses reviewed, seven (07) most often researched occupant energy behaviours significant in building energy consumption were identified and summarised in Table 3.1.

Table 3.1 Significant occupant energy behaviours in buildings

Occupant behaviour	Number of theses
Operation of plug-ins and electrical equipment *(personal heaters, fans, and electrical systems for space heating/cooling, office, and home appliances)*	25
Opening/closing windows	13
Turning lighting on/off	13
Occupant presence	12
Adjusting thermostats	9
Lowering blinds	5
Reporting discomfort	3

As seen in Table 3.1, most studies (50%) focused on the operation of plug-ins and electrical equipment, while a considerable number of studies (25%) focused on opening/closing windows, turning lighting on/off, and occupant presence. Additionally, few researchers have focused on adjusting thermostats, lowering blinds, and reporting discomfort. However, these include studies focusing on single or multiple energy behaviours. Different occupant behaviours can have a substantial impact on building energy consumption. For example, window-opening behaviour might lead to a significant variation in the building's EUI. According to Fabi et al. (2012), this variation equals a factor of four in commercial buildings in the USA and three in identical apartments in Denmark. However, with careful consideration, energy savings from occupant behaviour could constitute 10% to 20% of residential buildings and 5% to 30% of commercial buildings (Lin & Hong, 2013). Achieving energy savings at the higher end of the range (30%) may require a combination of well-implemented behaviour change programs, occupant engagement, and favourable building characteristics, which might not always be easily achievable in every commercial building setting. Therefore, studies seem to find low end savings. For example, a study that modified two energy behaviours: thermostat use and diffuser covering providing energy usage feedback, has estimated a modest 6% savings in energy use (Staats et al., 2004). Furthermore, Dietz et al. (2009) stated that occupant energy savings could reduce 7.4% of U.S. emissions.

3.4 IEQ and occupant energy behaviours

This section discusses the relationship between IEQ and occupant energy behaviours. From the literature, IEQ is broadly categorised into four main parameters; thermal comfort, IAQ, visual comfort, and acoustic comfort (Bluyssen, 2019; Hong, D'Oca, Turner, et al., 2015).

3.4.1 Thermal comfort

Thermal comfort is defined by ISO (2005) as "that condition of mind which expresses satisfaction with thermal conditions". Environmental parameters determine an occupant's thermal sensation: air temperature, air velocity, mean radiant temperature, relative humidity and personal parameters: metabolic rate and clothing factor (Asadi et al., 2017). Occupants can often operate windows and doors to improve room temperature and air exchange in a naturally ventilated building. In contrast, in mechanically ventilated buildings, occupants must accept the system operation or personally adjust their metabolic rate and clothing level and adjust themselves to the indoor environment (Daum et al., 2011). Furthermore, occupants tend to adjust thermostats, fans, and heaters to adapt the indoor environment to their preference when they feel thermally uncomfortable (Langevin et al., 2015).

The thermal comfort sensation varies from person to person. Therefore, buildings should enable occupant interactions to choose their preferred conditions to decrease thermal discomfort (Nicol & Humphreys, 2002). Accordingly, adaptive interactions such as clothing and desk fans help achieve perceived work performance and thermal satisfaction (Tanabe et al., 2015). Previous studies that provided personalised ventilation systems, such as individual air flow rate control and ceiling fans, found that most occupants prefer those systems over HVAC systems and accept them irrespective of the ambient air temperature (Chen et al., 2012). However, the occupants should not compromise the energy-savings of the building when they modulate their thermal preferences. Adjusting a thermostat to set the cooling set-point below 24 °C is an occupant energy waste behaviour (Sun & Hong, 2017). Another study by Nisiforou et al. (2012) showed that occupant misbehaviour in energy use leads to energy waste. In contrast, occupants' willingness to switch off plug loads and HVAC systems in unoccupied spaces contribute to avoiding energy waste (Sun & Hong, 2017).

On the other hand, it is anticipated that advanced building automation and control systems, specifically designed for HVAC controls, have the potential to achieve remarkable energy savings, surpassing 45% compared to typical HVAC energy consumption (Han & Zhang, 2020). This vast potential for energy savings through HVAC automation has driven substantial attention and investment in building energy management efforts. It is crucial to recognise that both HVAC automation and promoting energy-conscious occupant behaviour play pivotal roles in achieving overall energy efficiency in buildings. By combining these approaches, even more significant energy reduction and sustainability benefits can be realised. As a result, empirical studies have focused on developing adaptive control procedures to optimise windows, plug loads, and other building devices and systems for energy savings, while ensuring user comfort and respecting occupants' thermal preferences (Stazi et al., 2017).

3.4.2 Indoor air quality (IAQ)

IAQ refers to the air quality inside buildings and structures (Amasyali & El-Gohary, 2016) that is related to the health and comfort of occupants, where poor IAQ leads to Sick Building Syndrome (SBS) (Asadi et al., 2017). Further, respiratory health issues are expected among residential and office building occupants due to indoor air pollutants (Amasyali & El-Gohary, 2016). In addition, residential building occupants with respiratory disease are more concerned about IAQ, while occupants with typical health symptoms such as sore throat are less satisfied with IAQ in their houses. Several factors influence IAQ, like humidity, odour, crowding, and CO_2 concentration.

Primarily, indoor CO_2 concentration is used to control IAQ because it correlates directly with occupant presence (Nienaber et al., 2019; Wolf et al., 2019). Human exhalation has a much higher CO_2 concentration than outdoor air. Therefore, adequate ventilation is needed to dilute and remove the CO_2 accumulating in the indoor air (Wolf et al., 2019). Pavlovas (2004) recommended that more ventilation air is required to maintain proper IAQ when more people occupy space. For example, a CO_2 concentration level no greater than 700 ppm above outdoor air levels specifies ventilation rates that would satisfy a substantial majority (about 80%) of occupants (ASHRAE, 2019). Further, the minimum ventilation rate required in office spaces is 5 cfm per person of outdoor air to ensure adequate indoor air.

Previous studies suggest that the operation of windows is essential in a building to make IAQ pleasant, supply more ventilation, and reduce CO_2 concentration. As Andersen et al. (2013) found in their study, any correlations between behaviour and CO_2 concentration indicate relationships between air quality and occupant behaviour. Further, Calì et al. (2016)

elaborated that there is a significant statistical correlation between window openings and the CO_2 concentration where an increase in CO_2 concentration level inside the building leads to an increase of window opening likelihood for more than 45% of the windows. Also, IAQ influences the use/adjust of humidifiers and the opening/closing of internal/external doors (Amasyali & El-Gohary, 2016)

Though these actions by occupants improve the IAQ, they also cause increased energy consumption. For example, opening windows increases energy consumption due to changes in indoor temperature by allowing outside air into the building (Barlow & Fiala, 2007). A clear tendency can be observed that heating costs are positively correlated with lower air quality, where better air quality is traded for an improved thermal sensation (von Grabe, 2019). Moreover, energy-savings can be achieved by reducing the average ventilation rate via occupancy-controlled ventilation while maintaining a good indoor climate and better controlling indoor pollutant concentrations (Pavlovas, 2004).

Meanwhile, a connection between behavioural patterns and building energy management systems is highlighted (Dong et al., 2010). They developed and implemented sensor-based modelling to predict user behaviours by connecting the behavioural patterns to building energy, and comfort management systems, where results indicated a 30% potential for energy-savings without scarifying the IAQ. Developing an occupant behaviour model capable of simulating individual actions with a significant effect on IAQ helps to evaluate occupant exposure to the indoor environment (Dziedzic et al., 2019).

3.4.3 Visual comfort

Visual comfort is often a subjective impression of lighting quality, quantity, and distribution (Amasyali & El-Gohary, 2016). Moreover, occupant visual comfort in buildings ensures they are not subjected to excessive contrast, glare, and unacceptable brightness levels (Hong, D'Oca, Turner, et al., 2015). According to the ISO standard ISO 8995-1:2002, the general working areas should have a maintained work plane illuminance of at least 200 lx.

Light intensity primarily stimulates physiological, psychological, and physical human responses. Physical responses include switching lighting on/off, dimming, and adjusting blinds (Naspi et al., 2018). Lights turn on when indoor illuminance decreases and turn off when occupants leave the room, but switches are often located by the door instead of near desks, leading to delayed switching behaviour (Lindelöf & Morel, 2006). On the contrary, occupants were observed not to use overhead lighting during the day (Jennings et al., 2000). Therefore, occupants' artificial lighting preferences vary from one participant to another based on the accessibility of lighting controls (Sadeghi et al., 2016). Likewise, occupants interact with their blinds to avoid glare and gain daylighting (Chan & Tzempelikos, 2013). Psychological factors and views cause the opening of the blinds, while closed blinds are due to physiological reasons (Day et al., 2012). Other factors influencing the blinds' operation are the building's orientation, season, and sky conditions (Mahdavi, 2009). Lower energy consumption was expected with higher daylight utilisation, easy access to lighting controls, and user-centred control while assuring occupants' visual comfort (Moore et al., 2002).

3.4.4 Acoustic comfort

Essential acoustic comfort is keeping the background noise level within an acceptable range (Hong, D'Oca, Turner, et al., 2015). A noise exposure level below 85 dBA for eight hours is recommended to reduce workers' occupational noise-induced hearing loss (NIOSH, 2014). However, occupant relationship with aural stimuli goes beyond essential acoustic comfort and involves complex factors. Such factors are personal, contextual, social, and symbolic transactions that are often unattended yet of vital importance in acoustical design (Hong, D'Oca, Turner, et al., 2015). Although acoustic comfort performs poorly in IEQ and contributes to occupant behaviour, acoustics is not included in most BPS (Newsham et al., 2013). The noise transmission can be regulated through windows (von Grabe, 2019). Often, the occupants do not open the windows because of outdoor noise sources like traffic jams and indoor sources such as HVAC systems and noise from talking, walking, and drinking water systems (Asadi et al., 2017).

3.5 Factors influencing occupant energy behaviours

Researchers in this field classified factors influencing energy-driven occupant behaviour into various categories. For example, Schweiker (2010) identified that occupant behaviour is influenced by external factors such as temperature, humidity, airspeed, and illuminance, etc. and internal factors such as cultural background, attitudes, preferences, etc. The authors also indicated that compared to external factors, the influence of internal factors on occupant behaviour is very complex. Similarly, internal factors are biological, psychological, and social, while external factors are building and building equipment properties, physical environment, and time (Yoshino et al., 2017). Andersen et al. (2013) also indicated that building property ownership, available systems, and equipment influence energy behaviours.

Fabi et al. (2012) introduced a framework for classifying factors influencing energy-driven adaptive and non-adaptive behaviours by dividing those factors into five groups: physical environmental, contextual, psychological, physiological, and social, including internal and external factors. On the contrary, O'Brien and Gunay (2014) grouped the contextual factors into physical environmental factors that remain unchanged over a while, psychological factors related to individual and social factors, and physiological factors that are not immediate triggers.

Apart from the above categorisations, Peng et al. (2012) classified behaviours into environmentally-related: actions driven by environmental parameters; time-related: actions repeated in certain time-lapses; and random: actions depending on uncertain, not quantifiable factors based on an analysis of human behaviours in residential buildings. Based on Peng et al.'s study, Stazi et al. (2017) reviewed the occupants' behaviours inside buildings assessing the main driving factors for their actions, divided into environmental and time-related stimuli. The results of their study suggest that not only environmental factors play a crucial role in the use of building systems but also contextual factors, as well as routine and habits, primarily affect occupants' behaviours.

More recently, Schweiker et al. (2018) provided a framework to categorise factors influencing occupant behaviours into adaptive triggers, non-adaptive triggers, and contextual factors. Accordingly, adaptive triggers are physiological triggers that originate from a signal in the body that prompts the occupant to take action or physical environmental triggers that describe the indoor and outdoor environments. In contrast, non-adaptive triggers are factors that are independent of physical environmental triggers.

Accordingly, the factors identified in the previous research thesis can be categorised into six (06) main factors; physical environmental, physiological, psychological, contextual, social, and time-related. Table 3.2 identifies and classifies the significant, influential factors under those primary categories.

Table 3.2 Significant factors influencing occupant behaviours in buildings

Type of factor	Influential factors	Number of sources

Physical environmental factors	Indoor environmental conditions - Temperature, Humidity, Air speed, Radiant temperature, Noise, Air pressure, Indoor air quality	17
	Climate	11
Contextual factors	Building characteristics	9
	Building systems and appliances	6
	User-centred design - Usability and controllability of heating/cooling/ventilation	6
	Building elements	4
Time-related	Day and time	5
Social factors	Number of occupants in an organisation	4
	The education level	4
	Job-status and income	4
Physiological factors	Gender	4
	Metabolic rate	4
	Clothing insulation	4
Psychological factors	Attitudes, motivations, and values	4
	Subjective norms/normative beliefs	3
	Perceived behavioural control	3
	Personality traits	3

As seen in Table 3.2, seventeen (17) significant factors were identified under major influential categories. Two (2) sub-factors that significantly influence occupant behaviours were identified regarding the physical environmental category. Amongst, most of the studies (34%) have highlighted indoor environmental conditions as a significant factor that determines occupant behaviours. In comparison, most other studies (20%) showed climate conditions (ex., warm and winter seasons, region, weather conditions) as another significant factor affecting building occupant behaviours. In the contextual category, four (4) sub-factors were identified, where most studies (18%) have highlighted building characteristics (e.g. area, shape, size, texture, colour, elevation, etc.). Additionally, building systems and appliances, user-centred design, and building elements were highlighted in most studies as significant factors influencing occupant energy-driven behaviour.

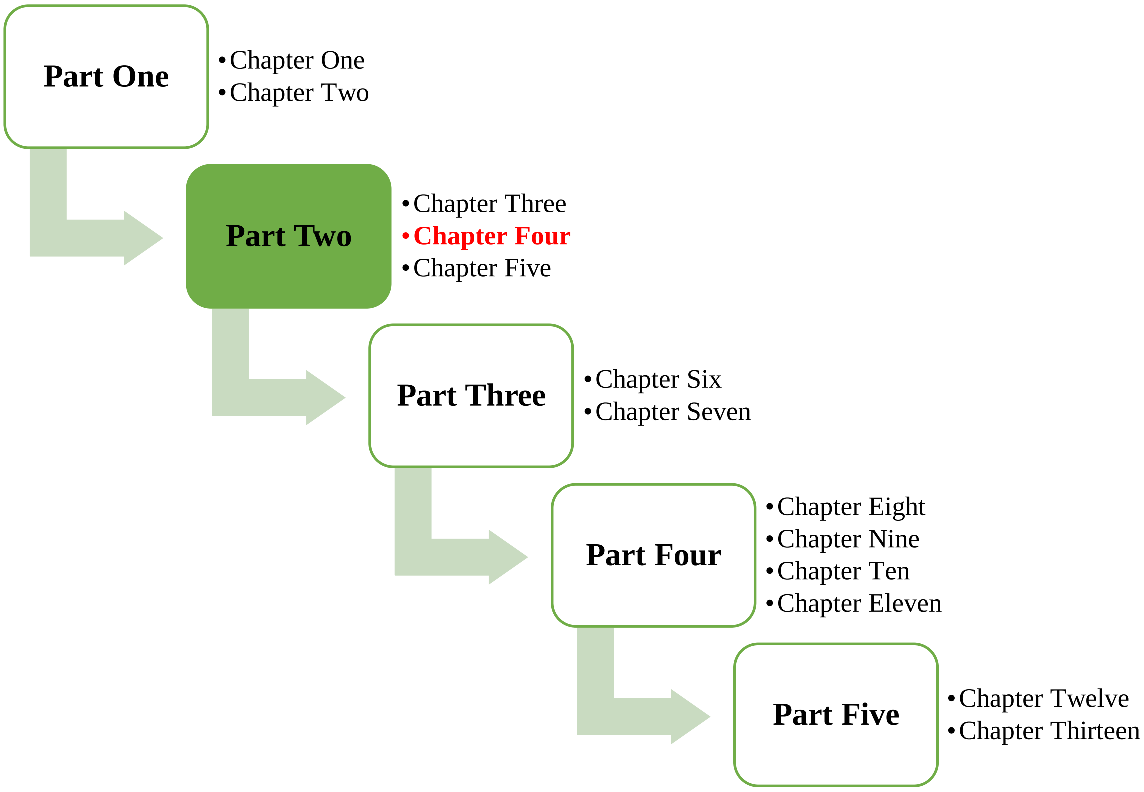
Regarding time-related factors, only one factor has been identified as significant. Most studies considered day and time, such as day of the week, time of the day, and duration, as significant factors determining occupant behaviour. Regarding social factors, most studies determined three (3) sub-factors; the number of occupants in an organisation, the education level, and job status and income. Three (3) factors appeared in most empirical studies considering physiological factors. Those factors are gender, metabolic rate, and clothing insulation. For psychological factors, most studies highlighted attitudes/motivations/values, subjective norms/normative beliefs, perceived behavioural control, and personality traits influencing occupant behaviour in buildings. Many previous studies highlighted physical environmental, and contextual factors compared to other factors. Therefore, the focus on other physiological, psychological, social, and time-related factors was rarely considered significantly influencing factors for energy-driven occupant behaviours in the previous research studies.

3.6 Conclusion

As most people spend more than 90% of their time indoors, the IEQ is essential in occupant behaviours and a building's energy efficiency. Improving building energy efficiency is one of the best strategies for reducing the energy consumption of buildings while maintaining the comfort and well-being of occupants. This paper reviewed previous studies on occupant energy behaviours, IEQ parameters, and factors influencing occupant energy behaviours to understand human-related causes of energy increase in buildings.

This study's findings show that most existing studies focus on actions such as the operation of plug-ins, opening/closing windows, turning lighting on/off, adjusting thermostats, and lowering blinds as measures employed by occupants to adapt to the indoor environment to their preferences. Non-adaptive behaviours were also highlighted, such as the occupants' presence and reporting discomfort. Accordingly, these behaviours are identified as significant to building energy consumption. Of critical consideration, many studies focus on a single energy behaviour; however, these energy behaviours are often inter-linked. Regarding IEQ parameters related to occupant energy behaviour, opening/closing of windows related to all the IEQ parameters considered: thermal comfort, IAQ, visual comfort, and acoustic comfort. Whereas operation of plug-ins and adjusting thermostats related to thermal comfort, turning lighting on/off and lowering blinds related to visual comfort. Therefore, IEQ caused to drive much of the significant energy-driven occupant behaviours. Many previous studies highlighted physical environmental, and contextual factors compared to other factors. Amongst indoor environmental conditions, climate, building characteristics, building systems and appliances, user-centred design, and building elements are the most significant factors influencing occupant behaviours. However, the focus on other physiological, psychological, social, and time-related factors was rarely considered significantly influencing factors for energy-driven occupant behaviours in the previous research studies.

Therefore, it is recommended to consider occupant comfort-related parameters and all the significant, influential factors to recognise the dynamic nature of occupant energy. Incorporating those into energy efficiency strategies in behaviour in diverse types of buildings is required. A scientific study that describes the dominant IEQ parameters and factors involved in energy behaviours needs to be conducted with the occupants in actual buildings.


Part One
•Chapter One
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4.0 Understanding social-psychological influences on occupant energy behaviours: A systematic review based on bibliometric and content analyses

Abstract

Understanding social-psychological drivers of occupant behaviours has attracted considerable research attention. The relationship between these two elements is pertinent in increasing energy-saving human building interactions and reducing occupant energy consumption. This study systematically reviews the literature on applying social-psychological theories to occupant energy behaviours and suggests future research directions. Seventy-nine (79) empirical research articles were collected by searching Scopus and Web of Science databases. The results show increased empirical research on social-psychological theories in occupant energy behaviour since 2008. The primary sources of publications were Scopus and Web of Science databases, and the research was conducted in China, the USA, and the UK. Lighting on/off, equipment and appliance usage, and adjusting heating and cooling thermostats are significant drivers of occupants' behaviour. The article emphasises the importance of understanding these factors to develop effective strategies for promoting energy-efficient behaviour. Future research trends could include more interdisciplinary research, developing new models and theories, and exploring the potential of emerging technologies. The implications of this article suggest that building designers and managers should consider social-psychological factors that influence occupants' energy behaviours.[2]

[2] This chapter is based on the following manuscript under review:

Weerasinghe, A.S., Rotimi, J.O.B., & Rasheed, E.O. (2023). Understanding social-psychological influences on occupant energy behaviours: A systematic review based on bibliometric and thematic analyses.

4.1 Introduction

Globally, the building energy use per floor area (m2) unit can reduce by 30% by 2030 to limit climate change (IPCC, 2019). The application of technical solutions has long been at the front-end centre of improving building energy performance (Li et al., 2018). However, the building owners and managers still struggle to achieve the desired energy performance (Y. Zhang et al., 2018) due to the challenges faced, such as high initial investment and long economic payback period, and lack of building information (Li et al., 2019).

Along these lines, the literature highly stresses occupant behaviour-related aspects to optimise the overall energy efficiency of buildings (Yoshino et al., 2017). Empirical studies show significant energy impacts and possible energy-saving opportunities via occupant energy behaviours. For example, a simple adaptive behaviour like opening windows increases the energy use of apartment buildings by 10 kWh/m2 per year (Fabi et al., 2013). Other adaptive behaviours, like adjusting HVAC systems and turning on/off lighting according to comfort preferences, also cause significant variations in the total energy consumption in buildings (Harish & Kumar, 2016). In another study, Sun and Hong (2017) highlighted energy waste behaviours like setting the thermostat below 24°C for cooling. However, these energy wastages can be offset by switching off the HVAC and plug loads when unoccupied (Sun & Hong, 2017). In commercial buildings, these energy-savings by occupants could vary from 5 to 30% (Hong & Lin, 2013; Pothitou et al., 2016).

Furthermore, more significant attention has been received towards occupant behaviour modelling and simulation. The research outputs like IEA-EBC Annex 66 and IEA-EBC Annex 53 provide methodological frameworks of behaviour models to enhance total energy predictions in buildings (Yan et al., 2017; Yoshino et al., 2017). The DNAS is a framework introduced for standardising the modelling of occupants' energy behaviours (Hong, D'Oca, Turner, et al., 2015). A significant opportunity is also highlighted to focus on occupant-centric design and operation in the post-pandemic world, considering the evolving flexible working practices (Mantesi et al., 2022)

In this context, the attention received towards occupant energy behaviours is threefold: occupant behaviour effects on energy, occupant behaviour modelling and simulation, and influential drivers. A set of studies focused on occupant behaviour impacts on energy, and the current standing and saving potentials of occupant behaviours are highlighted in those studies. For example, Hong et al. (2016) and Y. Zhang et al. (2018) highlighted the energy-saving potential and behavioural strategies by reviewing overall research trends and research gaps relating to occupant behaviour research. Regarding occupant behaviour modelling and simulation approach, the focus of the review studies differs from one study to another. It highlights the most suitable modelling technique for future research based on vast characteristics (Dong et al., 2018; Osman & Ouf, 2021; Uddin et al., 2021).

Furthermore, Paone and Bacher (2018) and Tam et al. (2018) pointed out the relevance of interdisciplinary approaches addressing the significant occupant behaviours and their drivers for occupant energy behaviour modelling. Identifying the drivers of occupant behaviours is challenging as they are complex, dynamic, and influenced by various internal, external, individual, and contextual drivers (Delzendeh et al., 2017). Correspondingly, most previous empirical research concentrated on drivers that can be easily captured, such as environmental, building-related, personal, and time-related drivers (Asadi et al., 2017; Schweiker et al., 2020; Stazi et al., 2017).

However, Deme Belafi, Hong, et al. (2018), reviewing 33 research based on survey or interview methods, identified the association between personal, social, and comfort factors. Furthermore, the authors found that the existing human-centred studies only considered environmental and engineering drivers to identify occupant behaviour patterns. Therefore, researchers have investigated occupant behaviours from a social-psychological point of view and introduced interdisciplinary approaches to uncover valuable insights into occupant energy behaviours. For example, well-known social-psychological theories such as the TPB and SCT were coupled with the DNAS framework (D'Oca et al., 2017). Likewise, empirical studies support the influence of TPB constructs such as attitude, subjective norms, PBC, and SCT constructs such as comfort and control aspects and behavioural and normative beliefs on occupant behaviours (Bavaresco et al., 2020). In another study, Li et al. (2019) introduced the MOA framework integrating social-psychological aspects from the TPB and the NAM. The authors determined the MOA's influence on energy-saving behaviours in offices where workplace norms and social interactions exist.

Accordingly, an increasing body of research investigated how sociological and psychological behavioural theories can better explain occupant behaviours and interactions with buildings (Stazi & Naspi, 2018). Understanding social-psychological drivers influencing occupant behaviours support implementing occupant-feasible energy-saving policy and goals (Hong et al., 2017). Also, this enables multidisciplinary collaborations between the social and technical disciplines while disseminating and sharing unique knowledge within the fields (Heydarian et al., 2020). At the same time, Heydarian et al. (2020) reviewed the extent of these applications, research methods, and the characteristics of such studies. They unveiled that most studies applied a limited number of theories that relevant data can be collected using quantitative research methods in social science, i.e., survey methodologies.

This questions whether a specific theory can accurately explain diverse occupant behaviours or interactions in different building settings. Therefore, a need remains to examine the social-psychological theories and their constructs to identify the most reliable drivers to assess occupant behaviours. This research thus sought to conduct a systematic literature review to determine the patterns or trends of previous research, understand the depth of existing knowledge, and reveal research gaps for further investigating social-psychological drivers of occupant behaviours. Specifically, the review aims to answer what social-psychological theories drive or underpin occupant behaviours, which theories are more frequent in each behaviour, which social-psychological drivers influenced the occupant behaviours most, and the future research trends and implications. The review results will help identify gaps to target future research in occupant behaviour. The review findings may enable building practitioners to understand how the social-psychological thinking of occupants influences their behaviours with the existing knowledge overview of occupant behaviours. Gaining that understanding would create effective occupant-centric energy policies to promote net zero energy goals and serve energy and environmentally responsible building occupants.

4.2 Research methods

4.2.1 The motivation for the systematic review

In recent years, the systematic literature review approach has been well-known in occupant behaviour literature (Delzendeh et al., 2017; Franceschini & Neves, 2022; Harputlugil & de Wilde, 2021). The systematic literature review can help identify diverse factors influencing occupant behaviours in different building disciplines (Fabi et al., 2012; Heydarian et al., 2020; Stazi et al., 2017). Accordingly, this systematic literature review aims to ascertain social-psychological theories and constructs within the context of occupant behaviours and explore future research directions. The study will map the specific literature in this area and answer the research questions about social-psychological drivers of occupant behaviours. Based on the clearly defined rationale, the systematic literature review approach is used for this study.

4.2.2 Steps of the systematic review

This systematic review was guided following the preferred reporting items for systematic reviews and the meta-analysis (PRISMA) 2020 statement by Page et al. (2021). The PRISMA statement includes a four-phase flow diagram of study selection and an expanded checklist with 27 items, which is helpful for critically appraising published systematic reviews (Page et al., 2021). The flow diagram describes the including of 1) identification, 2) screening and 3) inclusion criteria of the resources for the study, while the checklist items guide systematic review reporting under specific research title, abstract, introduction, methods, results, discussion, and conclusion (Mirzaei et al., 2020; Selçuk, 2019). Thus, the PRISMA statement results in transparent and complete research reporting (Ahmad et al., 2019). Figure 4.1 presents the three steps concerning this review, detailed in the subsequent sections.

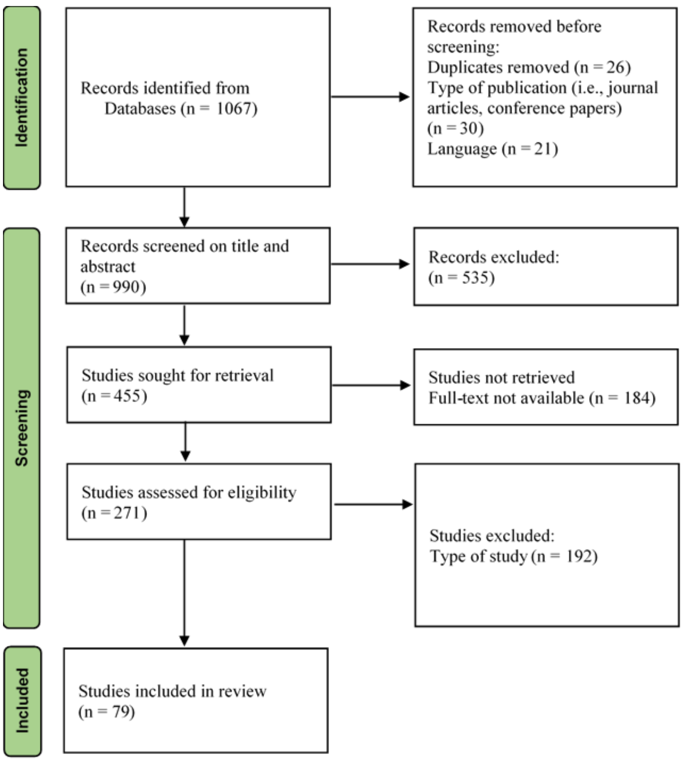


Figure 4.1 Systematic review process

Adapted from Page et al. (2021)

4.2.3 Identification of articles for review

An extensive list of keywords was identified to search relevant articles, including occupant behaviour, social theory, psychological theory, and energy. Table 4.1 indicates the five search strings that were used for established keywords. These keywords were systematically used to ascertain the social-psychological drivers of occupant behaviours. The studies were identified using major Global databases: Scopus and Web of Science. These databases provide comprehensive coverage of scientific studies published by numerous authors worldwide over many years. Different approaches were used for searching based on the coverage and nature of these databases. For example, the search on Scopus was carried out as indicated in Table 4.1. However, when searching in Web of Science, only three aspects were used (i.e., behaviour, social-psychology, and energy) with the Boolean operator AND. Accordingly, 1067 peer-reviewed articles published between 2008 and 2022 were obtained from searching databases. Scopus database search provided 1015 articles, and 52 were obtained from the Web of Science core collection. The duplicates, documents other than articles from journals and conferences, and articles that were not in English were removed at this stage before the screening stage.

Table 4.1 Keywords used for articles search

<table>
<tr><th>Search String</th><th>Aspect</th><th>Search Keywords</th><th colspan="4">Boolean Operator</th></tr>
<tr><td>1</td><td>Behaviour</td><td>"occupant behavio*" OR "human behavio*" OR "energy behavio*"</td><td rowspan="2">AND</td><td colspan="3"></td></tr>
<tr><td>2</td><td>Social</td><td>"social theory" OR "sociological" OR "sociology"</td><td rowspan="2">OR</td><td colspan="2"></td></tr>
<tr><td>3</td><td>Psychology</td><td>"psychological theory*" OR "psychology" OR "socio-psychological"</td><td></td><td rowspan="2">OR</td><td></td></tr>
<tr><td>4</td><td>Building</td><td>"window" OR "blinds" OR "shades" OR "thermostat" OR "lighting appliance" OR "adjusting clothing" OR "presence" OR "movement" OR "drinking beverages" OR "heating" OR "cooling" OR "ventilation"</td><td colspan="2"></td><td rowspan="2">AND</td></tr>
<tr><td>5</td><td>Energy</td><td>"energy-saving" OR "energy consumption" OR "energy use" OR "energy utilisation" OR "energy efficiency"</td><td colspan="3"></td></tr>
</table>

4.2.4 Screening criteria

First, the documents were screened based on the title and abstract, which were then screened if those appeared not to answer the research question. Second, these shortlisted papers in the first screening stage were included for data retrieval and synthesis, where it was prepared for full-text screening. In the third phase, retrieved studies were reviewed to assess their eligibility to include in the systematic review. This was done by examining the full content of the articles and screening the studies that considered one or more social-psychological theories, application of social-psychological constructs to assess one or more occupant behaviours or the building energy consumption/conservation in buildings. Data from the documents were extracted considering information on the publication date, geographical context, building settings, social-psychological theory and constructs, and occupant behaviours. In this phase, the studies were further narrowed down considering the type of study: studies focused on the built environment, factors of occupant behaviours, and energy consumption/conservation.

4.2.5 Inclusion and analysis of relevant studies

Seventy-nine articles were identified as suitable and relevant for this review. The relevant information from the selected documents was recorded in a Microsoft Excel spreadsheet, including author(s), year of publication, research field, social-psychological theory, core constructs, research location (country), building type, approach (methods, analysis, sample size), application (occupant behaviours, building systems, energy predictions made), and research gaps and further research. The selected documents were then reviewed and analysed using descriptive analysis, VOSviewer software to visualise bibliometric networks and content analysis.

Bibliometric data were analysed descriptively using frequency analysis for some aspects like yearly distribution of research, article source, country-specific article distribution, citation, and co-citation of the review articles. VOSviewer was used for creating co-occurrence, citation, and co-citation networks of the selected articles for the review. Many science mapping and visualisation tools are available such as Bibexcel, Publish or Perish, CiteSpaceII, CiteNetExplorer, and VOSviewer (Bankar & Lihitkar, 2019). VOSviewer and CiteSpaceII software tools have been widely used in most scientific research (Chen, 2017). Unlike most software tools, VOSviewer is specially designed to represent scientific maps of co-occurrence data and enables visualisation and straightforward interpretation of large scientific maps such as co-authorship, co-occurrence, and citation-based networks (van Eck & Waltman, 2022). VOSviewer offers text-mining functionality to extract data from bibliographic database files (van Eck & Waltman, 2022). Thus, VOSviewer software was chosen for this study and visualised the bibliometric networks using the data extracted from bibliographic database files. Finally, content analysis was used to analyse the relevant themes involving the selected articles for the review. In content analysis, qualitative data are codified into pre-defined themes for presenting and reporting information (Krippendorff, 2018). Accordingly, each document was coded under the themes that best described the focus of that study.

The systematic literature review results on social-psychological drivers of occupant energy behaviours begin with a bibliographic overview of studies and a conceptual discussion on social-psychological theories applied in occupant energy behaviour-related research. Next, it discusses the main themes identified by the review, including the social-psychological theories and their constructs, the application of social-psychological theories on occupant behaviours, and future research trends and implications.

4.3 Bibliometric overview of studies

4.3.1 Distribution of research based on the publication years and primary source

The systematic review used 79 research articles for social-psychological theories applied to occupant energy behaviour research. Figure 4.2 illustrates these publication outputs over time between 2008 to 2022. The first empirical results on social-psychological theories in occupant energy behaviour were published by Scherbaum et al. (2008), examining the factors related to energy-saving behaviours among employees in a university in the USA applying value belief norm theory (VBN). Since 2008, empirical research has observed a considerable rise, recording the highest of 13 articles in 2019. There is a development trend in applying social-psychological theories in researching occupant energy behaviours. For the past 15 years, behavioural theories have been attracting increasing interest from academic research, and there was an average of 5 articles per year. Given this significant rise in credible researchers' commitment (Malik et al., 2022), the study of applying behavioural theories to explain occupant energy behaviours is expected to continue with an ascendant track.

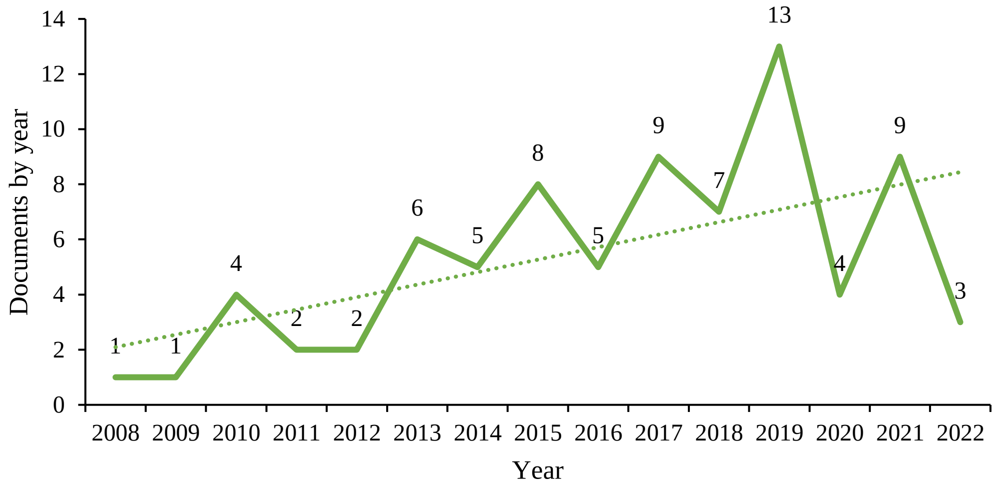


Figure 4.2 Articles over time for social-psychological theories applied to occupant energy behaviours

The analysis of primary sources of publications was extracted from the classifications by Scopus and Web of Science databases. Seventy-nine current review articles appeared in 34 scholarly journals and three international conferences. As given in Table 4.2, 11 journals contain 68% of the articles, while the rest appeared in 22 journals and three conferences. Energy Research and Social Science and Energy and Buildings journals include 25% of the articles selected for the current review and contribute 13 and 7 papers, respectively. Building Research and Information, Journal of Cleaner Production, Building and Environment, and Energy Policy journals contain the second 25% of the selected papers. Also, these articles crossed over more than one disciplinary background, including energy, environmental science, engineering, social science, economics, econometrics & finance, business, management & accounting, psychology, and computer science. The interdisciplinary character of social-psychological drivers of occupant energy behaviours integrates knowledge from multi disciplines. However, 80% of the selected articles were published in journals on the energy, environmental science, engineering, and social science disciplines.

Table 4.2 Journals in which social-psychological and occupant behaviour research has been published

#	Journal	No. of articles	Percentage (%)
1	Energy Research and Social Science	13	16.46
2	Energy and Buildings	8	10.13
3	Building Research and Information	5	6.33
4	Journal of Cleaner Production	5	6.33
5	Building and Environment	4	5.06
6	Energy Policy	4	5.06
7	Applied Energy	3	3.80

8	Ecological Economics	3	3.80
9	Energy Efficiency	3	3.80
10	Journal of Environmental Psychology	3	3.80
11	Resources Conservation and Recycling	3	3.80
	Others	25	31.65
The total of journals		34	
The total of articles reviewed		79	

4.3.2 Research sites analysis

The map in Figure 4.3 represents 25 countries that conducted two or more empirical studies on the influence of social-psychological drivers on occupant energy behaviours. Review articles in the current study were conducted in 25 countries, and two were conducted in a few countries. These two studies were recorded as separate articles. Of the three ranked highest, China (16 articles, 20.25%), the USA (14 articles, 17.72%), and the UK (14 articles, 17.72%), the research of China and the USA have highlighted in empirical studies (Heydarian et al., 2020). The current review includes 42 studies representing Eastern, Northern, Southern, and Western Europe regions, including a significant number of studies from the UK, Netherlands (7 articles, 8.86%), and Germany (6 articles, 7.59%), while more studies from Western Europe (Heydarian et al., 2020). Accordingly, these countries have considerably advanced research in this area.

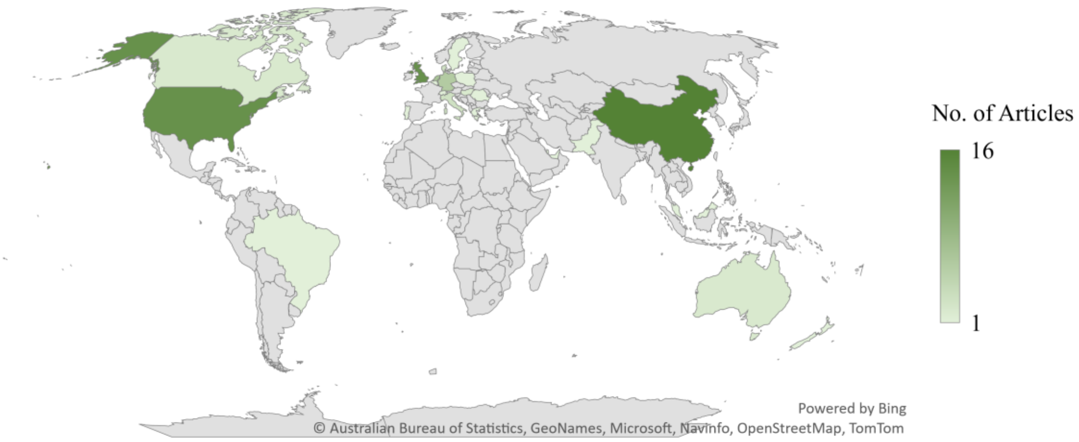


Figure 4.3 Geographical distribution of the selected articles

4.3.3 Co-occurrence analysis

Keyword analysis was performed on the bibliographic data of the selected publications. This is useful for identifying core contents and understanding keywords interconnections of articles. The co-occurrence keywords network mapping of author and index keywords specifies the research clusters within a particular field and visualises the trends in these publications (Abbasi et al., 2022). In VOSviewer, the keyword overlay visualisation map was created based on keyword co-occurrence and link strength. Although 697 keywords were identified, only the keywords with a minimum of five occurrences were extracted for mapping. The top 29 keywords were included in the map after eliminating generic terms (i.e., building). In network visualisation, the circle's size and the keyword's label determine its importance (van Eck & Waltman, 2022). The link between two keywords represents the connection between keywords, and the link strength and the distance between two keywords represent the strength of co-occurrence and their relative co-occurrence, respectively (van Eck & Waltman, 2022).

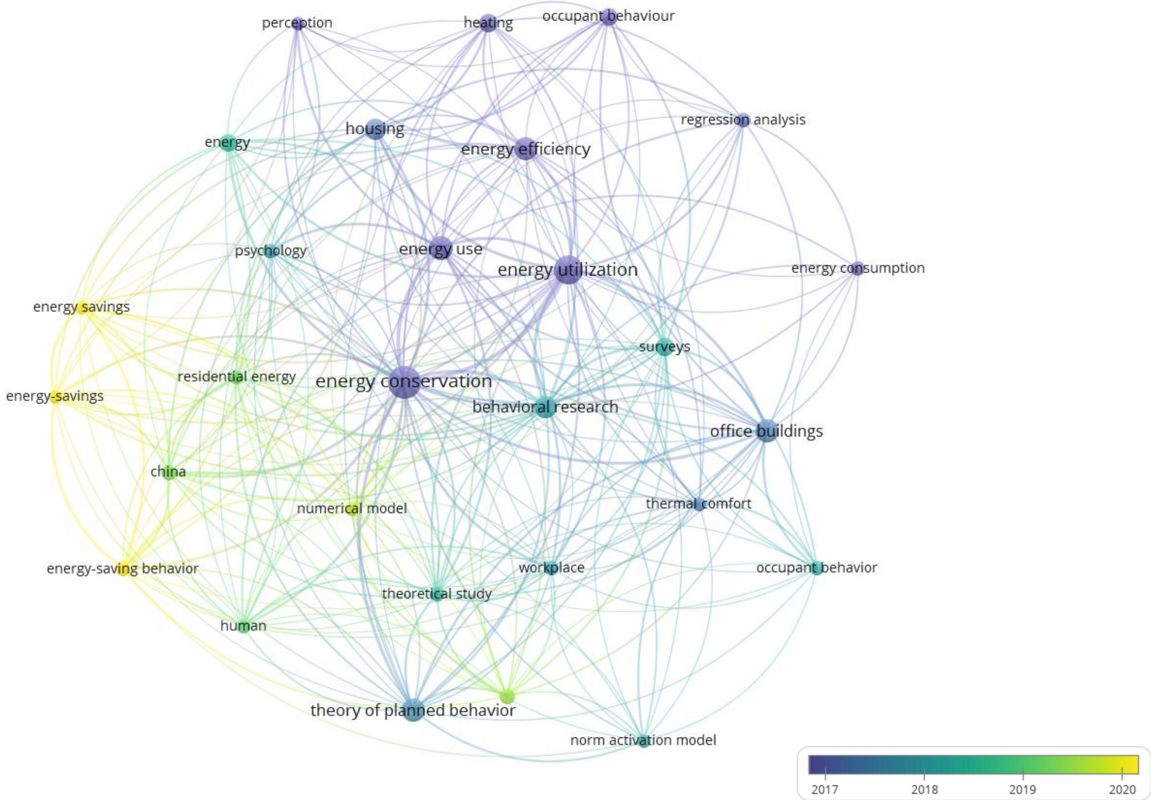


Figure 4.4 Keyword overlay visualisation on co-occurrence

The most frequent keyword with the highest number of total links is energy conservation, with a strength of 117, followed by energy utilisation, energy use, office buildings, theory of planned behaviour, energy efficiency, behavioural research, and housing, indicating the research focused on employing social-psychological theories to explain the occupant behaviours in both office and residential buildings. The colour scale was based on the average year of a keyword that enabled the analysis of trends of publications. A shift in trends of publications focus was observed based on the keyword co-occurrence from 2017 to 2020. Before 2016, the term occupant behaviour has more frequently used, while more recent publications published in 2020 or later use the term energy-saving behaviour. Lately, empirical research has primarily focused on numerically modelling these behaviours. Regarding social-psychological theories, the researchers focused more on the TPB in 2017 or before. Other theories, such as the NAM, appeared more frequently in 2018 or later. Increased awareness of the importance of coupling energy, social-psychological theories, and occupant behaviours is represented by the co-occurrence and strong links between these keywords in more recent publications.

4.3.4 Citation analysis

Citation analysis was used to evaluate the relative importance of the articles in the current review. Suppose an article has been frequently cited in other articles that can be considered an invaluable tool for literature review (Klavans & Boyack, 2017). The network visualisation map of the citations by counting the total article citations and the association with the specific current review articles was created using VOSviewer and illustrated in Figure 4.5. The citation analysis of 79 documents showed that only 61 cited other articles within this citation network or the local citation analysis. Out of 61 articles in the network, 16% have been linked only once. As seen in Figure 4.5, different clusters and the citation link strengths for each cluster are represented in different colours. The most prominent cluster is shown in red colour formed by Ding, Z.H. (2019), Gao, I. (2017), Liu, X. (2020), Liu, X. (2021), and Lo, S.H. (2014). These studies mainly considered the application of TPB on and energy-saving intentions of occupants while engaging in energy behaviours. Another cluster represented in green colour includes studies that focused on other theories like NAM and social practice theory (SPT). Furthermore, Table 4.3 represents the top 10 articles considering the global (the overall citations in the global databases) and local citations.

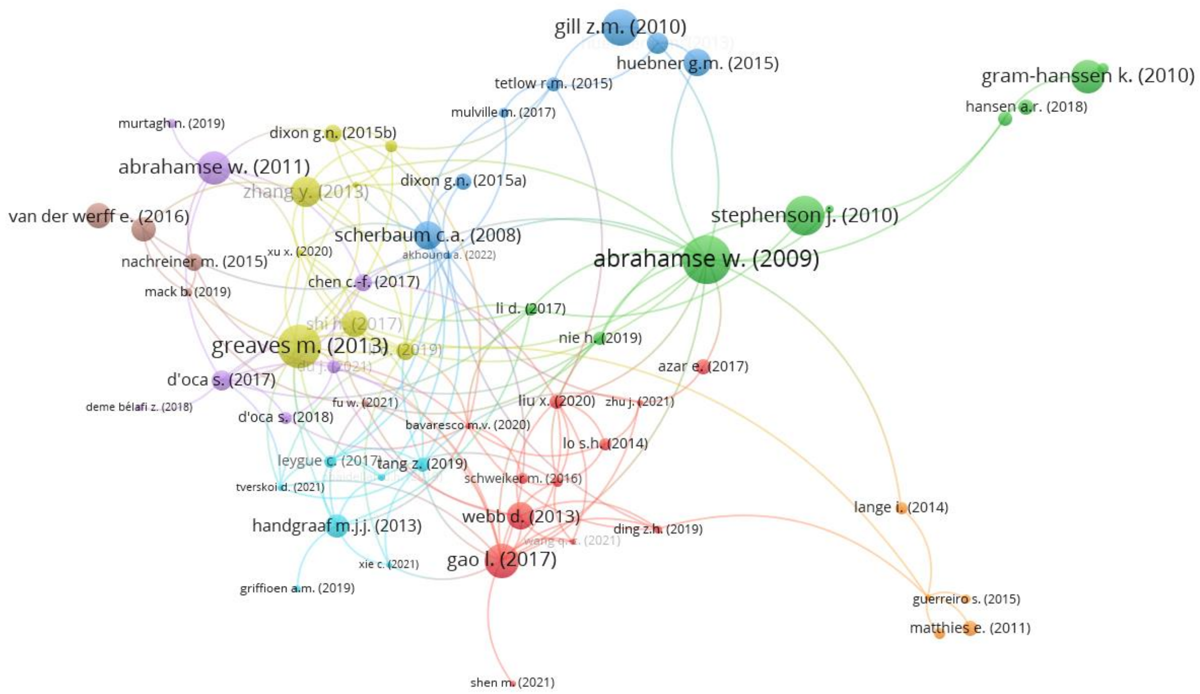


Figure 4.5 Citation network of articles

The variance between global and local citations indicates that social-psychology and occupant behaviour research has also received the attention of other disciplines. As shown in Table 4.3, the order of articles based on global and local citations is different. For example, Stephenson (2010) received the third rank in the global citation but is ranked eighth in the local citation, indicating that this article may receive more attention from research outside the social-psychology and occupant behaviour domain. The possible reason is that Stephenson (2010) has considered consumer energy behaviour. Abrahamse, Greaves, Stephenson, Gill, and Gao authored the most cited papers. However, considering the immediate impact of these publications, Gao (2017) outnumbered the highly cited papers with 50 citations per year, followed by Greaves (2013) with 42 citations per year. Table 4.3 supports the results of the citation network of documents.

Table 4.3 Top 10 articles considering global and local citations

#	Title	First Author	Year	Global Citations	Local Citations	Citations per year
1	"How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings?"	Abrahamse W.	2009	483	15	37
2	"Using the theory of planned behaviour to explore environmental behavioural intentions in the workplace"	Greaves M.	2013	380	12	42

3	"Energy cultures: A framework for understanding energy behaviours"	Stephenson J.	2010	317	4	26
4	"Low-energy dwellings: the contribution of behaviours to actual performance"	Gill Z.M.	2010	277	2	23
5	"Application of the extended theory of planned behaviour to understand individual's energy-saving behaviour in workplaces"	Gao L.	2017	249	14	50
6	"Standby Consumption in Households Analysed With a Practice Theory Approach"	Gram-hanssen K.	2010	233	2	19
7	"Factors Related to Household Energy Use and Intention to Reduce It: The Role of Psychological and Socio-Demographic Variables"	Abrahamse W.	2011	231	7	21
8	"Antecedents of employee electricity saving behaviour in organisations: An empirical study based on norm activation model"	Zhang Y.	2013	192	6	21
9	"Exploring Individual-Level Factors Related to Employee Energy-Conservation Behaviors at Work"	Scherbaum C.A.	2008	171	12	12
10	"Not irrational but habitual: The importance of "behavioural lock-in" in energy consumption"	Maréchal K.	2010	165	0	14

4.3.5 Co-citation analysis

A co-citation analysis indicates the peer recognition of a particular field's concepts, ideas, and methods (Trujillo & Long, 2018). A co-citation network or map represents cited articles (nodes) and the co-occurrence of articles (edges) in the reference list of articles selected for the current review (Aria & Cuccurullo, 2017). Furthermore, the co-citation relationship is represented by lines connecting jointly cited articles, and edge weights represent the frequency of two articles that were jointly cited (Aria & Cuccurullo, 2017). In the current review, the co-citation network was created using VOSviewer, considering the co-cited authors as the unit of analysis with a threshold of 10 citations. The co-citation network is given in Figure 4.6, and 139 authors were selected for the network. The clustering enables identifying research areas, topology, and patterns in a co-citation network (Chakraborty et al., 2021).

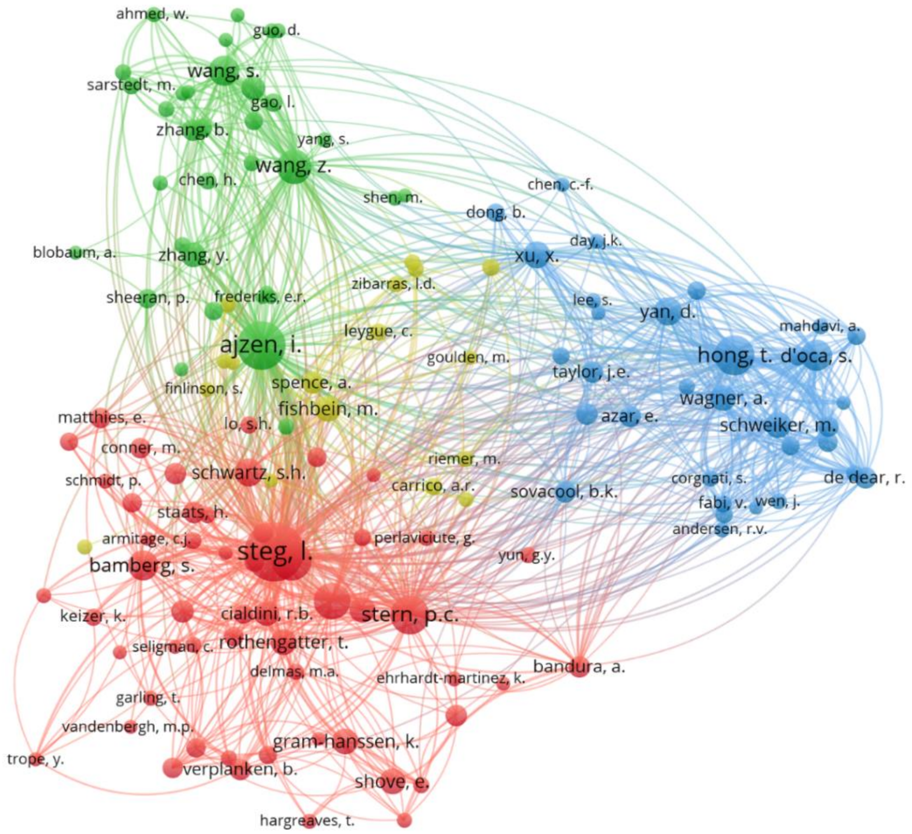


Figure 4.6 Co-citation network of authors relating to occupant behaviour and social-psychology research

As seen in Figure 4.6, different colours in the network represent the research authors with a close association in the same cluster. In the current review, the co-citation network contains four clusters, each with a different number of authors. The cluster with the highest number of authors is indicated in red and comprises 55 articles. The most significant nodes are Steg, L., Ajzen, I., Hong, T., Abrahamse, W., Stern, P.C., Vlek, C., Wang, Z., D'oca, S., Bamberg, S., and Wang, S. These can be considered as the most frequent co-cited authors in occupant behaviour research applying social-psychological theories.

To find out the focus area for each cluster, we have identified the top three papers in Table 4.4, which provides a general description of the research fields relating to each cluster. The table includes the author name, citation count, total link strength, and the specific research fields covered in the cited references. As seen in Table 4.4, the total citation count of the three authors has gradually decreased from clusters 1 to 4. In a closer look, cluster 1 mainly contains authors whose research focused on social and environmental psychology, pro-environmental behaviours, and VBN theory. Furthermore, the citation count of the first author, Steg L., is considerably higher, given the broader coverage of research areas by the particular researcher. Custer two mainly includes authors whose research focused on TPB and its applications. Ajzen I. was the founder of TPB, and his work has been applied in many research fields, including occupants' energy-saving behaviour. The third cluster includes a group of authors who collaborated to standardise contemporary research in occupant energy behaviours by introducing the IEA-EBC annexe series for identifying, analysing, and modelling occupant behaviour impacts on energy consumption and conservation. Cluster 4 highlights the further evolution of research in occupant energy behaviours, connecting authors whose research introduced new concepts and ideas to address social-psychological impacts.

Table 4.4 Highly cited authors in each cluster

Cluster	Author	Citations	Total link strength	Research Field
Cluster 1 (Red)	Steg L.	159	6391	Climate change; energy policy; environmental psychology; pro-environmental behaviour; value belief norm theory
	Abrahamse W.	72	3141	Energy conservation; social and environmental psychology
	Stern P.C.	70	3275	Human environmental interactions; value belief norm theory
Cluster 2 (Green)	Ajzen I.	108	4529	The theory of planned behaviour
	Wang Z.	54	2626	Application of the theory of planned behaviour; carbon emissions; household energy-saving behaviour; urban transportation
	Wang S.	41	1970	Application of the theory of planned behaviour, electric vehicles; household electricity-saving behaviour; non-cognitive and emotional factors
Cluster 3 (Blue)	Hong T.	74	3994	Energy-related occupant behaviour
	D'Oca S.	44	2627	Building physics; social-psychology; human dimensions of energy use
	Yan D.	36	1846	IEA-EBC annexe 66
Cluster 4 (Yellow)	Fishbein M.	32	1409	Behaviour and behaviour change; theory of reasoned action
	Spence A.	22	1195	Climate change; perception studies; psychology; sustainable behaviour
	Carrico A.R.	14	734	Energy conservation; environmental behaviour; feedback; peer education

4.4 Social-psychological theories for occupant behaviour in buildings

Behavioural theories rooted in psychological principles became notable as late as the 1930s, with the hierarchical theory of needs (Maslow, 1943) and the perceptual control theory

(PCT) (Wiener, 1948) being some of the earliest theories. Pro-environmental behaviour was not considered until the 1970s when proposed the NAM (Schwartz, 1977), SCT (Bandura, 1986), TPB (Ajzen, 1991), VBN (Stern et al., 1999), and the theory of environmental behaviour gained considerable attention. Subsequently, these prior theories were applied to occupant energy behaviour-related research and also were extended, and new theories were established, such as DNAS (Yan et al., 2017) and MOA (Li et al., 2019). These social-psychological theories were used to explain the occupant energy behaviours in the selected studies for the current review, and Figure 4.7 illustrates the frequency of 32 theories utilised by the 79 selected studies.

As seen in Figure 4.7, only a few theories were frequently applied in occupant energy behaviour-related studies. Amongst TPB has been applied in numerous studies, followed by NAM, SPT, DNAS, VBN, big five personality traits, SCT, and MOA, respectively. Since these theories were not explicitly developed for occupant energy behaviours in buildings, that may be caused to limit the application of particular theories. These commonly applied theories were reviewed and discussed in the latter part of this section. Such knowledge would allow future research to introduce a holistic framework that incorporates all social-psychological drivers involved in the occupant energy behaviours in buildings.

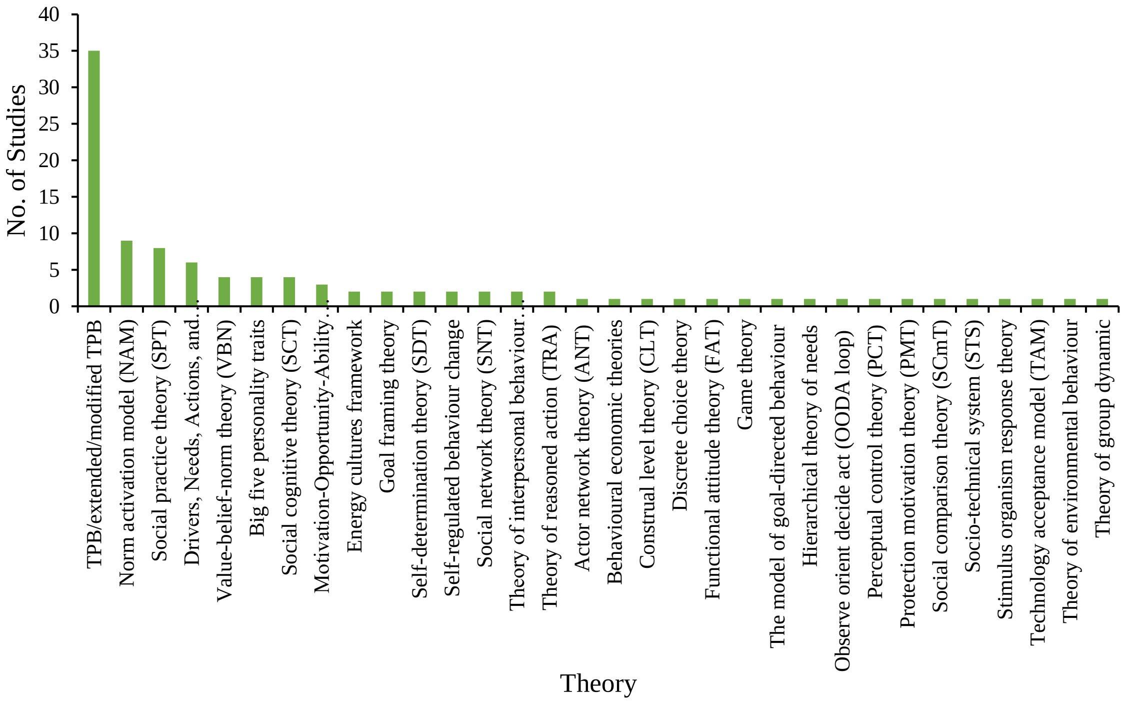


Figure 4.7 Social-psychological theories applied in the selected articles

4.4.1 Theory of planned behaviour (TPB)

The TPB was introduced to describe pro-environmental behaviours associated with energy utilisation through psychological factors (Ajzen, 1991). The theory adopts a cognitive approach to predicting an individual's behaviour intention through attitude towards that behaviour, subjective norm, and PBC (Shi et al., 2017), where it assumes that certain behaviours are based on existing knowledge (Xuan Liu et al., 2021). The TPB, in its original form, has been used for predicting a variety of occupant behaviours: household heat, electrical and water consumption, and energy performance of the building (Gill et al., 2010), intention and behaviours to save household energy (Chen et al., 2017; Liu et al., 2020; Nie et al., 2019) intention to save energy in universities (Dixon et al., 2014, 2015), the intent of occupants switch off lighting and appliances in office buildings when not in use (Lo et al., 2014; Menzes et al., 2012), energy-saving intentions in other entities like hotels and power grids (Wang et al., 2021; Xie et al., 2021) and intents to occupy pro-environmental behaviours like switching of PCs during long breaks and opting for energy-saving practices (Greaves et al., 2013; Shi et al., 2017). The studies also considered extended and modified versions of TPB, adding or removing one or a few psychological constructs. Most of these studies focused on occupants' energy-saving intentions at their workplaces (Akhound et al., 2022; Cibinskiene et al., 2020; Gao et al., 2017; Obaidellah et al., 2019; Tetlow et al., 2015; Xu et al., 2020), incorporating descriptive/injunctive/personal/social norms to TPB mostly. Also, the studies added other constructs such as access to control, awareness, habits, knowledge, motivation, responsibility, and self-efficacy. Another set of studies focused on identifying the residents' energy-saving intentions and behaviours (Ding et al., 2019; Huebner et al., 2013; Huebner et al., 2015; Lange et al., 2014), incorporating norms, habits, and beliefs. For example, occupants' self-reported energy-saving behaviours include wearing more layers instead of turning the heating up (Lange et al., 2014). Another study focused on energy-saving intentions in student dormitories (Du & Pan, 2021b).

In addition to the above two attempts, the literature highlighted that most studies integrated TPB with other theories to determine the impact on occupant energy behaviours. Influence on TPB constructs on adaptive behaviours: HVAC thermostats, windows, lights, and shades/blinds in offices and universities in Europe and the USA were investigated, incorporating the insights from building physics, DNAS ontology, and SCT (Bavaresco et al., 2020; D'Oca et al., 2017; Deme Bélafi & Reith, 2018). In the same context, Li et al.

(2019) and Tverskoi et al. (2021) applied a framework incorporating TPB, NAM, and MOA to analyse the influence of those psychological constructs on energy-saving behaviours relating to lighting, heater, fan, and air conditioning, and thermostat operation. Most recently, Rissetto et al. (2022) incorporated NAM and Self-efficacy theory with TPB to understand the psychological drivers leading to adaptive behaviours and occupants' comfort preferences relating to occupants' fan usage behaviour. Another set of studies focused on residential buildings where household energy consumption and intention to save energy (Abrahamse & Steg, 2009; Fu et al., 2021) and intention to pro-environmental behaviour (Macovei, 2015) were analysed by integrating NAM constructs. Similarly, Abrahamse and Steg (2011) integrated VBN constructs, and Xuan Liu et al. (2021) applied extended TPB based on occupants' Big Five personality traits to investigate household energy-saving intentions and behaviours. Social network theory (SNT) constructs are integrated with TPB to examine low-carbon household behaviours and reduce household carbon emissions (Yin & Shi, 2019). In another study, Zierler et al. (2017) investigated energy use intentions and behaviours by incorporating TIB constructs in an infrastructure case study. The TPB has been used in different forms across different contexts of buildings covering a broader scope of energy-saving behaviours.

4.4.2 Norm activation model (NAM)

A social theory was developed to explain the altruistic behaviours of occupants, which are performed for the benefit of society or the environment, often without self-interest (Schwartz, 1977). NAM constructs: awareness of consequence, the ascription of responsibility, and personal norms are used in predicting energy and pro-environmental behaviours and intention to save energy in residential buildings (Abrahamse & Steg, 2009; Fu et al., 2021; Macovei, 2015; Van Der Werff & Steg, 2015). Regarding non-residential buildings, the empirical studies focused on adaptive energy-saving behaviours relating to lighting, heater, fan, air conditioning, and thermostat operation in office buildings (Li et al., 2019; Rissetto et al., 2022; Tverskoi et al., 2021; Zhang et al., 2013). In another study, a modified NAM model was used to implement communication intervention for energy-saving university buildings in Germany (Matthies et al., 2011). Although NAM has been identified as one of the most influential models for explaining occupants' normative consideration that motivates energy-saving behaviours (Fu et al., 2021; Rissetto et al., 2022; Tverskoi et al., 2021), actual use of NAM was limited compared to the TPB.

4.4.3 Social practice theory (SPT)

Social practices are shaped by how people act in different material and cultural contexts (Schatzki, 1996). The SPT is more effective for understanding individuals' energy consumption behaviours by emphasising routine aspects and habits, material objects, and shared meanings (DellaValle et al., 2018). Therefore, energy consumption is inseparable from these complex social practices (Hansen et al., 2018). Mainly, the SPT has increasingly been applied in understating occupants' energy consumption in residential buildings based on occupants' heating and cooling practices (Gram-Hanssen, 2010; Hansen, 2016; Hansen et al., 2018), shock-ventilation practices (Galvin, 2013); and water heating practices (Hansen, 2016). These studies emphasised the energy consumption of residential buildings due to energy-consuming practices and applied the SPT to analyse the stability of consumer practices and opportunities for change (Gram-Hanssen, 2010; Hansen, 2016). Furthermore, a few of these studies proposed policy interventions and frameworks that improve the energy efficiency of building systems (Galvin, 2013; Hess et al., 2018). For example, Hess et al. (2018) analysed routinised energy consumption behaviours of residential buildings and suggested a framework that reflects individual, social, and material factors. Specifically, the materiality aspects support realising the comfort expectations of the occupants through social practices (Gram-Hanssen, 2010; Hansen et al., 2018). Additionally, the context-specific practices and cognitive biases that occur in domestic retrofit are studied to identify behavioural and social levers that can be used to enhance retrofit efficacy (Chiu et al., 2014; DellaValle et al., 2018). Moreover, implementing various behavioural interventions, including providing feedback on energy consumption, conducting energy-saving workshops, and promoting energy-saving habits through signage and reminders is effective in promoting energy-saving practices in residential buildings (Du & Pan, 2021a).

4.4.4 Drivers, needs, actions, systems (DNAS)

The DNAS framework introduced by IEA-EBC Annex 66 (Yan et al., 2017) is based on building physics and social psychology insights from an international survey investigating occupant behaviours in various buildings and cultures (D'Oca et al., 2017). Applying this framework in the USA and European contexts add insights into subjective aspects that affect occupant behaviours in offices (D'Oca, Pisello, et al., 2018). For example, the DNAS framework integrated with the constructs from TPB, SCT, and building physics was applied in investigating human-building interactions in offices and universities (Bavaresco et al., 2020; D'Oca et al., 2017; D'Oca, Pisello, et al., 2018; Deme Bélafi & Reith, 2018). Their main focus was occupants' HVAC thermostats, windows, lights, and shades/blinds behaviours that affect the energy consumption in buildings. Additionally, a DNAS framework with Semantic Trajectories in Dynamic Environments (STriDE) was developed to map the spatio-temporal movements of occupants (Arslan et al., 2019). In another study, four hot water heating typologies: on-demand, for all eventualities, and just enough, and sunny days were introduced based on the DNAS framework to use in residential buildings (Haines et al., 2019). The DNAS is a recently introduced framework that combines the psychological insights from TPB and SCT and the socio-demographic characteristics of the occupants, while the framework has the potential to combine insights from sociological theories like SPT.

4.4.5 Value belief norm theory (VBN)

The VBN theory proposes that occupants engage in energy-saving and pro-environmental behaviours driven by their values, beliefs, and norms (Stern et al., 1999). For example, occupants will likely show pro-environmental behaviours when feeling morally obliged (Heydarian et al., 2020). The empirical studies applied VBN to investigate households' energy-saving intentions and behaviours (Abrahamse & Steg, 2011), consumer behaviour in terms of electricity usage, laundry and dishwasher usage frequency, percentage of using incandescent bulbs (Hewitt et al., 2016), and use of intelligent energy systems (van der Werff & Steg, 2016). Another study investigated occupants' VBN factors relating to the energy-saving behaviours of university employees (Scherbaum et al., 2008).

4.4.6 Big five personality traits

The Big Five personality theory explains individual personality in five dimensions: extraversion, neuroticism, openness, agreeableness, and conscientiousness, which can describe a person's energy-saving behaviours (Costa Jr & McCrae, 1992; Xuan Liu et al., 2021). The application of this theory was mainly in the residential sector for identifying households' energy-saving intentions and behaviours (Xuan Liu et al., 2021), how practical eco-feedback and energy-saving tips on households (Shen et al., 2022), and a personality-based normative feedback mechanism to optimise household energy-saving behaviours (Shen et al., 2021). In the context of office buildings, three personality traits: neuroticism, extraversion, and openness, were applied to identify adaptive behavioural patterns: window opening, blind closing, use of ceiling fans, clothing adjustments, and thermal sensation and preferences (Schweiker et al., 2016)

4.4.7 Social cognitive theory (SCT)

The SCT explains occupant behaviours as a complex interaction of environmental, personal, and behavioural factors (Bandura, 1986). In other words, occupant behaviours are influenced by their perceived environment, comfort and control factors, personal beliefs, and past behaviours (D'Oca et al., 2017). The SCT constructs like knowledge and group dynamics were integrated with the DNAS framework to study the adaptive behaviours of occupants in office buildings (D'Oca et al., 2017; D'Oca, Pisello, et al., 2018; Deme Bélafi & Reith, 2018). In another context, Cornelius et al. (2014) applied SCT constructs: perceived self-efficacy and knowledge about behaviours to investigate high school energy-saving behaviours, such as switching off appliances when not in use. Although Bandura (1986) introduced six factors, namely reciprocal determinism, behavioural capability, observational learning, reinforcements, expectations, and self-efficacy, only a few factors have been used to investigate energy-saving behaviours.

4.4.8 Motivation, opportunity, ability (MOA)

The MOA theory originated three decades ago when it was initially used for understanding consumer behaviour dealing with data related to purchasing products (MacInnis et al., 1991). Recently, Li et al. (2017) adopted the theory identifying the effect of psychological factors on occupant energy behaviours. Accordingly, the authors developed a conceptual framework for investigating occupants' motivation, opportunity, and ability to energy-saving behaviours and estimating the implications of these interventions. According to the authors, occupants' perceptions of their energy consumption and behaviours to save energy are measured by motivation (M). This measure contains attitude, personal norms, the ascription of responsibility, and the awareness of the consequences of saving energy (Li et al., 2019). Another factor, opportunity (O), assesses their approachability to energy conservation-related information and environmental and personal drivers prompting energy-saving intentions. The opportunity component consists of subjective norm, descriptive norm, organisation support, accessibility to control, and time availability (Li et al., 2019). Occupants' interpretations of the information relating to their energy-saving behaviours, considering the prior knowledge of energy impacts and consequences, are measured using the ability (A) factor. The ability component comprises building occupants' PBC, perceived knowledge, and actual knowledge (Li et al., 2017). Subsequently, the MOA was adopted in studies by Li et al. (2019) and Tverskoi et al. (2021); however, further research is required to validate the performance of MOA for energy behaviours precisely to understand the behavioural intention of occupants.

4.5 The influence of social-psychological drivers on occupant energy behaviours

In this section, the influence of social-psychological drivers on occupant energy behaviours is summarised under the mainstream behaviours based on the focus of most studies. The main behaviours identified are lighting on/off, equipment and appliance usage, adjusting heating and cooling thermostats, adjusting computers/monitors, and opening/closing windows.

4.5.1 Lighting behaviour

Several studies (Abrahamse & Steg, 2009; Lazowski et al., 2018; Webb et al., 2013) have found that subjective norms significantly influence occupants' lighting behaviour. The subjective norms refer to the perceived social pressure on individuals from peers or colleagues when performing any behaviour (Gao et al., 2017; Li et al., 2019). Similarly, the researchers generally use the term "social norms" to explain subjective norms or the individuals' perception of people significant to them, and that guide their intention to behave in a certain way based on the viewpoint of those significant to them in a specific environment (Akhound et al., 2022; Azar & Al Ansari, 2017). In general, the occupants tend to base their behavioural intention to save energy upon the perceptions and approval of other occupants (Gao et al., 2017; Li et al., 2019). For example, occupants tend to adjust their lighting behaviour to conform to the perceived norm of the social group they belong to. The influence of peers and social feedback can also affect occupants' lighting behaviour (Abrahamse & Steg, 2009; Lazowski et al., 2018; Webb et al., 2013).

The studies by Gerhardsson et al. (2018) and Matthies et al. (2011) suggest that the PBC over the lighting system can significantly impact occupants' lighting behaviour. Similarly, the occupants tend to perceive higher ease of sharing control over lighting adjustments (Bavaresco et al., 2020; D'Oca et al., 2017; D'Oca, Pisello, et al., 2018). For instance, when occupants feel they have control over the lighting system, they are more likely to adjust the lighting to suit their preferences and needs (Gerhardsson et al., 2018). Consequently, the occupants were generally dissatisfied with the shared control of the adjusting lighting (Deme Bélafi & Reith, 2018). Also, it was identified that PBC has no significant effect on occupants' careful-use behaviours of lighting (Nie et al., 2019). For example, the study by Menzes et al. (2012) demonstrated a statistically significant negative correlation between PBC and energy use of lighting, which further showed that lack of PBC accounted for variations of 17% in electricity usage.

The studies also found that attitudes affect significantly and positively the intention to share the control of artificial lighting (Bavaresco et al., 2020; D'Oca et al., 2017; D'Oca, Pisello, et al., 2018). Another set of studies highlighted that attitudes strengthened occupants' intention to engage in energy-saving behaviours in lighting (Chen et al., 2017; Cornelius et al., 2014; Du & Pan, 2021b; Liu et al., 2020; Xuan Liu et al., 2021; Xu et al., 2020). However, evidence suggests that attitude often negatively affects energy-saving behaviours. For example, Abrahamse and Steg (2009) and Abrahamse and Steg (2011) explained variance in energy savings relating to lighting only to some extent by using attitude as a predictor.

Another set of studies (Dixon et al., 2015; Menzes et al., 2012; Obaidellah et al., 2019) showed that occupants' knowledge and awareness about the environmental impact of their lighting behaviour could influence their behaviour. When occupants know the energy-saving benefits of using less lighting, they reduce their lighting usage.

In summary, the studies reviewed here suggest that subjective norms, PBC, attitude, and knowledge and awareness are significant drivers of occupants' lighting behaviour. These findings have important implications for designing and managing lighting systems in buildings. By understanding the social-psychological factors that influence occupants' lighting behaviour, building managers and designers can develop strategies that encourage energy-efficient lighting behaviour and reduce energy waste.

4.5.2 Equipment and appliances

Most studies suggest that attitude and perception of energy use significantly affect occupants' equipment and appliance usage behaviour (Abrahamse & Steg, 2009; Cornelius et al., 2014; Hess et al., 2018; Mulville, 2017; Van Der Werff & Steg, 2015). For example, Abrahamse and Steg (2009) conducted a study on the energy use behaviour of Dutch households and found that attitudes significantly influenced energy use behaviour. Similarly, Hess et al. (2018) studied the energy consumption behaviour of households in the US and found that attitudes towards energy conservation are a significant predictor of energy conservation behaviour. In another study, Mulville et al. (2017) explored the factors influencing energy consumption behaviour in UK households and found that attitudes towards energy conservation are a crucial determinant of energy consumption behaviour. The issues related to powering down equipment during the day and overnight and the use of small electronic devices were discussed in their study. Personal values and beliefs can also influence occupants' equipment and appliance usage behaviour (Haines et al., 2019; Zhu et al., 2021).

Social norms significantly influence occupants' equipment and appliance usage behaviour (Abrahamse & Steg, 2009; DellaValle et al., 2018; Guerreiro et al., 2015; Handgraaf et al., 2013; Tetlow et al., 2015). For instance, Abrahamse and Steg (2009) found that social norms are the strongest predictor of energy-saving behaviour. Similarly, DellaValle et al. (2018) conducted a study on energy conservation behaviour in Italian households and also pointed out the significant influence of social norms on energy conservation behaviour. In another study, Guerreiro et al. (2015) studied the influence of personal norms on energy consumption behaviour in Portuguese households and found that perceived descriptive and injunctive norms had a significant impact on energy conservation behaviour. On a similar note, Handgraaf et al. (2013) and Tetlow et al. (2015) highlighted the significant influence of social norms in the contexts of Netherlands and UK households.

Studies indicate that behavioural interventions or providing feedback and information to occupants about their energy use can significantly impact their equipment and appliance usage behaviour (Abrahamse & Steg, 2011; Fu et al., 2021; Hewitt et al., 2016; Scherbaum et al., 2008). For example, a study by Abrahamse and Steg (2011) found that providing feedback on energy use through smart meters led to significant household energy consumption reductions. Similarly, Hewitt et al. (2016) found that providing personalised energy feedback and tips to university students reduced energy use in their dormitories. Another study by Scherbaum et al. (2008) found that providing energy-saving tips and real-time feedback on energy consumption led to significant reductions in energy use in office buildings. More recently, Fu et al. (2021) found that providing real-time feedback on energy consumption and personalised recommendations for energy-saving behaviours led to significant reductions in energy use among hotel guests. Overall, these studies suggest that attitude, social norms, and behavioural interventions are significant determinants of occupants' equipment and appliance usage behaviour.

4.5.3 Heating/cooling thermostat

Several studies found that occupants' thermostat behaviour is influenced by the perceived social norms of the building or household, as well as the actions of others. This includes the influence of building managers, family members, and neighbours (Abrahamse & Steg, 2009; Azar & Al Ansari, 2017; Bavaresco et al., 2020; Ding et al., 2019; Hansen et al., 2018; Liu et al., 2020; Yin & Shi, 2019). For example, it was found that occupants in a university building were more likely to adjust the thermostat to a comfortable temperature if they believed that others in the building were doing the same (Abrahamse & Steg, 2009; Ding et al., 2019). Similarly, Liu et al. (2020) and Yin and Shi (2019) highlighted the same observations regarding office and residential buildings in China, respectively. Azar and Al Ansari (2017) also found that social norms can vary across different cultural groups. Their study found different perceptions of the appropriate temperature range among different cultural groups of students.

The sense of control and autonomy over the heating/cooling system has been found to be a significant predictor of occupants' thermostat behaviour (Chen et al., 2017; D'Oca, Pisello, et al., 2018; Langevin et al., 2016; Murtagh et al., 2019; Zhang et al., 2013). This includes the ability to adjust the thermostat settings and the satisfaction with the temperature achieved. For instance, Chen et al. (2017) found that occupants in a university building were more likely to use the thermostat to regulate the temperature if they had control over it. In their study, occupants who had access to a programmable thermostat were more likely to use it to set the temperature according to their preference than those with a fixed thermostat. Similarly, D'Oca et al. (2018) found the same relating to occupants in a residential building. Langevin et al. (2016) conducted a study in a university building and found that occupants who had access to a web-based control system were more likely to use the thermostat to adjust the temperature than those who did not have access to the system. Murtagh et al. (2019) conducted a study in a residential building and found that providing occupants with a wireless thermostat control system could lead to significant energy savings.

Finally, Zhang et al. (2013) found that providing occupants with control over the temperature and ventilation in their office space could lead to higher occupant satisfaction and productivity.

The environmental attitudes and values of occupants can influence their thermostat behaviour, including their willingness to reduce energy consumption and adopt sustainable behaviour (Deme Bélafi & Reith, 2018; Maréchal, 2010; Yin & Shi, 2019). For instance, Deme Bélafi and Reith (2018) found that more environmentally conscious people tend to set their thermostats at lower temperatures during the winter months, thereby reducing energy consumption. Similarly, Marechal (2010) conducted a study to investigate the impact of personal values on energy consumption behaviour. In a more recent study, Yin and Shi (2019) examined the influence of environmental attitudes on energy-saving behaviour in the context of smart homes. These studies found that people who held more positive attitudes towards the environment were more likely to adopt energy-saving behaviours, such as reducing heating and cooling use and adjusting their thermostats based on their daily routines.

Providing occupants with information about their energy consumption and feedback on their thermostat behaviour has influenced their energy-saving behaviour (D'Oca et al., 2017; Du & Pan, 2021b; Lazowski et al., 2018; Li et al., 2019; Tverskoi et al., 2021). For example, D'Oca et al. (2017) and Lazowski et al. (2018) found that providing residents with real-time feedback on their energy consumption and thermostat behaviour significantly reduced energy use and improved comfort levels. In another study, Li et al. (2019) investigated the effectiveness of a smart thermostat system that gave occupants feedback on their energy consumption and allowed them to control their thermostats remotely. The study found that the smart thermostat system reduced energy consumption and increased occupant satisfaction. Recently, Tverskoi et al. (2021) investigated the effectiveness of providing occupants with personalised feedback on their thermostat behaviour. Overall, the studies suggest that social-psychological drivers such as social norms, PBC, attitudes, and behavioural interventions are essential in shaping occupants' heating/cooling thermostat behaviour.

4.5.4 Computer/monitors

Several studies, including Azar and Al Ansari (2017) and Lo et al. (2014), have found that attitudes and perceptions towards energy consumption and sustainability can significantly impact computer/monitor usage behaviour. For example, people who perceive themselves as environmentally conscious are likelier to turn off their computer/monitor when not in use. Giving occupants feedback and information about their energy use can also influence their computer/monitor usage behaviour. Studies by Greaves et al. (2013) and Tetlow et al. (2015) found that feedback on energy consumption can lead to decreased energy use.

Social norms can also play a role in computer/monitor usage behaviour, as demonstrated in studies by Cibinskiene et al. (2020) and Matthies et al. (2011). For example, people are likelier to turn off their computer/monitor when they see others doing the same. Occupants' habits are another factor that affects computer/monitor usage behaviour. Studies by Dixon et al. (2014) and Liu et al. (2021) found that people are likelier to turn off their computer/monitor when it is easy to do so and when they have formed the habit of doing so. Additionally, empowering occupants to control their energy use can influence their computer/monitor usage behaviour. Studies by Macovei (2015) and Xie et al. (2021) found that giving occupants control over their energy use through technology can lead to decreased energy use. Overall, these studies demonstrate that social-psychological drivers such as attitudes, behavioural interventions, social norms, habits, and PBC can significantly influence occupants' behaviour in relation to their computer/monitor usage.

4.5.5 Windows

Personal norms, such as the desire to save energy or reduce carbon emissions, significantly predict window behaviour (Bavaresco et al., 2020; Hansen et al., 2018; Matthies et al., 2011; Schweiker et al., 2016). For instance, Bavaresco et al. (2020) surveyed window behaviour in residential buildings in Brazil and found that personal norms regarding the environment were a significant predictor of the use of natural ventilation through windows. Furthermore, Bavaresco et al. (2020) and Schweiker et al. (2016) found that people more environmentally concerned were more likely to use blinds or curtains to control the amount of sunlight entering the room. Similarly, Hansen et al. (2018) conducted a field study on office workers in Norway and found that people who were more environmentally concerned were more likely to prefer natural ventilation over mechanical ventilation systems. In another study, Matthies et al. (2011) conducted a survey on window behaviour in Germany and raised the effects of persona norms on the use of shading devices such as blinds or curtains and found that people who were more environmentally concerned were more likely to keep windows closed when heating or cooling systems were in use.

Social norms, such as the behaviour of others in the same space, were found to have a significant influence on occupants' window behaviour (Du & Pan, 2021b; Gill et al., 2010; Nie et al., 2019). For example, Du and Pan (2021) conducted a field study on university classrooms in China and found that social norms, such as the behaviour of peers, were significant predictors of window behaviour. They found that students were probable to open or close windows if they observed their peers doing the same. Similarly, Gill et al. (2010) surveyed office workers in the UK and found that social norms, such as organisational culture, were significant predictors of window behaviour. They found that people were probable to open or close windows if they perceived that it was the norm among their colleagues or if it was encouraged by the organisation's policies. In another study, Nie et al. (2019) conducted a field study on office buildings in China and found that social norms, such as the perception of building occupants, were significant predictors of window behaviour. They found that people were more likely to use natural ventilation through windows if they believed it was the norm among their colleagues and if they perceived it was beneficial for their health and comfort.

The use of advanced technologies, such as smart windows or automated shading systems, may have the potential to influence occupants' window behaviour by enabling PBC (Zhang et al., 2013; Zhu et al., 2021). For example, Zhang et al. (2013) investigated the impact of smart windows on occupants' thermal comfort and window-opening behaviour in a naturally ventilated office building. The smart windows were designed to adjust their tint automatically based on the sunlight and heat entering the building. The study found that occupants were more likely to keep the windows closed when the smart windows were installed, as the windows helped regulate the temperature and glare levels in the building. The study also found that smart windows effectively maintained thermal comfort for the occupants, reducing the need for artificial cooling or heating. Similarly, Zhu et al. (2021) studied automated shading systems in residential buildings. The study investigated the impact of different shading systems (such as Venetian blinds and roller shades) on occupants' visual comfort and window-opening behaviour. The automated shading systems were designed to adjust themselves based on the position of the sun and the occupants' preferences. The study found that occupants were more likely to keep the windows closed when the shading systems were installed, as the systems helped reduce glare and heat gain. The study also found that the shading systems improved visual comfort for the occupants and reduced the need for artificial lighting.

Overall, the findings suggest that personal norms, social norms, and PBC play an important role in shaping occupants' window behaviour and that understanding these factors is essential for promoting sustainable and energy-efficient building design and operation.

4.6 Discussion and Conclusion

The systematic review analysed 79 research articles on social-psychological theories applied to occupant energy behaviour research. The analysis was based on publication years, primary sources, research sites, co-occurrence, and citation analysis. The results show that there has been a considerable increase in empirical research on social-psychological theories in occupant energy behaviour since 2008, with an average of five articles per year. The primary sources of publications were Scopus and Web of Science databases, and the interdisciplinary character of social-psychological drivers of occupant energy behaviours integrates knowledge from multiple disciplines. The research site analysis shows that China, the USA, and the UK have conducted the most empirical studies on the influence of social-psychological drivers on occupant energy behaviours. In addition, the co-occurrence analysis shows that the research has focused on employing social-psychological theories to explain occupant behaviours in both office and residential buildings. Behavioural theories have been attracting increasing interest from academic research, which is expected to continue with an upward trajectory.

However, only a few theories, such as the TPB, have been frequently applied in occupant energy behaviour-related studies. Most studies have incorporated TPB with other theories to determine the impact on occupant energy behaviours. The social-psychological factors that influence occupant energy behaviours are complex and multifaceted. The main behaviours identified in the literature review are lighting on/off, equipment and appliance usage, adjusting heating and cooling thermostats, adjusting computers/monitors, and opening/closing windows. The studies reviewed suggest that subjective norms, PBC, personal norms, attitudes, behavioural interventions, and knowledge and awareness are all significant drivers of occupants' behaviours. Building managers and designers can leverage these findings to develop strategies that encourage energy-efficient behaviour in occupants.

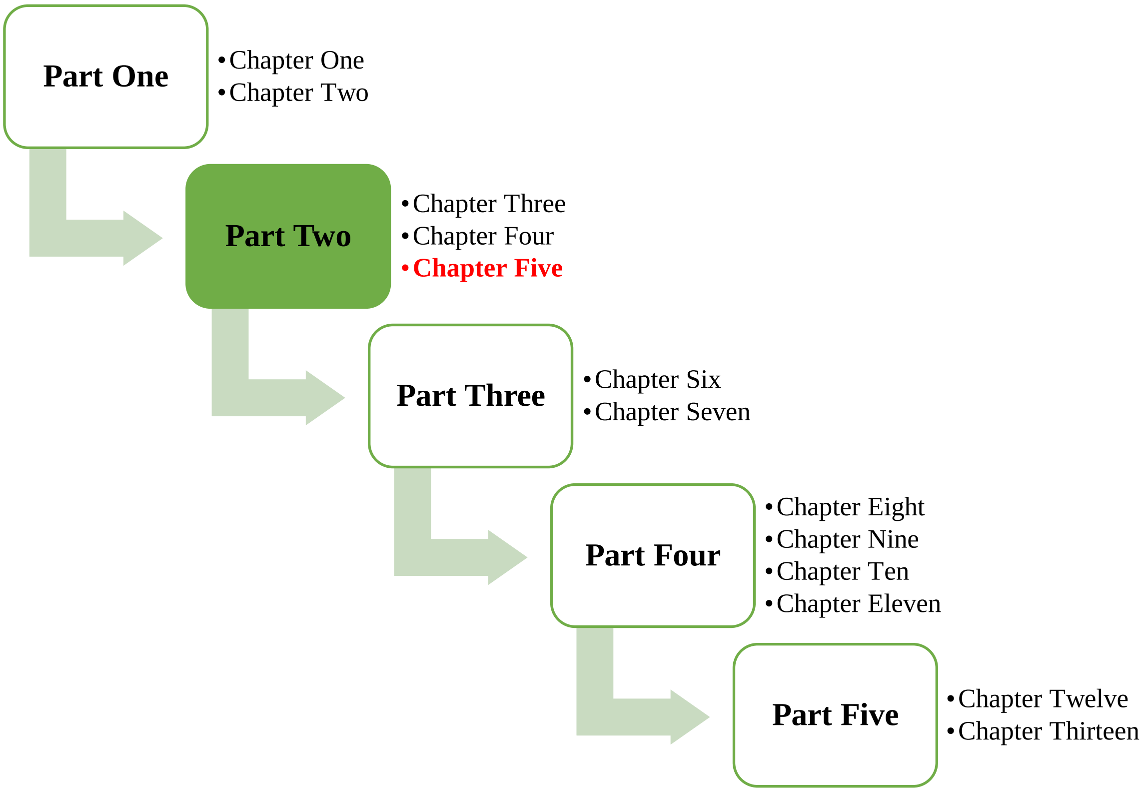
In conclusion, this systematic review highlights the increasing empirical research on social-psychological theories in occupant energy behaviour since 2008 and the need for a holistic framework that incorporates all social-psychological drivers involved in occupant energy behaviours in buildings. The research indicates that social-psychological factors play a significant role in shaping occupants' behaviour towards energy use concerning lighting on/off, equipment and appliances usage, adjusting heating and cooling thermostats, adjusting computers/monitors, and opening/closing windows, and both internal and external factors can influence occupants' behaviour. The article emphasises the importance of understanding these factors to develop effective strategies for promoting energy-efficient behaviour. It calls for future research to focus on identifying the most effective strategies, evaluating their impact on energy consumption, and examining the long-term effectiveness of these strategies.

4.6.1 Future research trends and implications

Future research trends could include more interdisciplinary research to understand better the complex interplay between social-psychological drivers and occupant energy behaviour. Future research could also develop new models and theories to explain occupant energy behaviour, considering contextual factors such as building type, climate, and culture. The co-occurrence analysis reveals a shift in research trends towards numerically modelling occupant behaviours. Future research could also examine the effectiveness of interventions to promote energy-saving behaviours and explore the role of technology in influencing occupant energy behaviour. The findings of this systematic review have implications for policymakers, building owners, and designers, who can use the knowledge created to promote energy-efficient buildings and behaviours.

The implications of this article are significant, as they suggest that building designers and managers should consider not only the physical aspects of a building but also the social-psychological factors that influence occupants' energy behaviours. By understanding these factors, designers and managers can create more effective interventions to promote sustainable behaviour in buildings. For example, they could use different strategies to influence attitudes, social norms, and PBC to encourage occupants to adopt more energy-efficient behaviours. They should also give occupants feedback and information on their energy use to encourage energy conservation. The use of advanced technologies that enable PBC, such as smart windows or automated shading systems, can also effectively influence occupants' behaviour towards energy use.

Additionally, future research trends should focus on exploring the potential of emerging technologies, such as artificial intelligence and machine learning, in predicting and influencing occupant energy behaviour. These technologies could provide occupants with more personalised and real-time feedback, helping them make more informed decisions about their energy use. Additionally, the research could investigate the impact of cultural differences on occupant energy behaviour and explore the potential of cultural sensitivity interventions in promoting sustainable behaviour in different contexts.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5.0 A dilemma between building indoor environment preferences and occupant energy behaviours

Abstract

Often, building occupants compromise the energy savings of the building when they modulate their comfort through occupant behaviours. Therefore, this study identifies the relationships among indoor environmental conditions, comfort preferences, and occupant behaviours to improve future energy modelling works on occupant behaviour in buildings. A self-administered online questionnaire survey was conducted using a purposive sample of 46 occupants selected from five educational office buildings. Results show that the occupants' satisfaction with IEQ, user-centred building controls, and furniture arrangements across the three office types: private, shared, and open-plan offices have a similar value except for thermal comfort in winter or summer, ventilation in winter, acoustic comfort, and access to lighting control. The results also show the relationships of 17 occupant behaviours with 15 comfort preferences, highlighting that occupants were highly concerned about satisfying individual IAQ and thermal comforts through their behaviours rather than saving energy and following management guidelines. Furthermore, IAQ and control over thermal and IAQ-related parameters such as heating, cooling, and ventilation are highly correlated with occupant behaviours, and these could be considered primary predictors of occupant energy behaviours. These relationships of IEQ and user-centred building controls with occupant behaviours could be utilised to enhance future occupant energy behaviour modelling approaches and pinpoint the wasteful energy behaviours.[3]

[3] This chapter is based on the following published conference paper:

Weerasinghe, A.S., Rasheed, E.O. and Rotimi, J.O.B. (2021). A Dilemma Between Building Indoor Environment Preferences and Occupant Energy Behaviours. In: L. Scott & C. J. Neilson (Eds.) Proceedings of the 37th Annual ARCOM Conference (pp. 794-803), Association of Researchers in Construction Management.

5.1 Introduction

With rapid urbanisation and industrialisation, most people spend 90% or more of their time indoors and in confined spaces, including living, learning, working, and travelling (Abdulaali et al., 2020). Therefore, indoor environments significantly affect building occupants' health, well-being, satisfaction, and performance (Wong et al., 2018). In recent years, many studies have investigated the IEQ of buildings regarding occupant satisfaction in comfort and productivity (Rasheed et al., 2019). Critical factors of IEQ are derived through those studies and include thermal comfort, IAQ, visual comfort, acoustic quality, and spatial comfort (Bluyssen, 2019).

Usually, humans' unconscious and conscious actions to control the physical parameters of the surrounding built environment to their preferences are possible when they are uncomfortable and trying to create a comfortable indoor environment (Nicol & Humphreys, 2002). Schweiker (2010) defined that these unconscious and conscious actions refer to occupant energy behaviour, where the occupants try to achieve the desired personal comfort level using various strategies. Building occupants influence the indoor environment through their presence and by modifying the building's systems and elements (Bluyssen, 2019), such as opening and closing windows, adjusting blinds, adjusting thermostat temperature, and turning the air conditioning on or off (Hong et al., 2017). The research by Fabi et al. (2012) and Hong et al. (2017) showed that occupant behaviours highly influence the increase in building energy demand. The contribution of occupant behaviours is exceptionally significant as the difference between predicted and actual energy use is mainly due to how occupants behave, their presence, and occupancy levels in buildings (Gaetani et al., 2016). The reliability of simulation results depends on the quality of the assessment of occupants' influence on buildings (Royapoor & Roskilly, 2015). Therefore, the occupants should not compromise the energy-savings of the building when they modulate their comfort.

Driven by these, it is believed that the design and control of indoor environmental conditions, occupant comfort preferences, and occupant energy behaviours are interconnected. A proper balance between those aspects is significant to reduce the energy wastage due to occupants while realising the energy-saving potentials of occupants. However, the focus on empirical studies is still limited to IEQ parameters such as thermal, IAQ, visual, and acoustics and their influence on occupant energy behaviours. For example, a study by Amasyali and El-Gohary (2016) highlighted the association between occupant behaviours and the building occupants' satisfaction level. Another study by Bavaresco et al. (2021) has connected the primary sources of discomfort to windows, blinds/shades, thermostats, and lighting in office settings. Their study only addressed triggers such as temperature, air, light, view, noise, and access to the thermostat as driving factors of occupant behaviours.

However, review studies often suggest other indoor environmental factors, such as furnishings, the spatial layout of workspaces, and the access for controlling heating, cooling, lighting, and others, as necessary (Fabi et al., 2012; Weerasinghe et al., 2020). For example, shared work areas and open-plan workstations also show a more significant impact on occupants due to the unwanted noise, disturbances, lack of storage space, privacy, and no control over the indoor environmental conditions (McElroy & Morrow, 2010; Mesthrige & Chiang, 2019). Onyeizu (2014) identified that occupants who have control over the temperature were highly satisfied with the thermal comfort of the space. To this end, occupant behaviours and comfort preferences in different types of offices may further be expanded by integrating indoor environmental conditions: thermal, IAQ, visual, acoustics, spatial comforts, and user-centred designs such as access to control indoor environmental parameters.

In New Zealand, studies on office environments indicated that the occupants prefer air-conditioned spaces over naturally ventilated spaces to fulfil their thermal comfort preferences (Rasheed et al., 2017) and acoustic improvements in office design to reach their perceived comfort level. However, the relationship among indoor environmental conditions, comfort preferences, and occupant behaviours are merely addressed in the context of New Zealand. Driven by this motive, this study explores the existing indoor environmental conditions, including IEQ, user-centred designs and furniture arrangements, and the occupants' satisfaction with these conditions. The paper also explores the prominent occupant energy behaviours and the occupant comfort preferences of office buildings in New Zealand. More importantly, the study compares the occupant's satisfaction with the indoor environment across different workplace arrangements, such as private rooms, shared rooms, and open-plan offices, and the relationship of occupant behaviours with indoor environmental conditions.

5.2 Methods

Often, quantitative methods such as surveys and questionnaires have been used to understand occupants and their energy-related behaviours and construct building energy models (Day & O'Brien, 2017). Moreover, Hong et al. (2017) showed that the survey method could provide more insights into occupant behaviours than experiments and field observations regarding various factors that drive behaviours. The current study used a survey method to explore the occupant's satisfaction with indoor environmental conditions, prominent occupant energy behaviours, and occupant preferences across different working arrangements. An online questionnaire was designed and administered through Qualtrics Survey software. This is a popular data collection platform used in contemporary research studies. The questionnaire consisted of four sections. Section 1 included occupants' background information, such as the job role, gender, occupancy period of the current workspace, and the characteristics of the workspace. In section 2, participants were asked to mention the office type that workstations are arranged in the building. Section 3 consisted of questions related to occupants' satisfaction, and they were asked to rate their satisfaction in terms of thermal comfort and ventilation in summer and winter, visual comfort and acoustic comfort, user-centred designs, and furniture arrangement. Section 4 focused on occupant behaviours and comfort preferences. All measures related to satisfaction were estimated by a Likert-type item of 1-7 (completely dissatisfied, mostly dissatisfied, somewhat dissatisfied, neither satisfied nor dissatisfied, somewhat satisfied, primarily satisfied, completely satisfied). The participants for the survey were purposively recruited from the university staff and PhD students regularly occupying office spaces from five buildings in a University in New Zealand. Emails were sent to 257 potential respondents inviting them to complete the survey. Forty-six valid responses from building occupants in office spaces were collected. Likert-type items have a clear rank order without an even distribution. Therefore, the data generated from these types of questions are considered ordinal data with a non-normal distribution of data (Guerra et al., 2016). Therefore, frequency analysis and Spearman rank correlation were used to analyse the data. The SPSS version 27 was used to conduct these analyses.

Cronbach's alpha reliability analysis was conducted to test the instrument's internal consistency, which shows how well the survey measures what the study wants to measure. The current study applied it to satisfaction with indoor environmental conditions such as

IEQ, user-centred designs, and furniture arrangements. Reviewing empirical studies, Taber (2018) explained that alpha reaching 0.70 is a sufficient internal consistency measure. The overall Cronbach's alpha value for the current occupant survey is 0.716, which shows an acceptable level of reliability for 13 constructs of this study.

5.3 Results and Discussion

5.3.1 Demographic information of participants

Five buildings in a University were selected for the current study that available office spaces for the staff and PhD students regularly occupying the buildings. The number of occupants in the buildings ranged between 12 to 96 and was occupied mainly by staff. The demographic information of participants is presented in Table 1. There were more males than females in the selected sample. Most participants had worked in their present work area for a year or more than a year. Furthermore, most participants were in shared offices that accommodated two to five people, and staff and students occupied the three types of office spaces; private room, shared, and open-plan. The current study compares occupant satisfaction levels and the practice of occupant behaviours across diverse workplace arrangements such as private rooms, shared rooms, and open-plan offices.

Table 5.1 Demographic information of participants

Demographic info		Staff	Students	Total
Gender	Male	12	13	25
	Female	16	5	21
Years in the present work area	Less than a year	11	10	21
	A year or more	17	8	25
Office type	Private Room	13	5	18
	Shared Space	12	8	20
	Open-plan Office	3	5	8
Location of workstation	Close to a window within 5 feet	23	11	34
	Centre of the office	2	2	4
	Close to an exterior wall within 5 feet	3	5	8

5.3.2 Occupants' satisfaction with IEQ across private, shared, and open-plan offices

Discomforts in IEQ and access to user control can be considered drivers of occupant behaviours. Therefore, building occupants were asked to rate their satisfaction with thermal comfort and ventilation in summer and winter, visual comfort and acoustic comfort, user control availability on heating, cooling, ventilation, lighting, and noise, and arrangement of workstation furniture and equipment (i.e. desk, chair, footrest, telephone, document holder and printer, etc.). The percentage of frequency values of occupant satisfaction with IEQ, user-centred building controls, and furniture arrangement is shown in Figure 5.1.

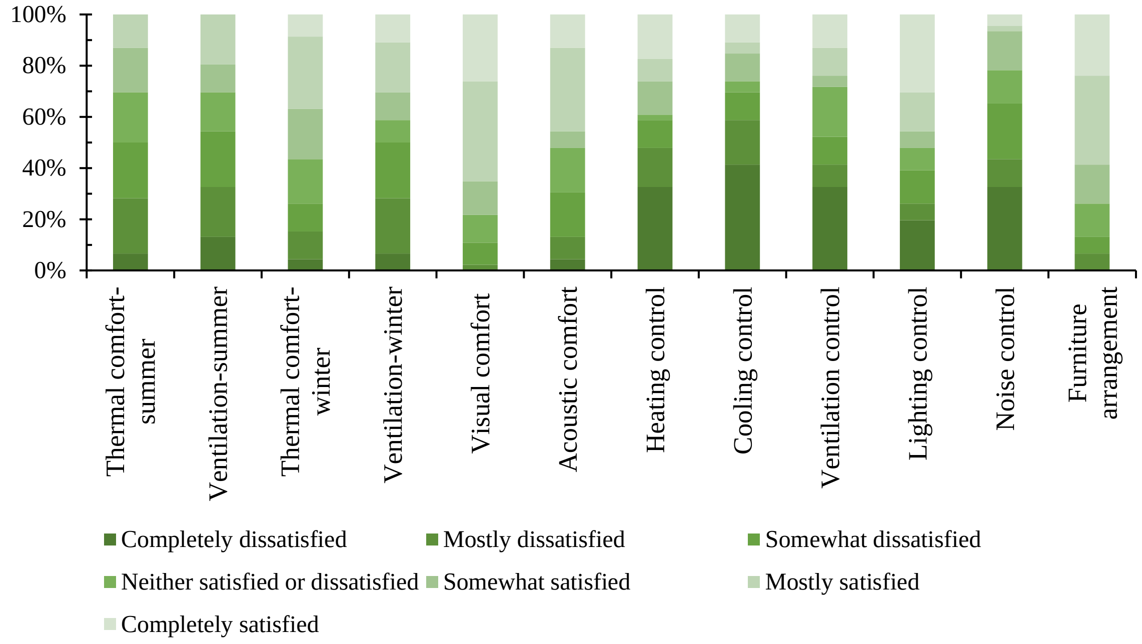


Figure 5.1 Occupants' satisfaction with the indoor environment

Overall, 50% or more than 50% of the building occupants rated their satisfaction with thermal comfort in winter, visual comfort, acoustic comfort, user control in lighting, and furniture arrangement as "somewhat satisfied" or higher. Going further, discussing the satisfaction with IEQ comfort, user control, and workstation furniture and equipment across different office types is also essential.

Occupants' satisfaction must be comprehensively understood to improve IEQ, user-centred designs, and workstation furniture and equipment arrangement across all office spaces. The literature identified that occupants' satisfaction could vary due to concerns over sharing building systems and controls. The median values of the satisfaction rating given by the building occupants across different office types: private, shared, and open-plan offices are presented in Table 5.2.

Table 5.2 Occupants' satisfaction across different office types

Indoor environmental condition	The median value of satisfaction		
	Private	Shared	Open-plan
Visual comfort	6	6	6
Furniture arrangement	6	6	6
Thermal comfort-winter	5	4.5	6
Acoustic comfort	5	4	6
Lighting control	4	6	4
Thermal comfort-summer	3	3.5	5
Ventilation-winter	5	3	3
Ventilation-summer	4	3.5	3
Heating control	4	2.5	2
Ventilation control	4	3.5	1
Noise control	3	2.5	3
Cooling control	2	1.5	2

As seen from Table 5.2, visual comfort and furniture arrangement were rated as the highest satisfaction across three office types. There was a similarity in the satisfaction rating by the occupant across private, shared, and open-plan offices in terms of visual comfort and furniture arrangement. Additionally, the building occupants in open-plan offices were highly satisfied with thermal comfort in winter and acoustic comfort, while those in shared offices rated higher satisfaction in access to lighting control. Furthermore, the same parameters in the other office types received a somewhat satisfactory or neutral opinion from the occupants. However, this is contrary to the previous studies that support the occupants in shared work areas and open-plan offices who are less satisfied due to unwanted noises and no control over the indoor environmental conditions (McElroy & Morrow, 2010; Mesthrige & Chiang, 2019). Thermal comfort in summer and ventilation in winter were rated as somewhat satisfactory in open-plan offices and private rooms, respectively, but the same received somewhat dissatisfaction across other office types. However, other parameters: ventilation in summer and user control in heating, ventilation noise, and cooling, were rated as dissatisfied or neutral across all three types of offices.

Overall, these results indicate that occupants across the three office types: private, shared, and open-plan offices have a similar satisfaction value except for thermal comfort in winter and/or summer, ventilation in winter, acoustic comfort, and access to lighting control. Since occupants' satisfaction across different office types is primarily similar, overall occupants' satisfaction with IEQ, user-centred controls, and workstation furniture and equipment can be considered triggers or drivers of occupant behaviours and comfort preferences, irrespective of office type. The following section analysed these occupant behaviours and comfort preferences in the office environment.

5.3.3 Occupant behaviours and comfort preferences

Referring to previous studies by Bavaresco et al. (2021), Hong et al. (2017) and Weerasinghe et al. (2020), 15 occupant behaviours and 15 comfort preferences were given as a multiple-choice questions in the questionnaire. The building occupants were asked to select the occupant behaviours they practice while working and the expected changes from these behaviours. These occupant behaviours and comfort preferences are summarised in Table 5.3 with the frequency (%) distribution, and the ranks were assigned in descending order.

Table 5.3 Occupant behaviours and comfort preferences

Occupant behaviour	Frequency (%)	Rank	Comfort Preferences	Frequency (%)	Rank
Open/close windows	78.3	1	To let in fresh air	76.1	1
Drink hot/cold beverages	73.9	2	To feel cooler	71.7	2
Adjust clothing	65.2	3	To feel warmer	71.7	3
Open/close internal doors	63.0	4	To increase air movement	67.4	4
Turn lights on/off	58.7	5	To improve air freshness	60.9	5
Adjust shades and blinds	56.5	6	To avoid outdoor sounds	43.5	6
Adjust computer screen brightness	54.3	7	To feel healthier	30.4	7
Adjust personal heaters	50.0	8	To avoid glare	28.3	8
Turn off the computer monitor	47.8	9	To have access to the outside view	26.1	9
Open/close external doors	43.5	10	To save energy	23.9	10
Moving through spaces	34.8	11	To increase artificial lighting	17.4	11
Report discomfort	32.6	12	To increase daylighting	17.4	12
Adjust portable/ceiling fans	28.3	13	To experience the variety of the outdoor climate	10.9	13
Adjust the room air conditioning unit	17.4	14	To hear outdoor sounds	6.5	14
Adjust thermostats	10.9	15	To follow management guidelines	4.3	15

As seen from Table 5.3, opening/closing windows and drinking hot/cold beverages were ranked the highest (more than 70%) among the other occupant behaviours. Further, adjusting clothing, opening/closing internal doors, turning lights on/off, adjusting shades and blinds, adjusting computer screen brightness, and adjusting personal heaters were practised by 50% or more occupants and ranked, respectively. Additionally, adjusting the computer desk was newly added by one of the occupants. Considering comfort preferences, most occupants (76%) were expected to let in the fresh air through open windows. At the same time, a considerably lower percentage of occupants were also expected to feel healthier, have access to an outside view, and experience the variety of the outdoor climate by opening windows. Another considerable percentage of occupants (71%) were expected to feel cooler or warmer depending on the temperature they experienced, which was achieved through drinking hot/cold beverages, adjusting clothing levels, and adjusting personal heaters. Other expectations were to increase air movement and fresh air, hear outdoor sounds by opening internal/external doors and avoid outdoor sounds by closing internal/external doors. Although most building occupants are visually satisfied, they expect to avoid glare by adjusting shades/blinds and computer screen brightness. However, many occupants highlighted turning lights on/off, although the concern about increasing artificial daylighting is reduced. Most occupants were expected to improve comfort conditions through their occupant behaviours, while 32% reported the discomfort to the building management. However, adjusting portable/ceiling fans, room air conditioning units, and thermostats have received a considerably lower percentage (10%-30%) due to the limited availability and accessibility to control these systems. Only very few occupants were expected to save energy and follow management guidelines through their OB, while most of the occupants were concerned about individual comfortability.

This reinforces the occupant behaviours association with indoor environmental conditions, as presented in previous studies, irrespective of office type. For example, Amasyali and El-Gohary (2016) explained that occupant behaviours, such as adjusting the thermostat, portable/permanent heaters, room air conditioners, portable/ceiling fans, and open/close doors, are associated with thermal comfort. Furthermore, indoor air quality is linked to opening/closing windows and doors and using/adjusting the humidifier. Similarly, Bavaresco et al. (2021) found that open/close windows and HVAC are related to thermal, acoustic, and IAQ; adjusting blinds and shades to visual and thermal comfort while turning lights on/off is affected by visual comfort. Additionally, the current study provides insights into drivers of drinking hot/cold beverages, adjusting clothing, adjusting computers, moving through spaces, and reporting discomfort. Most occupants are trying to reach their IAQ and thermal comfort preferences via occupant behaviours due to the lack of self-reported satisfaction with these parameters and their user control. The findings highlight the buildings' inability to perform up to the occupants' expectations. However, further studies are required to analyse the other social, physiological, and psychological drivers influencing occupant behaviours in office buildings and compare those with IEQ and user-centred design and control triggers.

Further, occupants were asked to rate the frequency of occupant behaviours practice and how influential these behaviours are towards comfort preferences. Figure 5.2 shows the frequencies of the rating by occupants.

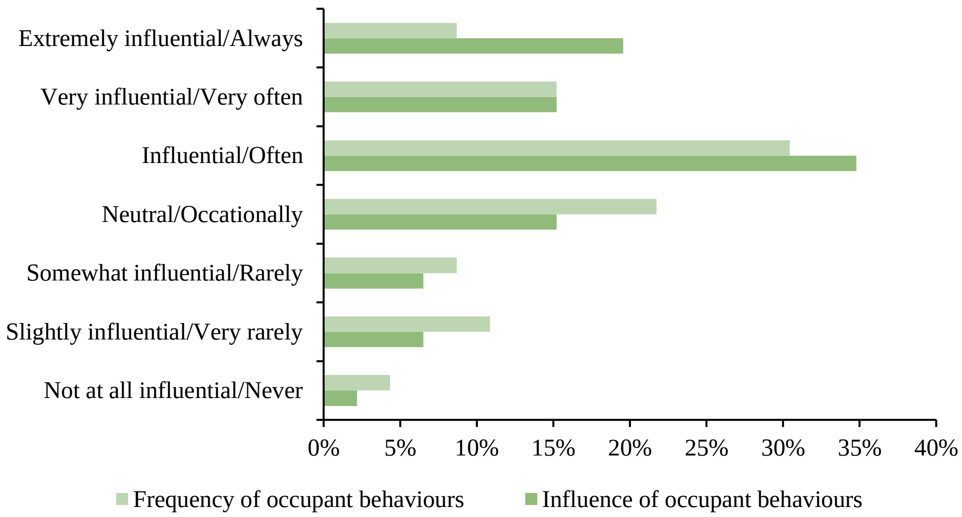


Figure 5.2 Occupant rating on influence and frequency of occupant behaviour practice

As shown in Figure 5.2, most of the building occupants rated "often" or more in the frequency of the practice of occupant behaviours. Similarly, the influence of occupant behaviours on the desired effect was rated as "influential" or more. Overall, the influence of occupant behaviours and frequency of occupant behaviours were rated by 60% and 54% of the building occupants as influential or often, respectively.

Finally, the Spearman rank correlation was run for the dependent variables: influence of occupant behaviours and frequency of occupant behaviours, and independent variables: IEQ, user-centred control, furniture arrangement, and office type. The Spearman correlation coefficient (r) measures a relationship's strength, which can take values from -1 to +1. However, there is no fixed definition of correlation strength (Weerasinghe, Ramachandra, et al., 2022). This study used the thresholds of $0 < r < 0.3$ (Weak), $0.3 < r < 0.7$ (Moderate), and r > 0.7 (Strong) (Ricciardy & Buratti, 2015). A significance level < 0.05 was considered to determine whether the relationships were significant. However, significant correlations have appeared only for the influence of OB. These results are summarised in Table 5.4.

Table 5.4 Relationship between the influence of occupant behaviour and indoor environmental conditions

Item	Influence of occupant behaviour	Significance (p-value)
Thermal comfort in winter	0.448*	0.002
Ventilation in winter	0.540*	0.000
Thermal comfort in summer	0.390*	0.007
Ventilation in summer	0.561*	0.000
Visual comfort	0.347*	0.018
Acoustic comfort	0.357*	0.015
Heating control	0.645*	0.000
Cooling control	0.576*	0.000
Ventilation control	0.531*	0.000
Lighting control	0.385*	0.008
Noise control	0.378*	0.010
Furniture arrangement	0.261	0.080
Frequency of occupant behaviours	-0.149	0.323
Office type	-0.142	0.348

As shown in Table 5.4, most independent variables show a moderately significant relationship with the influence of occupant behaviours, except furniture arrangement, office type, and frequency of occupant behaviours. Furthermore, heating control has the most substantial relationship (0.645) with the influence of occupant behaviours, closely followed by cooling control, ventilation in summer, ventilation in winter, and ventilation control. Overall, IAQ and control over thermal and IAQ-related parameters strongly bond with the occupant behaviours. This further cement the significant influence of thermal and IAQ-related drivers on occupant behaviours in office buildings. This finding agrees with Bavaresco et al. (2021) and extends the findings relating to the influence of user-centred designs and control over building systems on occupant behaviours in offices. Onyeizu (2014) suggested that occupants should be given more control over the IEQ in their local environment to achieve greater comfort.

5.4 Conclusion

This study aimed to uncover the relationships among indoor environmental conditions such as IEQ, user-centred design and furniture arrangements, comfort preferences, and occupant behaviours for integrating these relationships in future energy modelling of buildings. Results show that more than 70% of occupants were satisfied with visual comfort and furniture arrangement in office buildings. Further, IEQ, user-centred building controls, and furniture arrangements across the three office types: private, shared, and open-plan offices had a similar satisfaction value except for thermal comfort in winter and summer, ventilation in winter, acoustic comfort, and access to lighting control. Additionally, dominant behaviours and comfort preferences were identified based on the frequency distribution, which showed that dominant behaviours: opening/closing windows, drinking hot/cold beverages, adjusting clothing, and opening/closing internal doors were to satisfy individual IAQ and thermal comfort preferences. Furthermore, IAQ and control over thermal and IAQ-related parameters such as heating, cooling, and ventilation are highly correlated with occupant behaviours, and these could be considered primary predictors of occupant energy behaviours. These relationships of IEQ and user-centred building controls with occupant behaviours could enhance future occupant energy behaviour modelling approaches to reduce the gap between predicted and actual energy use while pinpointing the occupants' energy-wasteful behaviours. A better understanding of occupant behaviours and comfort preferences driven by subjective aspects of occupants would support policymakers, designers, and building managers to optimise the building energy performance from a building's design and construction stage. Based on surveying 46 occupants in office buildings, this study serves as the pilot study of research that aims to develop an interdisciplinary framework for occupant energy behaviours. Therefore, comprehensive research will address the study's limitations (i.e. purposive sampling, sample size).

Epilogue

This part identifies the prevalent occupant energy behaviours and the significant drivers that influence these behaviours in the New Zealand and international contexts. Chapter 3 presents the occupants' adaptive and non-adaptive behaviours and explains the relationship between IEQ parameters and these behaviours. It classifies the factors influencing occupant behaviours into physical environmental, contextual, time-related, social, psychological, and physiological categories. The chapter shows that most studies focused on a single behaviour and approached it based on objective factors.

Looking at social-psychological theories and constructs, chapter 4 proposes social-psychological constructs to investigate the subjective factors influencing occupant energy behaviours in office environments. As the research problem was defined based on the significant behaviours and factors, chapter 5 then conceptualises the relationships between indoor environmental conditions, comfort preferences, and occupant behaviours in office buildings in New Zealand. The chapter analyses the satisfaction ratings in IEQ parameters and observes the variations depending on the type of office. It proposes the importance of building managers considering comfort preferences for developing more effective energy efficiency strategies considering the dynamic nature of occupants' energy behaviours.

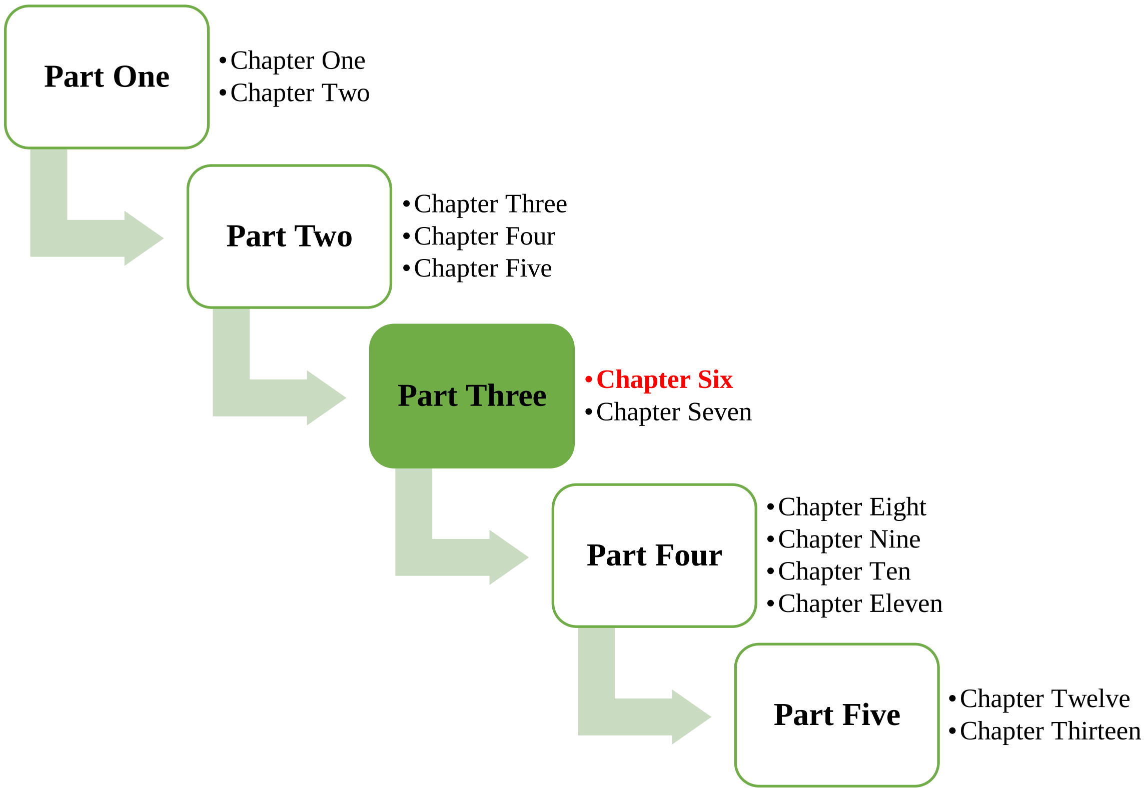
Thus, the actual outcome of Part 2 highlights a conceptual understanding of occupant behaviours, different influential factors, IEQ parameters, and comfort preferences and the relationships between these concepts. Altogether, it contributes to achieving Objective 1 fully. Accordingly, the next part of the thesis preliminarily analyses the relationship between these concepts.

PART 3 – PROBLEM ANALYSIS: PRELIMINARY FINDINGS

Prologue

Part three of this thesis analyses how organisations rationalise occupants' energy behaviours and comfort preferences in New Zealand office buildings and contributes to achieving Objective 2. Chapter 6 aims to improve organisational energy culture by combining the perspectives of building occupants and managers. It first examines occupants' beliefs and comfort preferences regarding IEQ and then the awareness and approach of building managers towards occupant energy behaviours, which achieves sub-objective 2.1. The chapter highlights the importance of a multi-disciplinary approach to understanding occupant energy behaviours in buildings and developing occupant-centred energy policies. The current methods and tools used to assess the influence of occupant behaviour on building energy consumption are inadequate, and the lack of relevant data on occupant behaviours makes it challenging for building managers to improve the energy performance of buildings.

To address these limitations, chapter 7 proposes a theoretical framework incorporating environmental and social-psychological factors to analyse occupant behaviours better. The chapter contributes to achieving sub-objective 2.2, which examines the interrelationships among occupant energy behaviours, IEQ satisfaction, user-centred control, and social-psychological aspects in New Zealand office buildings. The framework outlines five hypotheses, which will be tested using a logit model to enhance the accuracy of the occupant energy modelling.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6.0 A facilities management approach to rationalising occupants' energy behaviours

Abstract

This paper investigates building managers' approach towards occupant energy behaviours and rationalises organisational energy culture concerning their strategy to address occupants' preferences in New Zealand tertiary education office buildings. The research used grounded theory analysis by interviewing a purposive sample of 25 participants from a university. Also, semi-structured interviews were conducted with facilities managers, sustainability managers, and building occupants. The study results revealed that building managers oversimplify the multi-domain discomfort, energy impacts from occupant behaviours, and the influence of social-psychology aspects on occupants' actions. The organisational energy culture can be further improved by increasing occupants' knowledge and awareness of energy, sharing energy feedback with occupants to make energy-conscious occupants and giving them responsibilities to achieve the organisation's energy targets. This study enables opportunities to promote collaboration between building managers and occupants by comparing perspectives on occupant energy impacts.[4]

[4] This chapter is based on the following published Journal article:

Weerasinghe, A.S., Rasheed, E.O., & Rotimi, J.O.B. (2022). A Facilities Management Approach to Rationalising Occupants' Energy Behaviours [Article]. *Facilities*, 40(11/12), 774-792. https://doi.org/10.1108/F-02-2022-0025

6.1 Introduction

Technological advances by introducing automated building controls to achieve energy savings in buildings are seen as limiting human interaction (He et al., 2021). Nevertheless, occupants find a way to interact with the building systems and features, producing unpredictable and random occupant behaviours (Day & O'Brien, 2017). The way occupants interact with these systems and the built environment may be inconsistent with the initial design parameters of the building (Deuble & de Dear, 2012; Schakib-Ekbatan et al., 2015). Also, it causes a change in the use of electrical equipment and occupancy patterns than what was assumed in the design phase (Schweiker et al., 2018).

Usually, these behaviours are possible when occupants are uncomfortable and trying to create a comfortable environment by modifying building controls and systems (Heydarian et al., 2020). Occupant behaviours are deemed to improve IEQ in buildings via increased thermal, aural, visual, and IAQ comfort (Asadi et al., 2017; Bluyssen, 2019). Furthermore, Day et al. (2020) showed that assessing and understanding how occupants use different building systems is still necessary while enriching knowledge about multi-domain comfort stimuli for occupant behaviours. Therefore, building managers must implement energy-related initiatives based on occupants' IEQ beliefs, comfort preferences and multidomain discomfort sources when approaching occupant energy behaviours. However, the concern about these aspects is rarely addressed when building managers introduce technical innovations and improvements (Y. Zhang et al., 2018). Furthermore, occupants' reactions to these technologies are lower than anticipated, and occupant behaviours still demand higher energy than anticipated (He et al., 2021). Therefore, the research on the impact of occupant behaviours on energy consumption is currently attracting significant attention (Bavaresco et al., 2021; Hong et al., 2017).

However, studies highlighted a gap between organisational energy and occupant-centred policies and approaches (Goulden & Spence, 2015). Not only occupants but multidisciplinary efforts and knowledge are required to address occupant behaviours in buildings (Bavaresco et al., 2020; Hong et al., 2016). Accordingly, there is a potential opportunity to achieve energy efficiency in buildings through the various parties (designers, building managers, owners and occupants) who engage with buildings (Stazi & Naspi, 2018). For instance, the owners prioritise energy-efficient investments at the design or operational stage, and the building managers execute those technical innovations and improvements to achieve energy reduction targets in buildings (Day & O'Brien, 2017). Similarly, building managers' perception of occupant energy impacts (presence and movement, comfort, core function activities, behaviours and energy-savings) and how these perceptions affect their choices to engage in energy management practices are highlighted (Valle et al., 2019). Therefore, the occupants' role in the buildings is equally important as the other stakeholders due to their influence on energy through daily building interactions (D'Oca, Hong, et al., 2018).

Along these lines, a study that combines both occupants' and building managers' perspectives would compare these perspectives to improve organisations' energy culture. To this end, the current study first investigates the occupants' IEQ beliefs and comfort preferences, then the building managers' awareness and approach towards occupant energy behaviours to rationalise organisational energy culture concerning occupant-centric building design and operation. The authors argue that multi-disciplinary approaches are needed to interpret occupant energy behaviours in buildings; thus, the perspectives of building managers play a significant role when preparing occupant-centred energy policies.

6.2 Literature review

6.2.1 Occupant behaviours impact on energy

Numerous interactions with building systems are possible for occupants in their built environment (Schweiker et al., 2018). These include adaptive and non-adaptive occupant energy behaviours (Hong et al., 2017). Adaptive behaviours include adjusting windows, blinds, thermostats, lighting and plug-in equipment to adapt the indoor environment to occupants' preferences. However, plug-in equipment was further discussed in heaters, air conditioners, fans, computers and other electrical appliances (Gunay et al., 2016). This behaviour also includes changing clothing levels, drinking hot/cold beverages and moving through spaces to adapt to their environment. On the other hand, non-adaptive behaviours include occupant presence, operation of plug-in equipment, complaints regarding discomfort and inaction. Non-adaptive behaviours are typically actions that do not involve direct control over the environment or active adaption to the environmental conditions (Hong et al., 2017).

Energy impact from individual occupant behaviour has been studied in empirical studies and estimated possible energy-saving optimisations (Jia et al., 2017). For example, a significant variation in buildings' energy use intensity was estimated through window opening behaviour, and this variation was equal to a factor of four in commercial buildings in the USA (Fabi et al., 2012). Sun and Hong (2017) highlighted the willingness of occupants to switch off plugged loads and heating, ventilation, and air conditioning systems when unoccupied or leaving the spaces to contribute significantly to avoiding energy waste. Thus, keeping thermostats below 24°C was a waste of energy. In a more detailed perspective, Gunay et al. (2016) developed a model based on plug-in equipment load patterns during different periods in office spaces. Their study found that 75% of the plug-in equipment load occurs during unoccupied periods such as intermediate breaks, weekdays after working hours, weekends and vacations.

On the other hand, in terms of occupants' energy-saving potential, Hong and Lin (2013) and Pothitou et al. (2016) estimated savings of between 5% and 30%in commercial buildings. Staats et al. (2004) modified two energy behaviours: thermostat use and diffuser covering, providing energy usage feedback and estimated a modest 6% savings in energy use. Dietz et al. (2009) stated that occupant energy savings could reduce 7.4% of USA emissions. However, there is a gap between these estimations, and the actual energy use and occupant behaviours need to be fully understood for better energy optimisation (Jia et al., 2017). The findings from the empirical studies highlight that understanding occupant behaviours and associated factors influencing occupant behaviours is essential for energy-saving optimisations. Accordingly, the following section reviews the factors influencing occupant behaviours.

6.2.2 Influential factors of occupant behaviours

When building occupants are in discomfort, they may prefer to create a comfortable indoor environment by changing the surrounding environment's physical parameters (Abdulaali et al., 2020). It has been widely demonstrated that occupants vary in comfort preferences, satisfaction and indoor environment perceptions, leading to occupant behaviours' complex nature in buildings (Schakib-Ekbatan et al., 2015). For example, Amasyali and El-Gohary (2016) highlighted the association between occupant behaviours and the building occupants' satisfaction level. Another school of thought connects primary sources of discomfort to occupant behaviours (Bavaresco et al., 2020; Bavaresco et al., 2021; D'Oca, Hong, et al., 2018). Bavaresco et al. (2021) connected the primary sources of discomfort to windows, blinds/shades, thermostats and lighting in office settings while addressing triggers such as temperature, air, light, view, noise and access to the thermostat as driving factors of occupant behaviours. Further studies are needed to address the multiple comfort preferences of occupants, occupant-centric building design and operations and human-building interactions through big data and advanced sensing and modelling (O'Brien et al., 2020)

An extensive body of literature has focused on accurately identifying other influential factors for predicting energy impacts in the quest to find the impact of occupant behaviours on energy. For example, Schweiker (2010) categorised influential factors as external and internal. Internal factors include physical, psychological and social aspects, whereas external factors are the factors that influence an individual to stimulate their reaction, such as building and equipment properties, the physical environment and time-related. O'Brien and Gunay (2014) grouped the contextual factors into physical environmental factors that stay unchanged over time, psychological factors related to individual and social factors, and physiological factors that are not immediate triggers. Apart from these categorisations, Peng et al. (2012) and Stazi et al. (2017) classified behaviours into environmental-related: actions driven by environmental parameters; time-related: actions repeated in certain time-lapses; random: actions depending on uncertain, not quantifiable factors based on an analysis of human behaviours in residential buildings.

However, energy research practices based purely on objective factors of occupant behaviours may not highlight valuable insights from subjective aspects of occupant behaviours in buildings (D'Oca et al., 2017). Incorporating knowledge from social psychology may significantly improve those energy practices that usually develop deterministic and stochastic models for energy prediction (D'Oca et al., 2017; Yan et al., 2017). The importance of multi-disciplinary approaches to address the factors of occupants' energy behaviours, such as the frameworks that link the significant occupant behaviours and influential factors, has been pointed out for the possible integration of occupant energy behaviour modelling and simulation approaches (Paone & Bacher, 2018; Tam et al., 2018). Incredibly multi-disciplinary and international relationships are recommended to provide new insights into occupant adaptive behaviours (D'Oca, Hong, et al., 2018). Research must be extended to different climate zones or countries to find the variations of behaviours in different contexts, cultures, climates and socio-economic backgrounds (D'Oca et al., 2019; Rupp et al., 2021). Additionally, Day and O'Brien (2017) stressed the importance of including knowledge from multi-disciplinary fields to identify adaptive behaviours and their motivational factors. Hence, the current study looked into the OB-related research trends in

New Zealand, and the forthcoming section explains the focus of those studies and the identified gaps.

6.2.3 Occupant behaviours research in New Zealand

In participating nations of the OECD, including New Zealand, Australia, the UK and the USA, energy consumption in buildings has grown by 1.5% per year since 2012 (Conti et al., 2016). However, compared to other OECD countries, New Zealand needs more focus on improving its energy productivity (MBIE, 2017). Energy use makes up 40% of New Zealand’s total GHG emissions. Making changes in this area is the easiest and cheapest way for New Zealand to achieve its ambitious emissions reduction goal (EECA, 2020).

Energy savings are possible through renewable sources in the commercial, residential and transportation sectors (EECA, 2020), even though New Zealand uses about 1% more energy annually. Therefore, government, businesses and broader society have a pivotal role in reducing energy demand and saving energy from the early design and construction to post-occupancy. Previous New Zealand studies highlight the significant role that building occupants could play in energy-savings/management. This is possible through understanding occupants’ perceptions of thermal comfort, IAQ and acoustic comfort. For example, occupants prefer air-conditioned spaces over naturally ventilated areas (Lai & Yik, 2007; Rasheed et al., 2017; Russell & Ingham, 2010). Further, Rasheed et al. (2019) found that office workers prefer acoustic improvements in office design to reach their perceived comfort levels. These studies suggest that occupants require control over their operating environments since their performances depend on these (Rasheed et al., 2017). However, building designs do not reflect occupants’ different characteristics and expectations in New Zealand offices (Rasheed et al., 2021). Thus, the energy conservation strategies in New Zealand demand attention to occupant-related energy aspects of buildings.

O’Brien et al. (2020), reviewing building energy codes and standards of 23 countries, including New Zealand, showed that occupant-related aspects are mostly simplified in these energy codes. In the New Zealand, hourly schedules are required for estimating occupancy density and associated light and plug loads instead of the dynamic performance simulation currently being applied. Furthermore, energy modelling has excluded the blind adjustment behaviour of occupants and their impact on energy use. Therefore, more is required to understand the implication of occupant energy-related behaviour in New Zealand. The keywords searched into the Scopus database provided only seven out of 280 studies that focused on occupant behaviours and energy consumption in buildings in the New Zealand context. Table 6.1 presents four studies that have specifically investigated occupant energy-related behaviours.

Table 6.1 Overview of occupant energy behaviour related studies in New Zealand

Source	Source Type	Methods	Scope of the Study and outcome
Azizi et al. (2015a)	Journal	Questionnaire survey within two green buildings and two conventional buildings	Adjusting computers behaviour among office building occupants
Azizi et al. (2015b)	Journal	Questionnaire survey within two green buildings and two conventional buildings	Occupants' environmental, personal, and psychological adjustments in response to thermal discomfort
Azizi et al. (2019)	Journal	Review	A theoretical framework developed on behavioural interventionism (i.e., environmental restructuring, modelling, enablement) and habit theory
Weerasinghe et al. (2020)	Conference	Review	The importance of occupant comfort-related parameters and prominent drivers of occupant behaviours to recognise the dynamic nature of occupant energy behaviours

As seen from Table 6.1, the first three studies (Azizi et al., 2015a, 2015b; Azizi et al., 2019) are the branches of one study aiming to compare occupant behaviours in green and conventional buildings. For example, Azizi et al. (2015a, 2015b) compared occupant behaviours to cope with thermal discomfort in green and conventional buildings, considering the thermal comfort preferences. At the same time, their study found no difference in the behaviours like adjusting the thermostat and opening/closing windows between green and traditional buildings, even though the occupants in green buildings had control over temperature. Furthermore, the occupants in green buildings prefer personal adjustments such as drinking hot/cold beverages and moving through spaces over environmental adjustments. However, their study was limited to thermal comfort behaviours and occupants' computer usage behaviour from only one site and did not represent the entire office building population in New Zealand. Most importantly, the existing studies ignored the occupant lighting on/off behaviour and fan usage. On the other hand, Weerasinghe et al. (2020) reviewed the relationships between multi-domain comfort preferences, occupant behaviour and different drivers of occupant behaviours.

6.2.4 Research questions

The above review reveals a poor understanding of how indoor environmental discomfort and occupants' comfort preferences drive occupant energy behaviours and to what extent the organisational energy culture addresses the occupants' comfort preferences and energy behaviours. To this end, the current research addresses the following research questions:

[1] RQ1. What are building occupants' preferences compared to their prevailing comfort conditions?

[2] RQ2. How do building managers perceive the impacts of occupant behaviours on energy use?

[3] RQ3. How do building managers address the impact of occupant behaviours on energy use in their buildings?

6.3 Research methods

6.3.1 Research approach

In New Zealand, most academic research focused on occupants' perceptions of indoor environmental comfort, while the relationship between occupant comfort preferences and occupant behaviours is merely addressed in New Zealand. Additionally, qualitative studies are necessary for the international context to unveil the relationships between occupant behaviours and drivers influencing most occupant behaviours and make energy predictions more informative. Mixed methods are widely used in occupant behaviour studies and are identified as effective for quantifying behaviours and qualitatively obtaining occupant perspectives (Pereira et al., 2017). However, a mixed method that employs grounded theory using interviews to study occupant behaviours, predominantly residential low-energy buildings and Passivhaus, was suggested (Zhao, 2014). Day and O'Brien (2017) introduced qualitative data from interviews and open-ended survey responses in addition to quantitative methods. Similarly, template analysis, a form of grounded theory, has been used to analyse occupants' rebound behaviour after an energy-efficiency refurbishment (Walker et al., 2014). Moreover, Deme Belafi, Hong, et al. (2018) reviewed 33 pieces of research that used survey instruments or interviews for data collection to identify occupant behaviour patterns and factors to discover the interrelationships among human, social, and local comfort factors. These studies suggest the relevance of qualitative approaches to understanding building users' socio-economic concerns, occupants' comfort preferences, and the gap between design and reality. Bavaresco et al. (2021) also highlighted that interviews are valuable for identifying personal comfort preferences and social influence when sharing space and control systems with co-workers.

Thus, the current study adopted a novel grounded theory approach to occupant energy behaviours in office buildings to explore corporate energy culture and the reality of occupant comfort preferences alongside their behaviours and driving factors. It is hoped that this exploratory study would serve as a bottom-up approach to tackling the occupant behaviour influence on the overall energy consumption of buildings and geographically and exhaustively add to research in this field. Grounded theory analysis is used to identify occupants' IEQ beliefs and comfort preferences, building managers' awareness and approach towards occupant energy behaviours, and rationalise the organisational energy culture based on their approach to addressing the occupants' influence.

6.3.2 Research setting

This study investigates the impact of occupant energy behaviours on New Zealand office building occupants to optimise their user comfort and overall buildings' energy-saving. The study presents a grounded theory analysis of data collected from a University in Auckland, New Zealand. Table 6.2 describes the selected case study.

Table 6.2 Description of the case study building

	Description
Case type	Tertiary educational building
Construction year(s)	1984-1998
Building type	Office
Window and shading	Top-hung windows, Venetian blinds, and roller shades
Glazing	Single glazing
Ventilation and IAQ	Natural ventilation + no mechanical cooling or heating in most spaces, while some office spaces have central or split heating/cooling
Average daytime temperature	16 - 19°C in Spring 20 - 25°C in summer 17-21°C in Autumn 12-16°C in Winter
Average annual heating degree-day (HDD) with base 18°C	South Island - 2574
	North Island - 1595
	South Island - 43

Average annual cooling degree-day (CDD) with base 18°C	North Island - 135
Acoustic conditions	Human-generated, mechanical, and electrical sounds and ongoing construction site
Participants	25
Facilities managers (FM)	FM1, FM2, FM3 (have more than 20 years of experience)
Sustainability managers (SM)	SM1, SM2 (have more than 20 years of experience)
Occupants	O1, O2, O3, …, O20
Occupant types	Staff and PhD students who regularly occupy the office space
Energy management	The tertiary institution has in-house teams to manage energy and sustainability. FM1 is the on-site facilities manager, while FM2, FM3, M1, and SM2 sit far from the premises and contribute to energy and sustainability strategic planning. Energy performance is monitored through Building Management Systems (BMS) and assessed through energy benchmarks.

As shown in Table 6.2, the general climate in New Zealand shows an apparent variation (approximately ±10°C) between summer and winter, while around ±5°C temperature from summer to spring/autumn and winter to spring/autumn. Additionally, considering heating and cooling degree days, the number of HDDs tends to be lower in the country's northern locations where the study has taken place, and CDD tends to be lower in southern areas (Macara, 2018).

6.3.3 Data collection

The data collection consists of face-to-face semi-structured interviews with the building managers (FMs and SMs) with strategic and operational responsibilities within the selected case buildings. FMs were selected based on their engagement in energy management services delivery and interaction with building occupants, whereas SMs were selected based on their contribution to energy and sustainability-related policy development. Data from building occupants were collected using open-ended online questionnaires to collate the different stakeholder perspectives on occupant behaviours. These interviews were conducted between October 2020 and January 2021, and the allocated time is 30 to 45 minutes. The study comprised 25 participants (five building professionals and 20 occupants) at the theoretical saturation point. In grounded theory, data collection and analysis are repetitive until theoretical saturation is reached, where the properties of theoretical categories or themes are adequately developed and no longer require additional data (Saunders et al., 2019). This is achieved by constant comparison and theoretical sampling that goes hand in hand (Corbin & Strauss, 2014). In theoretical sampling, the participants with minimal differences are selected first and then with maximum differences to allow the rapid development of categories and data saturation (Jones & Alony, 2011). Moreover, a minimum sample size of 25-30 in-depth interviews is adequate in grounded theory studies for saturation and redundancy (Baker & Edwards, 2012; Dworkin, 2012). Table 6.3 summarises the participant profile showing most females (56%) and building occupants aged above 30 (88%) in the selected sample. Amongst the respondents, the majority (92%) lived in New Zealand for more than one year, and 40% spent more than 20 years of their time. Additionally, 64% have worked in the present work area for a year or more, suggesting most respondents were familiar with the New Zealand climate and have spent adequate time evaluating their workspace conditions.

Table 6.3 Profile of participants

Participants	Count	Percentage (%)
Occupation		
Facilities management	3	12
Sustainability management	2	8
University staff	15	60
PhD student	5	20
Gender		
Male	11	44
Female	14	56
Age		
Below 30	3	12
Above 30	22	88
Years in New Zealand		
Less than a year	2	8
1 – 10 years	4	16
11 – 20 years	9	36
More than 20 years	10	40
Years in Present Work Area		
Less than a year	9	36
A year or more	16	64

6.3.4 Data analysis

The essential elements of grounded theory include comparative technique, theoretical sampling, memo writing, coding, and categorising collected data (Corbin & Strauss, 2014). According to Birks and Mills (2015), initial purposive sampling directs the collection and generation of data, while concurrent data generation, display, and analysis are fundamental to grounded theory research design. The study purposively selected participants and data sources to collect and develop an inductive theory by coding, categorising, and connecting the data. This process is called constant comparison (Boeije, 2002). Theoretical sampling then starts from the codes and categories developed from the first data set to systematically select new participants who will provide data samples that are more likely to contribute to the development of the theory (Jones & Alony, 2011).

Memos record lengthy and in-depth thoughts of a researcher's thought process when undertaking a grounded theory (Birks & Mills, 2015; Corbin & Strauss, 2014). The constant comparison process includes three levels of coding; open coding, axial coding, and selective coding in inductive theory generation (Douglas, 2003). The initial open coding process created keywords for each significant relationship from the transcribed data. A total of 360 key phrases were identified during this stage. For example, the issues related to elevated temperatures were labelled as "too hot," while the occupants' adjustments relating to their clothing were labelled as "adjusting clothing." Later, the differences and similarities of each keyword were compared and assigned to categories and sub-categories, considering the relationships among these keywords. The label "too hot" was combined with other issues (e.g., too cold, slightly cold/hot) and created the sub-category of "thermal discomfort" under the core category of "indoor environmental discomfort." Similarly, adjusting clothing is a way of adapting oneself to indoor environmental conditions. Therefore, the "adapting themselves" sub-category was created under the core category of "occupant behaviours." The core categories were further examined in the selective coding phase and removed the unrelated keywords. An example of the analysis process is shown in Table 6.4.

Table 6.4 Examples from the coding process

	Example 1	Example 2	Example 3
Memo	Sometimes it feels like there is not enough oxygen. There are no windows in our office, so we cannot open anything to let in any fresh	Not too bad. We have a heat/cool pump in the middle area shared by people in surrounding	It is always a couple of degrees colder than I am comfortable with. Therefore, I always have to wear a jacket or

	air. The air conditioner is usually okay for temperature but in terms of freshness, not so much	offices who sometimes have different needs	cardigan. Incredibly annoying during the summer
Key Phrases	Air freshness Oxygen level Window control Temperature	Unique needs Shared space Appliance/systems	Too cold Adjusting clothing Seasonal effect Annoyance
Conceptualizing 1	Opening windows is essential to let in the fresh air and control the air movement due to the air conditioner only controlling the temperature	Thermal preferences are associated with the type of office and the distribution of the heating and cooling systems	Occupants tend to adapt themselves to the environment to cope with thermal discomfort
Conceptualizing 2	Building openings and building systems must go hand in hand to ensure both thermal comfort and indoor air quality	Occupants in shared offices have different thermal preferences according to the placement of heating and cooling systems	Occupants' actions to cope with thermal discomfort in different seasons affect them psychologically
Categories	Thermal comfort Poor indoor air quality Building drivers Adaptive behaviours	Building drivers Comfort preferences	Thermal discomfort Adaptive behaviours Environmental drivers Mood

Interview data were categorised along with four main themes:

[1] Comfort-related aspects

[2] Factors influencing occupant behaviours

[3] Behaviour impact on energy

[4] Occupant-centric energy culture

The first theme includes three categories generated from the grounded theory analysis: perceived indoor environmental discomfort, effects on occupants, and comfort preferences. The second theme consists of occupant behaviour factors. The third theme includes the influence of occupants on energy. The fourth theme from the data includes two categories: occupant-centric building design and operation and strategic plan for energy efficiency.

6.4 Results

6.4.1 Comfort-related aspects

Most of the building occupants perceived thermal discomfort in winter and summer. Occupant thermal discomfort occurred due to under or overestimated cooling/heating loads and unattended mechanical failures in the air-conditioned spaces. It can be argued that the degree of perceived thermal discomfort would depend on the actual use of the facility compared to design estimates at the initial stage. However, the latter further highlights the importance of recognising occupant discomfort by FMs and providing maintenance and energy services in accordance. An interviewee supported this view: *"It is always a couple of degrees colder than I am comfortable. Therefore, I always wear a jacket or cardigan. Incredibly annoying during summer" (O11).* On the other hand, the occupants in naturally ventilated spaces without mechanical cooling/heating systems constantly undergo variable indoor conditions.

Occupant discomfort was also identified concerning air quality. The building occupants revealed a relationship between window access and the fresh air supply or airflow. For example, as stated by one interviewee: *"Sometimes, it feels like there is not enough oxygen. Our office has no windows, so we cannot open anything to let in the fresh air. The air conditioner is usually okay for temperature but in terms of freshness, not so much" (O4).*

The occupants whose computer screens face the sunlight's direction highlighted lighting discomfort due to glare. However, those occupants dealt with this situation by lowering shades and blinds, which dissatisfied other occupants due to the lack of daylight and artificial lighting during the daytime. An occupant sustained this view: "*I get glare in the morning during sun-up rather than sundown. I lower the blinds because my eyes are light-sensitive, and I share the office with others. I cannot move my desk around. We have windows on two walls, so I cannot move anywhere to change this" (O9).* Another set of occupants feels discomfort due to limited access to lighting control. *"Lights are on even during the daytime, where we can access plenty of natural light and scheduled to turn off at night" (O1).* Some offices have occupant sensors, which automatically turn off lights when the occupant has no movement. On the other hand, occupants who work in offices where recent lighting improvements occurred expressed more satisfaction with visual comfort. In this context, it is reasonable to argue that an increased perception of FMs on energy-efficient lighting improvements can reduce the perceived lighting discomfort of occupants.

Most influences on occupant productivity were observed through unwanted interruptions and noise due to human-generated sounds such as talking, footsteps, and phone conversations in adjoining rooms and corridors, mechanical and electrical sounds such as telephone rings and ventilation fans, and outdoor sounds such as construction activities. Frequently disrupting the train of thought and complex tasks increased perceived loss of productivity, mood swings, and emotions. "*Interruptions and noise come from adjacent rooms and voices from the corridor. Also, it comes from fellow roommates (taking or making phone calls, visitors, friendly conversation). I must use my headphones to cancel the noise and minimise interruptions" (O13).* However, some occupants are good at turning out noises when they need to concentrate and even feel motivated to work when they are around them. Thus, FMs' perception of reducing mechanical and electrical sounds through improved insulation can increase the perceived lighting comfort of occupants.

Perceived IEQ beliefs and comfort-related aspects of occupants bring attention to the relationship between occupant discomfort and the lack of FM-related improvements in buildings. For example, occupants showed reasonable satisfaction with IEQ when building managers resolved technical and services-related issues that discomforted occupants. Furthermore, the above findings indicate the potential occupant behaviours that could bring the indoor environment up to occupants' expectations.

6.4.2 Factors influencing OB

FMs' understanding of the factors influencing occupant behaviours is vital in deciding the right strategy to overcome any energy impacts on building occupants. As highlighted by all the building managers, the outdoor temperature is the main factor driving the opening of windows in offices that do not have air conditioning or any form of cooling. For example, *FM1* states: "*Occupants often open windows during the intermediate time, soon after returning from outside in the lunchtime or summertime, and lecturers when they return to the office from the lecture hall."* Similarly, lack of air circulation was suggested as a driving factor of occupants' window behaviour, whereas the type of heating system, wall and ceiling insulations, and glazing available in the buildings affect occupants' windows, shades/lifts, and lighting behaviours. The buildings were built in the 90s; thus, the building managers are responsible for retrofitting building envelopes and façades to improve energy performance and occupant comfort.

Although they are fully aware of their role in addressing occupants' comfort-related issues, they feel less inclined to change the temperature and the lighting levels to suit individual needs due to the various comfort preferences of occupants. "*Somebody might want the room warmer while others like it cold" (FM2).* In other words, the number of occupants present in the office or building occupancy influences occupant behaviours, while the occupants' movement patterns are considered to model the energy consumption of buildings. Occupants offset the unattended indoor conditions by adjusting their clothing and drinking hot/cold beverages.

However, one professional mentioned that those environmental and contextual factors are speculative. They instead highlighted the influence of workplace and occupants' cultures or practices and the importance of a holistic understanding of how behaviours typically occur. *"Decontextualizing these behaviours while simply looking at the work culture and other cultures people bring to the workplace can help save energy" (SM1).* Similarly, *SM2* suggested that psychological thinking influences the occupants' behaviours, *"especially among female employees who undergo some health symptoms."* Any organisation focusing on occupants must fully understand the social-psychology constructs of occupant energy behaviours. Accordingly, FMs and SMs highlighted different viewpoints, and those perceptions may lead to different approaches to resolving occupant comfort issues.

6.4.3 Behaviour impact on energy

Most professionals highlighted that occupants use portable heaters even when air-conditioning systems are already running. This massively changes the setpoint temperature and leads to high energy consumption. Likewise, occupant windows and doors behaviours influence energy consumption under similar conditions. Other impacts were due to the occupants leaving computers and lights running overnight. This lighting behaviour was most visible in the public areas in the University buildings. *"The lights are often left on in communal spaces and smaller rooms like kitchens and the printing room because people assume other people will be coming back or the last person who leaves the building will turn off the lights. Few people turn the lights off whenever they leave a room" (FM1).*

However, this view is not shared by SMs. For example, *SM1* argued that *"most energy consumption is outside occupant behaviours."* Similarly, *SM2* stated, *"Carbon emission reduction due to switching away from fossil fuels dramatically impacts energy consumption."* From their point of view, even though occupant behaviours can help reduce energy targets, there are only marginal energy savings. These statements undermine the energy impact that various occupants can make upon the building while utilising building systems (e.g., heating/cooling, lighting, doors/windows, shades), equipment, and appliances (e.g., computers, portable heaters). Also, they appear to prioritise primary energy over end-use energy.

6.4.4 Occupant-centric energy culture

Building managers' measures to improve indoor conditions should be guided by occupants' comfort preferences, energy behaviours, and other influential factors. Accordingly, technologies like occupant-centric intelligent controls such as thermostats and occupancy sensors in heating/cooling and lighting are already in place. However, this automation is perceived to limit occupants' energy-wasteful behaviours rather than improve indoor conditions for occupants' comfort. For example, *"occupancy sensors are used in the teaching spaces and lecture theatres to control the lighting and heating/cooling requirements as per the presence of the occupants in an area" (FM1).* More specific to the comfort aspects of occupants, preheating and panel heaters are provided to certain colder areas of the buildings during winter and intermediate seasons. For example, *FM3* said they *"try to preheat the buildings in the morning in winter so that the occupants will not be walking into a cold building."* Notwithstanding, most energy-saving strategies were delegated to automation and management systems for energy management purposes (e.g., BMS, occupancy controllers), while FMs give up occupant comfort. For example, *"We spent much time and money upgrading integrated systems such as air-conditioning, heating, and ventilation to get better energy efficiency and control" (FM3).*

The facilities management relies on occupants to turn off computers and lights when BMS is not operating at night. Introducing automation and management systems limits the occupants' influence on building energy use; however, adding more responsibility on building managers, who are accountable for the energy bills resulting from occupants' actions. Along these lines, if enabled more authority for occupants while increasing access to building controls can reduce the occupants' impact on energy consumption. Likewise, SMs suggest giving individual autonomy over how occupants use their workspace, educating them to cope with those strategies, and sharing feedback on energy use. Thereby, occupants are better positioned to help the organisation's energy culture. As sustained by the SMs:

- *"Through awareness and education, occupants will be most compliant with space and carry out their work effectively. Significantly, providing energy feedback to occupants may positively impact occupants, where they may tend to have a second layer of cloth rather than adjust the heating. The occupants should be educated not to open windows when the heating and air-conditioning systems are in place and running" (SM1).*
- *"We can put thermometers where people have access and display information in the workplace. All energy reduction targets that raise awareness and compliance could be introduced in principle. Working with the facilities management team has a future scope in both areas. I firmly believe that making people much more aware of how the spaces are best used and what they can do to help achieve energy targets is a crucial approach to overcoming the impact of occupant behaviours on the energy consumption of our buildings (SM2).*

However, the FMs did not share the view about providing feedback to occupants due to ongoing feedback, and review is quite time-consuming due to the number of buildings they must manage simultaneously. Although FMS added a commitment to consider greater energy efficiency in buildings; however, they are not necessarily front of mind for decision-makers because there is a predominant financial bottom line engaged with improving occupant comfort in buildings.

6.5 Discussion

The above section includes research findings discussed under four themes around occupants' influence on energy consumption of buildings: IEQ beliefs and comfort-related aspects, factors influencing occupant behaviours, behaviour impact on energy, and occupant-centric energy culture. Table 6.5 summarises the theoretical perspectives of building occupants and managers based on these findings. These theoretical perspectives outline the practical issues and current approaches to addressing occupants' energy influence. Therefore, we discuss how these theoretical perspectives influence the overall energy culture of organisations and how we can improve the companies' facilities management approach towards occupants.

Table 6.5 Summary of findings regarding the improving facilities management approach

Theme	Theoretical Perspectives
Comfort-related aspects	Perceived indoor environmental discomfort
	Effects on occupants
	FM responsibility
Factors influencing occupant behaviours	Environmental aspects
	Contextual aspects
	Social-psychology aspects
Behaviour impact on energy	Primary impacts
	Marginal savings
Occupant-centric energy culture	Automation and management systems
	Knowledge and awareness
	Authority
	Decision making

Most building occupants revealed discomfort in thermal, air quality, lighting, and noise parameters, which indicates that mainly these discomforts were due to the lack of facilities management-related improvements in buildings. On the other hand, occupant satisfaction was observed with FMs' timely approach to technical and services-related issues and the availability of access to building controls. As Heydarian et al. (2020) described, when occupants are dissatisfied with how internal IEQ parameters operate, they tend to adapt the surrounding environment to their comfort level through their behaviours. If this way of occupants getting into building systems and equipment is oversimplified at the design stage, it will lead to an unexpected increase in energy consumption (Deuble & de Dear, 2012; Schakib-Ekbatan et al., 2015; Schweiker et al., 2018). This may also lead to poor building maintenance over the issues relating to the initial design by the building management. To what extent do building managers recognise the occupants' comfort and impacts determines the energy strategies that must be implemented within a particular organisation.

SMs interpret that environmental and contextual factors are somewhat speculative compared to the influence of social-psychology factors on individuals. In contrast, the literature highlights that the complex nature of occupant behaviours is due to several factors' combined effects. FMs interpret those as the most common factors like temperature, fresh air supply, building envelope and façade, and occupancy related. Valuable insights into social-psychology aspects are necessary for realistic energy estimations (D'Oca et al., 2017) and for maintaining comfortable thermal, air quality, lighting, and acoustic levels. Such understandings will influence the building managers' approach to occupants' interactions with building systems and equipment and resolve their comfort-related issues.

A contrasting scenario relates to the occupant behaviours' influence on energy. FMs recognised a significant impact from the occupants' lighting, computer, and heating appliance usage behaviour, and changes in these behaviours save significant energy. In contrast, SMs considered these savings are marginal compared to carbon emission targets and the related energy improvements that could be implemented in the university. However, the perception of SMs underestimates the energy impacts like plug loads when occupied (Gunay et al., 2016) and the significant energy-saving potentials of occupants (Pothitou et al., 2016).

It is shown that significant attention was given to building automation and management systems to improve the energy efficiency of buildings while limiting the occupants' engagement with building and technical systems. A lack of concern over occupant comfort-related issues is also visible in how FMs engage with the building and its occupants. On the other hand, SMs are attributed to giving the occupants authority around their workspace, knowledge, and awareness to cope with energy-saving opportunities. For example, providing energy-related feedback to occupants is significant to getting support from occupants. However, the FMs considered this a time-consuming task. Also, building managers' approach towards occupants' energy behaviours depends on considering top town strategic management and economic concerns. Ultimately, building managers execute energy-efficient investments in buildings prioritised by building owners (Day & O'Brien, 2017). In this context, the study reveals that building managers must bring these different views together and integrate them to maximise occupants' energy-saving potential.

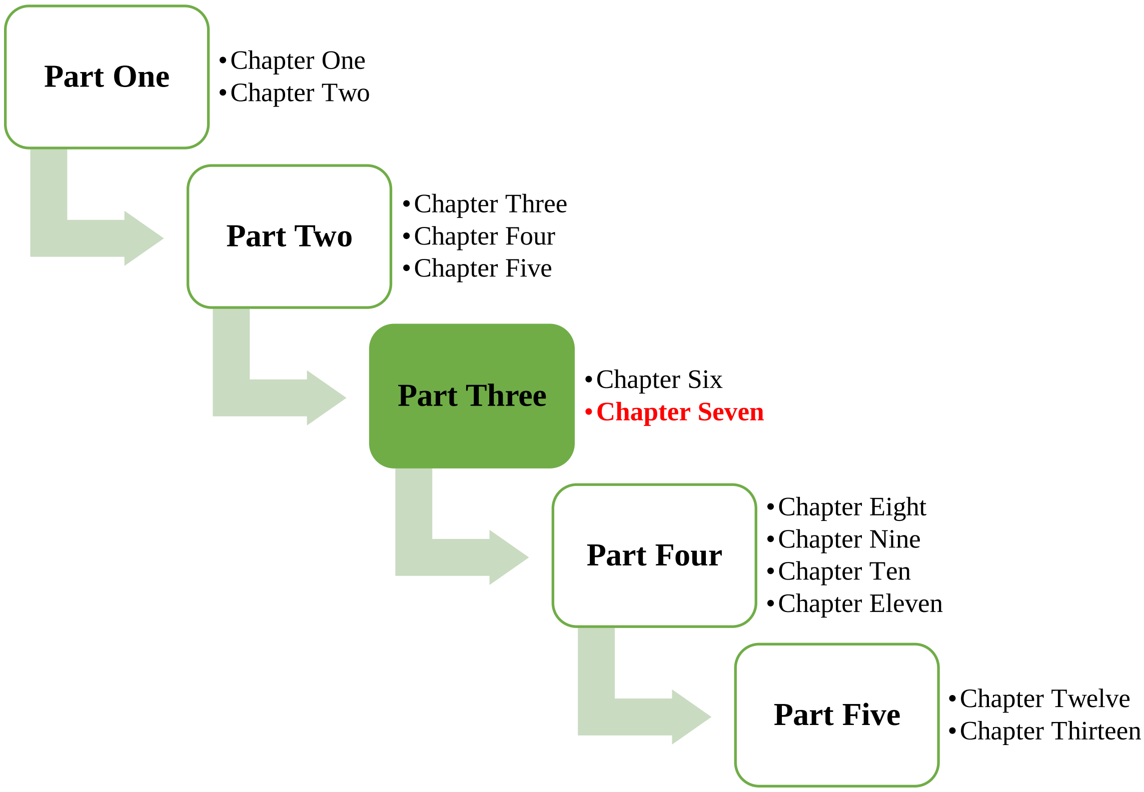
6.6 Conclusion

The current study discussed the building occupants' and building managers' perceptions regarding the impact of occupant behaviours on energy use. Additionally, this study identified a set of theoretical perspectives that outlines the perceived indoor environmental discomfort, effects, and FMs' responsibility as per occupants' perceptions, environmental, contextual, and social-psychology aspects influencing occupant behaviours, immediate impacts, and marginal savings from occupants, automation and management systems, knowledge and awareness, authority, and decision making as per the views of building managers. The following highlights the practical implications of the current study for the industry and the research, research limitations, and further research.

Implementing energy-saving improvements like automation and management systems was at the forefront of building managers' thinking. These technological improvements somewhat limit the occupant control over building systems and corner them into dissatisfaction; thus, the energy impacts of occupant behaviours continue. The study supports building managers in understanding occupants' discomforts, energy impacts, and social-psychology influence on individual behaviours, thereby contributing to decision-making. The study enables how occupants feel the indoor environment and how building managers prioritize the occupants' comfort and behaviours, thereby influencing building managers to embrace occupants to the companies' energy culture. Through channelling knowledge and awareness, energy feedback, and more responsibility for their impact on energy, the building managers may change the energy behaviour of occupants. Furthermore, FMs can integrate their perception of occupant engagement into the top-down decision-making structure and achieve the energy reduction targets of the company.

Knowledge of multi-domain comfort stimuli and the influence of environmental, contextual, and social-psychology factors on occupant energy behaviours are essential to consider alongside the advanced building design and technology to achieve energy reduction goals. The current study provides occupants' perspectives on IEQ beliefs, comfort preferences, and building managers' awareness and approaches towards occupant energy behaviours. These findings contribute to the existing research and literature to rationalise organisational energy culture concerning occupant-centric building design and operation. Furthermore, it highlights the significance of building managers in preparing occupant-centred energy policies and contributes to the multi-disciplinary approaches involved in research in this field. The research contributes to the missing link between occupant comfort preferences and occupant behaviour in the New Zealand context.

The current limitations of the study are building managers reflecting the company's strategic energy plan instead of their perspectives and the context-specific limitations (e.g., single case, tertiary office buildings, New Zealand context). Therefore, to refine the current study's findings, future research avenues should be considered in perceptions collected from multiple cases, studying different office buildings (e.g., commercial and educational), and expanding the research to different countries. Also, the current study is limited to the perceptions of the occupants and building managers. The themes and sub-themes that emerged from the study, such as multi-domain comfort stimuli and the influence of environmental, contextual, and social-psychology factors, need further investigation. Quantitative methods such as surveys (with a representative sample) and advanced statistical analysis methods could complement the current study by developing a comprehensive framework that evaluates occupant energy behaviours in office buildings.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7.0 Environmental and socio-psychological drivers of building users' behaviours: A case study of tertiary institutional offices in Auckland

Abstract

Better identification of comfort preferences and occupant behaviour drivers is expected to improve buildings' user-centred designs and energy operations. In order to understand the underline drivers of occupant behaviours in office buildings, this study evaluated the interrelationships among occupant energy behaviours, IEQ satisfaction, user control, and social-psychological factors influencing occupant behaviours in New Zealand offices. This study uses an occupant perception survey to identify behaviour patterns based on multi-domain comfort preferences. A case study was conducted in five University office spaces in Auckland, New Zealand. Data were collected from 52 occupants and analysed using descriptive and binary logistic regression analysis. IEQ, user control, motivation, opportunity, and ability factors were the independent variables considered. A model to predict the behaviours using environmental, building, and social-psychological aspects were developed. Results showed that the primary sources of IEQ discomfort were related to thermal and air quality, while occupants' IEQ satisfaction correlated with their comfort preferences. The outcomes emphasise how the connection between building systems and occupants' comfort preferences affects the choice of occupant behaviours in offices. Also, the primary occupant behaviours were drinking hot and cold beverages, opening/closing windows and internal doors, and adjusting clothing. The binary logistic regression analysis showed that occupants' perceived user control satisfaction is the main driver for increasing window actions. No other independent variable showed a statistically significant association with other behaviours. This study adopted a novel approach to assess the combined effects of comfort preferences, occupant energy behaviours, and various environmental, building and social-psychological factors for modelling energy-saving behaviours in office buildings.[5]

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[5] This chapter is based on the following published Journal article:

Weerasinghe, A.S., Rasheed, E.O., & Rotimi, J.O.B. (2022). Environmental and socio-psychological drivers of building users' behaviours: A case study of tertiary institutional offices in Auckland [Article]. *Journal of Facilities Management*. https://doi.org/10.1108/JFM-01-2022-0011

7.1 Introduction

Energy use by global building and construction sectors is rapidly increasing, while the end-use of built environments produces 36% of the global final (IEA and the UNEP, 2019). Literature highlights that people spend almost 90% of their time indoors, as a significant cause of continuous energy consumption (Abdulaali et al., 2020). Building occupants interact with building systems and components such as windows, doors, blinds/shading, lighting, heater, air conditioning, hot water, and electrical appliances to create a comfortable indoor environment (Delzendeh et al., 2017). These actions aim to improve occupants' thermal comfort, acoustic comfort, visual comfort, and IAQ, ensuring an optimised IEQ in buildings (Bluyssen, 2019).

Considerable attention has been given to understanding different occupant behaviours and analysing their impact on energy. Initiatives such as IEA-EBC Annex 66 provide a methodological framework for data collection, representation, evaluation, and integration of behaviour models (Yan et al., 2017). The outcomes of Annex 66 were the provision of guidelines to monitor and collect data for occupant behaviours and occupancy, report on existing occupant behaviours modelling and model evaluation methods and provide information on occupant behaviours case studies, large-scale surveys, and simulation modules. Furthermore, IEA-EBC Annex 53 contributes to occupant behaviours research to improve the predictions of the total energy use in buildings (Yoshino et al., 2017). This initiative employed an interdisciplinary approach to analysing and evaluating building energy use, integrating social and behavioural science, architectural engineering, building science, and computer modelling and simulation. Nevertheless, further studies must address the multiple comfort preferences of occupants, occupant-centric building design and operations, and human-building interactions through big data and advanced sensing and modelling (O'Brien et al., 2020).

Additionally, occupant satisfaction and acceptable thermal, air quality, visual, and acoustic comfort are studied (Bluyssen, 2019; Yun et al., 2008). It is also clear that occupant comfort preferences and needs drive human building interactions (Ozcelik et al., 2019). Furthermore, occupants are exposed to multi-domain sources of discomfort that continually affect their comfort satisfaction inside buildings (Heydarian et al., 2020). For example, occupants may be exposed to excessive cold when the HVAC is running, while they may feel too warm when natural ventilation occurs (De Vecchi et al., 2017). Moreover, occupants tend to open the windows and blinds to let more daylight in and close them to reduce overheating during the summer (Bavaresco et al., 2021). Accordingly, the occupant behaviours depend on their exposure to “no discomfort” or “multi-domain discomfort” situations (Ozcelik et al., 2019). Furthermore, occupants first tend to adjust the shades and blinds under simultaneous visual and thermal discomfort, while if a no-discomfort situation exists, their first choice is to adjust the desk fan (Ozcelik et al., 2019). Therefore, O’Brien et al. (2013) recommended adjusting blinds and shades under multi-domain comfort preferences. In addition to the primarily concerned thermal comfort aspects, studies suggest including comfort aspects like indoor air quality and noise level as triggers of window adjustment behaviour (Fabi et al., 2013; Haldi, 2010). Recently, another study highlighted that assessing and understanding how occupants use different building systems is still necessary while enriching knowledge about multi-domain comfort stimuli for occupant behaviours (Day et al., 2020)

However, predicting occupant energy behaviours is challenging due to their stochastic and complex nature. Accordingly, the DNAS framework standardises building monitoring, modelling, and simulating occupant energy behaviours (Hong, D'Oca, Turner, et al., 2015). To this end, many studies explored various drivers of occupant energy behaviours, where the influence of environmental and contextual drivers was proven first. For example, authors showed that temperature is the primary physical environmental trigger that drives the window opening and closing (Schakib-Ekbatan et al., 2015) and adjusting thermostats (Corgnati et al., 2014; Sarran et al., 2021) in residential and office buildings. The extended version of the DNAS framework includes demographic or physiological drivers that influence occupant behaviours (Putra et al., 2021). For instance, residential and office energy studies considered physiological factors such as gender, age, and metabolic heat (He et al., 2021; Sintov et al., 2019). Furthermore, nine contexts were introduced where building designers have the most significant control over occupant energy behaviour, including building and time-related factors (O'Brien & Gunay, 2014). All these factors that affect occupant energy behaviours may be crucial for occupants to reach the best indoor environment. Nevertheless, earlier research lacks broader views and has been limited to specific behaviours like window operation and HVAC adjustments (Harputlugil & de Wilde, 2021). Further studies on clothing and drinking beverages are essential in the office environment (Day & Gunderson, 2015; Deme Belafi, Hong, et al., 2018) that are driven by indoor temperature, local climate, metabolic rate, and gender of occupants (Chen & Chang, 2012; Schiavon & Lee, 2013; von Grabe, 2020). The energy modellers overestimate the occupants' clothing insulation in building energy simulation (BES) programs (Gauthier & Shipworth, 2014; Mustapa et al., 2016).

However, occupant behaviours can still be varied under similar indoor conditions in offices (Neves et al., 2020). Therefore, the importance of social-psychological factors relating to occupant behaviours research was introduced to uncover valuable insights from subjective aspects of occupant behaviours in buildings. For instance, social cognitive theory and the theory of planned behaviour were integrated into the DNAS framework (D'Oca et al., 2017). Also, the literature supports the impact of behavioural beliefs, normative beliefs, subjective norms, and PBC (Bavaresco et al., 2020; Bavaresco et al., 2021). Similarly, some of these factors were categorised and integrated into an MOA framework, incorporating social-psychological aspects derived from the NAM and the TPB (Li et al., 2019). The authors used the MOA framework to determine the factors influencing energy-saving behaviours in the office environment.

Assessing the combined effects of comfort preferences, occupant energy behaviours, and various influential drivers is a ground-breaking approach to modelling occupant behaviours for BPS (Carlucci et al., 2020). For instance, a recent study presented the interrelations between multi-domain comfort preferences with human building interactions that address occupant behaviours relating to windows, blinds/shades, HVAC, and lighting in office settings (Bavaresco et al., 2021). Nevertheless, future research intends to extend the identification of multi-domain triggers for the rest of the occupant behaviours, such as adjusting clothing, occupant presence, and other appliances (i.e., fans, heaters, kitchen appliances) usage. Although the recent studies considered environmental, contextual, and personal factors while highlighting subjective aspects such as attitude, subjective norms, and PBC (Bavaresco et al., 2021; Schweiker et al., 2020), further studies are necessary to address the uncertainties associated with selecting most appropriate variables for energy behaviour simulations. It is believed that some behaviours like windows, blinds, fan, and heater operations are still effective in keeping the occupants in comfort without compromising the energy thresholds of the buildings (Lee & Malkawi, 2014). Especially multidisciplinary and international relationships are recommended to provide new insights into occupant adaptive behaviours (D'Oca, Hong, et al., 2018). Research must be extended to different climate zones or countries to find the variations of behaviours in different contexts, cultures, climates, and socio-economic backgrounds (D'Oca et al., 2019; Rupp et al., 2021). In particular, further research is required to understand comfort-related aspects and social-psychological factors influencing energy-saving behaviours in office buildings. The accuracy of occupant energy modelling could be improved for future applications in this arena. Also, disseminating such research findings to building practitioners will enable them to improve the IEQ in offices based on occupant characteristics. This research addresses this critical knowledge gap by focusing on a theoretical framework integrating comfort-related and social-psychological factors.

7.1.1 Purpose of this study

In order to understand the underline drivers of occupant behaviours in office buildings, this study evaluates the interrelationships among occupant energy behaviours, IEQ satisfaction, user control, and social-psychological factors influencing occupant behaviours in New Zealand offices. Better identification of comfort preferences and occupant behaviours drivers is expected to improve buildings' user-centred designs and energy operations. This study proposes a theoretical framework by incorporating previous research findings on the influence of IEQ satisfaction, user control, and social-psychological drivers on occupant behaviours. Based on the proposed framework, a survey was conducted in a selected university case study in New Zealand, and a logistic regression analysis was conducted to test the proposed framework and research hypotheses. The paper is organised as follows:

- Section 7.2 introduces the theoretical framework and discusses the research hypothesis
- Section 7.3 explains the research design, data collection, including variables, building and occupant profiles, and the data analysis techniques
- Section 7.4 presents and discusses the results and the hypotheses' validation
- Section 7.5 concludes the research findings, including research implications, limitations, and further studies

7.2 Theoretical framework and hypotheses

This study developed a theoretical framework to analyse the determinants of occupant energy behaviours considering the environment, building, and social-psychological backgrounds in the office spaces. In the theoretical framework, the five main factors: IEQ satisfaction, user control, motivation, opportunity, and ability, are essential drivers of occupant behaviours (Refer to Figure 7.1).

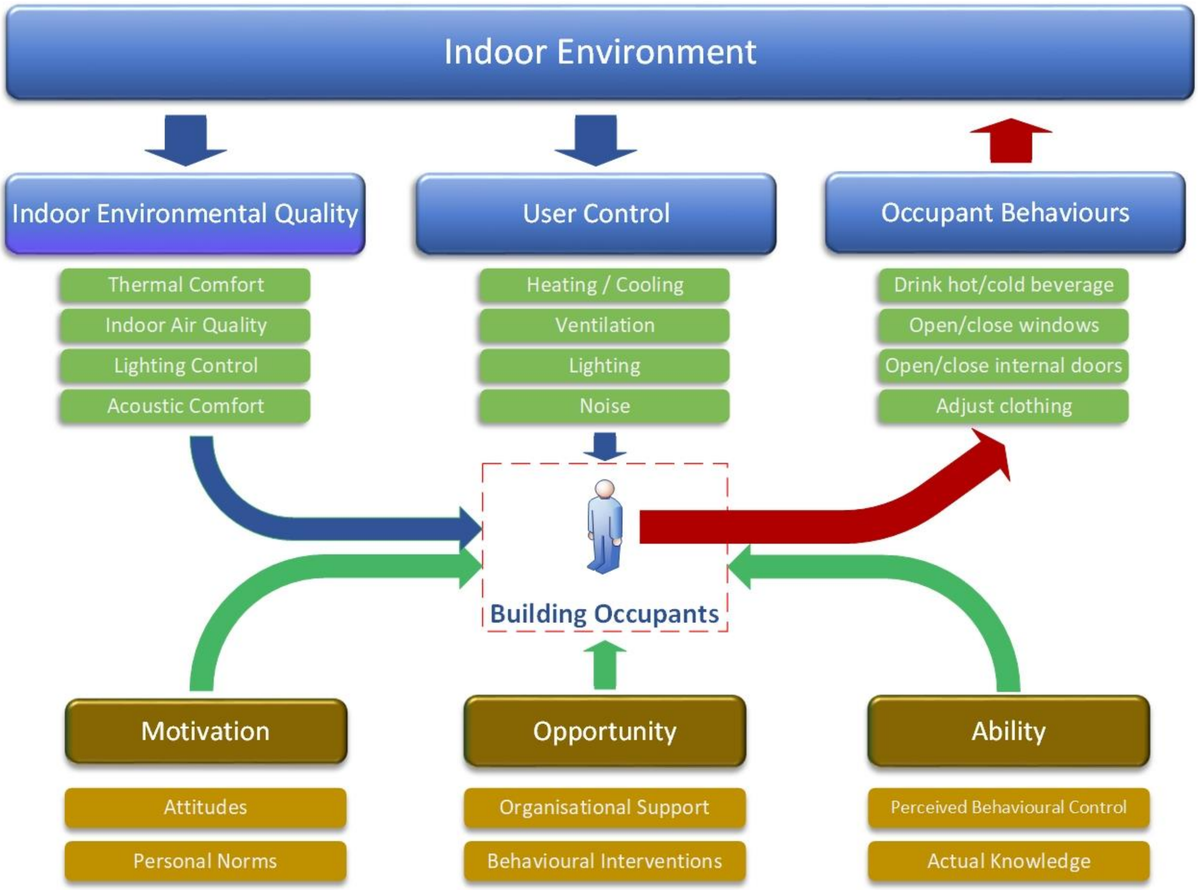


Figure 7.1 The theoretical framework for the study

Adapted from Bavaresco et al. (2021), D'Oca et al. (2017), Hong et al. (2015) Li et al. (2019)

The big picture of occupant behaviours research and the DNAS framework to represent energy-related occupant behaviours explain the several types of occupant energy behaviours to guide future research (Hong, D'Oca, Turner, et al., 2015; Hong et al., 2017). IEQ satisfaction and user control are derived from environmental and building factors influencing occupant behaviours, and they are collectively considered to represent occupants' comfort preferences. Occupant behaviours are believed to improve IEQ satisfaction in buildings via increased thermal, aural, visual, and IAQ comfort (Bluyssen, 2019). However, the way occupants interact with these systems and the built environment may be inconsistent with the initial design parameters of the building (Deuble & de Dear, 2012; Schakib-Ekbatan et al., 2015). Also, it causes a change in the use of electrical equipment and occupancy patterns than what was assumed in the design phase (Schweiker et al., 2018). Similarly, the building factors, such as the access for controlling heating, cooling, ventilation, and lighting, as necessary (Fabi et al., 2013). For example, with the opportunity to interact with the building controls, occupants are empowered to operate the building systems (Deuble & de Dear, 2012; Schakib-Ekbatan et al., 2015).

Aside from the environmental and building-related drivers, previous studies include other drivers of occupant behaviours in offices, namely time-related factors (Peng et al., 2012), contextual factors (Deme Belafi, Hong, et al., 2018; Wagner et al., 2018), the DNAS framework (Hong, D'Oca, Turner, et al., 2015), synthesis of physical and social-psychological factors (Hong et al., 2017), subjective and comfort-related drivers (Bavaresco et al., 2021). Thus, occupant behaviours are rationalised by their intentions in combination with behavioural controls, which aligns with the TPB (Ajzen, 1991). TPB predicts intentions through a cognitive approach using subjective norms and perceived behavioural controls (Ajzen, 1991; Shi et al., 2017), assuming that decisions to conduct certain behaviours are made based on the available information and knowledge (Ajzen, 2002; Xuan Liu et al., 2021). TPB could explain pro-environmental behaviours related to energy consumption using psychological factors/variables (Ajzen, 2002).

In this study, the MOA model is derived by integrating TPB and the NAM (Li et al., 2019), and under each of the motivation, opportunity, and ability factors constructs are the social-psychological aspects influencing occupant behaviours. Accordingly, motivation relating to energy captures occupants' "needs, values, concerns, and involvements in saving energy at the workplace performing the energy-saving behaviours (Li et al., 2017). The theoretical framework includes motivation factors: attitudes and personal norms directly affecting occupants' environmental intention and behaviour (Kim & Seock, 2019; X. Zhang et al., 2018). Opportunity includes the organisational factors external to the individuals but influences their energy-saving intentions (Michie et al., 2011). An organisation's encouragement to save energy supports occupants' pro-environmental behaviour (Xu et al., 2017), while introducing behavioural interventions further improves these energy-saving behaviours (Mulville, 2017). Therefore, the theoretical framework included organisation support and behavioural interventions contributing to opportunity. Ability is the psychological and physical capabilities required to interpret the information on energy-saving behaviour (Michie et al., 2011). The factors like PBC, perceived knowledge, and the actual knowledge of the building occupants explain their ability to save energy (Li et al., 2019). The PBC perceives the ease or difficulty of performing any behaviour (Ajzen, 2006).

Furthermore, actual knowledge reflects the ability to know energy-related facts, and perceived knowledge is the prior knowledge of energy use to achieve energy-saving behaviour. Thus, this study's theoretical approach includes PBC and perceived knowledge.

7.2.1 Research hypothesis

Five hypotheses were tested in the study considering the five independent variables selected for the binary logistic regression analysis. The null hypotheses (H0) were rejected if the significance level was ≤ 0.05 and were accepted the alternative hypotheses (H1). The hypothesis tested is listed here:

- $H0_1$ – IEQ satisfaction does not influence the occupant behaviours
- $H1_1$ – IEQ satisfaction influences the occupant behaviours
- $H0_2$ – User control does not influence the occupants' behaviours
- $H1_2$ – User control influences the occupant behaviours
- $H0_3$ – Motivation does not influence the occupants' behaviours
- $H1_3$ – Motivation influences the occupant behaviours
- $H0_4$ – Opportunity does not influence the occupants' behaviours
- $H1_4$ – Opportunity influences the occupant behaviours
- $H0_5$ – Ability does not influence the occupants' behaviours
- $H1_5$ – Ability influences the occupant behaviours

7.3 Methods

The methodological design presented in the current study scope is more related to the descriptive (explanatory) research purpose, positivism philosophy, deductive approach, and survey strategy. The descriptive nature of the study explains causal relationships among variables instead of the exploratory study that develops a conceptual model and a set of hypotheses for further inquiry (Saunders et al., 2019). The deductive approach involves the development of a theory that is then subjected to a rigorous test through a series of hypotheses and is most likely to be underpinned by positivist research philosophy (Saunders et al., 2019). Following the survey strategy, a questionnaire was used to study occupants' energy-related behaviours and develop occupant energy models (Day & O'Brien, 2017). The occupancy survey provides more insights than experiments and field observations regarding various factors influencing behaviours (Hong et al., 2017). Accordingly, an online questionnaire was distributed through the Qualtrics Survey platform from October 2020 to January 2021. Individual questionnaire links were emailed to potential respondents among university staff and PhD students who regularly occupied the office spaces in the selected five buildings and asked them to complete the survey.

7.3.1 Dependent and independent variables

As explained in the theoretical framework, the study investigates the causal relationships between the dependent variable: occupant behaviours, and the independent variables: IEQ satisfaction, user control, motivation, opportunity, and ability. Table 7.1 shows the aspects surveyed, associated survey questions, and responses to capture the occupants' perceptions for analysis.

As seen in Table 7.1, the dependent variable of the current scenario is the possibility of an occupant showing a primary energy behaviour, which was measured using binary levels yes=1 and no=0. All occupant behaviours considered in the study were listed in Table 5 alongside the relevant occupant comfort preferences.

Regarding independent variables, the IEQ satisfaction variable was surveyed in different IEQ parameters: thermal and air quality, lighting comfort, and acoustic comfort. Respondents were asked to state the level of satisfaction with each IEQ parameter using a 7-point Likert-type scale (1-completely dissatisfied to 7-completely satisfied). The binary logistic regression analysis considered the mean score of IEQ parameters. Next, the extent of user control available for heating, cooling, ventilation, lighting, and noise was surveyed, asking, "How much control do you personally have over your working environment's heating systems and appliances?". These controls were evaluated separately using a 7-point Likert-type scale (1-no control to 7-full control). After that, the mean score of each control was considered in the binary logistic regression analysis. The occupants' subjective perspectives on the social-psychological factors: motivation, opportunity, and ability, were measured using a 7-point Likert-type scale (1-strongly disagree and 7-strongly disagree). The respondents agreed on statements that indirectly measure these three parameters. The mean score of the statements under each parameter was continued for the regression analysis.

Table 7.1 Variables used and their coding

Aspects surveyed		Survey Question	Response	Variables
Gender		What is your Gender?	Male/Female	N/A
Age		What is your age?	Below 25, 25 – 34, 35 – 44, 45 – 54, Above 55	N/A
Ethnicity		How do you describe your ethnicity?	European, Māori, Asian, Pacific Peoples, African, and Other	N/A
Office type		Is your office or a normal work area?	Private room, shared office, open-plan office	N/A
Occupancy - working days		How many days do you spend in the building in a typical working week?	Less than 5 days/5 days or more	N/A
Occupancy - working hours		How many hours per day do you usually spend working on a computer screen?	Below 8 hours/8 hours or above	N/A
Occupant preferences		What changes do you expect in your work area by exercising the above adjustments?	Yes/No	N/A
Occupant behaviours		Which of the following adjustments do you personally exercise in your work area?	Yes/No	Dependent Variable
IEQ satisfaction (Environmental factors)	Thermal and air quality in winter	Overall thermal and air quality in winter	7-point Likert-type scales 1 – completely dissatisfied 7 – completely satisfied	Independent variable 1 (Mean score of IEQ factors)
	Thermal and air quality in summer	Overall thermal and air quality in summer		
	Lighting comfort	How would you describe the lighting quality in your regular work area?		
	Acoustic Comfort	How would you describe noise in your regular work area?		
User control (Building factors)	Heating control	How much control do you personally have over your working environment's heating systems and appliances?	7-point Likert-type	Independent variable 2 (Mean

	Cooling control	How much control do you personally have over your working environment's cooling systems and appliances?	scales 1 – no control 7 – full control	score of user control factors)
	Ventilation control	How much control do you personally have over your working environment's ventilation systems and appliances?		
	Lighting control	How much control do you personally have over your working environment's lighting systems and appliances?		
	Noise control	How much control do you personally have over your working environment's noise systems and appliances?		
Social-psychological factors	Motivation – Attitudes and personal norms	Motivation 1 - Saving energy at work is essential to me.	7-point Likert-type scales 1 – strongly disagree 7 – strongly agree	Independent variable 3 (Mean score of motivational factors)
		Motivation 2 - I change my behaviours to increase my performance/ productivity.		
		Motivation 3 - Actions I take to save energy depending on my comfort needs and preferences.		
	Opportunity – Organisational support and behavioural interventions	Opportunity 1 - The building manager's feedback on individual energy use is essential for changing my behaviour.		Independent variable 4 (Mean score of opportunity factors)
		Opportunity 2 - The building manager often sends energy use feedback.		
		Opportunity 3 - The building manager encourages me to be more energy-efficient		
	Ability – Perceived behavioural control and knowledge	Ability 1 - Doing something positive for the environment is desirable.		Independent variable 5 (Mean score of ability factors)
		Ability 2 - If I feel slightly cold/warm at the workplace, I will try to put on another layer of clothing/adjust my clothing level rather than use a personal heater/fan.		
		Ability 3 - Closing windows, turning off the lights, heaters, fans, etc., whenever I leave the office, and unplugging appliances when not in use can save energy		

7.3.2 Characteristics of the buildings

The study purposively selected five buildings with office settings, including private rooms, shared rooms, and open-plan offices at a University complex in Auckland, New Zealand. The buildings were equipped with central heating/cooling for most office spaces and split air conditioners for some spaces, while there was no mechanical heating/cooling or ventilation system in other areas. Natural ventilation was applied in those areas through operable windows allowing occupants to control over adjusting the indoor temperature. The inside temperature was variable between 18-22°C in winter and 19-24°C in summer and other seasons. The relative humidity was set between 40 and 70%, and the airspeed was 0.1-0.2 m/s for thermal comfort. An automatic fresh air intake activates when the CO_2 level exceeds 800 ppm, complying with WorkSafe New Zealand's recommended CO_2 level below 1000 ppm inside the building. Table 7.2 presents the details of the selected buildings.

Table 7.2 Profile of buildings

Building	Year of Completion	No. of Floors	HVAC	Glazing	No. of Individual Workstations
Build A	1984	1	Natural ventilation + No mechanical cooling or heating	Single	46
Build B	1995	4	Central heating/cooling	Double	82
Build C	1998	3	Central + Split heating/cooling	Double	96
Build D	1993	2	Central heating/cooling	Double	12
Build E	1998	6	Central heating/cooling	Double	21

7.3.3 Respondent demographics

The selected buildings have a population of 257 office occupants that count as staff and PhD students who regularly work on the buildings. Structured online questionnaires were sent to the total population of these buildings through the relevant school administrators, where 52 completed responses were achieved, making up a response rate of 20%. The data collection was conducted from October 2020 and January 2021. Usually, a sample with ten or more events per variable (EPV) is considered less biased (van Smeden et al., 2019). However, Vittinghoff and McCulloch (2007) found that confidence interval coverage, type I error, and relative bias problems are reasonably frequent when EPV=2–4, uncommon when EPV=5–9 EPV, and still observed when EPV=10–16. Therefore, the logistic regression analysis sample size was calculated using $N = EPV \times p/events\ fraction$, where EPV=5 (Vittinghoff & McCulloch, 2007) and the events fraction = ½ (van Smeden et al., 2019).

Given the five variables (p) in the current study, the above equation gives $N = 50$ as the minimum sample size. Table 7.3 includes the respondents' gender, age, ethnicity, and office-type information.

Table 7.3 Demographic information of participants

Demographic Info		Staff and PhD Students	
		Count	Percentage
Gender	Male	27	51.9%
	Female	25	48.1%
Age	25 - 34	24	46.2%
	35 - 44	10	19.2%
	45 - 54	13	25%
	Above 55	5	9.6%
Ethnicity	European	17	32.7%
	Asian	22	42.3%
	African	3	5.8%
	Other	10	19.2%
Office Type	Private office	18	34.6%
	Shared Space	22	42.3%
	Open-plan Office	12	23.1%

7.3.4 Data analysis

Descriptive or correlational methods are considered the backbone of studies when assessing the impact of occupant behaviours on the energy consumption of buildings (Wagner et al., 2018). Considering the above and the dichotomous nature of the dependent variables of the current study, the authors adopted descriptive and binary logistic regression analysis. Statistical Package for Social Sciences (SPSS) version 27 was used to conduct all statistical analyses.

In the first step, the responses received on IEQ user satisfaction, comfort preferences, and occupant behaviours were analysed using descriptive analysis to find the primary occupant behaviours based on the occupants' responses on comfort preferences and the thermal, air quality, visual, and acoustic user satisfaction levels in the selected case.

Next, binary logistic regression analysis was carried out that allows binary or dichotomous levels of measurements with only two categorical outcome variables for dependent variables (Kassambara, 2018). This statistical method is often used to infer the probability of windows opening based on environmental variables (Haldi & Robinson, 2008; Nicol, 2001; Rijal et al., 2007). Firstly, the assumptions of logistic regression were tested for its application. The dependent variable was measured using binary levels (yes/no), and the observations considered in the current study are independent and do not include repeated measurements.

The following assumption is that there is little or no multicollinearity among the independent variables. The multicollinearity between predictor variables was examined using collinearity statistics (Guerra et al., 2016; Stephanou & Varughese, 2021). However, no formal criterion for determining the expected tolerance value and Variance Inflation Factor (VIF) exists. A tolerance value of less than 0.1 and a VIF greater than 10 show significant multicollinearity (Chatterjee & Hadi, 2006). The logistic regression model is stable if there is no multicollinearity between the predictor variables with no apparent outliers. Based on the collinearity statistics, those variables with strong correlations can be removed from the analysis. Also, outliers were checked, creating box plots of Z-Score values of the independent variables (Kassambara, 2018).

The final assumption is that logistic regression requires the independent variables to be linearly related to the log odds. The linear relationship between the logit of the outcome and each predictor variable was tested, creating and inspecting the logit values (the inverse of the standard logistic function). Afterwards, the binary logistic regression analysis was carried out. The binary logistic model based on more than one predictor is expressed by the logit transformation given in equation 1, which describes a non-linear relationship in a linear form (Field, 2013).

$$\log\left(\frac{p}{1-p}\right) = a + b_1X_1 + b_2X_2 + \cdots + b_nX_n$$

Equation 7.1 Binary logistic model

Where p is the probability of a particular occupant behaviour given the predictor variables with values of $X1$, $X2$, …, Xn, a is the intercept of the equation, and $b1$, $b2$, …, bn are the coefficient of the predictor variables (Bruce-Konuah, 2014). The inverse of the logit transformation provides probability p by using equation 2.

$$\mathrm{p} = \frac{e(a + b_1X_1 + b_2X_2 + \cdots + b_nX_n)}{1 + e(a + b_1X_1 + b_2X_2 + \cdots + b_nX_n)}$$

Equation 7.2 Probability of p

where : e = the exponential function (approx. 2.72)

A significantly smaller model deviance than the null deviance shows that the model is the best fit to describe the outcome. The goodness of fit (R^2) varies between 0 and 1, determining how well the data predicts fits the observed data (Field, 2013). A value close to 1 indicates that the model predicts the outcome perfectly (Field, 2013). The significance of the predictors is measured through the odds ratio (OR) or test.

The logistic regression coefficient (b) is the estimated increase in the log odds of the outcome per unit increase in the exposure, while the exponential function of the regression coefficient (eb) is the odds ratio associated with a one-unit increase in the exposure (Szumilas, 2010). The OR measures the likelihood of an outcome with and without a particular exposure (Szumilas, 2010).

- $OR < 1$ exposure associated with lower odds of an outcome
- $OR = 1$ exposure does not affect the odds of an outcome
- $OR > 1$ exposure associated with higher odds of an outcome

The OR's precision is estimated using a 95% confidence interval (CI). A small CI shows a higher precision, while a large CI indicates a low precision (Szumilas, 2010). In practice, the 95% CI does not measure statistical significance like the p-value, often used as a proxy for the presence of statistical significance if it does not overlap the null value (OR=1) (Szumilas, 2010).

7.3.5 Assumptions tested

The collinearity statistics of predictors were run for the independent variables: IEQ, user control, motivational, opportunity, and ability factors. Based on the findings on IEQ satisfaction and comfort preferences, only the thermal and air quality-related aspects were considered when creating the covariates for IEQ and control. According to the collinearity statistics, the tolerances were more than 0.1, the VIF values were less than 10, and they only moderately correlated (1<VIF<5) with each predictor. The selected predictors can be applied to develop the binary logistic model for occupant energy behaviours due to the non-existence of multicollinearity between predictors.

One outlier (Zscore = -3.32667 < -2.68) was identified, illustrating the box plots of the Zscore values of the predictors. The outlier is related to observations of the Ability factors. Therefore, the outlier was modified using the median value for that observation instead of the mean value. Accordingly, the modified Z value equals -3.06007, which was still less than -2.68. However, the outlier was not eliminated from the dataset, assuming any or minimal impact. The statistics of the binary logistic regression were run by pairing independent variables with their log values. The significance values of the variables are greater than 0.05, and the relationship is not significant. Thus, the assumption is not violated.

7.3.6 The binary logistic regression modelling

The binary logistic regression was used to assess the possibility of drinking hot/cold beverages, opening/closing windows, opening/closing internal doors, and adjusting clothing driven by IEQ, user control, motivational, opportunity, and ability factors.

The goodness of fit statistics helps to determine whether the model adequately describes the data. This was tested using the Chi-square analysis. If the model is significant, this shows that the model shows a good fit and a significant improvement in fit compared to the null model. These test results for each energy behaviour are summarised in Table 7.4. However, only the model "adjust clothing" adequately fits the data, considering the p-value < 0.05. The Chi-square value for the overall "Adjust clothing model" was 13.35 at a significance of 0.020.

Table 7.4 Omnibus tests of model coefficients

Model items	Chi-square	df	Sig.
Drink hot/cold beverages	8.913	5	0.113
Open/close windows	7.811	5	0.167
Open/close internal doors	7.467	5	0.188
Adjust clothing	13.350	5	0.020

Nagelkerke's R Square is an approximate variation indicator of the dependent variable that the predictor variables in the model can account for. Table 7.5 presents the model summary for each dependent variable. Each Nagelkerke R^2 value implies that a combination of IEQ, user control, motivational, opportunity, and ability factors could explain 23.8%, 20.3%, 18.5%, and 31% of the variance in drinking hot/cold beverages, opening/closing windows, opening/closing internal doors, and adjusting clothing observed, respectively.

Table 7.5 Model summary[a]

Model items	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
Drink hot/cold beverage	47.268a	0.158	0.238
Open/close windows	52.768a	0.139	0.203
Open/close internal doors	59.616a	0.134	0.185
Adjust clothing	54.922a	0.226	0.310
a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.			

Table 7.6 indicates how well the developed models can predict the correct category once the predictors are added to the study. The percentage in the first two rows provides information regarding the specificity and sensitivity of the model in predicting group categories on the dependent variable.

Table 7.6 Classification table[a]

Observed		Predicted		
		No	Yes	Percentage Correct
Drink hot/cold beverages	No	3	9	25.0
	Yes	2	38	95.0
Overall Percentage				78.8
Open/close windows	No	5	9	35.7
	Yes	1	37	97.4
Overall Percentage				80.8
Open/close internal doors	No	7	11	38.9
	Yes	5	29	85.3
Overall Percentage				69.2
Adjust clothing	No	9	10	47.4
	Yes	5	28	84.8
Overall Percentage				71.2
a. The cut value is 0.500				

As seen in Table 7.6, specificity or the true negative rate refers to the % of cases predicted by the model to fall into the “no behaviour” category. In contrast, sensitivity or true positive rate refers to the % of cases predicted by the model to fall into the behaviour category. For example, the model correctly predicted that 25% of cases do not drink hot/cold beverages. In contrast, the model correctly predicted 95% of cases of drinking hot/cold beverages. Considering both scenarios, the overall accuracy rate was 78.8%, which is particularly good. Also, the model shows a good sensitivity where 95% were correctly predicted to drink hot/cold beverages based on the model. Likewise, the models for the other behaviours also indicate a good sensitivity. However, the model to predict open/close internal doors has a lower overall accuracy of 69.2% compared to other behaviours.

7.4 Results and discussion

7.4.1 IEQ satisfaction of occupants

Occupants in the selected buildings were asked to rate their comfort in thermal and ventilation in summer and winter, visual comfort, and acoustic comfort. The frequency, percentage, and cumulative percentage of occupants' responses on the given Likert scale of occupant satisfaction with IEQ are shown in Table 7.7.

As shown in Table 7.7, most respondents were satisfied with the office's visual and acoustic conditions due to the Venetian blinds and roller shades controlling external illuminance levels in the selected buildings. In both cases, most occupants were mainly satisfied with the current conditions. Thus, the selected buildings meet occupants' visual and acoustic comfort expectations.

On the other hand, the cumulative percentage of occupant responses highlighted that most occupants were dissatisfied with thermal and air quality comfort in winter and summer. Although the selected buildings had low-emissivity glazing windows that may be a helpful link in thermal performance by preventing cold in winter and reducing heat penetration in summer, only a few occupants showed satisfaction with thermal and air quality comfort in winter. Also, most of the selected buildings had air-conditioned spaces, and occupants were dissatisfied with the air quality. At the same time, a considerable percentage of occupants were neither satisfied nor dissatisfied, which makes only a slight difference between their satisfaction and dissatisfaction regarding thermal and air quality in summer and winter.

Considering that the selected buildings had mixed-mode ventilation, the results of the current study emphasised the thorough understanding of occupants' thermal and air quality preferences to improve the operation of mixed-mode ventilated buildings and user-centred design. Also, occupants may be exposed to excessive cold when the HVAC is operating, while they may feel too warm when natural ventilation occurs (De Vecchi et al., 2017). For instance, past works show that occupants respond to comfort sensations and environmental discomfort through adaptive behaviours (Haldi & Robinson, 2008).

Table 7.7 IEQ satisfaction levels

Likert Scale Levels	Thermal and air quality in winter			Thermal and air quality in summer			Visual comfort			Acoustic comfort		
	Frequency (F)	Percentage (P)	Cumulative (C)	F	P	C	F	P	C	F	P	C
Completely dissatisfied	3	5.77%	5.77%	7	13.46%	13.46%	0	0%	0%	2	3.85%	3.85%
Mostly dissatisfied	7	13.46%	19.23%	5	11.54%	25.00%	1	1.92%	1.92%	5	9.62%	13.47%
Somewhat dissatisfied	13	25.00%	44.23%	13	25.00%	50.00%	4	7.69%	9.61%	8	15.38%	28.85%
Neither satisfied or dissatisfied	9	17.31%	61.54%	10	19.23%	69.23%	6	11.54%	21.15%	10	19.23%	48.08%
Somewhat satisfied	4	7.69%	69.23%	8	15.38%	84.61%	7	13.46%	34.61%	3	5.77%	53.85%
Mostly satisfied	10	19.23%	88.46%	8	15.38%	99.99%	21	40.38%	74.99%	18	34.62%	88.47%
Completely satisfied	6	11.54%	100%	0	0%	100%	13	25.00%	100%	6	11.54%	100%

Furthermore, as those parameters may strongly link occupants' actions, it is critical to discuss the effect of perceived satisfaction of IEQ aspects on occupant behaviours (Yun et al., 2008).

7.4.2 Comfort preferences and occupant energy behaviours

The occupant comfort preferences and energy behaviours are presented in Table 7.8 alongside the frequency and percentage of respondents who selected each choice.

Table 7.8 Comfort preferences and occupant energy behaviours

Comfort Preferences	F	P	Occupant behaviour	F	P
To let in fresh air	38	73.08%	Drink hot/cold beverages	40	76.92%
To feel warmer	37	71.15%	Open/close windows	38	73.08%
To feel cooler	33	63.46%	Open/close internal doors	34	65.38%
To increase air movement	32	61.54%	Adjust clothing	33	63.46%
To avoid outdoor sounds	22	42.31%	Turn lights on/off	31	59.62%
To avoid glare	16	30.77%	Adjust shades and blinds	31	59.62%
To feel healthier	15	28.85%	Adjust computer screen/brightness	30	57.69%
To have access to outside view	14	26.92%	Turn off the computer monitor	25	48.08%
To save energy	13	25.00%	Adjust personal heaters	24	46.15%
To increase artificial lighting	10	19.23%	Open/close external doors	22	42.31%
To increase daylighting	9	17.31%	Moving through spaces	21	40.38%
To experience the outdoor climate	8	15.38%	Report discomfort	19	36.54%
To hear outdoor sounds	3	5.77%	Adjust portable/ceiling fans	14	26.92%
To follow management guidelines	3	5.77%	Adjust the room air conditioning unit	10	19.23%
			Adjust thermostats	5	9.62%
			Inaction (None of the above)	1	1.92%
			Adjust computer table	1	1.92%

As seen from Table 7.8, more than 50% of responses were received for the occupant behaviours: drinking hot/cold beverages, opening/closing windows, opening/closing internal doors, adjusting clothing, turning lights on/off, and adjusting shades and blinds. Occupant behaviours relating to windows and doors are interlinked with comfort preferences like letting in the fresh air, feeling warmer and cooler, increasing air movement, and hearing/avoiding outdoor noises (Bavaresco et al., 2021). However, only a few comfort preferences received more than 50% of responses, such as letting in the fresh air, feeling warmer, feeling cooler, and increasing air movement.

Considering other behaviours that received more than 50% of responses, drinking hot/cold beverages and adjusting clothing are more related to the preferences of thermal comforts, such as feeling cooler or warmer, than other comfort preferences. Specifically, these behaviours are related to indoor temperature, local climate, metabolic rate, and gender of occupants (Chen & Chang, 2012; Schiavon & Lee, 2013; von Grabe, 2020). However, the studies on drinking beverages and adjusting clothing are somewhat limited compared to the studies that focused on behaviours that have the most prominent and direct influence on energy, such as windows, lights, shades and blinds, computers, and personal heaters (Bavaresco et al., 2021; Fabi et al., 2013; He et al., 2021). Therefore, further studies on clothing and drinking beverages are essential in the office environment (Day & Gunderson, 2015; Deme Belafi, Hong, et al., 2018).

On the other hand, turning lights on/off and adjusting shades and blinds are more linked to visual comfort-related aspects. Although occupants' lighting behaviour has received a higher response, the concern about increasing artificial and daylighting received a lower response. For instance, Bavaresco et al. (2021) found that occupants adjust lights to increase daylighting or reduce artificial lighting in their study. Regarding adjusting shades and blinds, the current study responded less to most comfort preferences. However, the occupants open the blinds to let more daylight in, access outside view, and warm up the office while closing the blinds to reduce glare, overheating, and privacy (Bavaresco et al., 2021).

Additionally, all other behaviours received a less than 50% of responses. However, adjusting the computer screen/brightness can prevent glare and save energy by enhancing battery life. On the other hand, turning off the computer monitor contributes to energy saving. The results also imply that their attitude toward saving energy influences occupants' comfort-related behaviours. Additionally, only a few occupants expected to follow management guidelines through their occupant behaviours, which showed the significance of individual comfort preferences over managerial concerns. Furthermore, an inadequate response was received on adjusting portable/ceiling fans, room air conditioning units, and thermostats due to the limited availability and accessibility to control these systems. Similarly, a low response was recorded for non-adaptive behaviours such as moving through spaces and reporting discomfort to the building management. Apart from these behaviours, adjusting the computer table was suggested by one occupant. However, the links between those behaviours and comfort preferences are purely hypothetical concerning the lack of literature to strengthen these relationships.

Considering these grounds, the study selected drinking hot/cold beverages, opening/closing windows, opening/closing internal doors, and adjusting clothing as the primary behaviours and continued further analysis using logistic regression.

7.4.3 Occupant energy behaviours and the influence of factors

Table 7.9 Logistic regression coefficients of residential occupant behaviours

Model predictors		B	S.E.	Wald	df	Sig.	Exp(B) /OR	95% C.I.for EXP(B)	
								Lower	Upper
Drink hot/cold beverages	M	-1.128	0.576	3.833	1	0.050	0.324	0.105	1.001
	A	0.816	0.502	2.648	1	0.104	2.262	0.846	6.048
	O	-0.340	0.304	1.253	1	0.263	0.711	0.392	1.291
	IEQ	-0.122	0.402	0.092	1	0.761	0.885	0.402	1.948
	UC	0.040	0.320	0.016	1	0.900	1.041	0.556	1.950
	C	4.376	3.072	2.030	1	0.154	79.523		
Open/close windows	M	-0.124	0.438	0.080	1	0.777	0.883	0.375	2.082
	A	-0.079	0.451	0.031	1	0.861	0.924	0.382	2.237
	O	-0.126	0.303	0.173	1	0.678	0.882	0.487	1.596
	IEQ	-0.585	0.373	2.453	1	0.117	0.557	0.268	1.158
	UC	0.683	0.303	5.091	1	0.024	1.979	1.094	3.581
	C	3.055	3.081	0.983	1	0.321	21.218		
Open/close internal doors	M	-0.634	0.416	2.327	1	0.127	0.530	0.235	1.198
	A	-0.148	0.410	0.131	1	0.717	0.862	0.386	1.925
	O	-0.004	0.272	0.000	1	0.988	0.996	0.584	1.697
	IEQ	0.259	0.372	0.484	1	0.487	1.295	0.625	2.685
	UC	-0.382	0.283	1.823	1	0.177	0.683	0.392	1.188
	C	5.290	2.915	3.293	1	0.070	198.366		
Adjusting clothing	M	-0.607	0.425	2.038	1	0.153	0.545	0.237	1.254
	A	0.493	0.404	1.485	1	0.223	1.637	0.741	3.615
	O	-0.509	0.298	2.926	1	0.087	0.601	0.335	1.077
	IEQ	-0.408	0.380	1.154	1	0.283	0.665	0.316	1.400
	UC	-0.365	0.276	1.750	1	0.186	0.694	0.404	1.192
	C	5.650	2.970	3.620	1	0.057	284.333		
a. Variable(s) entered: **M**otivation, **A**bility, **O**pportunity, IEQ, **U**ser **C**ontrol, **C**onstant									

Referring to Table 7.9, occupants with a higher ability (perceived behavioural control and perceived knowledge) were 2.262 times (CI% 0.846-6.048) more likely to drink hot/cold beverages than those without perceived behavioural control and perceived knowledge. Accordingly, with the increased PBC and perceived knowledge, occupants believed to use actions to adapt themselves to their environment rather than to adapt the indoor environment to their needs or preferences. This may contribute toward energy-saving through fewer interventions with the building systems. Considering user control as the reference variable, occupants with more control over their indoor environment were 1.041 times (95% CI 0.556-1.950) more likely to drink hot/cold beverages than those in offices with no user controls. However, these associations were not significant ($p > 0.05$). The existing literature lacks studies to confirm the above association of drinking hot/cold beverages with the ability and user control-related factors. However, one study underlined indoor and outdoor temperatures and thermal sensations as influencers of occupants' drinking beverage behaviour (Rupp et al., 2021). Similarly, the results highlighted that the odds of drinking hot/cold beverages based on the variation in the IEQ parameter show a negative or decreasing relationship. If the occupants are thermally satisfied, their consumption of beverages reduces, where occupants may drink hot beverages to feel cooler and cold beverages to feel warmer.

On the other hand, a significant association was seen between user control and opening/closing windows. Occupants with more user control were 1.979 times more likely to open/close their office windows than those with less control over their indoor parameters. Interestingly, this odd of occupants' window behaviour given the user control does not reach statistical significance in the 95% CI of 1.094 to 3.581 spans 1.0. However, user control over building systems was considered the primary behaviour for adaptive behaviour in offices and integrated into the predictive modelling for window opening/closing (Bavaresco et al., 2021). Additionally, a decreasing association is found between IEQ and window behaviour, while the existing literature supports that satisfaction with temperature and air quality are linked with the window opening behaviour in offices proportionately with the window opening time (Yun et al., 2008). Accordingly, when the occupants' IEQ satisfaction increases, the odds of window behaviour decrease. However, another study compared the window behaviour in three offices and found varied behaviour under similar indoor conditions in offices (Neves et al., 2020). Thus, the association between IEQ satisfaction and window behaviour may be twofold, given the influence of other factors. Furthermore, the current study showed negative relationships between motivation, opportunity, and ability-related factors. At the same time, the literature supports positive and significant relationships contributed by attitude (β=0.71, p-value<0.05) and perceived behavioural control (β=0.50, p-value<0.05) towards occupant window behaviour (Bavaresco et al., 2020).

Regarding opening/closing internal doors, the odds of occupants opening/closing internal doors are 1.295 times higher when the occupants' IEQ satisfaction increases. Since a 95% CI of 0.625 to 2.685 spans 1.0 and the p-value (0.487) > α, this association was statistically insignificant. A lack of literature supports the association between selected parameters and the operation of internal office doors. A simulated model of door use based on airspeed using an agent-based modelling approach enables the agents to calculate Predicted Mean Vote (PMV) parameters to keep track of the comfort level and determine which behaviours are more effective in maintaining the occupants' comfort (Lee & Malkawi, 2014). However, using doors was not recognised as behaviour-optimised energy-savings and comfort. Therefore, the occupants' use of internal doors influenced by indoor environmental conditions may contribute to energy-wasting behaviour.

Likewise, the odds of an occupant adjusting clothing based on ability factors are 1.637 times higher than those who do not adjust clothing based on ability factors, with a 95% CI of 0.741 to 3.615. However, this association was not significant (p > 0.05). According to the positive association, when the value of ability factors increases, the odds of adjusting clothing increase. This is similar to the occupants' drinking beverages behaviour and contributes energy-saving while assuring occupants' comfort. However, the energy modellers overestimate the clothing insulation/level in BES programs (Gauthier & Shipworth, 2014). Similarly, the percentage of occupants who adjusted clothing was exceptionally low (Mustapa et al., 2016). Unlike the literature supports, the current study's findings highlight that adjusting clothing is a prominent behaviour among office building occupants and has a decreasing relationship with the IEQ and user control.

7.4.4 Hypotheses testing

The null hypothesis of the study states that the logistic regression coefficient (b1) is equal to zero or that there is no statistically significant relationship between the predictor (independent) variable and the response (dependent) variable. The alternative hypothesis states the opposite of this. Five hypotheses stated in the current study were tested based on the corresponding p-values. The null hypothesis was rejected for the relationship with a significance level of less than 0.05. Accordingly, there is a statistically significant relationship between user control, occupant behaviours, and motivation and occupant behaviours. IEQ satisfaction, opportunity, and ability factors have a significance level of more than 0.05. Therefore, the null hypothesis did not reject these relationships. Accordingly, there is no statistically significant relationship between occupant behaviours and these factors.

7.5 Conclusion

This study evaluated the interrelationships between user comfort preferences, occupant energy behaviours, and drivers in office settings. The survey approach was based on synthesising the literature on comfort preferences, occupant behaviours, and environmental, building, and social-psychological factors, and a case study was conducted in Auckland, New Zealand. Compared to earlier studies, the study adds significant knowledge on occupant behaviours in office settings based on the occupants' multi-domain comfort preferences. Also, by integrating binary logistic regression, the study evaluates perceived subjective aspects like social-psychological factors alongside the environmental and building user control-related factors, making the research in this field more interdisciplinary.

The occupants' satisfaction with IEQ parameters: thermal and air quality in winter, thermal and air quality in summer, lighting comfort, and acoustic comfort was evaluated and observed dissatisfaction with thermal and air quality in both seasons. Accordingly, this correlates with the main comfort preferences of occupants identified in the office setting as all related to the space's thermal and air quality improvement. Based on occupants' IEQ satisfaction and comfort preferences, the prominent occupant behaviours in the office setting were identified, including drinking hot and cold beverages, opening/closing windows and internal doors, and adjusting clothing. Considering the building characteristics, these outcomes also emphasise the complexity of balancing natural and mechanical ventilation in offices, how mixed-mode ventilation affects perceived IEQ satisfaction, and the choice of occupants' actions in offices. The predictive modelling approach used in the study (binary logistic regression) proved that occupants' perceived user control satisfaction is the main driver for the increase in window actions. Additionally, the negative but insignificant relationship between IEQ satisfaction and window behaviour is twofold and different from what most literature confirms. This may be due to the influence of individuals' social-psychological preferences, while most literature-based entirely on measurements of environmental parameters.

The current study suggests that building practitioners improve office IEQ based on occupant characteristics. These findings encourage building energy managers to address occupant motivation, opportunity, and ability-related issues in buildings. The results provide researchers with how social-psychological constructs of occupants influence the decision-making of their behaviours and thereby aid building designers and energy modellers in improving the internal environment and building systems to suit occupants' comfort preferences and actions. Overall, the study outcomes enable the improvement of social theories and subjective aspects related to office building spaces and systems.

However, except for the association between user control and window behaviour, the significance level was more than 0.05 in all the other scenarios. Therefore, variables in the binary logistic models do not show a statistically significant association with the dependent variables drinking hot/cold beverages, opening/closing internal doors, and adjusting clothing. Accordingly, this evaluation grasped hypotheses that may be tested using a larger sample size in future studies. Furthermore, the covariates created in the current analysis may not highlight the subjective aspects within the variables, such as attitudes, personal norms, organisational support, behavioural interventions, perceived behavioural control, and knowledge. Although these parameters were deemed essential in the existing literature, the direct influence of these aspects is still missing in the current evaluation. The minimum sample for logistic regression is based on the least frequent outcome and the number of independent variables (Field, 2013). The larger the sample size, the better the probabilistic model fits the observed data (Szumilas, 2010). Therefore, further studies are required to refit the model for more reliable predictions. Such an improved approach may explain how environmental, user control and social-psychological factors are interrelated with the occupants' actions and building interactions. Also, field studies may show how different the occupants' comfort preferences and perceived IEQ satisfaction are. This knowledge is vital to introducing acceptable thresholds of IEQ conditions for most workers. Such understanding is also critical for building managers to optimise energy-saving and occupants' productivity.

Epilogue

This part of the thesis analyses how organisations rationalise occupants' energy behaviours and comfort preferences in New Zealand office buildings. Chapter 6 in this part discusses the perceptions of building occupants and managers on the impact of occupant behaviour on energy use. It identifies theoretical perspectives on the IEQ beliefs and comfort-related aspects, factors influencing occupant behaviours, behaviour impact on energy, and occupant-centric energy culture that further classifies to sub-factors. The findings highlight the practical implications for the industry and research, including considering occupant comfort and behaviour when implementing energy-saving measures and preparing occupant-centred energy policies. It proposes further research to complement the current study using quantitative methods to evaluate occupant energy behaviours in office buildings.

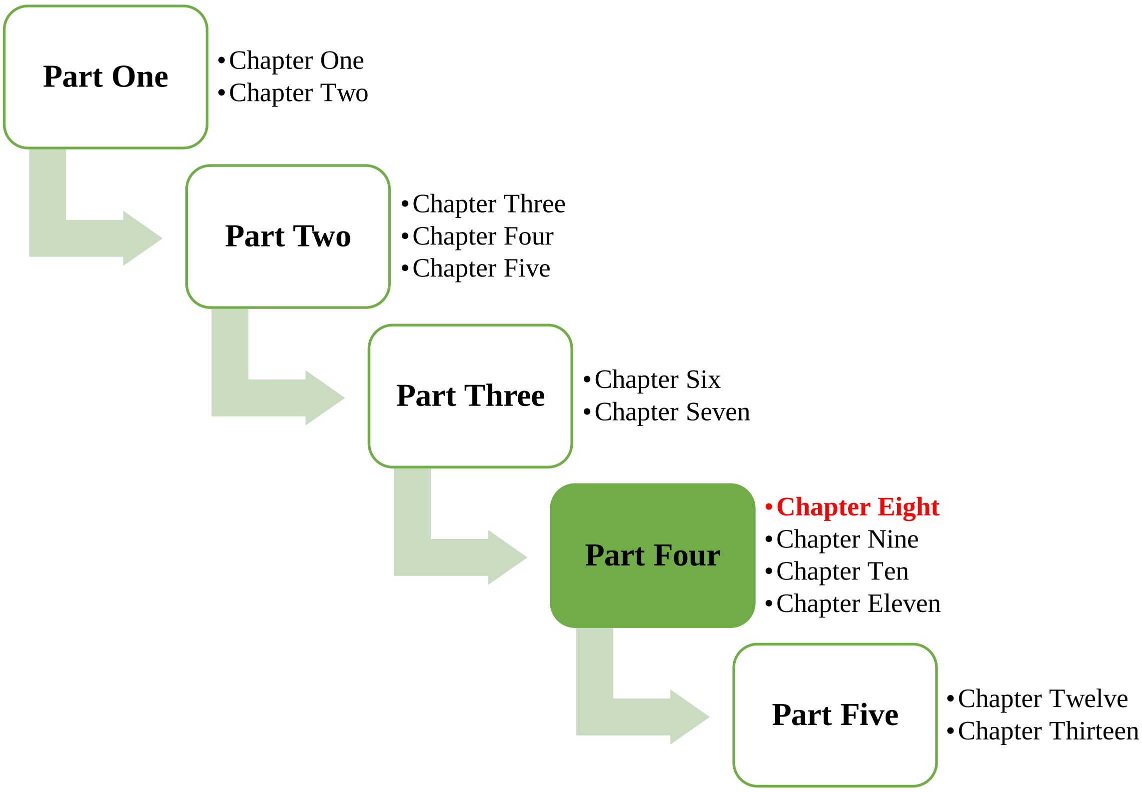
Chapter 7 evaluates the relationships between user comfort preferences, occupant energy behaviours, and drivers in office settings. It highlights the primary sources of indoor environmental discomfort and the significant influence of environmental factors on occupant behaviours. These findings support the need for an occupant-centric approach to building design and energy management. The chapter proposes further research with a larger sample to illustrate the statistically significant relationship of the factors on occupant behaviours better. The next part of the thesis thus moves to the primary analysis and findings of the thesis with an extensive sample of building occupants.

PART 4 – PROBLEM ANALYSIS: MAIN RESEARCH FINDINGS

Prologue

Part four of the thesis evaluates how occupants perceive decision-making regarding their energy behaviours in New Zealand office buildings and contributes to achieving objective 3. Chapters 8 and 9 feature distinct analyses based on a comprehensive occupancy survey conducted across five regions in New Zealand, whereas chapters 10 and 11 showcase analyses from a sample collected within a specific case study. Chapter 8 descriptively investigates the social-psychological insights into energy-saving behaviours in New Zealand office buildings based on demographic factors. Chapter 9 then quantifies their impacts to test hypotheses developed based on a theoretical model of relationships between social-psychological drivers and occupant energy behaviours. Both from the perspective of behavioural theories adopting a modified MOA approach. In this approach, motivation (M) measures an occupant's concern over individual energy consumption and behaviour involving saving energy. Opportunity (O) measures the occupants' accessibility to information on energy conservation and environmental and interpersonal drivers of energy-saving intentions. Ability (A) is how occupants interpret the information on energy-related behaviour based on their past knowledge of energy use, impacts, and consequences. Chapters 8 and 9 contribute to achieving sub-objective 3.1, modelling underlying relationships between social-psychological drivers and occupant energy behaviours.

Chapter 10 investigates the multi-domain comfort preferences linked to each behaviour focusing on multiple behaviours such as windows, doors, lighting, shades, blinds, fans, thermostats, computers, drinking beverages, clothing levels, and moving through spaces in New Zealand office buildings. The study considers seasonal variance and time-related factors in its analysis. Next, chapter 11 evaluates the influence of occupants' perceived indoor environmental comfort, control availability, demographics, and the social-psychological factors on these individual behaviours and contributes to achieving sub-objective 3.2. It determines the decision-making process of occupants on their behaviours in the New Zealand office building context. The chapter findings contribute to developing an ontology that integrates these core concepts to optimise the energy performance of existing buildings and improve future building designs.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8.0 Social-psychological insights into energy-saving behaviours: An occupant survey in New Zealand

Abstract

There is great potential for reducing energy consumption in office buildings through occupant energy-saving behaviours. While various factors influence these behaviours, previous studies emphasise environmental and contextual factors with little consideration of social-psychological factors. Therefore, this study investigates the social-psychological insights into energy-saving behaviours based on the general occupancy survey data collected from 294 office occupants in New Zealand. One-way ANOVA and descriptive analysis provide insights into user control availability, occupants' energy-saving behaviours, and social-psychological effects across different demographic groups. ANOVA results indicated significant differences (P value < 0.05) in the availability of user control, occupants' energy-saving behaviours, and social-psychological effects across the demographic groups, primarily visible across the ethnicity and region groups. The results further revealed an increasing trend (more than 60% of the respondents agreed) of adjusting to the indoor environment and occupants' social-psychological effects such as attitude, personal norms, perceived control regarding comfort needs and preferences, and actual and perceived knowledge to save energy. In addition, there was a lack of organisational support (40% or more than 40% agreed) and behavioural intervention (60% or more than 60% responses received), which is necessary for encouraging occupants to save energy while giving them more responsibility for their energy consumption. This study contributes decision-makers such as building owners, energy modellers, facilities managers, and policymakers to tailor energy-saving implications based on these social-psychological effects. Furthermore, the current study could be extended by applying more advanced statistical analysis methods to develop a comprehensive framework that evaluates occupant energy behaviours in office buildings.[6]

[6] This chapter is based on the following published conference paper:

Weerasinghe, A.S., Rasheed, E.O. and Rotimi, J.O.B. (2022). Social-psychological insights into energy-saving behaviours: An occupant survey in New Zealand. In K. Panuwatwanich et al. Proceedings of the 12th International Conference on Engineering, Project, and Production Management (EPPM2022) (pp. 9/1-9/12), Association of Engineering, Project and Production Management.

8.1 Introduction

Considerable attention has been given to the influence of occupant behaviours on building energy consumption. The studies have focused on understanding different occupant behaviours and analysing their impact on energy for certain behaviours. For instance, empirical studies define and classify the occupant energy behaviours in buildings as adaptive and non-adaptive behaviours (Hong et al., 2017; O'Brien & Gunay, 2014). Furthermore, studies pinpoint that adaptive occupant actions directly depend on occupants' comfort requirements and influence overall building performance in building energy consumption (Bavaresco et al., 2021; Wang et al., 2016). For example, more than 50% of total energy consumption was consumed after regular working hours in commercial buildings in South Africa due to occupants failing to turn off the lights and HVAC system when leaving the buildings (Masoso & Grobler, 2010). A study by Staats et al. (2004) estimated a modest 6% savings in energy by providing energy usage feedback regarding thermostat use and diffuser covering. In another study, Dietz et al. (2009) highlighted that a 7.4% of USA emissions reduction can be expected through occupant energy savings.

Furthermore, many pieces of research have been developed around understanding occupant behaviours for energy use predictions at the design stage. However, it has been observed that accurate forecasts of occupant behaviour have rarely been achieved due to the complex nature of occupant behaviours arising from multiple factors (Rupp et al., 2021; Uddin et al., 2021). For example, it is frequent to treat occupant behaviours as static and deterministic in energy performance simulation, although they are stochastic, diversified, and dynamic (Hong et al., 2018). Another set of studies estimated the building operation costs based on the building characteristics or energy-efficient technologies (Weerasinghe, Ramachandra, et al., 2021, 2022). However, a more realistic and robust representation and modelling of occupant behaviours could help to improve building simulation accuracy and understand the building design-operation performance gap (Wang et al., 2019). Similarly, there is a lack of collective agreement on occupant behaviour modelling and simulation approaches (Hong et al., 2017). Enriching knowledge about the effect of multiple factors may improve occupant behaviour models for Building Performance Simulations (Carlucci et al., 2020).

Recently, social-psychological perspectives of building occupants received increasing attention, emphasising the implication of behavioural theories and frameworks. Mainstream theories and frameworks are the TPB, NAM, SCT, DNAS, and MOA (D'Oca et al., 2017;

Fu et al., 2021; Hong, D'Oca, Turner, et al., 2015; Li et al., 2019; Xuan Liu et al., 2021). Within the occupants' energy-saving behaviour research, the majority emphasises the influence of attitude, personal norms, subjective norms, PBC, perceived awareness, and knowledge on the energy consumption of both residential and commercial buildings (Deme Bélafi & Reith, 2018; Li et al., 2019; Xuan Liu et al., 2021; Rissetto et al., 2022). Other aspects, such as individual personality traits, emotions, beliefs, and motivations, are mainly relevant to residential buildings (Hewitt et al., 2015; Mack et al., 2019; Murtagh et al., 2019; Shen et al., 2022).

However, Heydarian et al. (2020) found that social-psychological perspectives/constructs should be further evaluated to identify the best fit for implementing energy-saving practices in office buildings. Specifically, understanding occupants' mentality on energy-saving is significant as commercial buildings open to flexible working solutions but complex energy operations in the post-pandemic situation (Mantesi et al., 2022). Additionally, despite the highlighted need to understand the influence of various driving factors and integrate them into occupant behaviour modelling and simulation approaches, the literature lacks identification of social-psychological insights of occupants towards energy-saving behaviours (D'Oca, Hong, et al., 2018; Li et al., 2019; Shi et al., 2017).

Furthermore, research in different climate zones or countries to identify the variations of behaviours in a different context, culture, climate, and socio-economical background is recommended to provide new insights into occupant adaptive behaviours (D'Oca, Hong, et al., 2018; D'Oca et al., 2019; Rupp et al., 2021). Although empirical studies have developed various frameworks that include social-psychological factors (Bavaresco et al., 2021; D'Oca, Hong, et al., 2018; Li et al., 2019), the applicability of these frameworks are not evaluated for most countries. Primarily, in New Zealand, studies focused on occupant energy behaviours are limited (Azizi et al., 2019; Weerasinghe et al., 2020) and focused on the behaviours in response to thermal comforts (Azizi et al., 2015a), and computer usage behaviour of occupants (Azizi et al., 2015b). In contrast, these studies ignored the occupant lighting on/off behaviour, fan usage, clothing adjustment, moving through spaces, and occupants' non-adaptive behaviours such as reporting discomfort and taking no action. Furthermore, the studies do not represent the social-psychological effects on energy-saving behaviours.

Therefore, the current study aims to evaluate and identify the social-psychological insights relating to energy-saving behaviours across the general office building occupants in New Zealand. The specific objectives of the study include: (1) assessing the availability of user control; (2) identifying the occupants' energy-saving behaviours and practices; and (3) highlighting the social-psychological insights based on the socio-demographic characteristics of the general office building occupants in New Zealand.

The study contributes to the researchers in this field by highlighting the insights associated with social-psychological effects on adaptive and non-adaptive occupant behaviours in offices. It also helps building owners, energy modellers, facilities managers, and policymakers to promote energy-saving behaviours among office building occupants.

8.2 Literature Review

Experimental studies have demonstrated that occupants vary in comfort preferences, satisfaction, and indoor environment perceptions due to many factors confirming the stochastic, diverse and complex nature of occupant behaviours in buildings (Schakib-Ekbatan et al., 2015; Schweiker & Wagner, 2015). In addition, the availability and accessibility of user controls in the buildings are critical as it links humans and the building through their interactions with these building controls and systems (O'Brien & Gunay, 2014). For instance, Onyeizu (2014) identified that occupants who control the temperature were highly satisfied with the thermal comfort of the space. Similarly, a lack of user control leads to a potential lack of motivation to save energy (Papadopoulos & Azar, 2016).

Furthermore, previous studies also considered social-psychological constructs such as attitudes, social norms, PBC, knowledge, organisational support, and behavioural intervention (energy feedback, messages) (D'Oca et al., 2019; Li et al., 2019; Vellei et al., 2016). For example, the occupants with a more positive attitude toward saving energy are the ones who have the most intentions to conduct energy-saving behaviours (Obaidellah et al., 2019). On the other hand, Gao et al. (2017) stated that if occupants are aware of the significance of energy-saving behaviour, they hold a positive attitude and intend to save more energy.

Moreover, Nie et al. (2019) investigated the careful-use behaviours regarding appliance usage and lighting and found that the subjective norm variable had the most significant effect on behavioural intention. On the contrary, Chen et al. (2017) found that subjective norms were no longer significant in predicting intentions when additional factors were added to the regression model. While subjective norms highlight the perceived social pressure, personal norm indicates occupants' self-obligation to save energy by directly impacting environmental intention and behaviour (Kim & Seock, 2019).

Another aspect, PBC, was deemed positive, significantly affecting adaptive behaviour choices related to HVAC control, windows, and shades/blinds (Bavaresco et al., 2020). However, the higher degree of control and relevant knowledge and skills in energy-saving influence occupants' intention to practice a particular behaviour and save energy (Gao et al., 2017). For instance, occupants with higher perceived and actual knowledge of energy consumption and related savings are likelier to save energy than occupants without knowledge (Abrahamse & Steg, 2009).

Organisational support and behavioural intervention positively drive pro-environmental behaviours of the employees to promote energy-saving (Xu et al., 2017). Vellei et al. (2016) discovered that feedback intervention and occupants' perceived control promote energy-saving adaptive behaviours, such as wearing more clothes when they feel cold and controlling the windows more effectively. Behavioural intervention in providing energy feedback and report is usually analysed outside the social-psychological domain. Integrating this variable would facilitate the constraining factors identified in previous social-psychological frameworks. When energy-saving behaviours are considered individually, physiological and social-psychological factors are mainly related to adjusting thermostats and plug-ins behaviours. However, the studies that adopted social-psychological theories (Bavaresco et al., 2020; D'Oca et al., 2019; Li et al., 2019) focused on mixed behaviours.

The above-highlighted social-psychological constructs influence the occupants' energy-saving behaviours. However, the influence of these factors may vary significantly depending on the different contexts or demographic factors. Therefore, identifying social-psychological constructs influencing occupant behaviours should be carefully done by considering the effect of demographic factors (Hong et al., 2017). Notwithstanding the importance of demographic variables such as age, gender, population, culture, and location, the commercial buildings received limited attention. At the same time, the literature has widely covered residential building-related contexts such as household income, household size, number of children, age, and income (Hong et al., 2017). However, the specific results in residential buildings cannot be applied to office buildings due to the diverse and unique characteristics of those living there (Putra et al., 2021). In addition, many studies in the office building context showed the direct impact of socio-demographics on dependent variables (energy-saving intentions and occupant behaviours), while they failed to show how the influence of social-psychological constructs varies due to demographics (Azar & Al Ansari, 2017; Park & Nagy, 2020; Xie et al., 2021). Along these lines, the current study investigates the context-specific social-psychological insights on energy-saving behaviours in New Zealand office buildings.

8.3 Methods

This study explored the occupants' perceptions of accessibility to user control, occupants' energy-saving behaviours, and social-psychological effects on office building occupants in New Zealand. The study used a survey approach to capture the occupants' perspectives on user control, occupants' energy-saving behaviours, and social-psychological effects. In the past, quantitative methods such as questionnaire surveys were used to study occupants' energy-related behaviours and develop occupant energy models (Day & O'Brien, 2017), which provide more insights than experiments and field observations in this research field (Hong et al., 2017).

8.3.1 Survey structure and measures

The questionnaire consists of four (04) sections: background-related questions (gender, age, ethnicity, employment status, work duration, and region), user control and occupant behaviours-related questions, and the social-psychological factors of building occupants. The survey questions included in Table 8.1 were adapted from previous literature. The questions relating to attitude, subjective norms, and PBC were adapted from Abrahamse and Steg (2009), personal norms from Zhang et al. (2013), perceived and actual knowledge, organisation support, behavioural interventions, and accessibility to control were adapted from Li et al. (2019), while occupant behaviour related questions were adapted from (Hong et al. 2018). The questionnaire included multiple-choice questions for background-related questions, whereas all the other aspects were measured using a 5-point Likert scale representing 1- strongly disagree and 5-strongly agree.

Table 8.1 Survey questions and constructs

#		Questions	Social-psychological constructs
1	**Demographic information**		
2	**Availability of user control**		
	A	I have personal control over most of the appliances	
3	**Occupants' energy-saving behaviours**		
	A	I often report discomforts related to IEQ	
	B	I am willing to accept and do nothing about the existing indoor environmental conditions	
	C	I often adjust building appliances to satisfy my comfort preferences	
	D	I often adjust myself to the environmental conditions by adjusting clothing, drinking hot/cold beverages, and moving through spaces	
4	**Social-psychological effects**		
	A	Saving energy at work is important to me	Attitude
	B	I feel responsible at to save energy	Personal norms
	C	My co-workers expect me to save energy at work	Subjective norms
	D	Most of my co-workers expect me to turn off electrical appliances	
	E	Sharing control over building systems with my co-workers is easy	
	F	Saving energy during work is entirely within my control	Perceived behavioural control
	G	Actions I take to save energy depending on my comfort preferences	
	H	I am aware that reducing energy use will reduce cost	Actual knowledge
	I	I am aware that reducing energy use will reduce emissions	
	J	I am aware that reducing energy use will improve my organisation's image/reputation	
	K	I often close windows, turn off the lights, heaters, fans, computers, etc., whenever I leave the office, and unplug appliances when not in use	Perceived knowledge
	L	If I feel slightly cold at the workplace, I would put on another layer of clothing instead of using the heater	
	M	If I feel slightly warm at the workplace, I would adjust my clothing level instead of using the air conditioner	
	N	My company encourages employees to save energy	Organisational support
	O	My company rewards employees for saving energy	
	P	The feedback on individual energy use by our building management team is important for me to change my energy-driven behaviour	Behavioural interventions
	Q	Our building management team often sends energy use reports	

8.3.2 Data collection and Analysis

A questionnaire was disseminated in person and online through the Qualtrics survey platform from July to November 2021. The participants for the study were purposively selected from the general population of employees who work full-time and part-time in any office space in New Zealand. The total workforce of New Zealand who employed full-time and part-time as managers, professionals, community and personal service workers, and clerical and administrative workers equal 1,869,481, according to 2018 Census data (Stats NZ, 2022). A recent survey conducted in New Zealand concluded that only 22% (out of 2,560 respondents) would like to work from home daily, and the majority (67%) prefer a mix of working a few times a week or month remotely during COVID-19 and post lockdown situation (O'Kane et al., 2020). Accordingly, assuming a population proportion of 0.75 who work in an office space from the population selected, a minimum sample size of 289 with 95% confidence and a margin of error of 5% was considered for the current study (Calculator.net, 2022; Saunders et al., 2019). Accordingly, 294 valid responses were received from the survey distribution and continued for the analysis.

A most commonly used statistical method in the social sciences, ANOVA was used to analyse the variance of energy-saving behaviours and social-psychological perspectives in different demographic groups (i.e., age, gender, ethnicity, and location). After identifying any significant variance, the social-psychological perspectives were illustrated against those demographic variables. SPSS version 27 and Minitab 19 software were used for the data analysis.

8.3.3 Participants

The survey was conducted across the general office building occupants who work full-time and part-time in any office space in New Zealand. 294 respondents who filled out the questionnaire survey were used for the analysis. Table 8.2 summarises the demographics of the participants. As seen in Table 8.2, respondents consist of males (61.2%) and building occupants aged 30 or older (85%). Ethnicity-wise, most respondents were New Zealand Europeans (53.7%). Among the respondents, 90.8% work full-time, and 70.1% have worked in their current workplace for a year or more. These higher percentages on employment status and work duration provide insights into that most occupants are familiar with their surroundings. Most of the respondents (41.5%) are based in Auckland. Based on the demographic characteristics of the selected sample, gender, age, ethnicity, and region-related data were further utilised to identify the social-psychological insights.

Table 8.2 Demographics of the participants

Background	Responses	Percentage
Gender		
Male	180	61.2
Female	112	38.1
Prefer not to answer	2	0.7
Age		
30 or older	250	85.0
Under 30	44	15.0
Ethnicity		
NZ European	158	53.7
Other	73	24.8
Asian	54	18.4
Māori/Pacific peoples	9	3.1
Employment status		
Full-time	267	90.8
Part-time	15	5.1
Other	12	4.1
Work Duration		
A year or more	206	70.1
Less than a year	88	29.9
Region		
Auckland	122	41.5
Manawatu-Whanganui	106	36.1
Other	66	22.4

8.3.4 Demographic group analysis

One-way ANOVA was conducted to identify if any significant differences exist in the availability of user control, occupants' energy-saving behaviours, and social-psychological effects across the demographic groups. In ANOVA, if the P-value (significance level) is less than the α value of 0.05, there are significant differences across the groups. Table 8.3 includes the ANOVA results, and as highlighted in green, significant differences (P value < 0.05) exist for most of the selected variables and are primarily visible across the ethnicity and region groups. To visualise these differences in occupants' viewpoints on user control, energy-saving behaviours, and social-psychological effects, stacked-bar graphs are illustrated in the forthcoming section by descriptively analysing the occupants' responses.

Table 8.3 The ANOVA results of the demographic groups

#	Gender		Age		Ethnicity		Region	
	F	P	F	P	F	P	F	P
2A	1.673	0.189	6.044	0.014	11.659	<.001	43.376	<.001
3A	1.066	0.345	2.751	0.098	6.94	<.001	19.024	<.001
3B	2.177	0.114	8.12	0.005	1.727	0.160	1.758	0.173
3C	2.902	0.056	0.355	0.552	2.47	0.061	25.448	<.001
3D	2.466	0.086	2.074	0.150	2.099	0.099	5.825	0.003
4A	9.782	<.001	12.17	<.001	1.443	0.229	0.823	0.440
4B	10.416	<.001	6.695	0.010	5.99	<.001	2.556	0.078
4C	1.932	0.146	1.281	0.258	2.111	0.098	8.197	<.001
4D	0.498	0.608	6.795	0.009	1.088	0.353	5.334	0.005
4E	0.46	0.631	3.414	0.065	11.175	<.001	0.200	0.818
4F	0.309	0.734	3.348	0.068	4.739	0.003	4.226	0.015
4G	0.408	0.665	3.543	0.060	4.114	0.007	18.092	<.001
4H	1.084	0.339	1.723	0.190	0.892	0.445	2.256	0.106
4I	1.42	0.243	0.082	0.775	1.261	0.287	2.355	0.096
4J	1.749	0.175	0.077	0.782	3.415	0.017	2.651	0.071
4K	2.601	0.075	0.894	0.345	8.618	<.001	36.61	<.001
4L	0.891	0.411	0.212	0.645	6.562	<.001	8.749	<.001
4M	0.854	0.426	1.364	0.243	6.242	<.001	7.863	<.001
4N	2.378	0.094	1.034	0.310	5.363	0.001	5.495	0.004
4O	4.141	0.016	13.059	<.001	10.174	<.001	2.006	0.136
4P	4.791	0.009	1.313	0.252	6.215	<.001	9.552	<.001
4Q	2.232	0.108	19.461	<.001	9.666	<.001	10.186	<.001

8.4 Availability of user control

First, when asked if occupants have personal control over most of the appliances (windows, doors, blinds, thermostat, lights, heaters, fans, computers) in their workspace, more than 50% or more than 50% responded "somewhat agree" or "strongly agree" in most demographic measures (Figure 8.1), which is slightly different in the samples from under 30, other ethnicities, and Auckland categories. Results indicate that user controls are available in most respondents' workplaces, and most respondents have access to these controls, which might increase their ability to save energy.

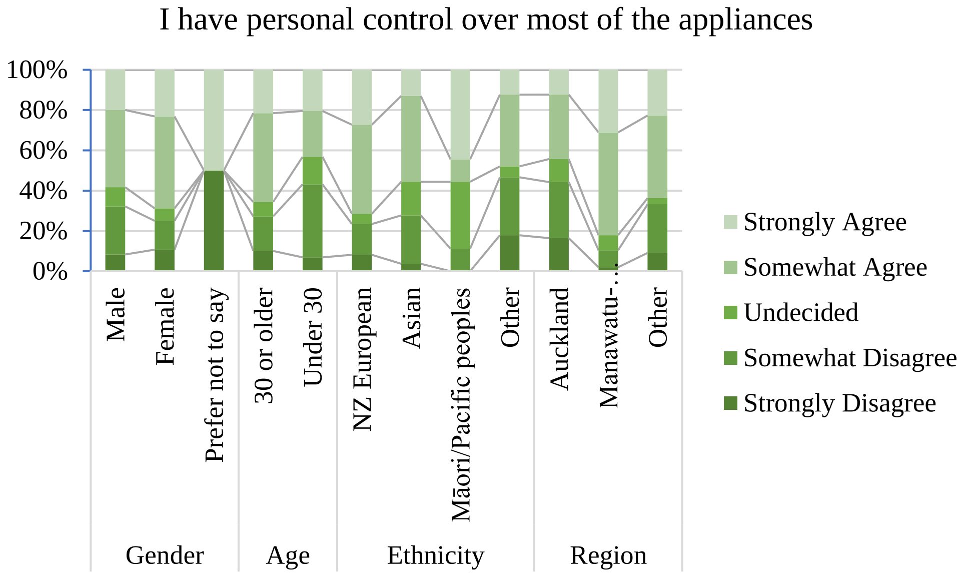


Figure 8.1 Personal control over office appliances

8.5 Occupants' energy-saving behaviours

Fig.2 illustrates the occupants' viewpoint on adaptive and non-adaptive behaviours. Adaptive behaviours include adapting the indoor environment to their preferences and adapting themselves to their environment. Non-adaptive behaviours include reporting discomfort, doing nothing, or accepting existing environmental conditions. As shown in Fig.2, when asked if they often adjust building appliances to satisfy their comfort preferences (3C), the majority (50% or more than 50%) indicated "somewhat agree" or "strongly agree", with a similar but increased trend (more than 60%) when asked if they often adjust themselves to the environmental conditions at their workspace by adjusting clothing, drinking hot/cold beverages, and moving through spaces (3D). In parallel, when asked if they often report discomforts related to IEQ to the building management (3A), the vast majority (more than 50%) either "somewhat disagree" or "strongly disagree". However, when asked if they were willing to accept and do nothing about the existing indoor environmental conditions in their workspace, similar agreement and disagreement (30%-40%) were observed because a considerable number of occupants responded: "undecided" (3B). These trends in Fig. 8.2 highlight that office occupants practice adaptive rather than non-adaptive behaviours. There is an increased motivation to adjust themselves to the indoor environment and interact with building systems.

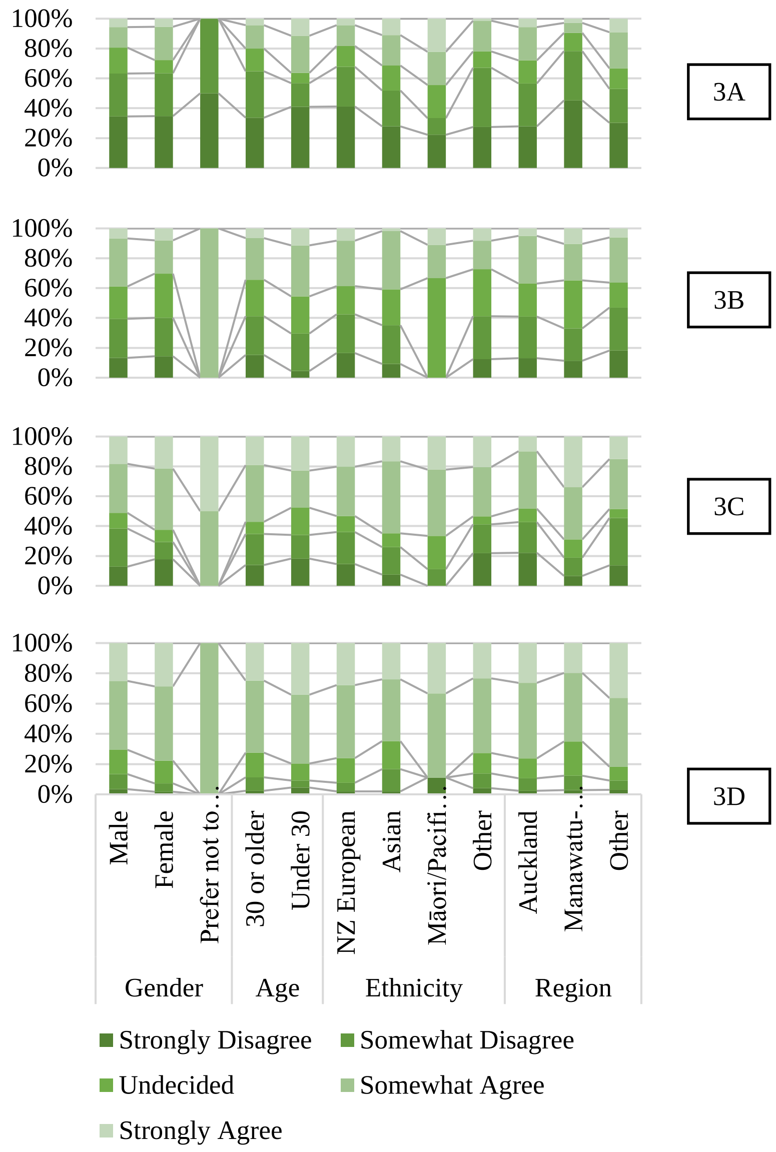


Figure 8.2 Occupants' energy-saving behaviours

8.6 Social-psychological effects

Social-psychology effects were investigated based on eight variables adopted by Li et al. (2019). Those variables are from both occupants and the organisation. Attitudes, personal norms, subjective norms, actual knowledge, perceived knowledge, and perceived behavioural control relate to the occupants, while organisation support and behavioural intervention relate to the organisational energy/building management.

8.6.1 Attitude

When asked if saving energy at work is essential to respondents, most respondents (more than 60%) answered "somewhat agree" or "strongly agree" except in one ethnic category, "prefer not to say". However, only two responses were received in this category; therefore, the response is insignificant (Figure 8.3). Results highlight the positive feelings of most respondents about performing energy-saving behaviours.

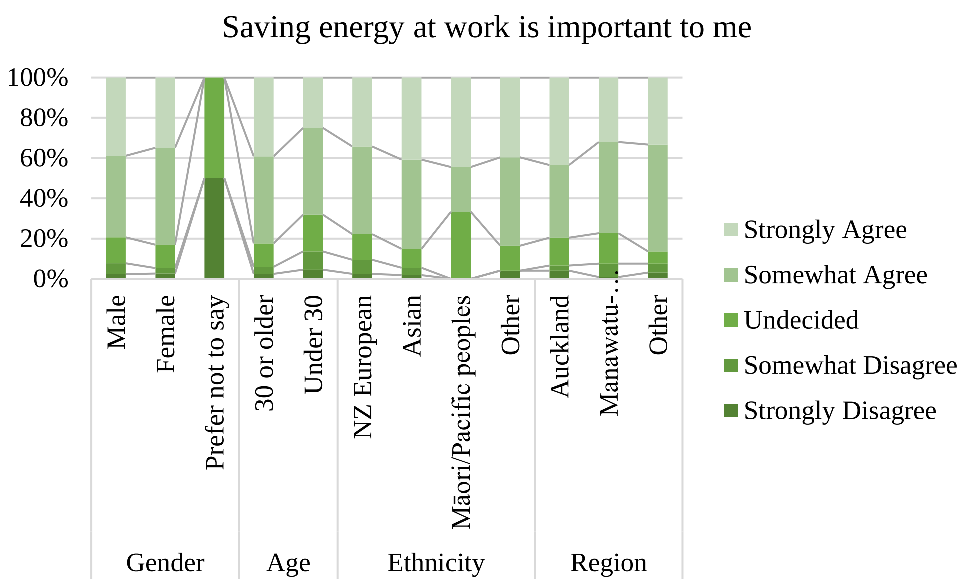


Figure 8.3 Attitude to save energy

8.6.2 Personal norms

The respondents were also asked if they feel responsible/obliged to save energy at work. A majority of respondents (more than 60%) either somewhat agree" or "strongly agree" (Figure 8.4), which indicates there is a self-obligation among respondents to commit energy-saving behaviours. This finding justifies the respondents' positive attitude toward saving energy.

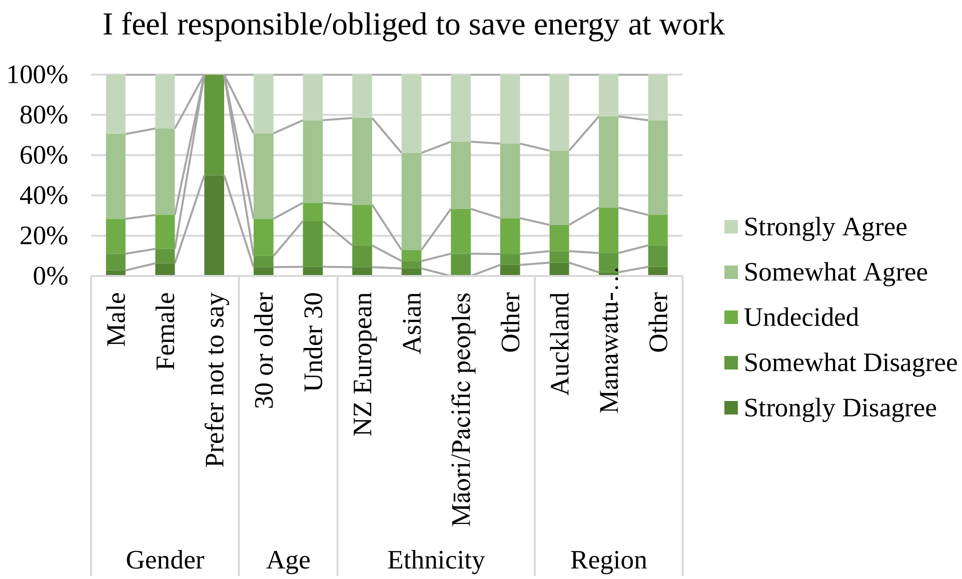


Figure 8.4 Personal norms to save energy

8.6.3 Subjective norms

Next, the respondents were asked if social pressure exists to engage or when engaging in energy-saving behaviours (Figure 8.5). When asked if their co-workers expect them to save energy (4C), similar agreement and disagreement (30%-40%) were observed because a considerable number of occupants responded "undecided". In contrast, when asked if their co-workers expect them to turn off electrical appliances when leaving (4D), 40% or more than 40% answered "somewhat agree" or "strongly agree" except in one region category, "Manawatu-Whanganui", which has a significant number of responses. This indicates that the respondents are more familiar with the specific actions/behaviours and believe some social pressure exists when taking such actions. However, they are unsure if social pressure exists to save energy. Similarly, 40% or more than 40% answered "somewhat agree" or "strongly agree" when asked if sharing control over building systems with co-workers is easy (4E). A slight change was observed in the ethnicity group "Māori/Pacific peoples" and the region group "Manawatu-Whanganui".

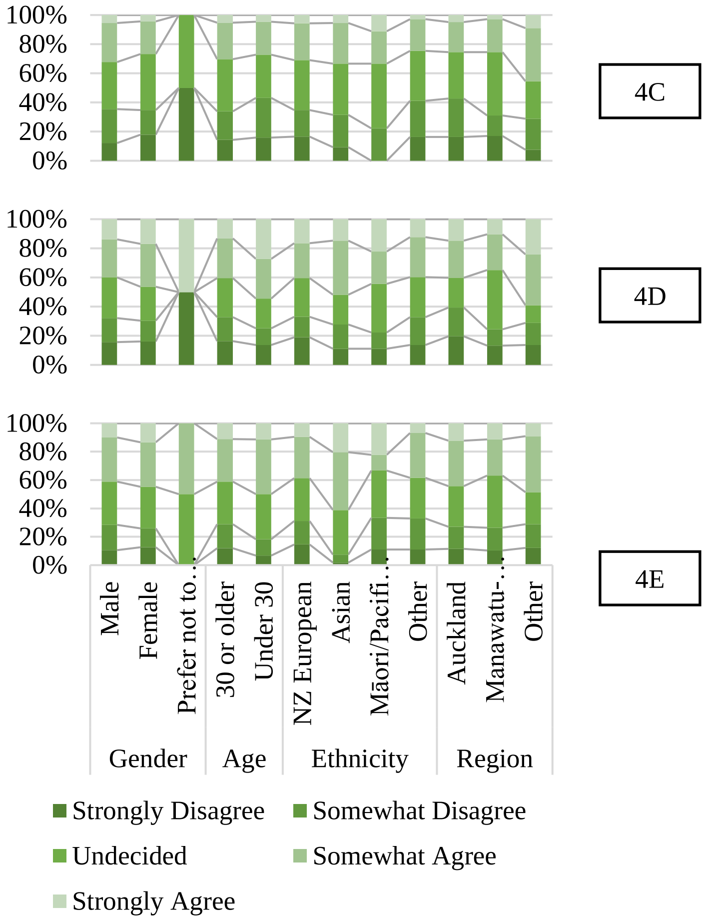


Figure 8.5 Subjective norms to save energy

8.6.4 Perceived behavioural control

Subsequently, the respondents were asked about perceived ease or difficulty saving energy at the workplace. As seen in Figure 8.6, when asked if saving energy during work is entirely within their control (4F), 40% or more than 40% responded "somewhat disagree" or "strongly disagree". However, in some categories, a similar agreement was also observed. Such categories include female, under 30, NZ European, and the region groups "Manawatu-Whanganui" and "other". In these samples, a similar number of participants either agreed or disagreed. In contrast, 60% or more than 60% answered "somewhat agree" or "strongly agree" when asked if their actions to save energy depended on their comfort needs and preferences (4G). This further justifies the respondents' positive attitude toward saving energy while ensuring their needs and preferences are satisfied.

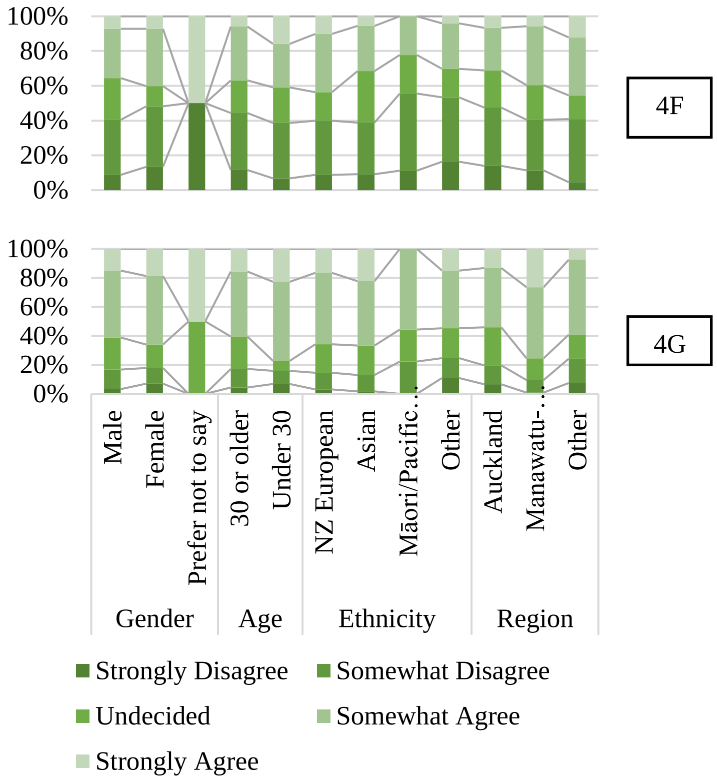


Figure 8.6 Perceived behavioural control to save energy

8.6.5 Actual knowledge

Figure 8.7 illustrates the respondents' psychological abilities to perform energy-saving behaviours. According to Figure 8.7, the respondents were first asked if they were aware that reducing energy use would reduce energy costs (4H), reduce carbon emissions (4I), and improve their organisation's image/reputation (4J); 60% or more than 60% agreed. In general, results indicate the respondents' relatively strong mental ability to save energy and perform energy-saving behaviours.

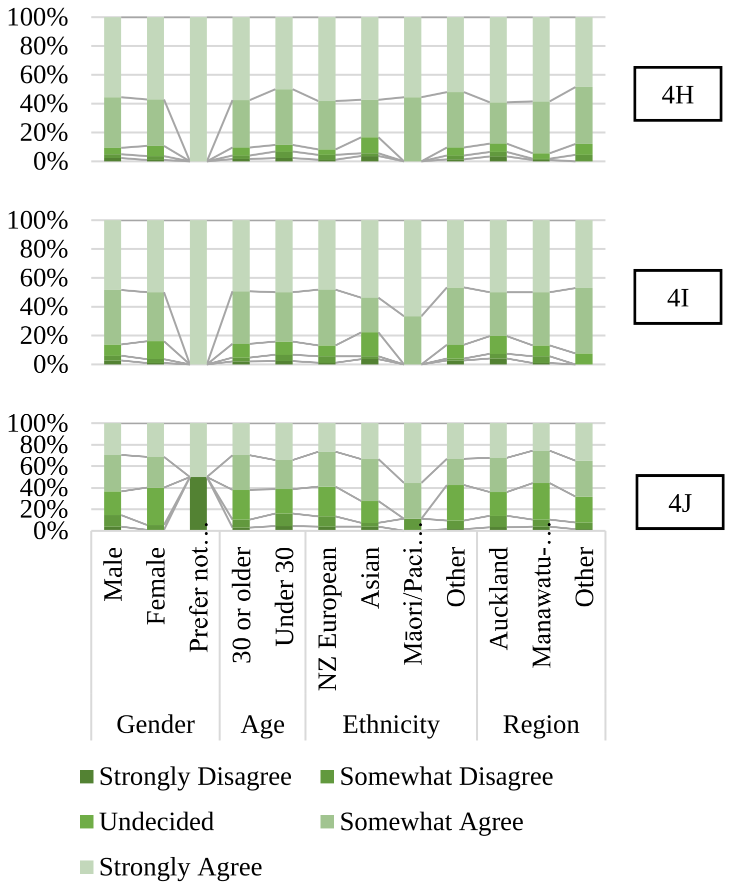


Figure 8.7 Actual knowledge to save energy

8.6.6 Perceived knowledge

Subsequently, the perception of respondents' knowledge about saving energy was investigated, and Figure 8.8 summarises the results. When asked if respondents often close windows, turn off the lights, heaters, fans, computers, etc., whenever they leave the office, and unplug appliances when not in use (4K), the vast majority (60% or more than 60%) either "somewhat agree" or "strongly agree", with similar insight when asked if they feel slightly cold at the workplace, they would put on another layer of clothing instead of using the heater (4L). If slightly warm, they would adjust their clothing level instead of using the air conditioner (4M) (60% or more than 60%). These results highlight that most respondents know how to save energy by practising the right behaviours.

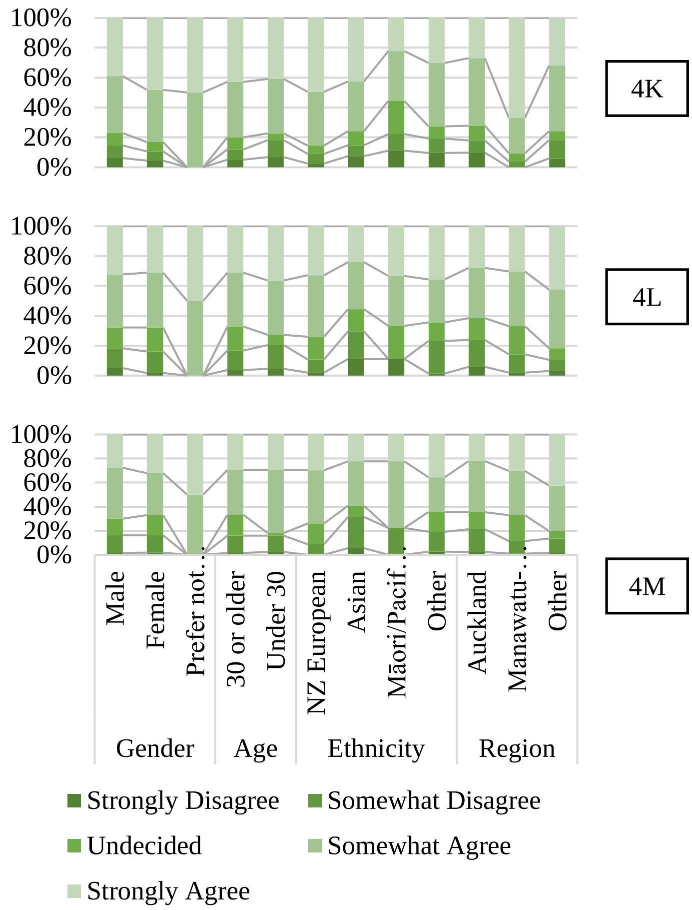


Figure 8.8 Perceived knowledge to save energy

8.6.7 Organisational support

While the above sum up the social-psychological insights relating to occupants, the respondents were asked about the organisation's support and intervention toward saving energy (Figure 8.9). When asked if their companies encourage employees to save energy (4N), most respondents (40% or more than 40%) answered "somewhat agree" or "strongly agree". In contrast, 60% or more than 60% answered "somewhat disagree" or "strongly disagree" when asked if the company rewards employees for saving energy (4O). The findings highlight that the occupants believe their organisations only partly provide energy-saving opportunities.

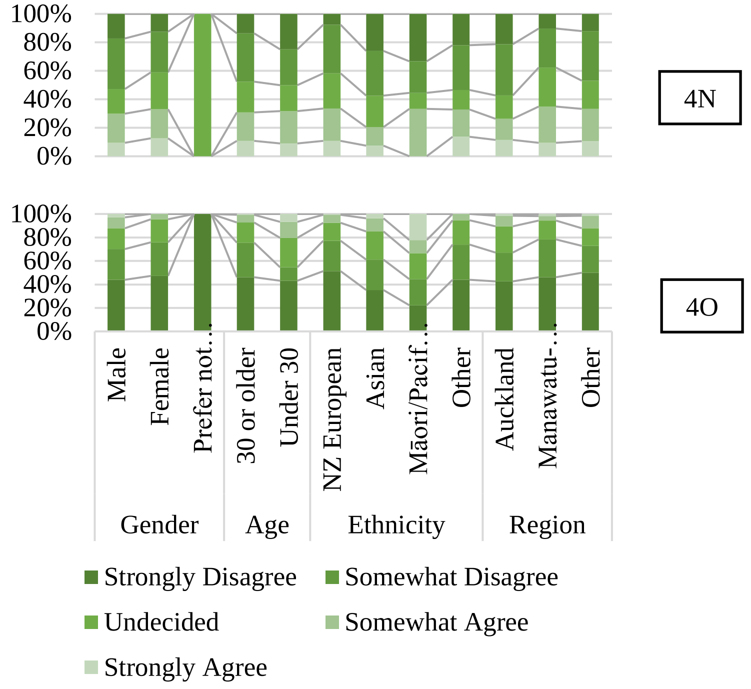


Figure 8.9 Organisational support to save energy

8.6.8 Behavioural interventions

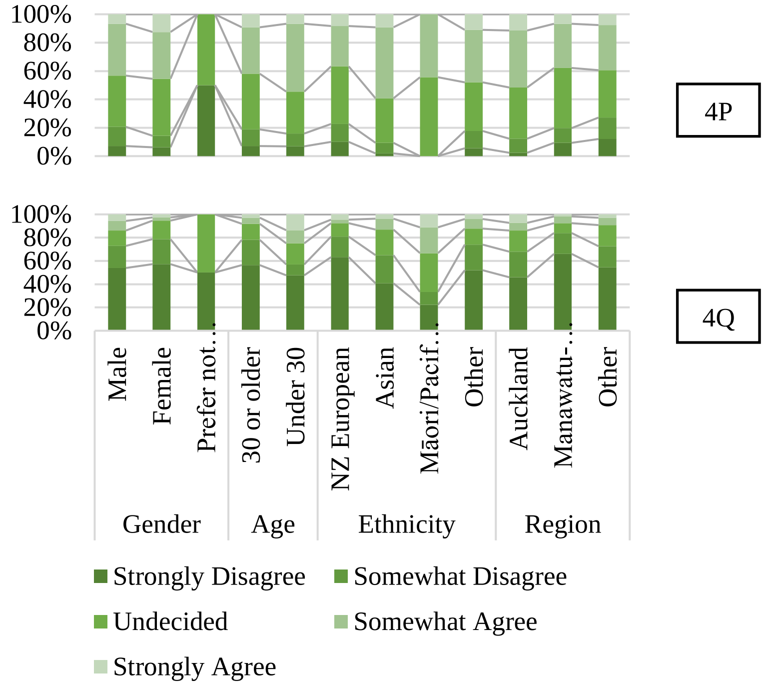


Figure 8.10 Behavioural interventions to save energy

Finally, the respondents were asked about the extent of organisational interventions to energy-saving behaviours (Figure 8.10). When asked if the feedback on individual energy use by the building management team is crucial for them to change energy-driven behaviours (4P), most respondents (40% or more than 40%) answered "somewhat agree" or "strongly agree”, while a similar percentage of respondents unable to make a decision. However, when asked if building management teams often send energy use reports to employees (4Q), the vast majority either “somewhat disagree” or “strongly disagree”, indicating 60% or more than 60% in most groups. The findings indicate a lack of behavioural intervention from the organisations, thus a lack of opportunity for occupants to practice energy-saving behaviours.

8.7 Discussion

The following discussion of results is expressed in insights into access to user control, energy-saving behaviours, and social-psychological effects, along with specific recommendations. Starting with user control, results indicate the availability and accessibility of user controls within New Zealand office workplaces as an enabler of saving energy. The findings confirm the results of previous studies (O'Brien & Gunay, 2014; Papadopoulos & Azar, 2016) that have observed a direct relationship between building user controls and energy reduction or energy-saving behaviours. Regarding occupant energy behaviours, the study found that the occupants mainly adjust themselves to the indoor environment than adjust the building environment to their preferences interacting with building systems and appliances. However, the previous studies primarily focused on energy use due to the occupants’ interaction with building systems and appliances (Weerasinghe et al., 2020). For instance, significant energy use was highlighted in behaviour choices related to HVAC control, windows, shades/blinds, and lighting (Bavaresco et al., 2020).

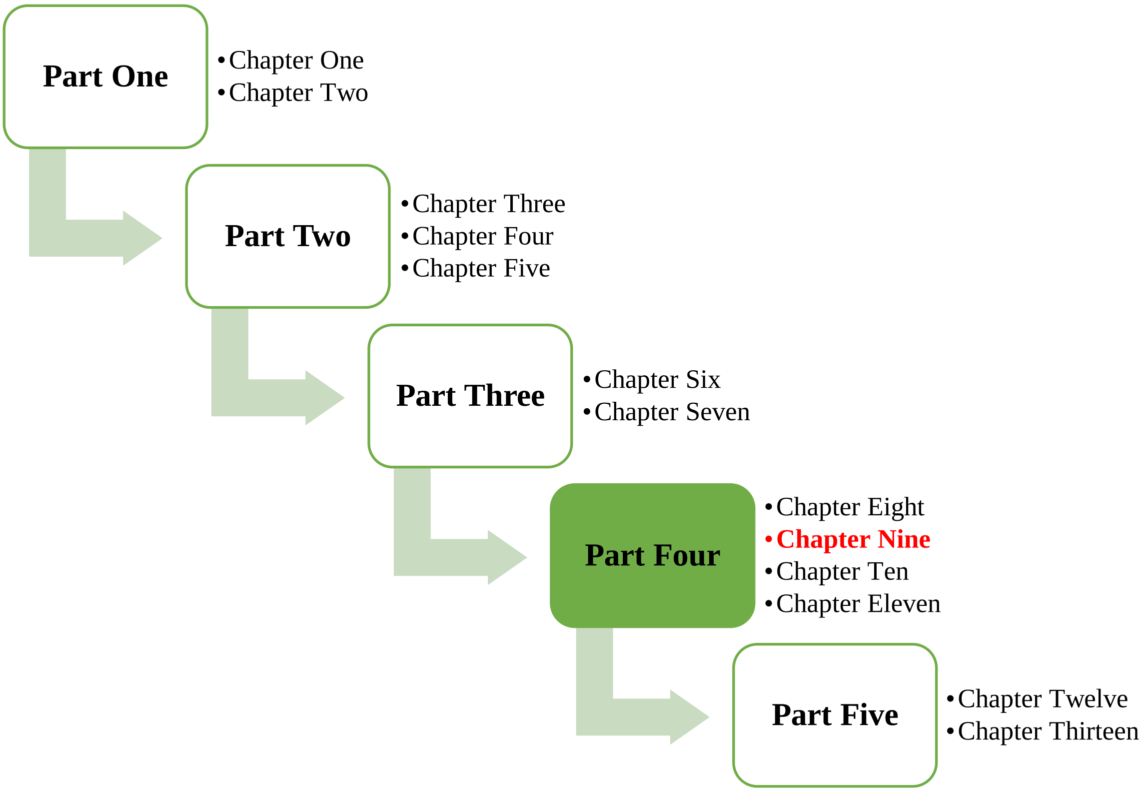
The current study identified social-psychological effects in eight factors representing attitudes, social norms, PBC, occupants’ knowledge, organisational support, and behavioural intervention. Accordingly, results highlighted the positive attitude of occupants toward saving energy. Furthermore, occupants in New Zealand office buildings believe they are self-obligated to commit energy-saving behaviours. Additionally, the occupants are more likely to save energy if those actions satisfy their needs and preferences. These personal norms and the PBC of occupants also justify their positive attitude toward saving energy. Similarly, previous studies highlighted that these occupants with a positive attitude most intend to conduct energy-saving behaviours (Gao et al., 2017; Obaidellah et al., 2019). Individuals are more likely to save energy with a positive attitude, high PBC, and strong personal norms (Gao et al., 2017). Regarding subjective norms, the occupants in the current study believe there is some social pressure when taking specific actions, such as turning off electrical appliances and sharing control over building systems at the workplace. However, they are unsure if social pressure exists to save energy. As Chen et al. (2017) found, subjective norms were no longer significant in predicting occupants' intentions when other substantial factors exist. Considering occupants' actual and perceived knowledge, a higher agreement was received, highlighting their relatively strong mental ability and awareness to save energy and perform energy-saving behaviours. The findings confirm the results of previous studies (Gao et al., 2017) that emphasised that relevant knowledge on saving energy influences occupants' energy-saving behaviours.

However, the findings highlighted that the occupants believe that they do not get enough support and intervention from their organisations to save energy, thus a lack of opportunity to practice energy-saving behaviours. Although organisational support and behavioural interventions positively drive employees' pro-environmental behaviours (Vellei et al., 2016; Xu et al., 2017). Based on the above discussion, an increasing agreement trend is visible with social-psychological effects such as attitude, personal norms, and actual and perceived knowledge entirely within their control. However, subjective norms such as social pressure and PBC to save energy follow a trend of majority disagreement. A similar trend was observed in terms of organisational support and interventions. These trends are primarily similar across different demographic groups. Therefore, the authors recommend providing more organisational support (e.g., rewards to those who save energy, awareness of energy) and behavioural interventions (e.g., energy use report, feedback) to encourage occupants to save energy and practice energy-saving behaviours while providing some levels of responsibility or control to save energy, thereby to increase occupants' satisfaction with their comfort conditions.

8.8 Conclusions

This study presents social-psychological insights relating to energy-saving behaviours across the general office building occupants in New Zealand. The study includes insights into (1) user control availability, (2) occupants' energy-saving behaviours, and (3) relevant social-psychological effects. The study focused on general building occupants in office buildings in New Zealand, where the data were collected from 294 participants. The data were analysed using one-way ANOVA to identify the differences across the demographic groups, and then stacked-bar charts were used to illustrate relevant insights. The empirical results revealed an increased trend of adjusting themselves to the indoor environment and occupants' social-psychological effects such as attitude, personal norms, and actual and perceived knowledge to save energy. In addition, according to occupants' perspectives, there was a lack of organisational support and behavioural intervention, which is necessary for encouraging occupants to save energy while giving them more responsibility for their energy consumption.

A vital contribution of the study is that decision-makers such as building owners, energy modellers, facilities managers, and policymakers can consider these social-psychological effects to promote energy-saving behaviours among office building occupants. Academic researchers can also benefit by extending the current study to occupant energy modelling and building performance simulation. Finally, knowing how social-psychological constructs influence occupants' decision-making or behaviours will facilitate the choice of advanced building design and technologies to achieve energy reduction goals. As the current study is limited to identifying fundamental social-psychological insights, future studies can focus on applying more advanced statistical analysis methods to develop a comprehensive framework that evaluates occupant energy behaviours in office buildings. Furthermore, the study could be extended to enable other social-psychological dimensions, such as occupants' motivations, beliefs, and personal traits, while also considering the influence of socio-demographic factors like educational background, workplace characteristics, occupancy schedule patterns, etc.


Part One
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9.0 Modelling of underlying social-psychological effects on occupant energy-related behaviours

Abstract

Occupant energy-related behaviour research practices based on objective factors may not provide helpful insights that can derive from social sciences perspectives. This study examined how motivation (i.e., attitudes, personal norms), opportunity (i.e., subjective norms, organisational support, behavioural interventions, accessibility to control), and ability (i.e., perceived behavioural control, perceived and actual knowledge) explain the occupant energy-related behaviours in offices. In-person and online questionnaires were distributed across the general population of office occupants in New Zealand, and 294 valid answers were achieved. The social-psychological effects on the choices of occupant energy behaviours are evaluated using a PLS-SEM analysis. The results showed that improving energy-saving opportunities through subjective norms, organisational support, behavioural interventions, and accessibility to control increases the occupants' PBC and perceived knowledge to perform occupant energy-related behaviours. These opportunities and ability drivers then improve the occupants' motivation, building a strong attitude and obligation to save energy in the office environment. Understanding these social-psychological factors are essential, as they utilise the development of occupant energy-related behavioural tools and integrate them with building energy performance simulations. Furthermore, the study assists in designing buildings to suit occupants' comfort preferences and actions.[7]

[7] This chapter is based on the following published Journal article:

Weerasinghe, A. S., Rotimi, J. O. B., & Rasheed, E. O. (2023). Modelling of underlying social psychological effects on occupant energy-related behaviours [Article]. *Building and Environment*, 231, 110055. https://doi.org/https://doi.org/10.1016/j.buildenv.2023.110055

9.1 Introduction

The end-use of building construction and operation contributed to around 35% of energy and related emissions (UNEP, 2021). Globally, energy demand per unit of floor area (m2) is expected to be reduced by 45% by 2030 to align with the Net Zero Carbon goal introduced to limit climate change (UNEP, 2021). Although the COVID-19 pandemic caused a demand shift from the commercial to the residential sector due to the shift from a status quo of working from the office to working from home, the energy demand for commercial offices is expected to bounce back (UNEP, 2021). Recent research by González-Torres et al. (2022) reported an energy share of 54% in Japan and 44% in the US by the commercial and public sectors. In addition, the OECD countries share the most significant portion of the energy consumed by commercial buildings (González-Torres et al., 2022), making New Zealand's commercial sector responsible for a large share of energy use, GHG emissions, waste generation, and water withdrawals (Trading Economics, 2020). Indeed, the commercial building sector in New Zealand makes up to 40% of energy and GHG emissions (EECA, 2020), and reducing this demand secures the path to zero carbon in New Zealand.

Various methods have been introduced to reduce energy usage in buildings, where implementing energy-efficient technologies and energy-saving through building occupants is prominent (Gao et al., 2017). While embedding technologies and appliances is the commonly accepted practice in buildings to improve energy efficiency, this method is associated with a strong rebound effect that most likely increases the individuals' consumption (Berkhout et al., 2000; Georges et al., 2017; Zhang & Peng, 2017). Moreover, many researchers are attentive to the energy-related impacts of occupant behaviours due to the deficiencies in technological implementations (Fu et al., 2021). Occupant behaviours or occupant energy-related behaviours include the behaviours to adapt the indoor environment to the occupants' preferences (i.e., adjusting windows, doors, blinds, thermostats, fans, lighting, and appliances), the behaviours that help occupants to adapt themselves to the environment (i.e., adjusting clothing levels, drinking hot/cold beverages, and moving through spaces), and other non-adaptive behaviours: occupant presence, reporting discomfort, and take no actions about their environment (Gunay et al., 2016; Hong et al., 2017). For example, 7–15% of energy-saving is possible by promoting behaviours (Dietz et al., 2009; Jareemit & Limmeechokchai, 2019). In another study, Sun and Hong (2017) estimated a 20% variance in energy-saving due to individual behaviours. For commercial and public buildings, the energy-saving due to behavioural change was even higher and estimated to be up to 30–40% (Pothitou et al., 2016; Yun, 2018).

In addition, the focus on what drives occupant energy-related behaviours is important along this process to investigate the human and building interactions. Much research is focused on understanding the behaviours to improve energy predictions when designing a building. Nevertheless, accurate forecasts are rarely achieved due to the complex nature of occupant energy-related behaviours arising from multiple factors (Delzendeh et al., 2017; Rupp et al., 2021; Uddin et al., 2021). In BPS, occupant energy-related behaviours are frequently treated as static rather than dynamic and complex (Hong et al., 2018). Enriching knowledge about the effect of multiple factors may improve occupant behaviour models for BPS (Carlucci et al., 2020). However, given the complexity of factors, most previous studies focused on influential factors that can be easily captured (Asadi et al., 2017; Schweiker et al., 2020; Stazi et al., 2017). Therefore, synthesising social-psychological perspectives to assess occupant energy-related behaviours received recent attention (Chen et al., 2020; D'Oca et al., 2017; Hong et al., 2017). These social-psychological perspectives emphasise the influence of attitude, personal norms, subjective norms, PBC, perceived awareness, and knowledge on energy consumption in both residential and commercial buildings (Deme Bélafi & Reith, 2018; Li et al., 2019; Xuan Liu et al., 2021; Rissetto et al., 2022).

Several theories are widely adopted when identifying the most critical social-psychological factors influencing occupant energy-related behaviours (Bavaresco et al., 2020; Heydarian et al., 2020). The TPB and the extended or modified versions of TPB is used to explain pro-environmental behaviours contributing to energy consumption (Xuan Liu et al., 2021; Shi et al., 2017). For example, TPB pays attention to occupants' energy-saving intentions at workplaces by incorporating personal and social norms into the original TPB constructs: attitude, subjective norm, and PBC (Cibinskiene et al., 2020; Obaidellah et al., 2019; Xu et al., 2020). Although another theory, the NAM, has been identified as one of the most influential models for explaining occupants' normative consideration that motivates their energy-related behaviours (Fu et al., 2021; Rissetto et al., 2022; Tverskoi et al., 2021), actual use of NAM was limited compared to TPB. SCT also explains that energy-related behaviours are influenced by occupants' perceived environment, comfort and control factors, personal beliefs, and past behaviours (D'Oca et al., 2017). Based on these three theories, integrated frameworks were further developed to uncover valuable insights into occupant energy behaviours in buildings. Such frameworks include the DNAS, which integrates insights from TPB, SCT, and socio-demographic characteristics of the occupants (Hong, D'Oca, Turner, et al., 2015). Furthermore, MOA incorporates social-psychological aspects derived from NAM and TPB (Li et al., 2019). DNAS adds insights into subjective aspects that affect occupants' HVAC thermostats, windows, lights, and shades/blinds behaviours in US and European offices and universities (Bavaresco et al., 2020; D'Oca et al., 2017; D'Oca, Pisello, et al., 2018; Deme Bélafi & Reith, 2018).

Although empirical studies have developed various frameworks that include social-psychological factors (Bavaresco et al., 2021; D'Oca, Pisello, et al., 2018; Li et al., 2019), the applicability of these frameworks is not evaluated for most countries, and their underlying working mechanism is still unclear. Additional research is necessary to justify the performance of the MOA framework in understanding occupant energy-related behaviours (Li et al., 2019; Tverskoi et al., 2021). Research in different countries/climate zones to identify the variations of behaviours in different contexts, cultures, climates, and socio-economic backgrounds recommends breakthrough results on adaptive behaviours (D'Oca et al., 2019; Rupp et al., 2021). For example, heterogeneous effects on human psychology lead to different energy consumption habits and pro-environmental behaviours (Ma et al., 2013; Mi et al., 2021). In the New Zealand context, Stephenson et al. (2010) and Stephenson et al. (2015) introduced an energy culture framework to identify opportunities for behaviour change through cognitive norms, energy practices, material culture, and external influences on energy consumption behaviour. However, this study focuses on electricity consumer behaviour in residential buildings and business energy behaviour. Added knowledge of social-psychological effects on occupant energy behaviours is critical, along with advanced building technologies, when achieving energy targets in New Zealand (Weerasinghe, Rasheed, et al., 2022b). Accordingly, the current study is an attempt to fill this gap.

9.1.1 Study objectives

This study explores underlying relationships between social-psychological drivers and occupant energy behaviours from the perspective of behavioural theories adopting a modified MOA approach. The study addressed the following research questions. First, what are the significant social-psychological factors affecting occupant energy behaviours in the office context? Second, how do these factors shape the behaviours of office building occupants? The forthcoming sections of this paper are organised to discuss the theoretical framework and research hypotheses in section 9.2. Section 9.3 describes the research methods employed in the study. The data analysis and results of the study are presented in section 9.4. Section 9.5 discusses the findings with practical implications, limitations, and recommendations for further studies, and section 9.6 concludes the study.

9.2 Modified MOA framework and research hypotheses

The MOA theory originated three decades ago and is used to understand consumer behaviour in purchasing products based on processed information (MacInnis et al., 1991). Recently, Li et al. (2017) adopted MOA to identify social-psychological effects on occupant energy behaviours. The authors developed a conceptual framework for exploring occupants' motivation, opportunity, and ability levels on energy use behaviours and estimating these interventions' energy-saving implications. According to the authors, motivation (M) measures an occupant's concern over individual energy consumption and behaviour involving saving energy. Opportunity (O) measures the occupants' accessibility to information on energy conservation and environmental and interpersonal drivers of energy-saving intentions. Ability (A) is how occupants interpret the information on energy-related behaviour based on their past knowledge of energy use, impacts, and consequences. Motivation includes attitudes, personal norms, the ascription of responsibility, and awareness of energy savings consequences (Li et al., 2019). The opportunity component includes subjective norm, descriptive norm, organisational support, accessibility to control, and time availability (Li et al., 2019). The ability component includes PBC, perceived and actual knowledge of building occupants (Li et al., 2017). Subsequently, the MOA framework was used in studies by Li et al. (2019) and Tverskoi et al. (2021); however, additional research is necessary to justify the performance of this framework on occupant energy-related behaviours and to understand the behavioural intention of occupants.

This paper adopts a modified MOA approach removing the constructs: awareness of consequences, the ascription of responsibility, descriptive norms, time availability, and adding behavioural intervention. As Zhang et al. (2013) explained, the awareness of consequences and the ascription of responsibility are antecedent constructs contributing to personal norms. For example, the ascription of responsibility and personal norms depend on the same factor (Li et al., 2019). If occupants do not observe their colleagues' energy-saving efforts but believe in caring about energy-saving, the opportunity can be a pressuring factor

(Li et al., 2019). Therefore, descriptive norms were removed from the study framework. In addition, Li et al. (2019) further explained that time availability does not affect occupant energy-related behaviours as not much time is required for those behaviours. Furthermore, the modified MOA approach is considered appropriate for this study for the following reasons. The modified framework includes all three TPB constructs: attitude, PBC, subjective norms, and personal norms that previous studies primarily included in the extended TPB models (Akhound et al., 2022; Cibinskiene et al., 2020; Obaidellah et al., 2019) and other constructs: organisational support, behavioural intervention, accessibility to control, perceived knowledge, and actual knowledge that was rarely added to extended models. The modified framework also focused on the causal effect of higher-order constructs: motivation, opportunity, and ability on occupant energy behaviours creating direct and mediating causal effects on these behaviours. The modified MOA framework, including the hypothetical relationships, is illustrated in Figure 9.1.

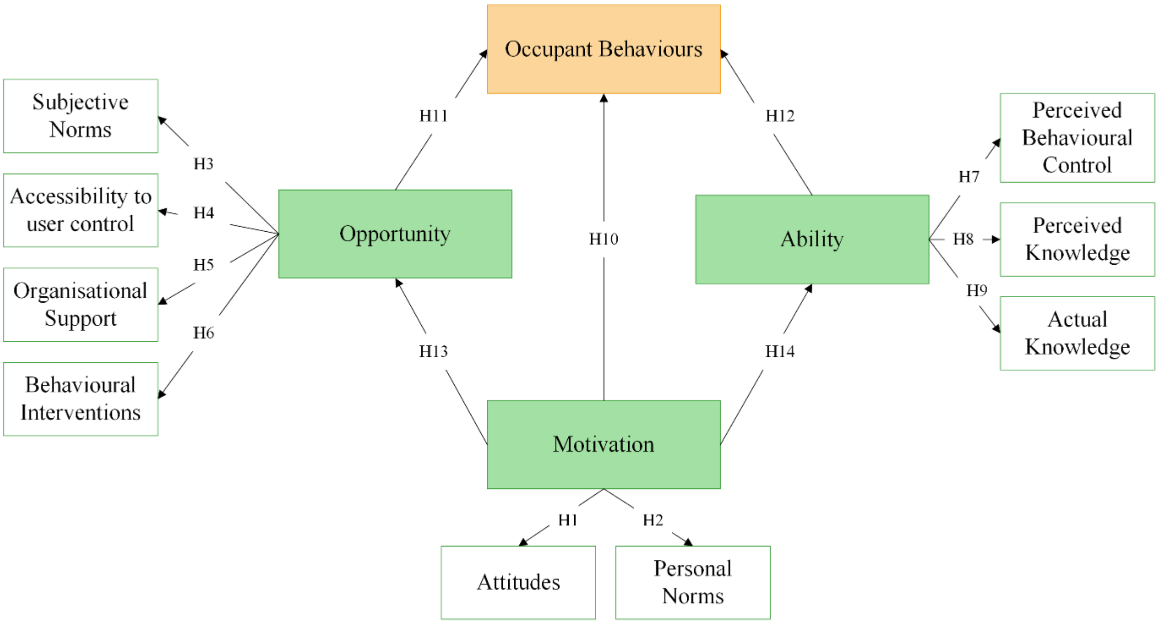


Figure 9.1 Overview of modified MOA framework

9.2.1 Attitude

The effects of building occupants' attitudes on their interaction with the building systems and other actions have been investigated in most studies. Attitude refers to negative or positive feelings of individuals to accomplish a particular behaviour (Gao et al., 2017). In most studies, it was highlighted that the occupants with a more positive attitude toward saving energy are the ones who have the most intentions to conduct energy-saving behaviours (Du & Pan, 2021b; Xuan Liu et al., 2021; Xie et al., 2021). As per previous studies, attitudes positively and significantly affect the intention to share control of adjustable thermostats, operable windows, shades and blinds, and artificial lighting (Bavaresco et al., 2020; D'Oca, Pisello, et al., 2018; Deme Bélafi & Reith, 2018). Another set of studies highlighted that attitudes strengthened occupants' intention to interact with lighting, equipment and appliances, heater/air conditioners, thermostats, fans, and windows (Chen et al., 2017; Liu et al., 2020; Nie et al., 2019). Attitude also strongly predicts pro-environmental behaviours like switching off lights and computers when unattended and adjusting clothing instead turning on the heater and air conditioner (Dixon et al., 2015; Macovei, 2015; Obaidellah et al., 2019). Gao et al. (2017) stated that occupants who know the significance of energy-related behaviours hold a positive attitude and intend to save energy. For example, the occupants who actively apply environmentally friendly attitudes to their lifestyle experienced lower heating expenditure in residential buildings (Lange et al., 2014; Menzes et al., 2012).

H1. Attitude is positively related to the motivation of occupants' energy-related behaviours

9.2.2 Personal norms

Personal norms refer to one's feelings of moral obligation regarding energy-saving (Abrahamse & Steg, 2011). The direct and significant impact of personal norms that indicates occupants' self-obligation to commit energy-saving behaviours was evident in previous studies relating to occupants' environmental intention and workplace behaviour (Akhound et al., 2022; Gao et al., 2017; Li et al., 2019). For example, in their study, Rissetto et al. (2022) showed that personal norms significantly influence fan operation behaviour with high loading. In another study, personal norms positively affect employees' electricity-saving behaviour, where a high level of responsibility, awareness of consequences, and organisational pro-environmental climate positively influence personal norms. However, the organisational electricity-saving climate negatively moderates this because the occupants may save electricity to meet the organisational expectations and the external pressure, not because they want.

In contrast, when the organisational climate is weak, the occupants' obligation strongly influences electricity-saving behaviour (Zhang et al., 2013). Similarly, Cibinskiene et al. (2020) added that when employees feel morally obliged toward the environment or have higher personal norms, they are keen on saving energy extensively in the work environment. Furthermore, personal norms mediate the environmental worldviews (Scherbaum et al., 2008) and energy-saving intentions, strongly impacting occupant behaviours (Du & Pan, 2021b).

H2. Personal norms are positively related to the motivation of occupant energy-related behaviours

9.2.3 Subjective norms

The subjective norms are the supposed social pressure on individuals from peers or colleagues when performing behaviour (Gao et al., 2017; Li et al., 2019). Similarly, researchers generally use the term "social norms" to explain subjective norms or the individuals' perception of people significant to them, and that guide their intention of behaving a certain way based on viewpoints of those significant to them in a specific environment (Akhound et al., 2022; Azar & Al Ansari, 2017). Generally, occupants tend to base their energy-related behavioural intentions upon the perceptions and approval of other occupants (Gao et al., 2017; Li et al., 2019). For example, the occupants are most likely to save upon the revelation of the saving behaviours of their peers, beating the focus on environmental, societal, and financial benefits (Laskey & Kavazovic, 2011). In offices, subjective norms significantly positively affected sharing control over lights and shades/blinds, respectively (Bavaresco et al., 2020; D'Oca, Pisello, et al., 2018; Deme Bélafi & Reith, 2018). Furthermore, office employees are motivated to save energy when their colleagues and managers anticipate (Tang et al., 2019) and provide feedback and information on saving energy (Mulville, 2017). Similarly, Xie et al. (2021) explained that organisational interventions by formulating rules, conducting peer evaluation, and mutual supervision between employees to guide energy-related behaviours help them realise the organisation's energy goals.

H3. Subjective norms are positively related to the opportunity for occupant energy-related behaviours

9.2.4 Organisational support and behavioural interventions

Organisational support reflects the company's commitment and encouragement in promoting occupant energy-related behaviours (Li et al., 2019), which positively supports its employees' pro-environmental behaviour (Xu et al., 2017). Zhang et al. (2013) suggested that organisations can promote electricity-saving behaviour by making employees feel that the organisation encourages and reinforces these behaviours. When such support and encouragement exist, employees are naturally motivated to save electricity, helping organisations achieve their energy-saving prospects (Zhang et al., 2013). In addition, the organisation's rewards to employees based on their energy-saving contributions promote their energy-saving behaviours (Xu et al., 2017). In another study, Azar and Al Ansari (2017) showed that the occupants who earlier had low motivation to save energy significantly improved after they received instructions from facility management to save energy.

Like organisational support, occupants' behavioural interventions are another significant construct to improve their energy-saving behaviours. Integrating behavioural interventions, such as energy feedback and awareness messages, promotes the occupants' energy-saving behaviours (Mulville, 2017). Previous studies introduced behavioural interventions to observe these influences on occupants' use of plug-ins and whether energy savings are possible through implementing those interventions. For example, Acker et al. (2012) explored reducing plug load profiles of computers and monitors, fans and heaters, and other office equipment through occupant energy-related behavioural intervention. This study used plug strips to turn off the power when the sensor does not detect any occupancy. Accordingly, it showed a substantial annual saving of 0.60 kWh per square footage of floor by turning off power to all devices plugged into the controlled outlets.

Furthermore, the authors used conventional behaviour-based interventions, such as sending emails to turn off equipment when unoccupied. However, the authors suggested further studies to identify the saving potential of those behavioural interventions. Recently, Wang et al. (2017) analysed the financial feasibility when implementing behavioural interventions such as smart strips and plug loggers in office buildings supporting the occupants' plug load management. In another study, a metric of sustainability that includes energy-saving measures for computers, monitors, and phones was introduced (Lasternas et al., 2014). Accordingly, this intervention achieved a 23% energy-saving due to the occupant's behaviour change. Similarly, Kamilaris et al. (2015) assessed individual energy feedback's influence on personal computers' energy savings. Kim et al. (2022) introduced a cloud-based eco-feedback and gaming platform, particularly regarding energy-saving thermostat behaviours in residential buildings. A positive effect was observed on thermostat behaviours, increasing room air temperature during the cooling season. The gamification interventions encourage appropriate human-building interactions by letting occupants earn points and rewards that lead to such interactions (Konstantakopoulos et al., 2019)

H4. Organisational support is positively related to the opportunity for occupant energy-related behaviours

H5. Behavioural interventions are positively related to the opportunity for occupant energy-related behaviours

9.2.5 Accessibility to control

Accessibility to control assess the individual's degree of actual controllability over building systems like heating, cooling, ventilation, and lighting (Li et al., 2019), which PBC may not accurately reflect. The occupants may be unable to save energy if they do not own control over building systems and appliances (Li et al., 2017). For instance, when occupants have more control over the environment, they change their energy behaviours (McMakin & Malone, 2002). In a similar context, occupants are satisfied with the space's thermal conditions when given more control over the thermostat (Onyeizu, 2014). Additionally, studies suggested that comparing perceived satisfaction and efficacy over indoor environment control is relevant to addressing occupants' random behaviours (D'Oca et al., 2017). Along these lines, Vellei et al. (2016) discovered that occupants' control promotes energy-saving adaptive behaviours, such as wearing more clothes when they feel cold and controlling the windows more effectively. The occupants' response to the availability and accessibility of building control systems were concerns of many studies (D'Oca et al., 2017). In a more recent study, Xiaoqi Liu et al. (2021) showed the feasibility and energy-saving potential of the HVAC system when combining the control strategies and occupant feedback on thermal preference. On average, 20% of the energy-saving is achieved while maintaining overall occupant satisfaction at the same level.

H6. Accessibility to control is positively related to the opportunity for occupant energy-related behaviours

9.2.6 PBC

PBC refers to the perceived ease or difficulty of conducting the behaviour (Gao et al., 2017; Li et al., 2017; Tetlow et al., 2015). Previous studies often highlight the PBC influence on occupant energy-related behaviours (Li et al., 2019). A few studies highlighted that high PBC promotes energy-saving intentions (Du & Pan, 2021b; Greaves et al., 2013; Webb et al., 2013; Xie et al., 2021). For example, Xie et al. (2021) explained that greater PBC levels combined with positive views and perceived more substantial expectations from others about occupant energy-related behaviours increase the employees' intentions toward energy-saving in commercial buildings. In another study, Chen et al. (2017) identified PBC as the second strongest predictor of cooling and heating energy-saving, which support the claims by Abrahamse and Steg (2009) and Abrahamse and Steg (2011) that enhanced levels of PBC promote energy-savings. PBC positively and significantly affects the adjustments of adaptive behaviours relating to windows, shades and blinds, lighting, and HVAC thermostats in office buildings (Bavaresco et al., 2020; D'Oca et al., 2017; D'Oca, Hong, et al., 2018; Deme Bélafi & Reith, 2018) and the occupants tend to perceive higher ease of sharing control over these adjustments.

H7. PBC is positively related to the ability of occupants' energy-related behaviours

9.2.7 Perceived and actual knowledge

Perceived knowledge explains how occupants perceive their knowledge of energy-saving, while actual knowledge has been used to measure occupants' psychological abilities to perform behaviours in existing studies (Li et al., 2019). Unlike actual knowledge, perceived knowledge refers to the necessary past knowledge to reach the expected outcome (Abrahamse et al., 2007), which is not often accurate due to the influence of personal judgment (Li et al., 2019). Occupants with higher perceived and actual knowledge of energy use and related savings are expected to save more energy than occupants without much knowledge (Abrahamse & Steg, 2009). Furthermore, relevant knowledge and skills in energy-saving influence occupants' intention to practice a particular behaviour and save energy (Gao et al., 2017). Occupants' perceived knowledge can be considered in their energy-saving behaviours during different times of the day. For example, the occupants tend to switch on lights upon arrival and keep them on until they leave the office, where the first lighting switch-on event occurred at the start of daily occupancy (Yun et al., 2012). Another study found that 91% of lighting adjustments occurred soon after the occupants' arrival and shortly before the occupants left (Yao, 2014).

Similarly, Kwong et al. (2014) showed that plug load of computers after working hours contributes substantially to the energy demand, and a 19% reduction can be achieved with careful measures such as turning off when not in use unplugged. In a more detailed perspective, Gunay et al. (2016) developed a model based on plug-in equipment load patterns during different periods in office spaces, where 75% of the plug-in equipment load accounts during the unoccupied periods such as intermediate breaks, weekdays after working hours, weekends, and vacations. Knowledge of such patterns has been used in previous studies to measure the occupants' perceived knowledge influence on their behaviours (Li et al., 2019).

H8. Perceived knowledge is positively related to the ability of occupants' energy-related behaviours

H9. Actual knowledge is positively related to the ability of occupants' energy-related behaviours

Moreover, Table 9.1 presents the hypothetical relationships that explain direct and mediating causal effects between higher-order factors and occupant energy-related behaviours. Establishing potential causal effects between each higher-order factor is a pressing knowledge gap, as most existing literature prioritised the effects of social-psychological constructs like attitudes, subjective norms, and PBC causally linked to one of these higher-order factors.

Table 9.1 Research hypotheses for direct and mediated effects of MOA constructs

Hypotheses	Direct and indirect effects
H10	The motivation has a positive and direct effect on occupant energy-related behaviours
H11	The opportunity has a positive and direct effect on occupant energy-related behaviours
H12	The ability has a positive and direct effect on occupant energy-related behaviours
Hypothesised mediating effects on motivation	
H13	The opportunity will mediate the motivation effect on occupant energy-related behaviours
H14	The ability will mediate the motivation effect on occupant energy-related behaviours

9.3 Research methods

This study aimed to explore and identify the underlying relationships between social-psychological drivers and occupant energy-related behaviours. As illustrated in Figure 9.2, the authors first reviewed existing behavioural theories, conceptualised the modified MOA effects on occupant behaviours, and created the hypotheses. The authors also identified the potential causal effects and counterfactuals between study variables to investigate later. Consequently, a general occupancy survey across New Zealand was conducted to assess the above hypotheses, focusing on social-psychological constructs influencing occupant energy-related behaviour in office buildings. The data collected were cleansed and prepared for further analysis. The data were also checked for sources of CMB, such as respondent-related (i.e., the same respondent rates both independent and dependent variables, personality traits, lack of education/experience) and measurement-related effects (i.e., item complexity, ambiguity, scale formats, style of response, order of questions, group items and labelling them) using a statistical control (Kock et al., 2021). Afterwards, a PLS-SEM was conducted to explore the relationship between constructs.

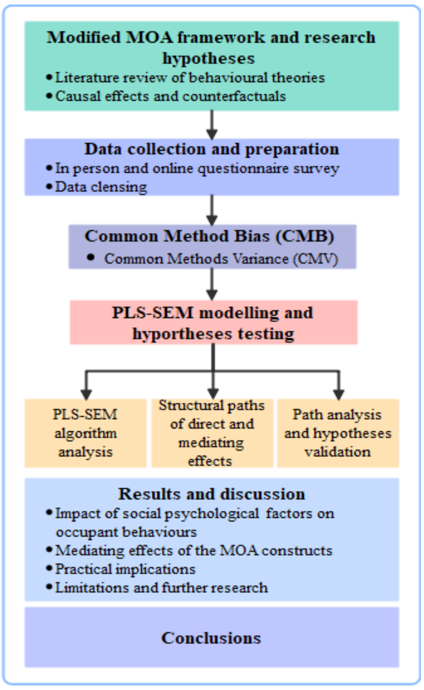


Figure 9.2 Research design

9.3.1 Survey composition and measures

The first section of the survey consisted of background-related questions (i.e., gender, age, ethnicity, region, employment status, and duration). The second section presented the measures of social-psychological aspects that may influence occupant energy behaviours. The authors identified several earlier studies that investigated the influence of social-psychological factors on occupant behaviours and modified them to the current study context (see Table A1 in annexures). The attitudes, subjective norms, and PBC measures were mainly influenced by Abrahamse and Steg (2009). Only one question to measure attitude focusing on saving energy at work is included in the questionnaire. Questions that measure subjective norms consider the influence of co-workers and shared control over building systems on occupants' energy-saving actions. In addition, the questions to measure PBC raise whether occupants' actions to save energy are entirely under their control and comfort preferences. The measure of personal norms reflecting occupants' responsibility to save energy was primarily adopted from work by Zhang et al. (2013).

Moreover, measures of perceived and actual knowledge, organisational support, behavioural interventions, and accessibility to control were adopted by Li et al. (2019). Further, knowledge measures occupants' awareness of energy-saving benefits, while perceived knowledge measures whether occupants know how to save energy and follow up on those. Organisational support and behavioural interventions mainly focus on measuring organisations' encouragement and reward for saving energy and the effect of energy feedback. The measures of accessibility to control consider the availability of personal control over office appliances and systems. The questions on occupant energy-related behaviours were created based on the classification of adaptive and non-adaptive behaviours by Hong et al. (2018). The wording of the statements was further improved using a pilot study of 10 participants to make it appropriate for this context. The questionnaire included multiple-choice questions for background-related questions, whereas all the other aspects were evaluated using a 5-point Likert-type scale representing 1-strongly disagree and 5-strongly agree.

9.3.2 Data collection and study participants

The participants for the study were purposively selected from the general population of employees who work full-time and part-time in any office space in New Zealand. The total workforce of managers and professionals in New Zealand who fulfil the above conditions equals 1,869,481, according to 2018 Census data (Stats NZ, 2022). In a recent survey of 2,560 respondents, the majority (67%) prefer working a few times a week remotely, while only 22% prefer working from home daily during COVID-19 and post-lockdown situations in New Zealand (O'Kane et al., 2020). Therefore, a minimum sample size of 289 respondents with 95% confidence and a 5% margin of error was considered for the current study assuming a population proportion of 0.75 who work in an office space from the population selected (Calculator.net, 2022; Saunders et al., 2019). Quantitative data were collected in person and conducted online through the Qualtrics survey platform from July to November 2021. First, the uncompleted or the responses with missing data were removed from the responses received. Second, each response's standard deviation (SD) was calculated concerning all the answers a respondent gave. The responses with an SD of less than 0.25 value were removed. Accordingly, a total of 294 valid responses were continued for analysis.

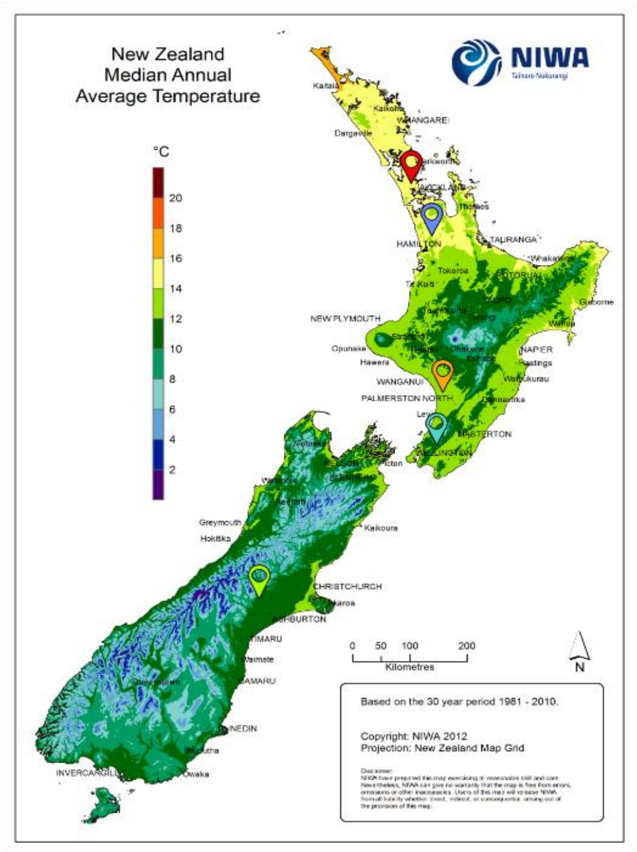


Figure 9.3 New Zealand median annual temperature

Adapted from NIWA (2022). This work is licensed under a Creative Commons Attribution 4.0 International License

Among the selected sample of office employees, 61.2% are male, and 38.1% are female. Most building occupants are aged 30 or older (85%), and only 15% are under 30. Considering the participants' office setup, 49.7% occupy private rooms, 24.1% in shared offices with 2–3 people, 18.4% in open-plan offices with 4–9 people, and 7.8% in open-plan offices with 10 or more than 10 people. Most participants come from the New Zealand European (53.7%) ethnic group, 18.4% Asian, 3.1% from Māori/Pacific peoples, and 24.8% from other ethnic groups. Most participants (41.5%) come from the Auckland region, while 36.1% are based in Manawatu-Whanganui and 22.4% in other regions: Waikato, Wellington, and Canterbury. Figure 9.3 illustrates the median annual average temperature in New Zealand and marks the respondents' locations.

The typical summer temperatures in the Auckland region range from 22°C to 26°C, while in winter, it is 12°C to 17°C. The temperatures in the Waikato region also range in the same levels. In the Manawatu-Whanganui and Wellington regions, the temperatures range from 19°C to 24°C in summer and 10°C to 14°C in winter. In the Canterbury region, however, the temperatures can be lower compared to the above regions, typically the temperatures in summer range from 18°C to 26°C and 7°C to 14°C in winter (NIWA, 2022). Also, most employees (90.8%) work full-time, and 70.1% have worked in their current workplace for a year or more. These higher percentages on employment status and work duration provide insights showing that most occupants are familiar with their surroundings.

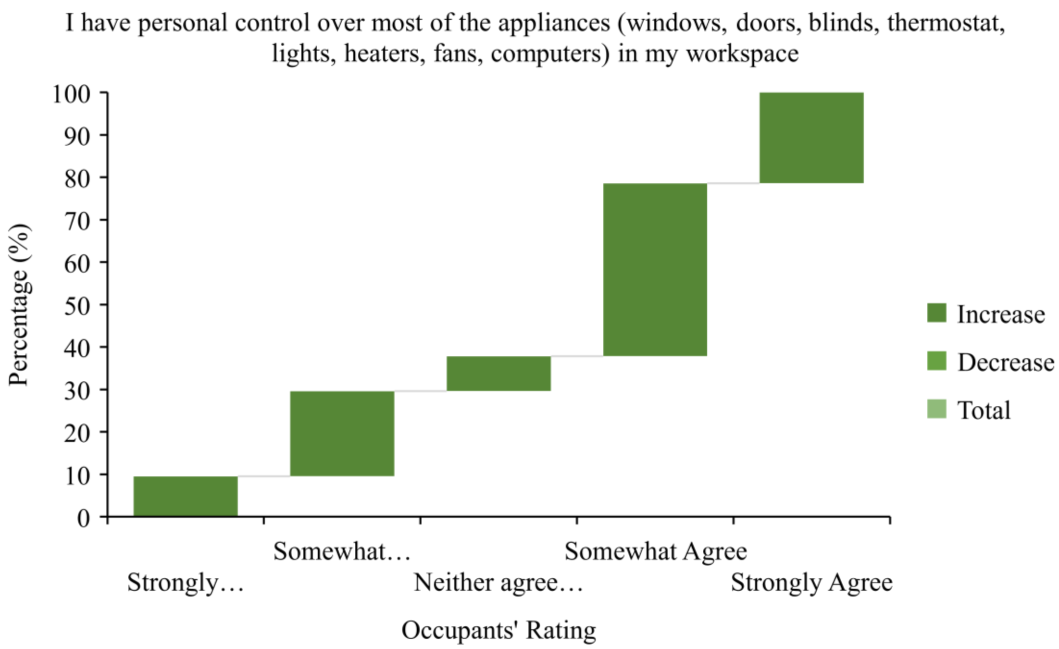


Figure 9.4 Personal control over the building systems and appliances

Considering the accessibility to control building systems and appliances, Figure 9.4 illustrates the occupants' rating on the availability of personal control over the building systems and appliances in their workplace. Accordingly, the majority rate (40.8%) "somewhat agree", while another considerable portion (21.4%) stated, "strongly agree". This reveals that most participants in their workspace control windows, doors, blinds, thermostats, lights, heaters, fans, and computers. As the study did not collect specifics about these systems and appliances, it was assumed that most participants have individual heating/cooling units in their workplaces.

9.3.3 Common methods variance (CMV) analysis

CMB may occur using the same measurement instrument or response technique to measure independent and dependent variables within one survey (Jakobsen & Jensen, 2015). The actual relationship between the variables can be distorted because of different sources of CMB and lead to systematic error variance, identified as CMV (Podsakoff et al., 2012; Richardson et al., 2009). The study must be free from CMB; otherwise, it may impact the reliability of measures and the results' validity (MacKenzie & Podsakoff, 2012), leading to false conclusions regarding the scale's reliability (Baumgartner & Steenkamp, 2001), affecting the correlation among hypothesised relationships of variables and incorrectly reject/failing to reject the null hypothesis (Kock et al., 2021). The statistical techniques used post-data collection identify potential CMB. One such technique is Harman's single-factor test, which is widely used in empirical studies (Fuller et al., 2016). Harman's unrotated exploratory factor analysis suggests that common method bias is present if one factor accounts for more than 50% of the variance (Fuller et al., 2016). Therefore, the study tested CMB using Harman's single-factor analysis for the study variables.

However, Fuller et al. (2016) recommended using other techniques and Harman's test to overcome shortcomings. Specifically, for PLS-SEM, identifying CMB based on variance inflation factors (VIF) using the full collinearity approach is recommended (Kock, 2015). Accordingly, multicollinearity was checked when estimating the path analysis.

9.3.4 PLS-SEM analysis

A PLS-SEM analysis tested the theoretical framework and research hypotheses. All data analyses were conducted within the SmartPLS4 (4.0.7.6.) software. PLS-SEM is a nonparametric statistical method showing the relationships between manifest or observed and latent variables, quantifying their impacts to test hypotheses developed based on the theoretical model (Schumacker & Lomax, 2016). The SEM has been used in various contexts, especially in energy behaviour research, where many dependent variables exist (Bavaresco et al., 2020; Li et al., 2019). Furthermore, SEM allows researchers to solve research questions by developing multivariate test models within the study (Akinyode, 2016). The study determined the standardised factor loadings of each social-psychological construct (latent variable) and created structural model path coefficients to assess relationships between constructs and observed variables (indicators) and the relationship among the higher-order constructs.

In SME analysis, latent variables or constructs are assessed through the impact of observed variables or indicators. The latent variables of this study are attitude, personal norms, subjective norms, PBC, actual knowledge, perceived knowledge, organisational support, behavioural interventions, non-adaptive behaviours, and adaptive behaviours. The observed variables or indicators for those constructs are given in Table A1. The dependent variable in the current study was occupant energy-related behaviour, and the social-psychological factors were the independent variables. The developed SEM model was represented in a path diagram, where circles represent latent factors, and rectangles represent indicators in the measurement model. Measurement models can be represented as reflective and formative measurements (Coltman et al., 2008). In a reflective measurement model, the equation gives the relationship between a latent variable and its observed indicators (9.1). The reflective measurement model was evaluated based on outer loadings (> 0.70), composite reliability (CR > 0.70), AVE (AVE > 0.50), and HTMT Ratio.

$$x = lY + e$$

Equation 9.1 Measurement model

where;

x = observed indicator

Y = latent variable, the loading l is a

l = regression coefficient between x and Y (loading)

e = random measurement error

A linear combination of indicators forms the construct in a formative measurement model, and the indicators do not necessarily have to correlate strongly (Sarstedt et al., 2021). Two indicators must be distinguished in a formative model: causal and composite (Bollen & Bauldry, 2011; Pearl, 2009). Causal indicators give an error term implying that the indicators did not perfectly measure its constructs, and it captures all the other causes that the causal indicators do not capture (Bollen & Bauldry, 2011). A measurement model with causal indicators can be explained using equation (9.2):

$$Y = \sum_{k=1}^{K} w_k \cdot x_k + z$$

Equation 9.2 Measurement model with causal indicators

where;

w_k = the contribution of x_k (k = 1..., K) to Y

z = error term associated with Y

However, the measurement model using composite indicators is different, and the researchers assume the indicator fully defines the constructer (Sarstedt et al., 2021) based on the way research is designed and knowledge from previous studies. The credibility of the SEM depends on the credibility of these causal assumptions (Bollen & Bauldry, 2011). Thus, the error term in formative modelling with composite indicators is set to zero (z = 0) and takes the following equation:

$$Y = \sum_{k=1}^{K} w_k \cdot x_k$$

Equation 9.3 Measurement model using composite indicators

where;

Y = linear combination of indicators x_k (k = 1..., K) weighted by w_k = indicator weight

The causal effects can also be identified using the covariance between observed variables considering path coefficients or the covariance of the error terms (Pearl, 2009). Henseler et al. (2015) identified that the measurement model is arranged to form a new entity with composite indicators. More recently, concepts like attitudes, perceptions, and behavioural intentions were measured using composite indicators (Nitzl & Chin, 2017). In the current study, latent variables are endogenous (denoted Y) and exogenous (denoted X). The occupant energy-related behaviour was endogenous, while motivation, opportunity, and ability were exogenous variables. These are the second-order factors (a composite of several first-order factors) which identify first-order factors contributing to them (Rissetto et al., 2022). In the structured model, rectangles illustrated first-order factors, and circles illustrated second-order factors. Single-headed arrows connecting second-order factors with first-order factors and other second-order factors represent one factor that has hypothesised direct and indirect or mediating causal effects on each variable. The PLS-SEM algorithm and bootstrapping were run several times to investigate the different causal and counterfactual effects. The results of the SEM process are outlined, presenting the causal model that scores most favourably on the significance and relevance of path coefficients ($p < 0.05$) and multicollinearity (VIF < 3.0) (Pearl, 2009).

The minimum sample size in PLS-SEM is usually determined based on a few methods: the 10-times rule (Hair et al., 2017), the minimum R-squared (Cohen, 1992), and the inverse square-root method (Kock and Hadaya, 2018). The study considered the minimum sample size based on the inverse square root method among these different methods. This method calculates the sample size when the probability of the path coefficient and its standard error ratio is greater than the test statistic critical value for a given significance level (Kock & Hadaya, 2018). The minimum sample size (nmin), assuming a standard power level of 80% and the significance level of 5%, is given by the following equation,

$$nmin = \left[\frac{2.486}{\beta min}\right]^2$$

Equation 9.4 The minimum sample size

βmin is "the value of the path coefficient within the minimum magnitude in the PLS path model," assumed to be between 0.15 - 0.2 (Kock & Hadaya, 2018). Accordingly, for the current study, the minimum sample size required ranges from 155 - 274, and the study has 294 responses which is adequate for SEM analysis.

9.4 Results

9.4.1 Common method bias (CMB)

Before constructing the SEM model, a single-factor analysis was performed to identify the CMB variance. The results are presented in Table A2, revealing 18.87% of the total variance from the first set of factors. The CMB variance cannot influence the study outcome as the study variance is less than 50%. Subsequently, Cronbach's alpha (α) was measured for the 22 study variables, and an α value of 0.754 was acquired, which is greater than the acceptable level of 0.70 (Kline, 2015).

9.4.2 Construct reliability and validity

The reliability and validity of social-psychological constructs were evaluated using the PLS-SEM algorithm (creating a measurement model) before verifying the study hypotheses (refer to Figure 9.5). Thereby, the researcher evaluates whether the proposed model is suitable for representing the data sample. Construct reliability evaluates how the model variables consistently measure the dependent variable (Kline, 2015). Further, this was assessed using the CR parameter, and a CR estimate between 0.60 to 0.70 is considered acceptable in exploratory research (Hair & Alamer, 2022). The abbreviations used in Figure 9.5 are summarised in Table 9.2.

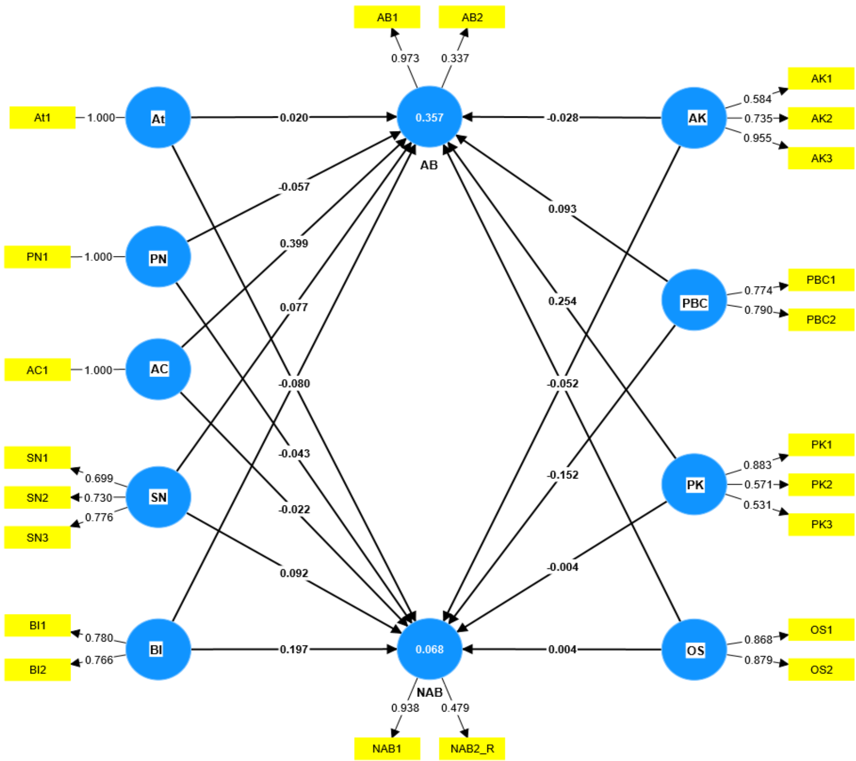


Figure 9.5 Standardised estimates of the measurement model

As presented in Table 9.2, all CR values of latent variables range between 0.710 to 0.865, except for the constructs with one indicator showing a value of 1.000. Therefore, the construct reliability for latent variables was established. The convergent validity reflects how well the selected indicators measure the construct (Kline, 2015). The standardised factor loadings and AVE were used to estimate the convergent validity (Hair & Alamer, 2022). Table 9.2 illustrates that factor loadings of each indicator ranged between 0.563 and 0.899. All indicators showed a factor loading greater than 0.7 except for three. Considering AVE, the values ranged from 0.535 to 0.762, and all constructs have AVE values greater than 0.50.

Along with these results, the construct reliability and convergent validity were established for each study construct.

Table 9.2 Results of PLS-SEM algorithm analysis

Constructs	Indicators	Loading	CR	AVE
Attitude (At)	At1 - Saving energy at work is important to me	1.000	1.000	1.000
Personal norms (PN)	PN1 - I feel responsible at to save energy	1.000	1.000	1.000
Subjective norms (SN)	SN1 - My co-workers expect me to save energy at the workplace	0.698	0.781	0.543
	SN2 - Most of my co-workers expect me to turn off electrical appliances	0.749		
	SN3 - Sharing control over building systems with my co-workers is easy	0.763		
Organisational support (OS)	OS1 - My company encourages employees to save energy	0.888	0.865	0.762
	OS2 - My company rewards employees for saving energy	0.858		
Behavioural interventions (BI)	BI1 - The feedback on individual energy use by our building management team is important for me to change my energy-driven behaviour	0.804	0.748	0.597
	BI2 - Our building management team often sends energy use reports	0.740		
Accessibility to control (AC)	AC1 - I have personal control over most of the appliances (windows, doors, blinds, thermostat, lights, heaters, fans, computers) in my workspace	1.000	1.000	1.000
Perceived behavioural control (PBC)	PBC1 - Saving energy during work is entirely within my control	0.756	0.758	0.611
	PBC2 - Actions I take to save energy depending on my comfort preferences	0.807		
Actual knowledge (AK)	AK1 - I am aware that reducing energy use will reduce costs	0.711	0.853	0.661
	AK2 - I am aware that reducing energy use will reduce emissions	0.837		
	AK3 - I am aware that reducing energy use will improve my *organisation's* image/reputation	0.882		
Perceived knowledge (PK)	PK1 - I often close windows, turn off the lights, heaters, fans, computers, etc., whenever I leave the office, and unplug appliances when not in use	0.638	0.774	0.535
	PK2 - If I feel slightly cold at the workplace, I will put on another layer of clothing instead of using the heater	0.792		
	PK3 - If I feel slightly warm at the workplace, I will adjust my clothing level instead of using the air conditioner	0.756		
	NAB1 - I often report discomforts related to IEQ	0.899	0.710	0.563

Non-adaptive behaviours (NAB)	NAB2 - I am willing to accept and do nothing about the existing indoor environmental conditions	0.563		
Adaptive behaviours (AB)	AB1 - I often adjust building appliances to satisfy my comfort preferences	0.737	0.714	0.555
	AB2 - I often adjust myself to the environmental conditions at my workspace by adjusting clothing, drinking hot/cold beverages, and moving through spaces	0.753		

9.4.3 Discriminant validity

Moreover, the degree to which one construct differs from other constructs or the dependencies between latent variables was assessed using HTMT Ratio, Fornell-Larcker criterion, and cross-loadings representing discriminant validity (Fornell & Larcker, 1981; Henseler et al., 2015). Table 9.3 presents HTMT ratios or correlation estimates to show the relationships between latent variables. Accordingly, all HTMT ratios were less than the required limit of 0.90, except for organisational support and behavioural interventions. The square roots of the AVE values need to be greater than correlation estimates between variables when considering the Fornell-Larcker criterion (Fornell & Larcker, 1981). The values in bold included in Table 9.3 represent each construct's square root of the AVE. All square roots of AVE values are greater than correlations between constructs, except for organisational support and behavioural interventions. All indicators showed the highest cross-loadings on the constructs they were hypothesised to measure (see Table A3). However, attitude and personal norm indicators had high cross-loadings on each other. Therefore, considering all the measures, the results support the discriminant validity for most constructs.

Table 9.3 Correlations and SQRT of AVE

	Mean	SD	AK	At	PK	PN	AC	PBC	SN	OS	BI
AK	4.153	0.779	0.773								
At	4.070	0.957	0.519	1.000							
PK	3.878	0.812	0.271	0.162	0.680						
PN	3.820	1.071	0.483	0.726	0.195	1.000					
AC	3.450	1.286	0.097	0.045	0.265	0.099	1.000				
PBC	3.241	0.868	0.184	0.117	0.461	0.214	0.689	0.782			
SN	3.035	0.882	0.245	0.333	0.310	0.395	0.372	0.736	0.736		
OS	2.573	0.996	0.246	0.263	0.101	0.310	0.086	0.459	0.741	0.873	
BI	2.561	0.838	0.460	0.395	0.288	0.451	0.056	0.593	0.694	1.246	0.772

9.4.4 Proposed structural model and hypotheses analysis

The PLS-SEM measurement model was used to analyse 294 responses and determine the relationships between indicators and latent variables. Consequently, the structural model identifies pre-assumed causal associations among latent variables and specifies direct and indirect effects between latent variables for hypotheses verification (Byrne, 2013). The bootstrap method examined the direct and indirect social-psychological effects on occupant energy-related behaviours. In PLS-SEM, bootstrapping was conducted by creating random subsamples of 5,000 with a bias-corrected and accelerated (BCa) bootstrap interval to determine those effects (Hair & Alamer, 2022). The parameter estimates: outer loadings, and path coefficients (β) obtained from bootstrapping are used to derive the 95% confidence intervals for testing significance. In SEM, a high coefficient value shows a strong causal relationship, while a low coefficient indicates a weak relationship between dependent and independent variables. The positive and negative signs indicate how the relationship varies between the variables. For example, positive means the value of the independent variable varies directly with the value of the dependent variable, while negative means the relationship is inverse (Chan et al., 2017).

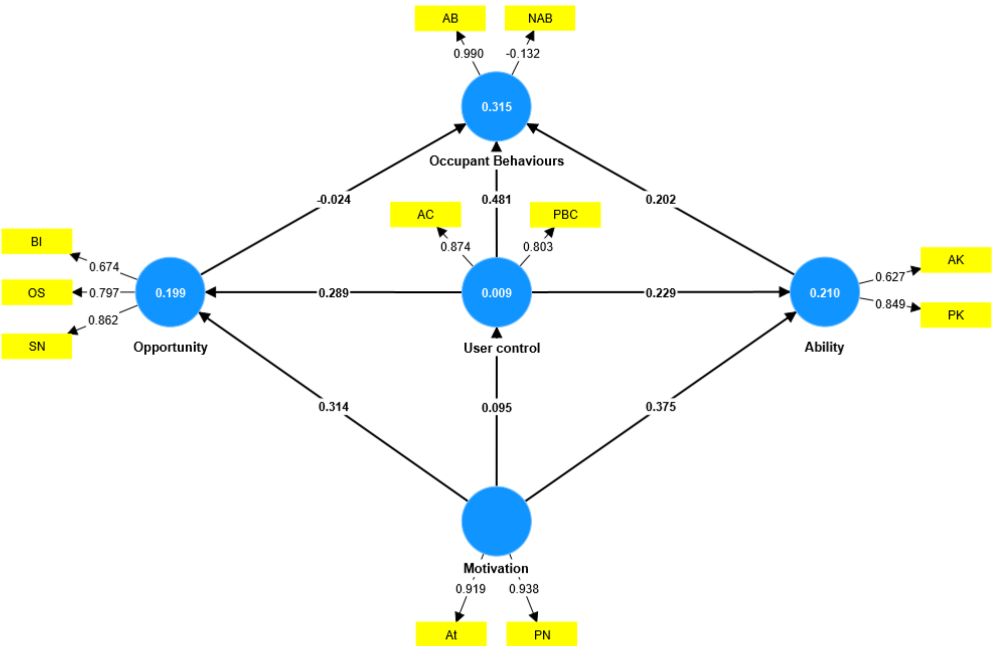


Figure 9.6 One of several causal models tested in the path analysis

Several SEM models were tested during the path analysis process creating new indirect relationships between higher-order constructs and new higher-order constructs based on the nine constructs considered in the current study. Figure 9.6 provides an example of one of such models tested for causal relationships. Although VIF values were supported, most of these models' path coefficients of indirect and mediating relationships were insignificant.

Figure 9.7 illustrates the developed structural model with its path coefficients. Covariances of higher-order constructs are presented in Table A4 (in the appendix) to show the causal effects from observed associations of the higher-order constructs in the current study (Pearl, 2009). Table A5 summarises the covariance matrix of all latent variables. Additionally, the covariances of all the observed variables are presented in Table A6 (in the appendix) to defend the causal relationships hypothesised in the study (Pearl, 2009).

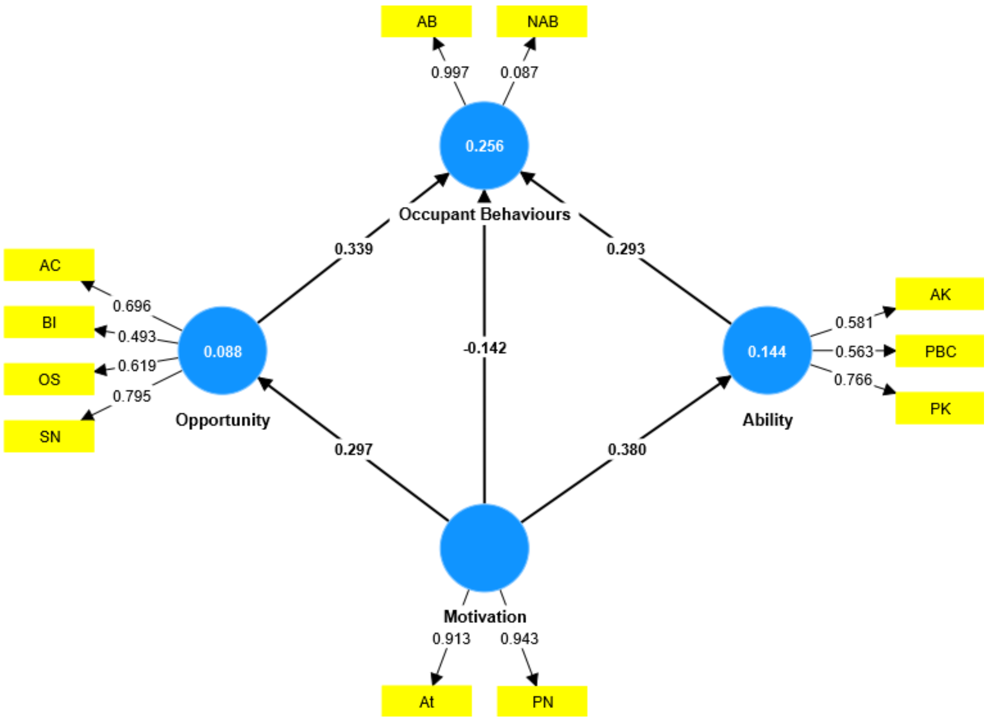


Figure 9.7 Structural paths of direct and mediating effects

Table 9.4 shows the effect of path coefficients in verifying research hypotheses. The attitude (β= 0.913, $p < 0.05$) and personal norms (β= 0.943, $p < 0.05$) showed positive and significant relationships with the motivation for the occupant energy-related behaviours, and therefore, both hypotheses 1 and 2 were supported. The latent variables: subjective norms (β= 0.795, $p < 0.05$), organisational support (β= 0.619, $p < 0.05$), behavioural interventions (β= 0.493, $p < 0.05$), and accessibility to control (β= 0.696, $p < 0.05$) were positively and significantly associated to the opportunity for the occupant energy-related behaviours, and therefore, Hypotheses 3 to 6 were accepted. Similarly, PBC (β= 0.563, $p < 0.05$), perceived knowledge (β= 0.766, $p < 0.05$), and actual knowledge (β= 0.581, $p < 0.05$) demonstrated positive and significant relationships with the ability for occupant energy-related behaviours and supported the Hypotheses 7 to 9. As with these second-order factors (motivation, opportunity, and ability), Hypotheses 10 and 11 showed significant relationships. The study hypothesised a positive relationship between motivation and occupant energy-related behaviours. However, the motivation (β= -0.142, $p < 0.05$) showed a negative relationship in the model. Therefore, Hypothesis 10 was rejected. Additionally, opportunity (β= 0.339, $p < 0.05$) and ability (β= 0.293, $p < 0.05$) were positively related to the occupant energy-related behaviours.

Table 9.4 Path analysis and hypotheses validation

Hypotheses	Regression paths	β	SD	p	VIF	Validation
Results of direct effect analysis between first-order and second-order factors						
H1	At -> Motivation	0.913	0.034	0.000	2.115	Accept
H2	PN -> Motivation	0.943	0.029	0.000	2.115	Accept
H3	SN -> Opportunity	0.795	0.070	0.000	1.414	Accept
H4	OS -> Opportunity	0.619	0.139	0.000	1.749	Accept
H5	BI -> Opportunity	0.493	0.164	0.001	1.531	Accept
H6	AC -> Opportunity	0.696	0.131	0.000	1.125	Accept
H7	PBC -> Ability	0.563	0.138	0.000	1.040	Accept
H8	PK -> Ability	0.766	0.096	0.000	1.053	Accept
H9	AK -> Ability	0.581	0.182	0.001	1.015	Accept
Results of direct effect analysis among second-order factors						
H10	Motivation -> Occupant energy-related behaviours	-0.142	0.062	0.011	1.192	Reject
H11	Opportunity -> Occupant energy-related behaviours	0.339	0.078	0.000	1.327	Accept
H12	Ability -> Occupant energy-related behaviours	0.293	0.086	0.000	1.414	Accept
Results of mediating effect analysis						
H13	Motivation -> Opportunity -> Occupant energy-related behaviours	0.101	0.031	0.001	2.192	Accept
H14	Motivation -> Ability -> Occupant energy-related behaviours	0.111	0.037	0.001	2.192	Accept

Both opportunity (β= 0.101, $p < 0.05$) and ability (β= 0.111, $p < 0.05$) mediated the relationship between motivation and occupant energy-related behaviours positively and significantly. Accordingly, motivation simultaneously offers a positive and significant (β= 0.212, $p < 0.05$) effect on occupant energy-related behaviours through all mediators. Therefore, both Hypotheses 13 and 14 were accepted. Furthermore, the direct effect of motivation on occupant energy-related behaviours was negative, and the total effect (β=

0.069, p= 0.129) was insignificant, indicating a full mediating effect on occupant energy-related behaviours by opportunity and ability. Collinearity statistics of outer and inner models showed a VIF value of less than 3.0 for each construct, indicating that the model is not at a critical level from biased causal inference.

9.5 Discussion

This study examined how social-psychological drivers: attitudes, personal norms, subjective norms, organisational support, behavioural interventions, accessibility to control, PBC, and perceived and actual knowledge might explain the occupant energy behaviours in office buildings. The study also examined how motivation, opportunity, and ability to save energy might mediate the influence of individuals' energy-related behaviours. Understanding these social-psychological factors is essential, as they can be utilised to develop occupant behaviour tools and integrate them with building energy performance simulation.

9.5.1 Impact of social-psychological factors on occupant energy behaviours

The PLS-SEM algorithm and bootstrapping analysis for social-psychological factors suggest that each observed variable from the questionnaire fits into the relevant constructs: motivation, opportunity, and ability.

The analysis of the motivation construct can be interpreted as two components: energy-saving attitudes and responsibility/obligation to save energy (personal norms). The high factor loadings of each component: attitudes (0.913) and personal norms (0.943), may express a significant variance in motivation. Therefore, occupants' strong attitudes and personal norms influence their motivation to practice occupant energy-related behaviours, as supported by previous studies (Du & Pan, 2021b; Li et al., 2019). Furthermore, the high correlation and cross-loading (0.726) between the indicators of attitude and personal norms reveal a causal relationship, and they can be either reliable indicators or affected by some other unobserved factors (Pearl, 2009). The covariance results of these indicators show positive changes in adaptive behaviours (AB1 and AB2) while negative changes in non-adaptive behaviours (NAB1 and NAB2). Accordingly, the increase in attitudes and personal norms increases adjustment of building appliances and themselves considering environmental preferences and vice versa. However, the increase in these two variables results in a decrease in reporting discomforts and no-action behaviours of occupants. Although such a relationship exists, the covariance value indicates a weak relationship.

The items representing perceived social pressure to engage in occupant energy-related behaviour (subjective norms), energy rewards and encouragement (organisational support), energy feedback from building managers (behavioural intervention), and accessibility to user control represent and contribute to the opportunity construct. The analysis of subjective norms showed a high factor loading (0.795) with opportunity construct and showed significant correlations with organisational support (0.741) and behavioural interventions (0.694). Subjective norms indicate a positive association with adaptive and non-adaptive behaviours regarding covariances. Organisational support and behavioural interventions also showed positive covariances in adaptive and non-adaptive behaviours, while the accessibility to control only showed a positive relationship to adaptive behaviours (Cov = 0.525). Theoretically, the occupants' intention to save energy is influenced by the expectations of their colleagues and managers (Tang et al., 2019) and their interventions by providing energy feedback and guidelines (Mulville et al., 2016; Xie et al., 2021), and the degree of control they have over their environment (D'Oca et al., 2017). Combining the effects of organisational support and interventions and control strategies positively influences occupant energy-saving behaviours and user comfort. Thus, it will reduce reporting discomfort (Xiaoqi Liu et al., 2021). The availability of information through these channels is a great deal for individuals to have solid energy-saving intentions and thus reflect on their behaviours.

The unique construct ability interprets the energy-related behaviours based on their experience with energy use impacts. The items from the questionnaire that measures perceived ease or difficulty in saving energy (PBC), use of knowledge on energy-saving (perceived knowledge), and the ability to perform energy-related behaviours (actual knowledge) are all contributing to the ability construct. Perceived knowledge showed a higher coefficient (0.766) than PBC and actual knowledge. Although all of them contribute to a single construct, the factors essentially do not show a strong causal relationship between them, as revealed in cross-loadings and the covariance matrix, but show a positive relationship to the ability construct. One possible explanation could be that saving energy in offices needs little effort and no detailed knowledge to perform the behaviours (Li et al., 2019). However, this is highly influenced by personal judgment (Li et al., 2019). All these variables show a positive relationship with adaptive behaviours, while only actual knowledge reveals a positive association with non-adaptive behaviours. Strong PBC and perceived knowledge reveal a solid intention to save energy (Du & Pan, 2021b; Gao et al., 2017; Xie et al., 2021). Subsequently, more human-building interactions are expected, reducing the reporting of discomfort-related complaints (Hong et al., 2017).

9.5.2 Mediating effects of the MOA constructs

Mediating effects of the motivation, opportunity and ability constructs were analysed, considering their relationship to occupant energy-related behaviours. In the current study, the occupants' energy behaviours were primarily identified using two components, adaptive and non-adaptive behaviours, each measuring through the items given in the questionnaire relating to adjusting building systems and appliances, clothing, drinking beverages, and moving through spaces to save energy, and reporting discomfort or do nothing about the existing indoor environmental conditions. However, path coefficients analysis showed a less significant relationship (0.087) between non-adaptive and overall occupant energy behaviours. Therefore, a significant portion of occupant energy behaviours is expressed only through adaptive behaviours. This is a significant drawback that exists in past studies as well. The studies focused mainly on adaptive human building interactions such as lighting, heating, air conditioning appliances, and thermostats (D'Oca et al., 2017; Li et al., 2019; Shi et al., 2017), while the focus on adaptive behaviours such as adjusting clothing, drinking hot/cold beverages, and moving through spaces and non-adaptive behaviours is usually ignored thus not adequate to support the empirical findings of the current study. A possible reason for this could be that all behaviours cannot be summarised in a unique construct as occupant energy-related behaviours, and the adaptive and non-adaptive behaviours are substantially different.

Along these lines, path coefficients for motivation, opportunity, and ability constructs were mainly considered for their influence on adaptive behaviours. The current study modified the MOA model from Li et al. (2019), and the direct effects of all three constructs and indirect effects mediated by opportunity and ability constructs were evaluated for their influence on occupant energy behaviours. The direct effect analysis showed that opportunity and ability positively and significantly affect occupant energy-related behaviours; therefore, both hypotheses referring to the influence on occupant energy-related behaviours (H11 and H12) were confirmed. Unlike these two constructs, motivation indicated a negative but significant effect and hypothesis H10 was not confirmed due to this negative relationship. The total effect of motivation on occupant energy-related behaviour was insignificant, indicating that opportunity and ability fully mediate motivation (Refer to Table 9.5). Thus, on condition that Hypotheses H11 and H12 confirmed there is causality from the opportunity to motivation and ability to motivate, implying that these two constructs have multiplier effects on occupants' motivation to perform energy-related behaviours.

Table 9.5 Total effects of MOA constructs on occupant energy-related behaviours

Regression paths	Path coefficients	Standard deviation	P-values
Ability -> Occupant energy-related behaviours	0.293	0.086	0.000
Motivation -> Ability	0.380	0.100	0.000
Motivation -> Occupant energy-related behaviours	0.069	0.061	0.129
Motivation -> Opportunity	0.297	0.080	0.000
Opportunity -> Occupant energy-related behaviours	0.339	0.078	0.000

Opportunity demonstrates the most substantial total effect (direct and indirect effects) on behaviour among the three MOA constructs. The effect of ability comes second, while motivation was not significant. Furthermore, the indirect effect of motivation on occupant energy-related behaviours suggests that improving individuals' opportunity and ability levels make them more driven toward performing energy-saving behaviours. The previous research supports giving instructions to guide energy use (Azar & Al Ansari, 2017; Xie et al., 2021), peer evaluation, and mutual supervision between employees (Xie et al., 2021) to save energy. In addition, occupancy sensors, plug strips, and loggers were introduced to reduce specific appliance plug loads (Acker et al., 2012; Wang et al., 2017), and giving them more control over the environment is also vital to drive occupant energy behaviours (McMakin & Malone, 2002; Onyeizu, 2014). These implications provide more opportunities and improve the occupants' ability to perform energy-saving behaviours through improved perceived knowledge. The behaviours considered in the current study require no detailed knowledge and little effort to perform (e.g., switching off appliances, putting on a clothing layer, etc.), as supported in the literature (Li et al., 2019). As opportunity and ability constructs enable more potential for energy-saving through continuous support, intervention, and awareness, the occupants' motivation to save energy will be subsequently improved.

9.5.3 Practical implications

A key takeaway from the current study is that improving energy-saving opportunities through subjective norms, organisational support, behavioural interventions, and accessibility to control intensifies the occupants' ability: perceived behavioural control and perceived knowledge to perform occupant energy-saving behaviours. The solid opportunity and ability drivers then enhance the occupants' motivation to save energy with a strong attitude and responsibility towards energy-saving in their office environment. As suggested in the study, the organisations can use different interventions like peer evaluation, energy feedback, formulation of clear rules, and increased user control to convince occupants of the company's expectations in saving energy. Further, this is more effective than just awareness. The study developed an MOA information model that facilities managers and energy modellers can utilise for future occupant energy monitoring, modelling, and decision-making approaches. Furthermore, the insights into this complex decision-making on the occupants enable improving future monitoring and modelling approaches from conventional ones based on building physics and occupancy profiles. Accurate energy predictions at the design stage save energy and cost at the operation and maintenance stage of the building. Additionally, combined with cutting-edge building design and technology strategies, social-psychological aspects are excellent drivers for achieving energy reduction goals. The information enabled at the building level can be embedded into net zero carbon and energy targets at a policy level.

9.5.4 Limitations and further research

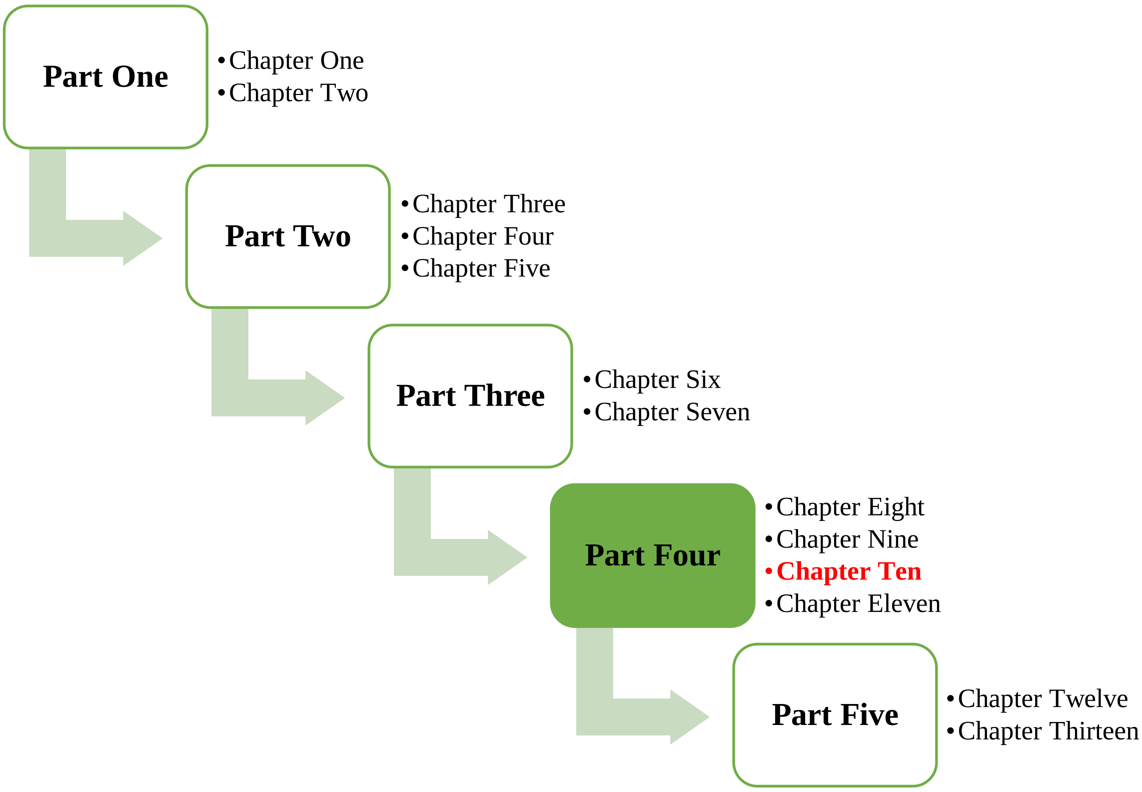
Although the research has essential academic and industry-related implications, limitations exist, and future research directions will be given to overcome these limitations. First, the current study is cross-sectional and based on a self-reported survey of occupants in several organisations. People often overrate their energy-saving intentions in self-reports due to societal expectations. Therefore, future research could use field observation alongside in-person surveys to monitor the actual occupant energy-related behaviour and individual energy consumption data over time.

Second, although the minimum sample was achieved, data were collected using a purposive sample across New Zealand. This may restrict the generalisability of the results for the broader office population characterised by personal characteristics (i.e., gender, age, ethnicity, etc.) and participants' office setup (e.g., size, type, number of co-workers, location, types of energy appliance provided, etc.). Furthermore, occupant energy-related behaviours (i.e., adjusting thermostats, heaters, and blinds, turning on/off lights) are often affected by environmental (i.e., temperature, humidity, rainfall, wind, etc.) and building-related characteristics (i.e., types of equipment and appliances, user control availability, operation of building system and appliances, etc.). Future studies can consider normalising the effects of these external characteristics to avoid biases not measured in the survey. The findings from one context may not be suitable for another; therefore, future research could try to gather data from more countries and regions. In addition, this study collected data from July to November 2021, when the countrywide lockdowns were still effective in New Zealand due to the Covid 19 pandemic. Some participants from the selected sample may work from home when completing the questionnaire, which may have influenced the reported values.

Third, although the study hypotheses were validated, path coefficients of second-order factors (i.e., motivation, opportunity, and ability) are still small but improved compared to the same reported by Li et al. (2019). The final model only represents path coefficients among second-order factors and occupant energy-related behaviours. Therefore, further research is needed to investigate the causality between social-psychological factors and occupant behaviours, specifically when developing a theoretical framework of how social-psychological factors affect occupant energy-related behaviours. Additionally, the study used only one indicator/observed variable in each construct attitude, personal norms, and accessibility to control. Along these lines, future research can use two or more indicators to measure each construct and showcase which first-order factors contribute significantly to the outcome factor (i.e., occupant energy-related behaviours). The behaviours considered in the current study were based on the main categories of occupant behaviours introduced by Hong et al. (2017) and Gunay et al. (2016). Therefore, future studies can be extended to represent individual occupant behaviours while integrating other variables such as environmental (i.e., temperature, air quality, acoustic, visual) and contextual factors (i.e., building and time-related factors) to evaluate the validity of this work.

9.6 Conclusion

Using a general survey across New Zealand offices, this study used a modified MOA framework to evaluate social-psychological effects on occupant energy behaviours. The study first established the significant social-psychological factors (first-order factors) contributing to motivation, opportunity, and ability (second-order factors) and then created path models between second-order factors and occupant energy-related behaviours. This approach helps to explain the energy-related behaviours of office occupants. The study found that the significant social-psychological factors contributing to motivation include attitudes and personal norms; opportunity with the collective contribution of subjective norms, organisational support, behavioural intervention, and accessibility to user control; and ability with PBC, perceived and actual knowledge. With these influences, opportunity and ability are significantly related to occupant energy-related behaviours, while motivation has a relationship that is mediated by opportunity and ability. Considering occupant energy-related behaviours, these social-psychological factors significantly influenced adaptive behaviours (i.e., adjusting appliances, clothing, drinking beverages, and moving through spaces). Based on occupant energy-related behaviours, the proposed MOA model contributes to developing future occupant energy monitoring, modelling, and decision-making approaches. Additionally, findings may have implications on the potential policy implication on prioritising the influence of office building users in achieving net zero energy goals by 2050. Further investigation is necessary to tailor the human-building interactions when adding new energy-efficient technologies and strategies to office scenarios.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10.0 Self-rated motivational drivers for occupant behaviours: A case study of tertiary office buildings

Abstract

Occupant behaviour is a significant contributor to the energy consumption of buildings. Dynamic and complex factors drive occupant behaviours, necessitating a focus on how occupants' comfort preferences, perceived user control, and other subjective factors influence such behaviours. Therefore, this paper presents findings from a case study of occupants' perceived environmental beliefs, individual control, and multi-domain reasons for their behaviours, considering the seasonal variance and time-related factors in a New Zealand tertiary office building. The data were collected through online surveys from 99 office occupants and evaluated using descriptive analysis to highlight the relationships between the study variables. The results highlight that the occupant behaviours are motivated by their comfort preferences and other subjective aspects. However, occupants may be conservative in evaluating the perceived IEQ satisfaction and control, and their influence is relatively unknown. Therefore, the study will help researchers, policymakers, energy modellers, and building managers identify these hindrances to improving occupant behaviour models.[8]

[8] This chapter is based on the following published conference paper:

Weerasinghe, A.S., Rasheed, E.O. and Rotimi, J.O.B. (2022). Self-rated Motivational Drivers for Occupant Behaviours: A Case Study of Tertiary Office Buildings. In S. Perera & M. Hardie (Eds.) Proceedings of the 45th Australasian Universities Building Education Association (AUBEA) Conference, (pp. 995-1004), Western Sydney University.

10.1 Introduction

Despite the high energy-consuming systems in buildings to improve user comfort, research reports occupants' dissatisfaction over these generally accepted indoor environmental conditions (Cheung et al., 2022). Interaction between building occupants and the indoor environment creates unique challenges in building energy use, overall performance, and occupants' comfort satisfaction (Bavaresco et al., 2021; Hong, D'Oca, Turner, et al., 2015). Previous research indicates that occupant behaviours (i.e., window use, blind use, thermostat adjustment, lighting adjustment, and appliance usage) generate 47% more heating energy in commercial buildings (Schakib-Ekbatan et al., 2015). Therefore, unpredictable and random occupant behaviours are possible depending on access to building systems to modulate the building's thermal, air quality, visual, and acoustic conditions for their preferences (Heydarian et al., 2020). Building occupants and buildings have a two-way interaction where existing indoor environmental conditions influence the occupant behaviours, which in return, the way occupants behave influences the future status of the indoor environment (Azar et al., 2020). For instance, the occupants adjust the thermostat to cope with the indoor environment, which can aggravate the dissatisfaction and deviate the actual energy consumption from what was predicted (Hong, D'Oca, Turner, et al., 2015). Recently, the influence of occupant behaviours in buildings gaining attention to optimising occupant comfort and energy efficiency in buildings (D'Oca et al., 2017).

10.1.1 Previous research

The existing occupant behaviour models are primarily based on building physics, occupancy presence, and movement (Yan et al., 2017). The literature already supports the influence of indoor environmental parameters such as thermal, visual, air quality, and acoustic on occupant behaviours (Hong, D'Oca, Turner, et al., 2015). For example, office building occupants mostly tend to open windows in the summer rather than winter (Bourikas et al., 2018). Similarly, Park and Nagy (2020) introduced HVACLearn, an Occupant-Centric Controller (OCC) for thermostats, those occupants could express the thermal sensation as too cold or too hot. In another study, He et al. (2019) explained that indoor or outdoor temperatures are the primary triggers of fan usage. The researchers have produced occupancy models for accurate building simulations incorporating occupant schedules and thermal set points to improve the predictions on random walk patterns (Das et al., 2019).

Unlike the above behaviours, the occupants determine the blind position based on solar radiation, illuminance, and glare (Bavaresco & Ghisi, 2020).

Apart from the above environmental factors, studies suggested that comparing perceived satisfaction and effectiveness over the individual control of the indoor environment in buildings is relevant to addressing occupants' random behaviours (D'Oca et al., 2017). For instance, Vellei et al. (2016) discovered that occupants' perceived control promotes energy-saving adaptive behaviours, such as wearing more clothes when they feel cold and controlling the windows more effectively. The occupants' response to the availability and accessibility of building control systems were concerns of many studies (D'Oca et al., 2017). Some studies also focused on time-related aspects as crucial factors of occupants' interaction with building systems and appliances, particularly the day and time. Different approaches have been used to evaluate the window opening frequency, and it was found that the opening frequency increases at specific times (Stazi et al., 2017). Furthermore, the occupants switch on lights upon arrival and keep them on until they leave the office (Norouziasl et al., 2019). However, studies focus on only a few behaviours and their essential factors. Therefore, a comprehensive study focusing on most behaviours and the combination of influential factors is timely needed.

10.1.2 Research aim and questions

Significant interest has been given to investigating the influence of IEQ satisfaction and multi-domain comfort preferences on occupant behaviours (Bavaresco et al., 2021). However, the scope of these studies is limited only to a few of the selected behaviours, like operating windows, blinds and shades, adjusting thermostats, and switching on/off artificial lights. Although these studies focus on seasonal variance and its influence on IEQ satisfaction and comfort preferences, the focus is not on particular time-related factors. At the same time, the previous studies emphasise the influence of extending these investigations to different geographic locations (i.e., countries and regions). To this end, this study aims to evaluate the office building occupants' perceived beliefs on IEQ and the availability of individual control over building systems and appliances, then analyse the multi-domain reasons that drive occupant behaviours giving due consideration to the seasonal variance and time-related factors in the New Zealand context. Within the scope of this study, the focus has been given to investigating occupant behaviours like windows, doors, lighting, shades and blinds, fans, thermostats, computers, drinking beverages, adjusting clothing levels, and moving through spaces.

The specific questions that the study is trying to answer are; RQ1. What do occupants perceive about their indoor environment and the availability of control? RQ2. What are the multi-domain reasons that drive specific occupant behaviours? RQ3. How do occupant behaviours differ at different time instants in a typical day?

10.2 Research methods

The study investigates the relationship among office building occupants' perceived beliefs on IEQ, the availability of individual control over building systems and appliances, and the multi-domain reasons for their behaviours in a university case in New Zealand. The study adopted a survey approach. A questionnaire was developed referring to the knowledge from IEA-EBC annexe 66 on the definition of occupant behaviours (Yan et al., 2017), factors affecting occupant behaviours (Fabi et al., 2012), and thermal, visual, acoustic, and air quality discomfort-related and other subjective drivers (i.e., physiological and social-psychological reasons) (Bavaresco et al., 2021). For instance, Yan et al. (2017) explained that "occupant behaviour includes occupant presence, movement, and interaction with building energy devices and systems". Fabi et al. (2012) divide the factors influencing occupant behaviours into five categories physical environmental, contextual, psychological, physiological, and social, including internal and external factors. Within the scope of this research, the study focuses on physical environmental (i.e., IEQ satisfaction, season) and contextual (i.e., availability of control, time-related) factors.

The questionnaire consists of three sections. The first section includes questions relating to different IEQ parameters: indoor temperature, indoor air quality, lighting (natural and artificial light), and noise (inside and outside noise) for both seasons according to a unique five-point Likert-type scale for each parameter. The two extremes of the Likert scale were coded as 1 (too cold, too stuffy, too dark, too quiet) and 5 (too hot, too draughty, too bright, too noisy). Section two asks about the control available for workplace appliances and building systems using a three-point Likert-type scale (no control – 1 and full control – 3). Also, if any appliance and system were unavailable at the workplace, occupants could select "not available." In the third section, the multi-domain reasons and the occurrence of behaviours during different time instants (i.e., upon arrival, during the daytime, and upon leaving) in terms of interaction with windows, doors, lighting, shades and blinds, fans, thermostats, and computers, as well as other behaviours like drinking beverages, adjusting clothing levels, and moving through spaces. These questions were given in check-all that-apply questions format. The questionnaire was distributed online through the Qualtrics survey platform from August 2021 to January 2022. Individual links were sent to 1258 office occupants of three office buildings in the university, which had the most participants during the COVID and post-lockdown period in New Zealand. However, there were only 266 participants who were the primary occupants of the selected offices. Accordingly, 99 valid responses were collected, excluding the incomplete responses, and the responses came from occupants who did not work in office space. The response rate is 37% from the 266 primary occupants. The data collected were evaluated using descriptive analysis to highlight the relationships between the study variables using MS Excel and Visual Paradigm Online software.

10.3 Findings and Discussion

10.3.1 Participant profile

As seen in Table 10.1, respondents comprise most males (53%) and building occupants aged 30 or older (92%). Ethnicity-wise, most respondents were New Zealand Europeans (70%). Amongst the respondents, 77% have worked in the building for a year or more, 67% have worked in the current workplace for a year or more, and 52% work five days or more every week. These higher percentages on work duration provide insights into that most occupants are familiar with their surroundings.

Table 10.1 Demographics of the participants

Demographic		Count	Percentage
Gender	Male	52	53%
	Female	47	47%
Ethnicity	NZ European	69	70%
	Asian	10	10%
	Māori or Pacific	3	3%
	Other	17	17%
Age	30 or older	92	93%
Work duration in the building	A year or more	76	77%
	Less than a year	22	22%

Work duration present workspace	A year or more	66	67%
	Less than a year	32	32%
Days of work	5 days or more	51	52%
	Less than 5 days	47	47%
Age	Under 30	7	7%

10.3.2 Occupants' perceived beliefs on IEQ

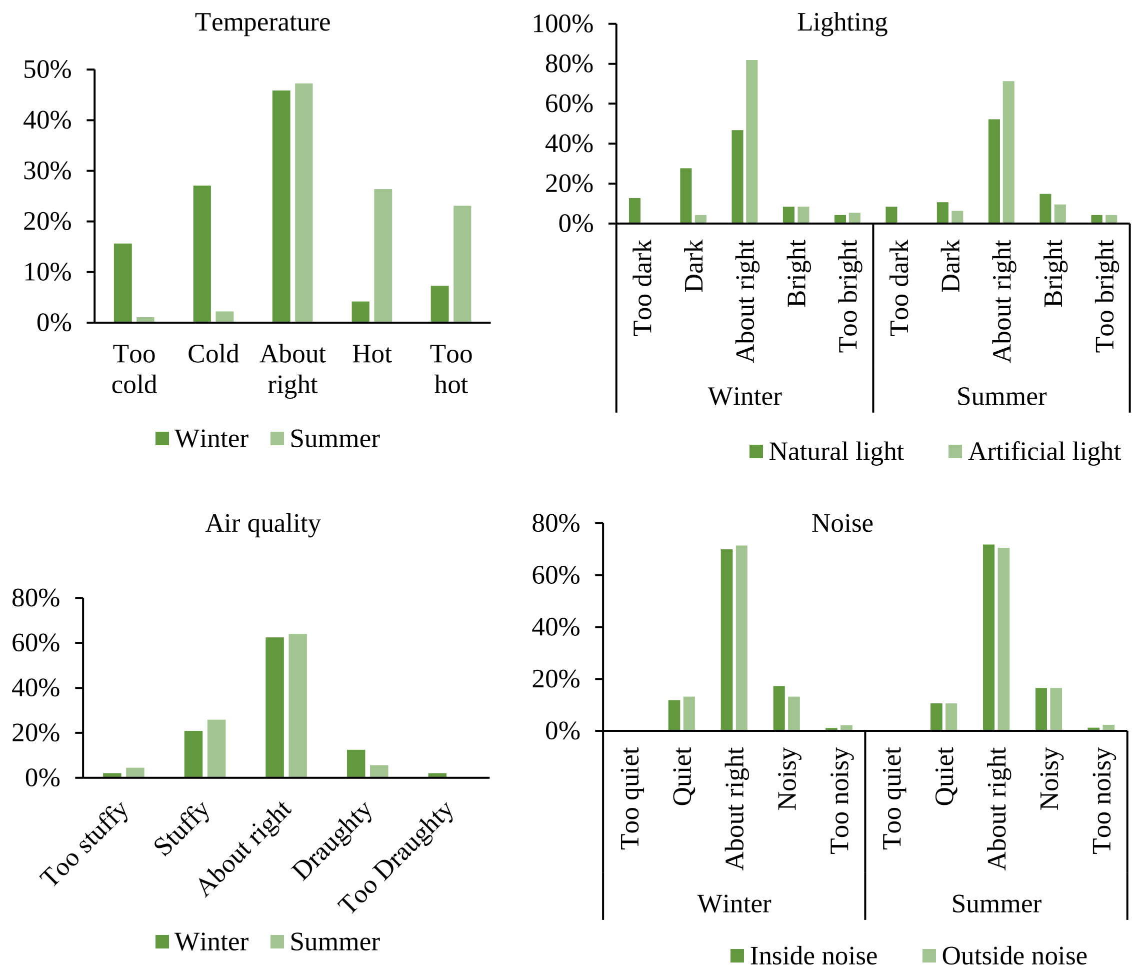


Figure 10.1 Occupants' perceived beliefs on temperature, air quality, lighting, and noise

Figure 10.1 shows the percentage of occupants' perceived beliefs on each parameter. An average of 45% in temperature, 63% in air quality, and 70% in inside and outside noise indicated "About right". Although occupants' beliefs in natural light and artificial light show a slight deviation, it shows a similar pattern in winter and summer, while a majority (more than 45%) believe the noise is "Above right". Additionally, when considering the temperature parameter, 43% of participants responded, "Too cold" and "Cold" in winter, while 49% responded, "Too hot" and "Hot" in summer. Regarding air quality, more than 20-30% of participants indicated that the environment is "Too stuffy" and "Stuffy" in winter and summer. Another parameter influenced by seasonal factors is lighting, where 40% indicated the natural lighting is “Too dark” and “Dark” during winter.

10.3.3 Availability of individual control over building systems and appliances

Figure 10.2 illustrates the percentage of occupants rating the availability of individual control over the indoor environment and building systems at their workspace. As shown in Figure 10.2, more than 50% of participants have full control over windows, doors, shades and blinds, artificial lights, personal fans, and computers. The occupants’ full control over portable heaters (38%) and thermostats (17%) is significantly less compared to the above systems. However, some participants have somewhat control over portable heaters and thermostats; therefore, overall control over these two items is slightly higher than 50% but comparably less than the other systems. The appliances and systems with the least control are ceiling fans (less than 10% control). The amount of control available on building appliances and systems can significantly influence the occupants’ behaviours. With this in mind, the forthcoming section analyses the multi-domain reasons for these related behaviours to determine the influence of IEQ satisfaction and individual controls motivating occupant behaviours.

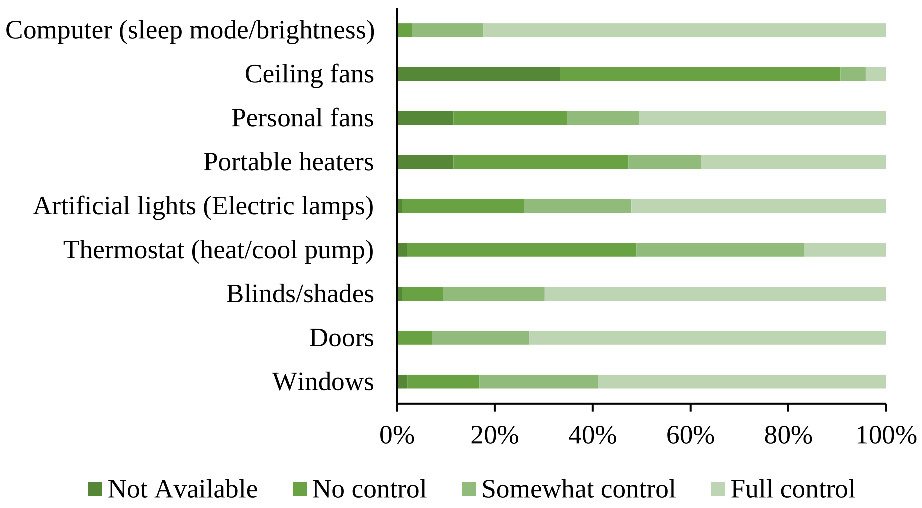


Figure 10.2 Occupants’ rating for the availability of individual control

10.3.4 Multi-domain reasons for their behaviours

In this section, the paper analyses the multi-domain reasons for occupants’ behaviours. The self-disclosed multi-domain reasons for these behaviours are illustrated in Figures 10.3 to 10.6, and the sum of responses is greater than 100%. For a given action (e.g., opening windows during the summer to feel cooler), each percentage represents the proportion of that particular action compared to others.

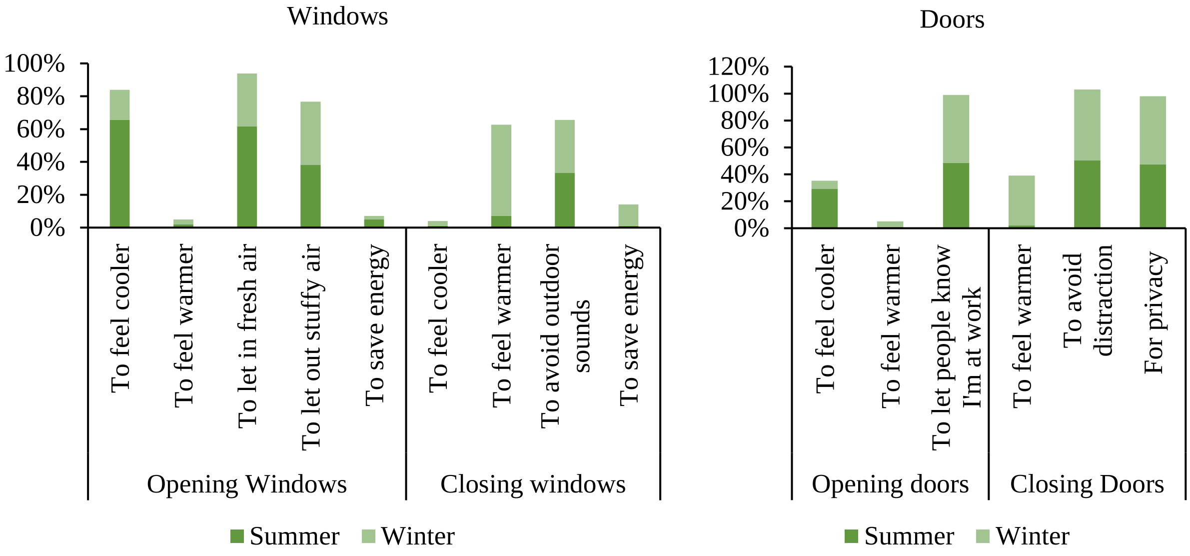


Figure 10.3 Multi-domain reasons for adjusting windows and doors

As seen in Figure 10.3, the occupants mainly open windows to feel cooler (66%) and to let in fresh air (62%) in summer. In winter, more than 32% of occupants open windows to let in the fresh air. On the other hand, occupants close windows mainly to feel warmer (56%) in summer. However, some drivers seem unaffected by seasons – 30-40% responded to opening windows to let out stuffy air and closing windows to avoid outdoor sounds. Other motivational drivers: saving energy received fewer responses in both seasons, highlighting that occupants mainly prioritise their personal needs when adjusting windows. The seasonal effect was mainly observed when occupants opened doors to feel cooler (29%) in summer and closed doors to feel warmer (37%) in winter. However, other subjective drivers are unaffected by seasons. An average of 50% of occupants reported opening doors to let people know they were at work and closing doors for privacy and avoid distraction. In both cases (windows and doors), most occupants show opposite actions to feel cooler and warmer.

As illustrated in Figure 10.4, although lighting adjustments were investigated considering the seasonal variance, all drivers seem unaffected by the season. Most occupants turn on lights because they like lights on when working and the office is too dark. These drivers show slight changes (less than 10%) across summer and winter: like lights on when working (36% in summer and 41% in winter) and the office being too dark (25% in summer and 34% in winter). Also, what stimulates turning on lights does not necessarily influence turning them off. Occupants reported turning off the lights to save energy (24% in summer and 19% in winter) and because they like natural lighting (20% in summer and 12% in winter).

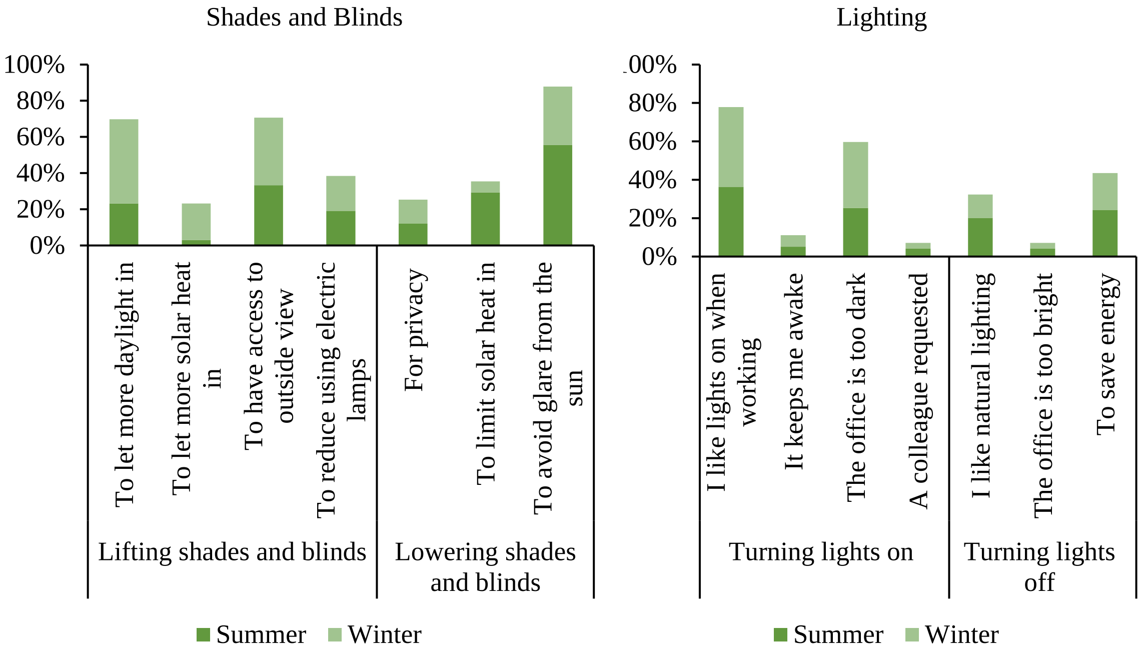


Figure 10.4 Multi-domain reasons for adjusting lights and shades and blinds

Other subjective drivers showed fewer responses and were unaffected by the seasons (i.e., it keeps me awake, a colleague requested, the office is too bright). Like windows and door adjustments, the multi-domain comfort preferences (thermal and visual) influence the adjustments of shades and blinds with seasonal variance. Most occupants reported that they lift/open shades and blinds in winter to let more daylight in (46%) and to let more solar heat in (20%), while they lower/close shades and blinds to avoid glare from the sun (56%) and to limit solar heat in (29%). However, visual preferences are essential in both seasons, and a considerable number of participants responded that they lift/open shades and blinds to let more daylight in (23%) in summer and lower/close shades and blinds to avoid glare from the sun (32%) in winter. The occupants also lift shades and blinds to access the outside view (~35%), unaffected by the season. Other motivational drivers that were unaffected by the season are to reduce using electric lamps (19%) and privacy (12%).

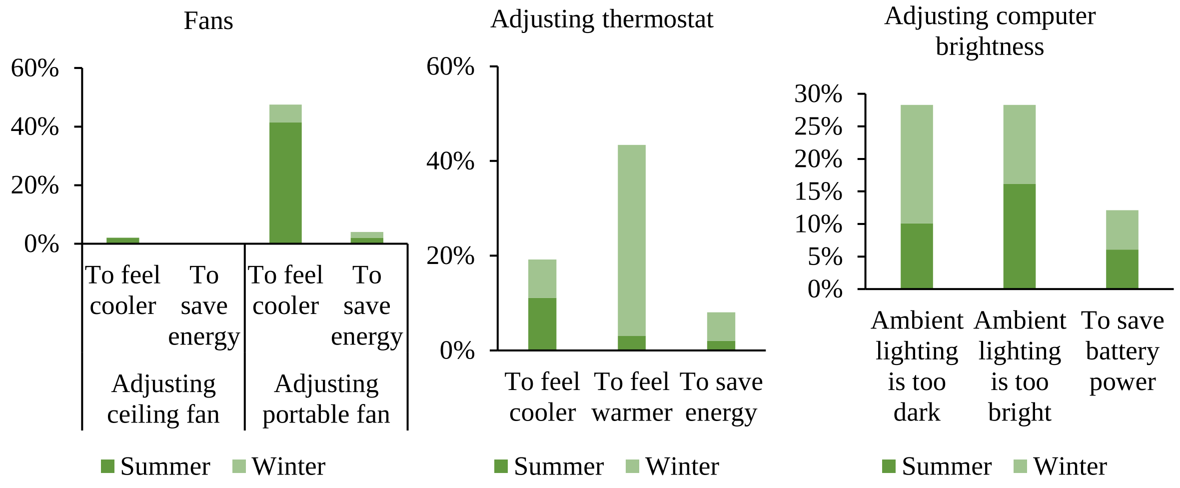


Figure 10.5 Multi-domain reasons for adjusting fans, thermostats, and computers

As seen in Figure 10.5, motivational drivers on occupants' adjustments of ceiling fans, portable fans, thermostats, and computer brightness were investigated, considering seasonal variance. Most occupants (66%) responded that they adjust portable fans to feel cooler in summer. Regarding fans, that is the only significant response received, while the other motivational driver: saving energy, does not add up to this behaviour. Moreover, most (40%) reported adjusting thermostats to feel warmer during winter, while another 11% reported that this behaviour is motivated by their preference to feel cooler in summer. Thus, adjusting the thermostat is significantly influenced by seasonal variance. Unlike other behaviours, adjusting computer brightness received less than 20% responses for each motivational driver and was only slightly influenced by the seasonal effect. The opposite actions were observed across the two seasons, where occupants adjusted computer brightness due to ambient lighting being too dark in winter (18%) and too bright in summer (16%).

As presented in Figure 10.6, drinking beverages are motivated by thermal comfort preferences and other subjective drivers affected by the season. The opposite actions were reported where occupants drink cold beverages to feel cooler (51%) in summer and hot beverages to feel warmer (44%) in winter. Occupants also drink beverages to take short breaks during work, which is again affected by the seasonal variance. While the choice of drink (cold/hot) has been unchanged during summer (54%), a significant decrease was observed in drinking cold beverages (44%) and an increase in drinking hot beverages (64%) in winter.

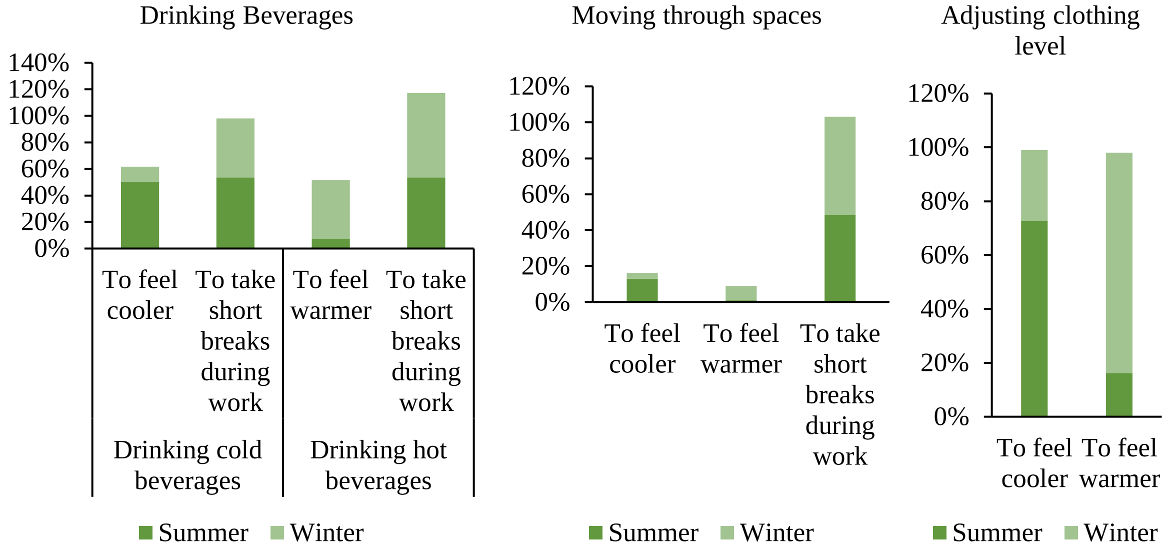


Figure 10.6 Multi-domain reasons for drinking beverages, moving through spaces, and adjusting clothing levels

Similarly, occupants' preference to take short breaks during work significantly motivated moving through spaces. Notably, 55% of occupants reported moving through spaces in winter, and 48% reported moving through spaces in summer to take short breaks during work. The seasonal influence is not apparent relating to this motivational driver. However, fewer occupants responded that they move through spaces to feel cooler in summer (13%) and warmer in winter (8%). Therefore, moving through spaces behaviour was slightly influenced by the season. Possibly offset by the following behaviour: adjusting clothing level. A majority indicated adjusting their clothing to feel cooler in summer (73%) and warmer in winter (82%). Depending on the indoor temperature level during the two seasons, 26% of occupants also reported the clothing behaviour to feel cooler in winter, while another 16% responded to this behaviour as feeling warmer in summer.

10.3.5 Time-related drivers influencing occupant behaviours

The occupant behaviours were assessed regarding their occurrence during different time instants: upon arrival, during the daytime, and upon leaving. Figure 10.7 illustrates the punch card diagram drawn using the responses (counts) received for each behaviour for these three time-related drivers. As shown in Figure 10.7, most occupants turn lights on and open doors upon arrival in both summer and winter. Although most occupants practice opening windows upon arrival in summer, it is significantly less in winter. Rather many occupants responded that they adjust their clothing upon arrival in winter, highlighting the influence of seasonal variance on their behaviours. Upon arrival in both seasons, other considerable behaviours are drinking hot beverages and lifting shades and blinds while adjusting the thermostat, mainly in winter. Upon leaving, most occupants responded that they turn off lights and close doors and windows in summer and winter while adjusting clothing in winter before leaving the workplace. Compared with arrival and leaving, most behaviours occur during the daytime in both summer and winter, and most behaviours are unaffected by the season. The seasonal influence was significantly visible for opening windows while adjusting portable fans and thermostats was slightly affected by season. Other behaviours: drinking hot/cold beverages and adjusting clothing levels were significantly practised by occupants during daytime compared to arrival and leaving and were unaffected by season. A few more behaviours were identified that were unaffected by the season. Notably, moving through spaces and lowering shades and blinds behaviours were higher than arrival and leaving instants, while occupants showed lesser practice on opening doors and turning lights than upon arrival. Similarly, closing doors is less during daytime compared to upon leaving. However, closing windows showed a similar pattern upon leaving and during the daytime, while lifting shades and blinds had a similar pattern upon arrival and during the daytime.

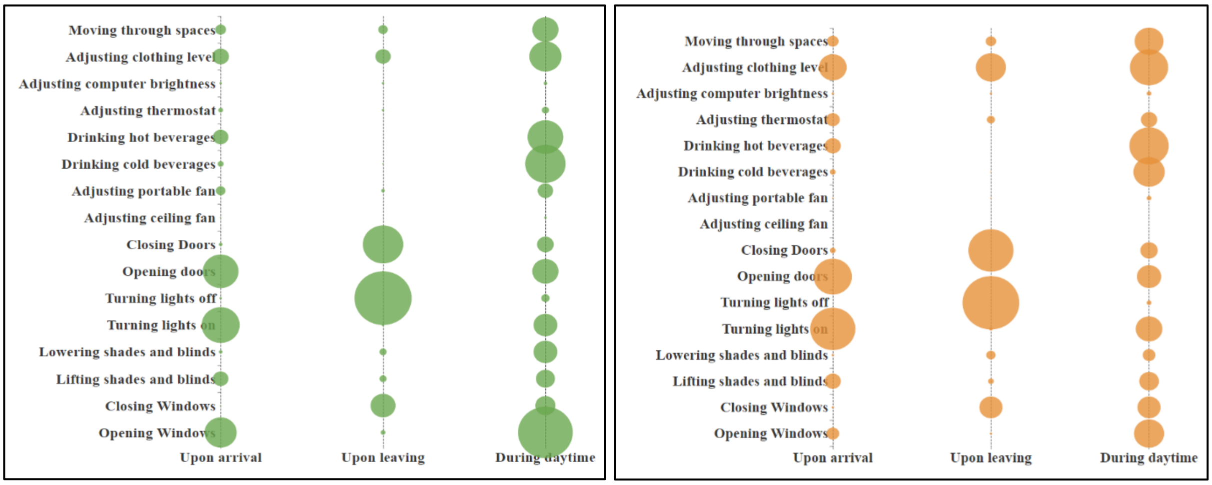


Figure 10.7 Occupant behaviours during different time instants: upon arrival, upon leaving, and during the daytime in Summer (left side) and Winter (right side)

10.4 Discussion

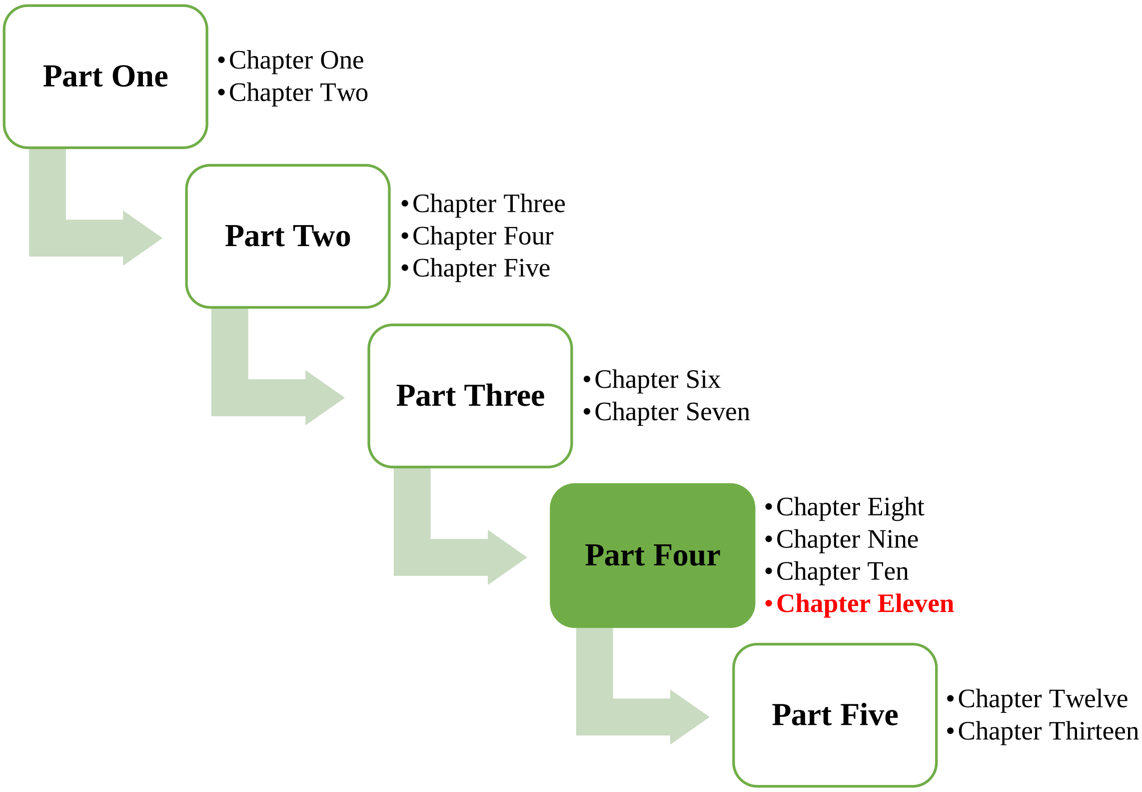
The results show mostly a neutral belief on thermal, air quality, visual, and acoustic parameters in the workspace, thus indicating occupants' satisfaction or being in the comfort/acceptance range. However, a significant proportion of occupants also reported thermal discomfort mainly influenced by seasonal variance, and comparably fewer occupants reported discomfort in other parameters. Our results partially align with Cheung et al. (2022), who reported the most satisfaction with artificial and natural lighting and the least satisfaction with the stuffiness, noise level, and air movement compared to the temperature. Overall perceived control for portable heaters and thermostats was limited compared to other building systems and appliances. Thermal and air quality satisfaction levels increased when perceived control over building systems and appliances increased (Vellei et al., 2016). However, our study needs in-depth evaluations to validate this relationship further.

Multi-domain drivers for occupant behaviours were highlighted in the current study. Notably, personal comfort preferences (a combination of the physical environment and physiological factors) play a significant role in opening and closing windows and doors in summer and winter. The literature supports occupants' tendency to open windows in the summer rather than winter (Bourikas et al., 2018). Furthermore, occupants open windows to have fresh air and close windows to reduce outdoor noises (Bavaresco et al., 2021). Additionally, our results suggest that occupants' door behaviour is mainly driven by subjective factors, unlike windows. Our results highlighted that habitual reasons mainly cause occupants' lighting behaviours than ambient features.

Regarding shading and blinds, our results support that occupants adjust those depending on the radiation, illuminance, and glare (Bavaresco & Ghisi, 2020). Also, appreciating the outside view and the concern about their privacy are other motivating drivers of this behaviour. Thermal comfort preferences were highlighted as the main drivers of adjusting portable fans and thermostats than occupants' intentions to save energy. However, ceiling fans are rarely adjusted because they are unavailable in many offices, and occupants cannot control them. The current study's findings support the literature that explains occupants' thermal expectations as the primary triggers of fan usage and thermostat behaviour (He et al., 2019; Park & Nagy, 2020). Although most occupants have control over their computers, an average of 35% adjust computer brightness based on ambient lighting and their intention to save energy. The responses to drinking beverages, moving through spaces, and adjusting clothing levels highlight that many occupants prefer personal adjustments to thermal preferences or their interactions with building appliances and systems. Drinking beverages and moving through spaces are mostly habitual and contributing to metabolic rate, thus widely influencing indoor thermal comfort (Fabi et al., 2012; Hong, D'Oca, Turner, et al., 2015). Considering time-related factors, occupants mostly turn on lights and open doors upon arrival and turn off or close them when leaving, which has also been reported in the literature regarding lighting behaviour (Norouziasl et al., 2019). Although opening and closing windows are also practised upon arrival and leaving, most occupants tend to adjust windows during the summer, when the indoor temperature gradually increases during the day (Stazi et al., 2017). At the same time, personal adjustments like clothing, drinking beverages, and moving through spaces are also primarily visible during the day.

10.5 Conclusion and further research

This study enables the essential links between IEQ beliefs, user control, and the multi-domain drivers for occupant behaviours. From a theoretical point of view, IEQ satisfaction and control availability may significantly influence occupant behaviours. Similarly, our results highlight that the occupant behaviours are motivated by their comfort preferences and other subjective aspects. At the same time, the results highlighted that occupants might be conservative in evaluating the perceived IEQ satisfaction and control, and their influence is relatively unknown on the occupant behaviours. Therefore, the research can be further extended by integrating physiological factors (gender, age, ethnicity) and social-psychological factors (attitudes, norms, interventions) to dot the missing links between occupant decision-making on their behaviours. Compared to the existing studies in this field, the study investigated the multi-domain reasons and time-related patterns of occupant behaviours relating to windows, doors, lighting, shades and blinds, fans, thermostats, computers, drinking beverages, adjusting clothing levels, and moving through spaces, while the previous studies limited to only a few of the behaviours at once. Accordingly, the study will help researchers, policymakers, energy modellers, and building managers identify these hindrances to improving occupant behaviour models. However, the data is collected from three selected buildings of one case study; therefore, the energy culture and other characteristics of the selected case study could affect the occupants' behaviour. Therefore, further research is recommended with an increased number of cases. Additionally, most respondents were European, older than 30, and occupy single offices. Therefore, encouraging future research to address these personal and contextual limitations for a more robust understanding of energy-related behaviours in diverse settings.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11.0 Occupants’ decision-making of their energy behaviours in office environments: A case of New Zealand

11.1 Abstract

Understanding how occupants behave and interact with building systems is vital to energy efficiency in buildings. The building occupants’ behaviours are complex and influenced by diverse factors. A deep understanding of underlying environmental, contextual, social, and psychological factors is the first step of many in establishing the relationship between the indoor environment and occupants’ behaviours. The current study investigates the influence of occupants’ perceived indoor environmental comfort, the availability of control, and the social-psychological impacts on occupant behaviours in a New Zealand context. The data were collected through online surveys, and 99 office occupants responded. A machine learning technique was applied to identify the critical factors influencing the decision-making of occupant behaviours. Of the occupant behaviours considered in the study, adjusting windows, doors, shades and blinds, and drinking beverages were mostly practised (> 70%), while adjusting lighting, personal fans, thermostats/heaters, and computers (40%-70%) were moderately practised by occupants. The availability of specific user controls was the main predictor of most occupant behaviours, followed by social-psychological factors like actual knowledge, perceived knowledge, behavioural interventions, subjective norms, organisational support, personal norms, attitudes, and perceived behavioural control. The indoor environmental parameters such as indoor temperature, indoor air quality, natural light, and inside noise were highlighted as most influential in decision-making for occupant behaviours. Additionally, the demographic factors: gender, work duration, days at work, and permanence/temporariness of workspace, were also impactful. Knowing how complex occupants’ decision-making on their behaviours is helps building managers use this sensitive information to enhance building energy performance and enable more energy feedback to the occupants to raise their awareness. Such information is helpful for intelligent environmental control systems loop with eco-feedback and to establish occupant-centric buildings or features.[9]

[9] This chapter is based on the following published Journal article:

Weerasinghe, A.S., Rasheed, E.O., & Rotimi, J.O.B. (2023). Occupants’ decision-making of their energy behaviours in office environments: A case of New Zealand [Article]. *Sustainability*, 2023, 15, 2305. https://doi.org/10.3390/su15032305

11.2 Introduction

Over the years, buildings' energy consumption has increased intensely due to increased floor area to accommodate the growing population and improved IEQ standards, with people spending more time indoors for various purposes (Gaetani et al., 2020). The requirements set in numerous energy policies and building regulations to improve energy performance in the built environment are yet to be met at national and international levels (Santangelo et al., 2018). Therefore, plenty of opportunities exist to reduce energy consumption in buildings. Research efforts have spoken for the primary contributors to building energy consumption where accomplishing most energy efficiencies are possible, including climate, IEQ, building envelope, building systems and equipment, building operation and maintenance, and occupant behaviours (Yoshino et al., 2017). The predicted and actual building energy performance discrepancies are caused mainly by the uncertainty introduced by occupant behaviours (Jia et al., 2019; Lee & Malkawi, 2014).

Occupant behaviours are characterised by occupants' presence, movement, and interaction with building energy systems and equipment (Yan et al., 2017). As the intended users of buildings, the human factor is evidenced through numerous actions, including windows, shading and blinds, lighting, thermostats, appliances, and clothing adjustments (Carlucci et al., 2020). Therefore, incorporating occupant behaviour information into BPS will enhance the accuracy of energy simulation by reducing the uncertainties involved in BPS and is also helpful in better managing building operations for optimal systems and behaviour interventions (Lee & Malkawi, 2014). However, occupant behaviours are conventionally treated as fixed schedules in building simulation tools, simplifying complex nature (Yan et al., 2015). Significant energy consumption variations result from diverse and dynamic interactions and energy use patterns among building occupants (Chen et al., 2012). Researchers worldwide emphasise the importance of thoroughly understanding how occupants behave and interact with building systems.

Different occupant behaviour models are being developed for BPS, including schedules, profiles or rule-based, deterministic or statistical, non-probabilistic or data-based, probabilistic or stochastic, agent-based or object-oriented, and virtual models (Franceschini & Neves, 2022). Given the stochastic manner of occupant behaviours, data-driven behavioural models based on non-probabilistic (i.e., data mining, machine learning), probabilistic (i.e., Markov chain, logit analysis, survival analysis), and agent-based modelling have been widely known for their ability to provide valid, practical, and easy to understand behaviour patterns (Hong et al., 2017; Malik et al., 2022). Recently, studies have focused on moving from deterministic schedules or rule-based BPS models (O'Brien et al., 2017). Such data-driven models can predict occupant behaviour and energy consumption from the available data without detailed building information (Amasyali & El-Gohary, 2018). On the other hand, data mining techniques like clustering, Bayesian network, decision tree, ANN, and SVM overcome the shortcomings of traditional techniques for BPS (Hong et al., 2017). The applicability of different models can vary according to the availability of input data, purpose, complexity, and implementation (Dong et al., 2018; Jia et al., 2017).

However, Franceschini and Neves explained that the existing occupant behaviour models mainly focus on one single behaviour, and they should simultaneously include multiple behaviours to accurately represent the interconnections among a few behaviours (Franceschini & Neves, 2022). For example, most of the existing research focuses on one or a few behaviours relating to windows, shades and blinds, lighting, thermostat, plug-in equipment, and occupant presence and movement in buildings (Hong, D'Oca, Taylor-Lange, et al., 2015; Hong, D'Oca, Turner, et al., 2015). Another major hindrance is that many studies focus on the drivers of occupant behaviours that are easier to measure and quantify (i.e., environmental, context, and time-related factors). At the same time, the influence of physiological and social-psychological factors is also essential but usually ignored (Franceschini & Neves, 2022). Similarly, Santangelo et al. (2018) argued that the results derived from stochastic models are hard to replicable; instead, those provide the potential insights to assess the impact of occupant behaviour on energy consumption. Furthermore, the existing models must undergo rigorous validation to evaluate their reliability and application (Franceschini & Neves, 2022; Hong et al., 2017). Therefore, the studies report that the existing BPS tools integrated with occupant behaviour models are not at full potential to support energy decision-making (Santangelo et al., 2018).

Occupants may be exposed to variable environmental conditions based on how the building is designed and operated (Cheung et al., 2022; De Vecchi et al., 2017). Moreover, during building operations, the interactions between occupants and the environment directly affect the building’s performance (Yang & Wang, 2013). Discussing the effects of perceived IEQ satisfaction on occupant behaviours is crucial as the human-building interactions are more apparent with dissatisfaction (Heydarian et al., 2020; Yun et al., 2008). Increased energy consumption is expected if these interactions are oversimplified at the design stage (Schakib-Ekbatan et al., 2015; Schweiker et al., 2018). Furthermore, Day et al. (2020) emphasised assessing how occupants use different building systems through knowledge of multi-domain comfort stimuli by combing a few or all indoor environmental parameters. The occupant behaviours that lead to positive energy savings or excessive energy consumption are evident with user control (Li et al., 2019; Vellei et al., 2016; Weerasinghe, Rasheed, et al., 2022b). If given control by building management, the occupants may adjust the building systems, like lighting and HVAC, to reach their desired comfort preferences (Weerasinghe, Rasheed, et al., 2022b). For example, the occupants tend to initially adjust the desk fans in no discomfort situations while adjusting the shades and blinds first, where thermal and visual discomfort occur concurrently (Ozcelik et al., 2019). Correspondingly, Bavaresco et al. highlighted that the behaviours like opening windows and lifting blinds depend on occupants' desire to have more daylight in their space and closing them when the occupants want to reduce overheating, especially during the summer season (Bavaresco et al., 2021). Hence, occupant comfort preferences and user-centred control are essential contributors when developing occupant behaviour models.

Along these lines, significant interest has been given to investigating IEQ satisfaction, availability of controls, and multi-domain comfort preferences (Bavaresco et al., 2021). However, the scope of these studies is limited only to a few of the selected behaviours, like operating windows, shades and blinds, adjusting thermostats, and switching on/off artificial lights (Bavaresco et al., 2020; Bavaresco et al., 2021). Deme Belafi, Naspi, et al. (2018) also suggested adjusting fans, doors, clothing, and drinking beverages, especially for the office environment. Although these studies focus on seasonal variance and its influence on IEQ satisfaction and comfort preferences, the focus is not on particular time-related factors highlighted in the empirical research.

At the same time, the previous studies emphasise the influence of extending these investigations to different geographic locations (i.e., countries and regions) and building typologies (i.e., office, school, residential). A significant set of studies emphasises the subjective aspects, including social-psychological constructs and personal factors (i.e., age, gender, ethnicity) relating to human-building interactions (Yun et al., 2008). However, recent investigations into social-psychological theories unveiled that most studies applied a limited number of constructs that can be easily collected using quantitative research methods in social science (i.e., survey methodologies) (Li et al., 2019; Yun et al., 2008). This questions whether the specific constructs can accurately explain the observed occupant behaviours or interaction with different building systems. Amongst the many social-psychological constructs, the studies primarily highlight the influence of the TPB constructs: attitudes, subjective norms, and PBC (Chen et al., 2017; Gao et al., 2017; Obaidellah et al., 2019). Other mainstream theories include the NAM, which focuses on awareness of consequence, the ascription of responsibility, and personal norms (Fu et al., 2021; Rissetto et al., 2022), and the SCT, offering knowledge and group dynamics (Cornelius et al., 2014; Deme Bélafi & Reith, 2018). Additionally, some frameworks extended or modified from these theories, such as DNAS (Yan et al., 2017) and MOA frameworks (Li et al., 2017). These frameworks combine social-psychological constructs from several theories and contribute to a more accurate representation of occupant behaviours. For example, Li et al. (2019) combined the constructs from TPB and NAM theories and added new constructs, namely accessibility to control, organisational support, actual knowledge, and perceived knowledge. These include organisational support, rewards for energy-saving, and behavioural interventions such as energy feedback and awareness that positively drive pro-environmental behaviours of the employees to promote energy-saving (Xu et al., 2017). That said, additional research is necessary to evaluate the applicability of these frameworks on occupant behaviours in different geographic locations and building typologies.

Research has yet to present a more comprehensive study filling the above gaps. Occupant behaviour-related models and tools can provide essential feedback to optimise the energy performance of buildings and the respective simulation and modelling. However, these potentials are not yet fully realised due to the lack of informed models on occupant behaviour-related data. The dynamic and diverse nature of occupant behaviours creates vagueness in building energy simulations, thus, the discrepancies between predicted and operational energy consumption. The existing occupant behaviour frameworks do not fully integrate the subjective aspects, such as occupants' comfort preferences and social-psychological thinking, along with environmental, contextual, physiological, and time-related parameters. However, developing such a framework focused on specific subjective and objective drivers of each behaviour could enhance occupant behaviour-related data monitoring and collection to optimise the operational performance of existing buildings and to improve the future designs of buildings. Specifically, in the New Zealand, the lack of research on occupant energy behaviours brings down the potential energy savings from commercial office buildings. In this panorama, the current study aimed to evaluate the decision-making path flow of the occupants before raising a specific behaviour in the New Zealand office building context. Unlike the previous studies, the focus has been given to investigating multiple occupant behaviours, including windows, doors, lighting, shades and blinds, fans, thermostats, computers, drinking beverages, adjusting clothing levels, and moving through spaces with the influence of multi-domain aspects relating to the indoor environment, building user control, social-psychological, and demographics of the occupants. The specific questions that the study tried to answer are;

- RQ1. What do occupants perceive about their indoor environment and the availability of control?
- RQ2. What are the specific social-psychological impacts on occupant behaviours?
- RQ3. What triggers the specific occupant behaviours?

The forthcoming sections of this paper are organised to discuss the research methods in section 11.3. Section 11.4 explains the research and discussion regarding perceived comfort in IEQ, availability of user control, social-psychological factors, decision tree analysis, and excluded behaviours from the analysis. Section 11.5 concludes the study with a summary of key research findings, practical implications, limitations, and further studies.

11.3 Materials and Methods

11.3.1 Survey Approach

The current study evaluated the combined influence of the multi-domain aspects: indoor environment, building user control, social-psychological, and demographics of the occupants on specific occupant behaviours. The study's research design is a case study survey conducted in a simple descriptive manner (one-time-only survey) in which a survey is administered to the case (Bavaresco et al., 2020). The study selected a small sample of the selected case to describe the occupant behaviours and the specific drivers influencing these behaviours of the particular population. This primary method is employed in occupant behaviour-related research (Chen et al., 2017; Ozcelik et al., 2019). A questionnaire was distributed online through the Qualtrics Survey platform from August 2021 to January 2022. Individual links were sent to 1258 office occupants of three office building blocks in a university with the most participants during the COVID and post-lockdown period in New

Zealand. However, there were only 266 participants who were the primary (occupants in a designated office space) occupants of the selected offices. Ninety-nine (99) valid responses were collected, excluding the incomplete responses, and the responses came from occupants who did not work in office space. The response rate is 37% from the 266 primary occupants.

11.3.2 Characteristics of the Buildings

The study purposively selected three medium-rise (5 to 12 floors) buildings in the selected case with different office settings, including open-plan, shared, and single offices. The selected buildings mostly follow similar building characteristics. Table 11.1 presents the profile of these buildings, categorising the characteristics into environmental, building-related, social, and time-related factors. The buildings have similar environmental characteristics, except that the year of completion varied from 1968 to 1981, and the outdoor temperature ranges from 9°C–18°C, while the indoor temperature is variable. The contextual building factors primarily vary for building size and the number of floors. The buildings' usable floor area ranges from 3671m² to 5590m², and the number of floors is between 4 to 8. Building shapes are rectangular and square, oriented in North West and North East directions, and have single glazing on every side of the buildings. The buildings have split AC into some office spaces, mixed mode ventilation including natural and mechanical ventilation, and heating provided through shared boilers with radiators/convectors/AHU/FCU. The number of occupants in dedicated office spaces varies from 137 to 321. Additionally, the buildings have equipment use schedules for ventilation and heating systems, which most systems operate between 7 am to 5 pm and 6.30 am to 6 pm.

11.3.3 Demographic Profile of Participants

Table 11.2 presents the participants' demographics considering their physiological and work-related factors. The survey participants include most males (53%) and females (47%). Ethnicity-wise, the majority are New Zealand (NZ) European (70%), with Asian (10%), Māori or Pacific (3%), and other ethnicities (17%). The participants are a diverse set of occupants in New Zealand. The majority includes 30 years old or older (93%), while occupants under 30 years old are only 7%.

Table 11.1 Profile of buildings

Building Characteristics		Building A	Building B	Building C			
				C1	C2	C3	C4
Environmental factors	Year of completion	1971	1974	1968	1968	1968	1981
	Life cycle (years)	80					
	Site/Location	Palmerston North					
	Outdoor temperature (avg.)	9°C – 18°C					
	Indoor temperature	Variable					
	Wind velocity	7m/s					
	RH	80%					
Building factors	Size (Usable Floor Area [UFA], Gross Floor Areas [GFA])	5590m² UFA 6285m² GFA	4074m² UFA 4496m² GFA	3671m² UFA 4088m² GFA	3631m² UFA 4041m² GFA	4543m² UFA 4982m² GFA	4547m² UFA 4969m² GFA
	No. of floors	8 useable floors + basement & roof plant	5 useable floors & roof plant	4 useable floors & roof plant	4 useable floors & roof plant	5 useable floors & roof plant	5 useable floors & roof plant
	Storey height (m) (avg)	3.350m	3.658m	3.658m	3.658m	3.658m	3.658m
	Building height (m)	27.356m	18.29m	18.59m	18.59m	22.24m	22.24m
	Shape	Rectangular		Square			
	Building orientation	NW					NE
	Glazing type	Single					
	Glazing orientation	N, S, E, W					
	Air conditioning (AC) system	Some Split AC					
	Ventilation type	Mixed mode					
	Heating system/appliances	Shared Boiler with Radiators/FCU		Shared Boiler with convectors/AHU/ FCU			

	Office type	Open plan, shared & single offices, & meeting rooms	Open plan, shared & single offices, meeting & consulting rooms	Single offices, meeting rooms & teaching/research labs			
Social factors	No. of occupants (dedicated office spaces)	321	198	137	172	174	256
	Energy feedback	Nil					
Time factors	Equipment use schedules	Yes. Ventilation & heating					
	Air changes per hour	Variable					
	Switch on times and events	7 am to 5 pm			6.30 am to 6 pm		

In the selected building, most occupants work in single offices (54%), the occupants who work in shared offices comprise another 33%, and 13% work in open-plan offices. Additionally, most (77%) work in the building for a year or more, and 67% work in the current workplace for a year or more. Amongst the occupants, 52% work five days or more weekly, while 47% work less than five days. These higher percentages on work durations in terms of building, current workspace, and the number of days working provide evidence that most occupants are familiar with their surroundings.

Table 11.2 Demographics of the participants

Demographic		Count	Percentage (%)
Gender	Male	52	53%
	Female	47	47%
Ethnicity	NZ European	69	70%
	Asian	10	10%
	Māori or Pacific	3	3%
	Other	17	17%
Age	30 or older	92	93%
	Under 30	7	7%
Office Type	Single	53	54%
	Shared	33	33%
	Open-plan	13	13%
Work Duration in the Building	A year or more	76	77%
	Less than a year	22	22%
Work Duration Present Workspace	A year or more	66	67%
	Less than a year	32	32%
Days of Work	5 days or more	51	52%
	Less than 5 days	47	47%

11.3.4 Variables of the Study

The study surveyed the occupant behaviours and multi-domain aspects relating to the indoor environment, building user control, and social-psychological factors. The appropriate occupant behaviours were identified, referring to knowledge from IEA-EBC annexe 66 on the definition of occupant behaviours (Yan et al., 2015) and the classification given for occupant behaviours (Hong et al., 2017). For example, Yan et al. explained that occupant behaviour includes occupant presence, movement, and interaction with building energy devices and systems (Yan et al., 2017). The survey included a list of behaviours in a nominal and categorical variable (yes/no) format, and the authors asked the occupants to select their behaviours.

The multi-domain aspects that influence occupant behaviours were identified according to the classification given by Fabi et al. (2012), where the factors were divided into five categories physical environmental, contextual, psychological, physiological, and social. This classification was later adopted in a few studies (O'Brien & Gunay, 2014; Yoshino et al., 2017). Furthermore, D’Oca et al. developed an occupant behaviour motivational survey framework that considers the physical environment, physiological, psychological, social, and contextual factors shaped by geographical context, driving occupant motivations of different social groups and cultures and norms (D'Oca et al., 2017). Regarding physical environmental factors, Asadi et al. (2017) reviewed the influence of IEQ parameters on occupant behaviours highlighting the main parameters of temperature, air quality, lighting, and noise. These parameters were measured according to a unique five-point Lik-ert-type (1 to 5) for each parameter;

- Indoor temperature: Too cold, cold, about right, hot, too hot
- Indoor air quality: Too stuffy, stuffy, about right, draughty, too draughty
- Natural/artificial light: Too dark, dark, about right, bright, too bright
- Inside/outside noise: Too quiet, quiet, about right, noisy, too noisy

Contextual factors are mainly discussed in terms of building-related factors. For instance, O’Brien and Gunay categorised nine contexts where building designers have the most significant control over occupant energy behaviour, where the availability and accessibility of individual/user control are highlighted (O'Brien & Gunay, 2014). The control was available for workplace appliances, and building systems were measured using a three-point Likert-type (no control, somewhat control, full control). If any appliance and system were unavailable at the workplace, occupants could select “not available.”

The study adopted the MOA framework introduced by Li et al. (2019) to evaluate the influence of social-psychological factors. The factors surveyed include attitude, personal norms, subjective norms, behavioural interventions, organisational support, accessibility to control, PBC, actual knowledge, and perceived knowledge. These factors were measured using a five-point Likert scale (1 to 5) for strongly disagree, disagree, undecided, agree, and strongly agree.

11.3.5 Reliability of the Survey Data

The reliability of the collected data was analysed using Cronbach's alpha (α) value relating to the independent variables. The acceptable level of α value is 0.70, which measures internal consistency (Cronbach, 1951). Regarding the indoor environment, building user control, and social-psychological measures, 37 variables were considered for this analysis. The α value of these variables is 0.713, greater than the acceptable level. Therefore, the survey responses are acceptable and sufficiently reliable for further analysis.

11.3.6 Evaluation of Multi-domain Aspects

The collected data were first analysed using descriptive analysis concerning the indoor environment, building user control, and social-psychological factors. Notably, the responses received on the indoor environment and building user control were analysed using frequencies for variability. The responses received for social-psychological factors were analysed by calculating the mean for central tendency and SD for variability (Boone & Boone, 2012).

11.3.7 Decision Tree Analysis

This study adopted a decision tree-based approach to evaluate the predictors of occupant behaviours in office buildings based on the indoor environment, building user control, social-psychological factors, and demographic factors. Decision tree analysis is a non-parametric supervised machine learning method used for tree-based classification or predictions of a dependent variable (target attribute) based on values of independent variables (predictors) (Lu & Ma, 2020; Rizvi et al., 2019). As the decision tree is non-parametric, no prior assumptions are needed considering the probability distributions of predictive variables (Han et al., 2012). In the decision tree, various predefined groups or categories are developed based on the data set and given a top-down branched graphical classification model or rule expressions (Ryu & Moon, 2016). The target attribute is the Root node of the tree diagram, and the nodes after splitting the root nodes are called Decision nodes. The nodes that cannot split further are identified as the Leaf or Terminal nodes.

Decision tree models can handle data and regular attributes and are insensitive to missing values. Decision tree models provide highly efficient forecasting by faster calculations and straightforward interpretations compared to other machine learning models, such as ANN and SVM. Also, the decision trees do not need prior assumptions on probability distributions of predictive variables (Han et al., 2012; Lu & Ma, 2020).

Decision trees are suitable for analysing the current study's data as it naturally supports nominal and categorical variables (Farrelly, 2017). The target attributes (occupant behaviours) were collected as nominal and categorical variables assigning "yes" if a particular occupant checked the behaviour and "no" if they did not select that behaviour. Predictor variables relating to the user control were assigned "yes" if they responded somewhat control/full control and "no" if they chose no control/not available. Regarding IEQ and social-psychological factors, no changes have been made. All categories of the Likert scale were used when creating decision tree models, and the model decided on a floating-point number classifying the occupants' responses into two groups.

Various classification algorithms have been used in previous studies when forming decision trees. The most common types of algorithms are Chi-squared Automatic Interaction Detection (CHAID), Classification and Regression Trees (CART), Quick, Unbiased, Efficient Statistical Trees (QUEST), C4.5 and C5.0 (Lu & Ma, 2020; Rizvi et al., 2019). CART algorithm was selected to predict an occupant showing particular behaviour using IEQ, user control, social-psychological, and demographic factors. CART uses historical data to construct the decision tree, which is suitable for categorical data and robust to outliers (Shao & Lunetta, 2012). CART transforms the independent variables from one set of numbers into another without changing the tree structure (Shao & Lunetta, 2012). CART considers splitting the data based on maximum homogeneity, where all cases have the same value in a terminal node for the target attribute. The impurity measure defines the predictor nodes in maximum homogeneity (Ryu & Moon, 2016). The study used the Gini index, which is most broadly used in research in this field (Bavaresco et al., 2021). Gini considers squared relationship probabilities for each dependent variable classification using the following splitting rule (Bavaresco et al., 2021).

$$Gini\ index\ (V) = 1 - \sum_{i=1}^{n} (p_i)^2$$

Equation 11.1 Gini index

V represents the Gini index

n is the number of class labels

p_i is the proportion of i^{th} class label

Another study empirically compared the performance of decision trees, ANN, and linear regression under varying sample sizes. This study highlighted that linear regression and the decision tree performed better when the sample size was small (100 or 500), while ANN was better when it was 1000 or 10,000 (Kim, 2008). Therefore, the sample size of the current study is enough for the decision tree analysis. Validation assesses how well the developed tree model performs when generalising to a larger population. Due to the small sample size in the current study, cross-validation was considered by dividing the sample into 10 subsamples of equal size (k-folds). This method treats the first fold as a validation set, and the model is fit on the remaining $k - 1$ folds and produces a single final tree model calculating the average risk of all trees (Khalifa et al., 2021; Rizvi et al., 2019). Tree models in the present study were developed using the SPSS Statistics 28.0.0.0 software version.

11.3.8 Scope of Analysis

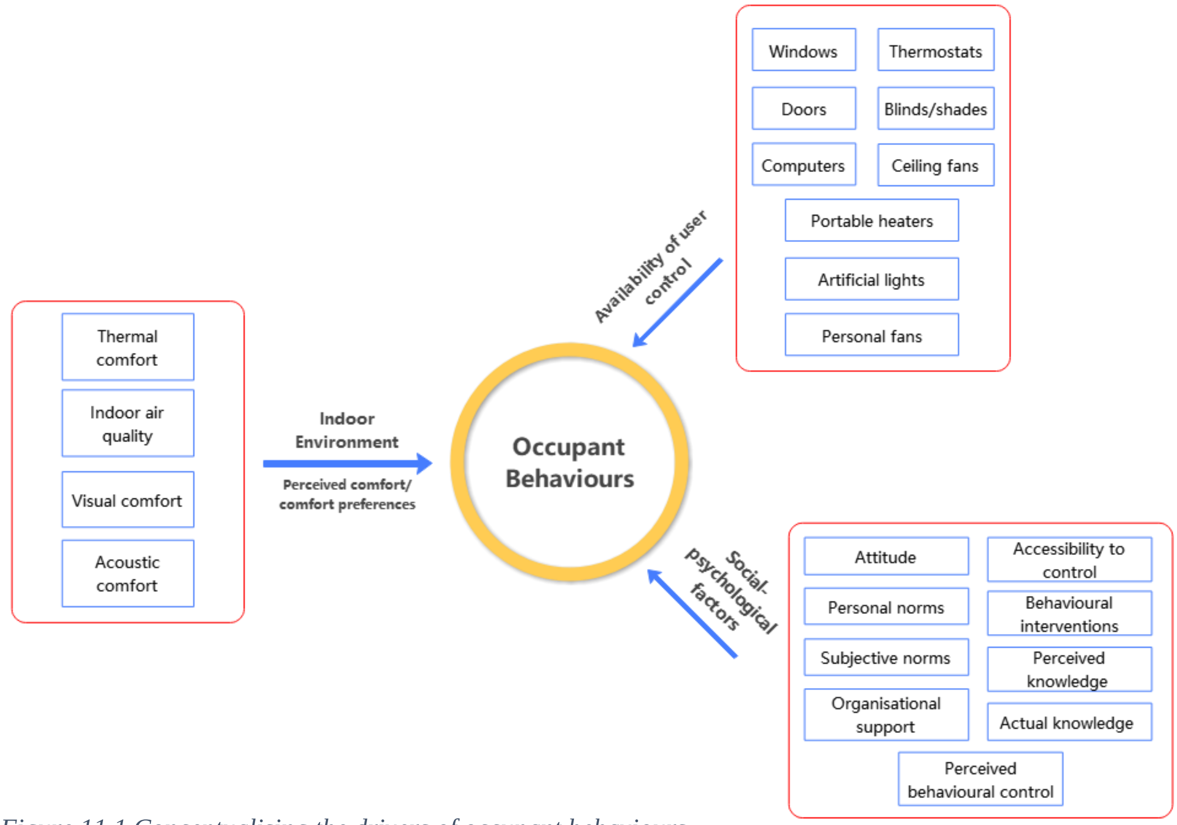


Figure 11.1 Conceptualising the drivers of occupant behaviours

The study surveyed multi-domain aspects relating to the indoor environment, building user control, social-psychological, and demographics of the occupants. First, the occupants' perceived beliefs on IEQ, the availability of individual control over building systems and appliances, the social-psychological insights, and the conduct of occupant behaviours were evaluated to understand the occupants' perception and belief on these constructs. The developed conceptual framework for the drivers of occupant behaviours is illustrated in Figure 11.1. Second, a machine learning algorithm was used to evaluate the combined influence of all these constructs and to identify the significant triggers/drivers of occupant behaviours. A substantial portion of studies relating to occupant behaviour modelling is being conducted in countries such as the USA, the UK, Europe, and China. This is the first research that focuses on deepening the evaluation of drivers for occupant behaviours in the context of New Zealand in order to broaden the geographical spectrum. The study selected a case of a University in New Zealand to achieve this aim. The current study identifies behaviour triggers and quantifies occupant behaviours within the scope of occupant behaviour modelling (Lee & Malkawi, 2014). The information enabled in the decision path algorithms created in the current study can be linked to future occupant behaviour models and BPS tools for specific behaviours (Malik et al., 2022). Furthermore, Tables B1 to B7 in the Appendix present the previous research on each behaviour and summarise the factors they considered influencing each behaviour.

11.4 Results and Discussion

11.4.1 Perceived Comfort in IEQ

Figure 11.2 summarises the percentage of occupants' perceived IEQ comfort on the six parameters: temperature, air quality, natural light, artificial light, inside noise, and outside noise. The graphs show that most occupants believe the conditions are "about right" for all parameters. However, in most cases, this revolves around 50% of responses, while another 50% of occupants responded with discomfort within their environment considering the two extremes of the parameters (too cold/hot, too stuffy/draughty, too dark/bright, too quiet/noisy).

Considering the office temperature, 43% of occupants responded, "too cold" or "cold" in winter. In comparison, 49% responded "too hot" and "hot" in summer, highlighting the seasonal influence on indoor temperature. Therefore, building managers need to estimate heating/cooling loads in buildings, accurately considering the occupants' expectations. In both seasons, an average of 45% perceived the indoor temperature was "about right," indicating they may meet their thermal comfort expectations. Another parameter, air quality, shows that many occupants perceived that the air quality did not reach the extremes - "too stuffy" or "too draughty." While a majority, about 63%, perceived the air quality is "about right," only around 20-30% of participants indicated that the environment is "too stuffy" or "stuffy" in winter and summer. Only less than 20% perceived "draughty" and "too draughty" in winter, whereas only 13% indicated "draughty" in summer. Compared to the temperature, more occupants are satisfied with their indoor air quality expectations, and the seasonal variance less influences the air quality.

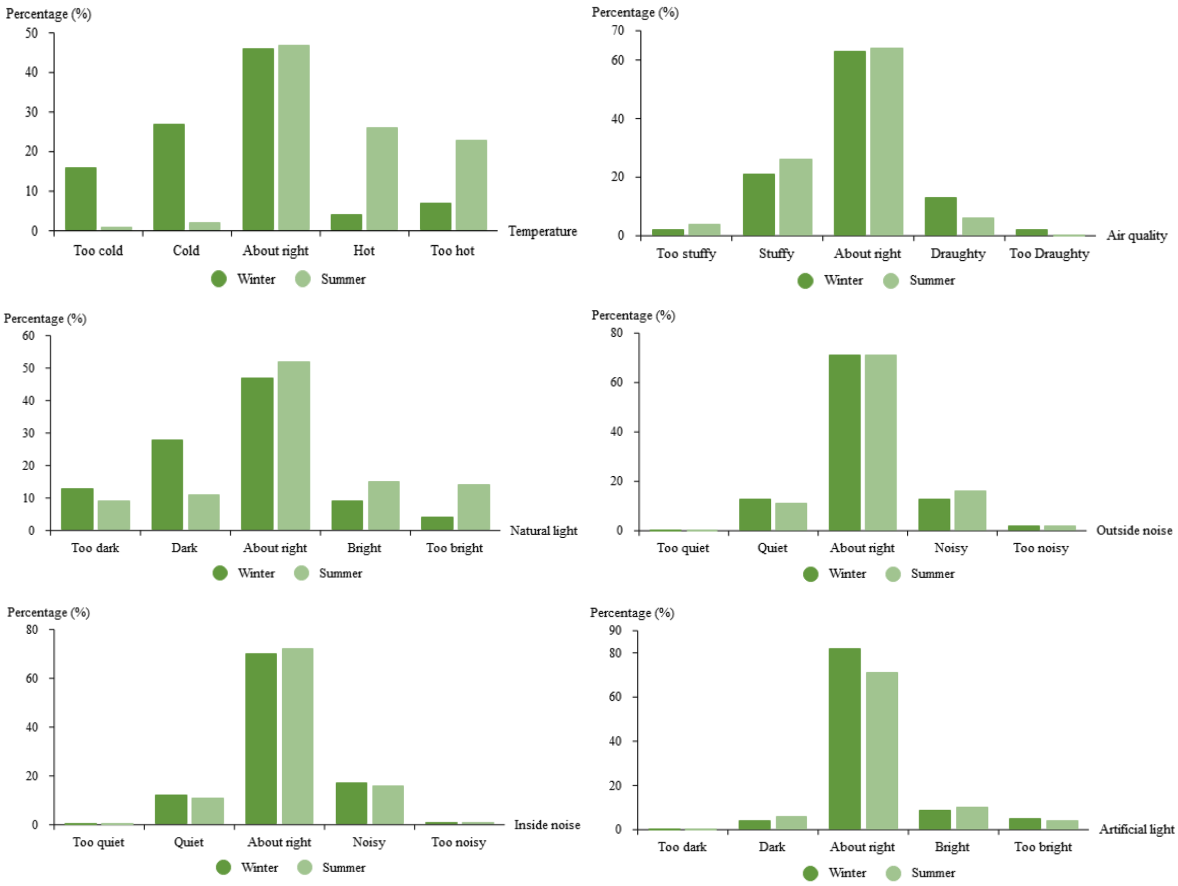


Figure 11.2 Perceived comfort in temperature, air quality, lighting, and noise

Regarding lighting, the discomforts are highlighted much more in natural than artificial light. An average of 52% indicated that the natural lighting level inside the offices is "about right" during summer and winter. However, natural lighting is influenced by the season, and 40% of occupants indicated the natural lighting is "too dark" or "dark" during winter, whereas 21% indicated it is "too bright" or "bright" in summer. These estimations are considerably higher than the other extremes in both seasons. Considering artificial lighting, the majority, 80%, indicated the lighting is "about right," highlighting that the artificial lighting is designed to meet the office space requirements irrespective of the seasonal variance. The last parameter, noise, indicated that 71% of respondents believe inside and outside noise conditions are "about right" in both seasons. Less than 20% of occupants indicated "quiet" or "noisy" in both seasons. Therefore, the inside and outside noise levels only affect some occupants, who may be most sensitive to the noise and easily distracted.

The above results revealed that most occupants perceived discomfort in temperature, air quality, and natural light. The indoor environment's temperature and natural lighting conditions are also mainly influenced by seasonal variance. However, most occupants perceived comfort in other parameters: artificial light and inside and outside noise. Weerasinghe, Rasheed, et al. (2022b) identified that the discomforts arise due to the lack of building management improvements, and occupant comfort satisfaction was observed with their timely approach to services-related and building controls-related matters. On the one hand, study results support the claims of Cheung et al., who reported the least satisfaction with the stuffiness and air movement and the most satisfaction with artificial lighting (Cheung et al., 2022). As the selected buildings have split AC and mixed-mode ventilation, occupants may be exposed to variable temperatures (i.e., too cold and too warm) in different seasons (De Vecchi et al., 2017). Accordingly, occupants may respond to comfort sensations and environmental discomfort through occupant energy behaviours (Heydarian et al., 2020; Yun et al., 2008). Looking into the above insights, all these environmental parameters can influence more or less the decision-making of occupants regarding their energy behaviours. Therefore, these parameters are considered in the decision tree analysis.

11.4.2 Availability of User Control

Figure 11.3 shows the pie charts for each building system and appliance based on the occupants' rating of the availability of individual control over those systems and appliances at their workspace. In the current study, most occupants have full control over the building systems and appliances. Specifically, 70% or more than 70% have full control over computers, doors, shades, and blinds, while more than 50% can fully control windows, artificial lights, and personal fans. However, considering the portable heaters and thermostats, only 38% and 17% indicated full control, respectively, which is significantly less. However, some participants have somewhat control over portable heaters and thermostats; therefore, overall control over these two items is slightly higher than 50% but comparably less than the other systems. Therefore, more than 30%-50% of occupants have no control over portable heaters and thermostats. Considering ceiling fans, only 4% indicated full control and many (57%) indicated no control. Compared to other systems, occupants have the least control over the ceiling fans.

Figure 11.3 Availability of user control in building systems and equipment

Given the percentage of control availability, this explains the perceptions of occupants on indoor environmental parameters. For example, the lack of control over thermostats and portable heaters may link to perceived thermal discomfort. Ventilation is a good source of ensuring indoor air quality. The access to open windows and doors and operating air conditioners and personal fans improve the occupants' perception of air quality. As most occupants control windows, doors, and personal fans, the perceived discomfort in air quality may be reduced. The perceived discomfort with natural lighting may link to increased control over shades and blinds and the lack of control over artificial lighting. This view is supported by Vellei et al. (2016) explained: when perceived user control increases, the thermal and air quality satisfaction levels increase. Many studies highlighted that the availability of user control is relevant to addressing occupants' random behaviours (Li et al., 2019). If given control, occupants promote energy-saving adaptive behaviours, such as controlling the windows more effectively (Vellei et al., 2016). Weerasinghe, Rasheed, et al. (2022b) brought attention to the fact that occupants' interactions with windows, doors and portable heaters when the air-conditioning system is in operation could massively change the set-point temperature and lead to high energy consumption. However, lack of control is only one factor attributing to perceived discomfort, and there can be other factors (i.e., poor environmental conditions and physiological factors).

Therefore, the amount of control available on building appliances and systems can subsequently influence the occupants' behaviours, or it can be the most influential over other factors and may negatively or positively affect the energy. Along these lines, the availability of user control over the said systems and equipment was brought forward for the decision tree analysis.

11.4.3 Social-psychological Factors

This subsection synthesises occupants' social-psychological expectations relating to occupant energy behaviours. Social-psychological factors were evaluated using a five-point Likert scale coding negative options: strongly disagree = 1 and positive options: strongly agree = 5. Nine factors were considered: attitude, personal norms, subjective norms, behavioural interventions, organisational support, accessibility to control, PBC, actual knowledge, and perceived knowledge. The mean score of these factors was calculated, and the summary of the results is presented in Table 11.3. The mean values are higher for actual knowledge, accessibility to control, perceived knowledge, attitude, personal norms, and PBC. Compared to these factors, the mean score of subjective norms, organisational support, and behavioural interventions is < 3. Therefore, the occupants showed negative perceptions of the latter three factors. In terms of SD values, all SD values are < 2 indicating all the responses are close to the respective mean values of each factor.

Table 11.3 Mean and SD of each social-psychological aspect relating to the occupant behaviours

Factor	Description	Mean	SD
Actual knowledge	Awareness of energy-saving benefits	3.979	0.964
Accessibility to control	Individual's degree of actual controllability over building systems	3.953	0.850

Perceived knowledge	Use of knowledge on energy-saving	3.942	0.985
Attitude	Energy-saving attitudes	3.872	0.901
Personal norms	Responsibility/obligation to save energy	3.563	0.984
PBC	Perceived ease/difficulty in saving energy	3.160	1.168
Subjective norms	Co-workers' expectations of their peers saving energy and sharing control with co-workers	2.678	1.133
Organisational support	Organisation encouragement in saving energy and rewarding for savings	1.932	1.121
Behavioural interventions	Organisation or the building managers providing energy feedback to occupants	1.899	1.255

The above results revealed that the occupants have the highest agreement on actual knowledge, accessibility to control, and perceived knowledge. Knowledge constructs indicate the occupants' relatively strong mental ability and awareness to save energy and perform energy-saving behaviours (Gao et al., 2017). Attitude, personal norms, and PBC are the other constructs that most occupants agreed upon. The occupants are more likely to save energy when occupants have a positive attitude towards energy-saving, self-obligation to commit energy-saving behaviours, and perceived control in saving energy (Gao et al., 2017). Occupants with a positive attitude are most likely to commit energy-saving behaviours (Gao et al., 2017; Obaidellah et al., 2019). Regarding subjective norms, the occupants have a lower agreement if social pressure exists to save energy. Chen et al. (2017) support that subjective norms may not significantly predict occupants' intentions to save energy. The constructs that received the lowest agreement were organisational support and behavioural interventions that indicate occupants do not get enough support and intervention from their organisations to save energy. Although these positively drive occupant energy behaviours (Vellei et al., 2016; Xu et al., 2017).

11.4.4 Decision Tree Analysis

Figures 11.4 to 11.13 were drawn based on the results of the decision tree analysis. The dependent variable of each decision tree model is occupant behaviour, which has two classes, "Yes" or "No". The root of these models contains all 99 observations in this dataset. Figure 11.4 summarises the results of decision tree models of opening and closing windows.

As seen in Figure 11.4, 80% of occupants responded that they open windows, while 76% responded to closing windows. Availability of window control is the main predictor of both opening and closing window behaviours. Most of the participants who had the window controls interacted with windows, while only 3% of occupants did not open windows, and

6% did not engage with closing windows, although the control was available. The risk of misclassifying occupants in these behaviours is similar to the prediction accuracy. The overall prediction accuracy of models reached 96.9% for opening windows and 93.8% for closing windows. According to the current models, control availability is far more important than all the other predictors and improves the purity of all nodes with the most homogeneity. Similarly, Bavaresco et al. (2021) identified the availability of window control as the main predictor of adjusting windows.

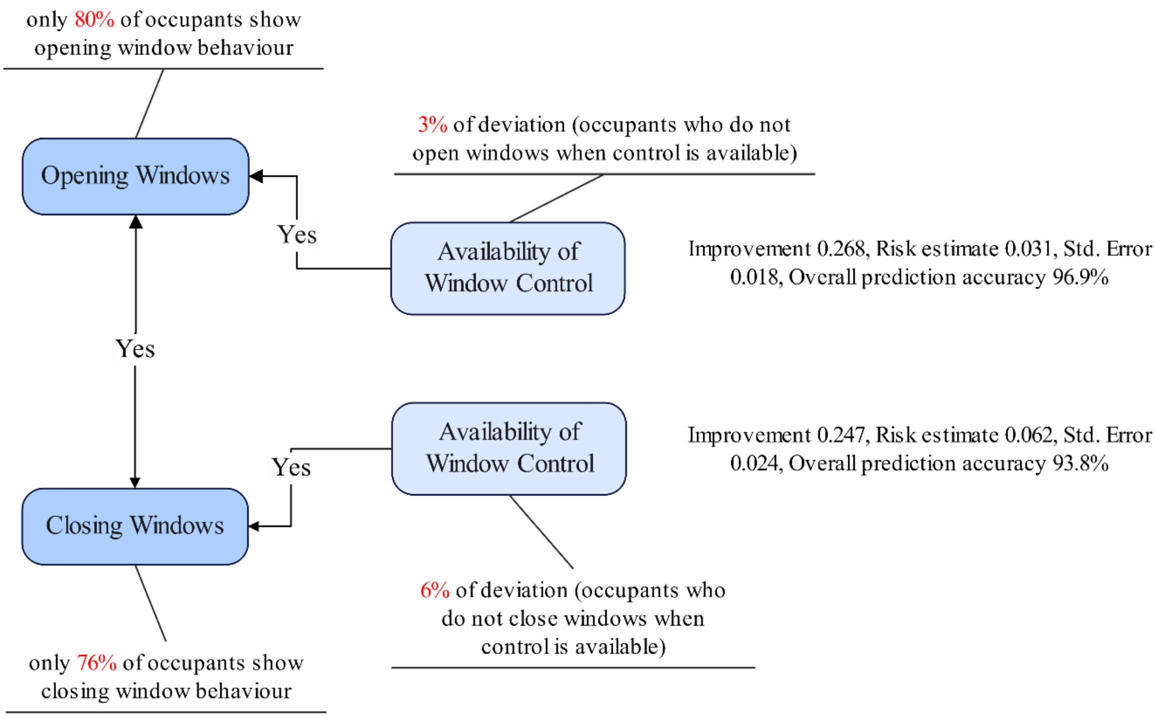


Figure 11.4 The decision-making path diagram of occupants' window behaviours

Additionally, the authors identified environmental, personal, and social-psychological factors influencing the occupants' decision-making on windows, such as IEQ satisfaction, attitudes, frequency of negotiation, age, IEQ productivity, and satisfaction: indoor temperature, indoor air, and daylighting. For example, occupants who are least satisfied with the indoor environmental conditions open the windows more, while those who are more satisfied tend to close the windows more. Environmental conditions influence is widely studied regarding occupants' window behaviour. For example, the previous literature's main highlights were the temperature (Deme Belafi, Naspi, et al., 2018), indoor CO_2 concentration, and relative humidity (Park & Choi, 2019).

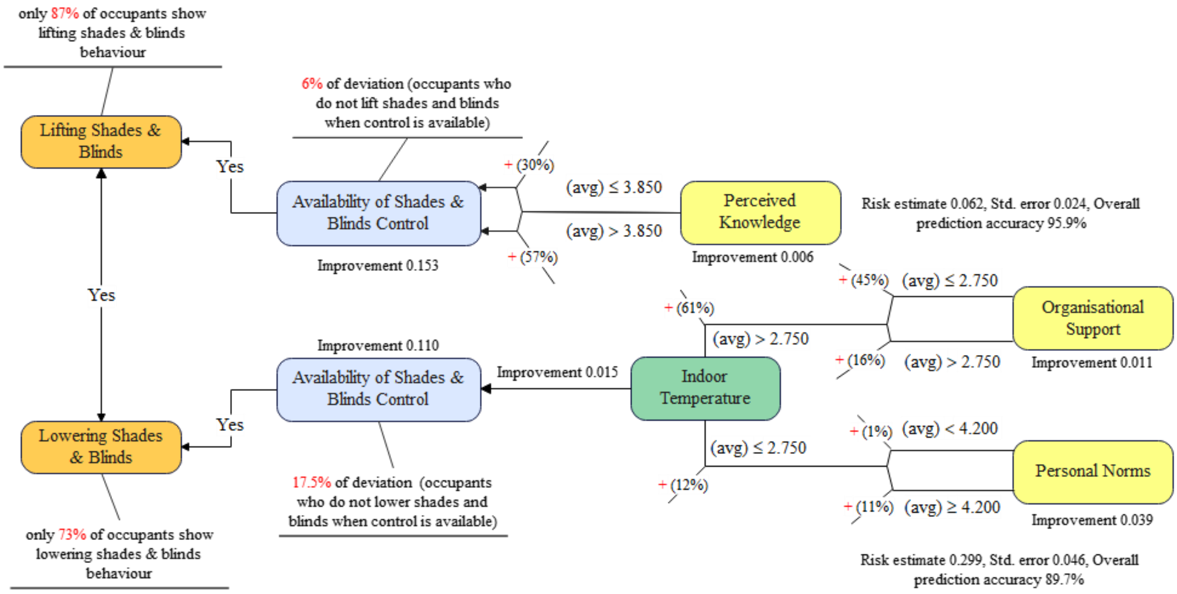


Figure 11.5 The decision-making path diagram of occupants' shades and blinds behaviours

Figure 11.5 illustrates the summary results of the decision tree models of adjusting shades and blinds. As shown in Figure 11.5, 87% of occupants indicated lifting shades and blinds in their workplace, while 73% responded to lowering shades and blinds. The most influential predictor of shades and blinds behaviour is the availability of shades and blind control, followed by the occupants' perceived knowledge. The occupants who use their knowledge of energy-saving more tend to lift shades and blinds more. This model achieved a 95.9% prediction accuracy, with a 6% risk of misclassification per the cross-validation. The other predictors for lowering shades and blinds are in-door temperature conditions, organisational support and personal norms. The model, including these three predictors and the availability of control, achieved an 89.7% of prediction accuracy. The majority lower the shades and blinds when occupants perceive the indoor temperature discomfort, the organisation's encouragement to save energy and reward for savings is less, and the occupants' responsibility to save energy is more. Although the observed deviation of occupants who did not engage in lowering shades and blinds is 17.5%, a risk estimate of 30% was given from the model, indicating misclassifying an occupant into this behaviour driven by the model predictors. Our findings aligned with the fact that the availability of controls influences the adjustment of shades and blinds (Bavaresco et al., 2021). Another factor that influences the lowering of shades and blinds is the indoor temperature (Bavaresco et al., 2021). According to the authors, most occupants close the shades and blinds when satisfied with the indoor temperature.

Furthermore, the authors highlighted other significant predictors: IEQ satisfaction, intention, attitudes, ease of sharing control, and the frequency of negotiation, where authors showed the inverse relationship between IEQ satisfaction and adjusting shades and blinds. However, our study highlights the influence of other social-psychological factors: perceived knowledge, organisational support, and personal norms. Zhang et al. (2013) supported that when the organisational support is weak, the occupants' obligation/responsibility strongly influences energy-saving behaviour. Similar to window behaviour, the influence of environmental conditions was widely highlighted in the existing literature regarding shades and blinds. For instance, solar radiation (Bavaresco & Ghisi, 2018), building occupancy, illuminance, and glare (Gunay et al., 2017) influence the adjustment of shades and blinds.

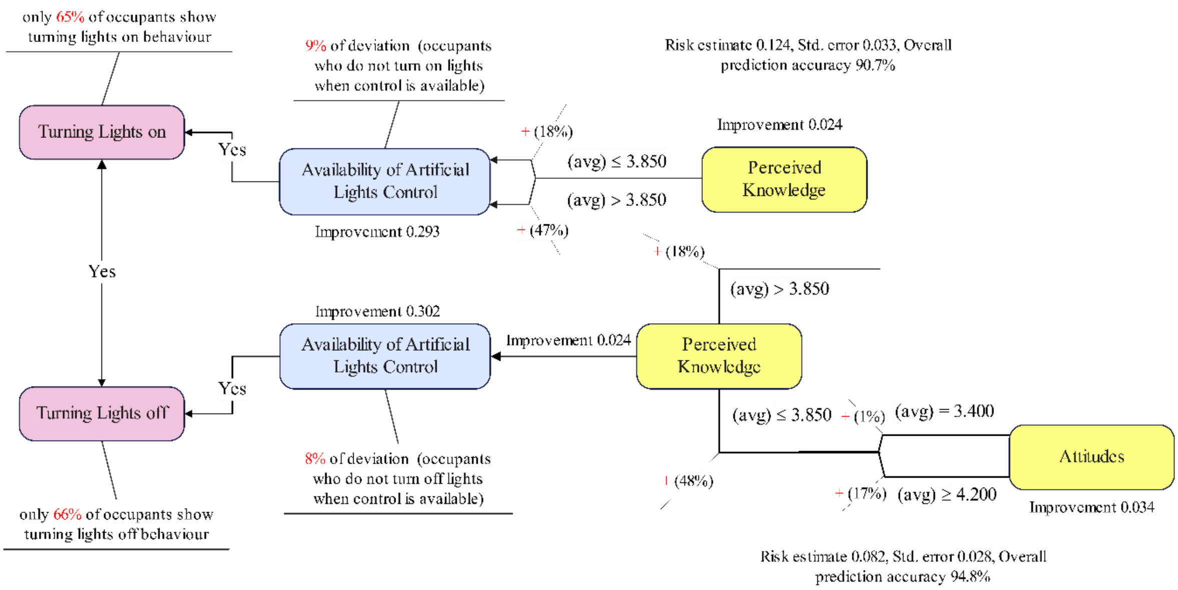


Figure 11.6 The decision-making path diagram of occupants' lighting behaviours

Figure 11.6 summarises the decision tree analysis results on occupants' lighting behaviours. According to Figure 11.6, the lighting behaviour is relatively lower than the behaviours relating to windows, shades, and blinds. Overall, 65% of occupants turned lights on at their workplace, and 66% turned them off. The main predictors of these behaviours include the availability of artificial lighting control, while other factors are perceived knowledge and attitudes. According to the model, the occupants who use their energy-saving knowledge more turn on the artificial lights if the control is available, while the turning-on behaviour is expected but much lower when this knowledge is less. However, an inverse relationship between perceived knowledge was observed considering the turning off lights. The occupants with strong energy-saving attitudes but utilise energy-saving knowledge less would turn off lights more if the control is available. Even though the risk estimates of turning lights on (12.5%) and tuning lights off (8%) are lower, the models are counterintuitive. Bavaresco et al. (2021) highlighted the availability of lighting control as the main predictor of adjusting the lighting in the buildings. Unlike, Bavaresco et al. (2021) study, our study highlights attitude as a contributing factor for turning off lights, not turning them on. However, more focus has been given to the related environmental factors like illuminance level (Park et al., 2019) and time-related factors (i.e., upon arrival, upon leaving) (Norouziasl et al., 2019), while our study highlighted the influence of social-psychological factors on occupants' lighting behaviour that supported by (Li et al., 2019). Even an occupant with lower energy-saving knowledge may turn off the lights if the control is available, and a strong energy-saving attitude is also a factor. Furthermore, occupants' strong perceived knowledge was reflected when 91% of lighting adjustments occurred soon after the occupants' arrival and shortly before the occupants left (Yao, 2014).

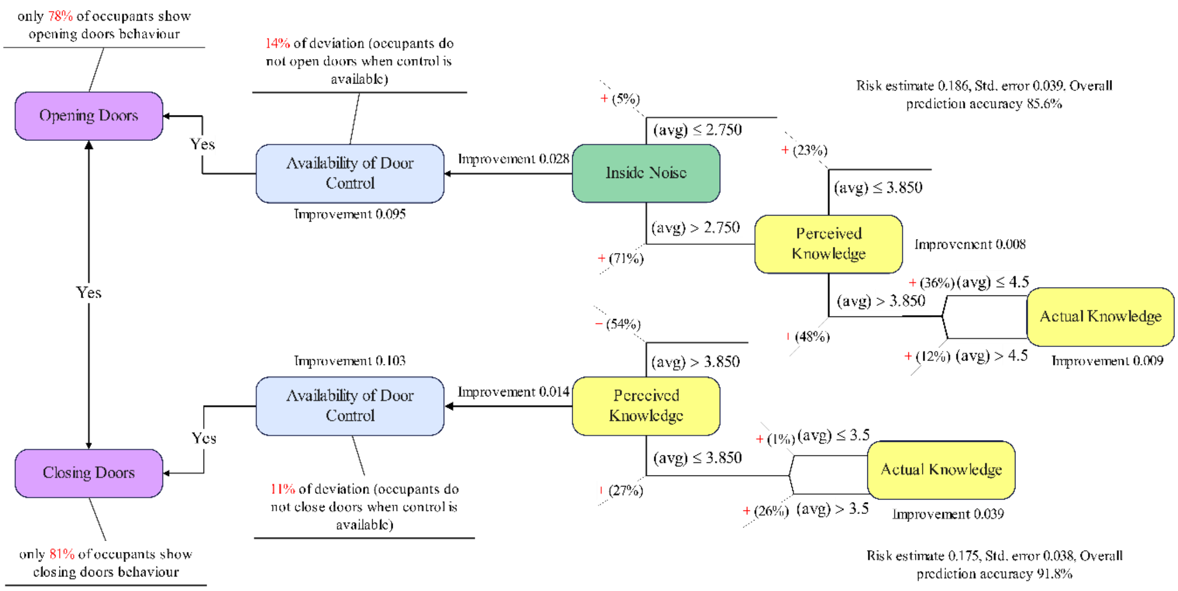


Figure 11.7 The decision-making path diagram of occupants' doors behaviours

The decision tree models of the opening and closing doors are presented in Figure 11.7. As seen in Figure 11.7, 78% of occupants show opening doors behaviour, while 81% show closing behaviour. The control availability for the doors is the main predictor for both models. Other common predictors of both models are perceived knowledge and actual knowledge. However, opening doors depend on the inside noise level, and most opening occurs on the noisy side. This could be the noise inside their office space (i.e., single, shared, open-plan), from corridors and the following office spaces. Most opening doors are also linked to occupants who use their energy-saving knowledge more and lack awareness of energy-saving benefits. The risk estimate of this model is 18.6%, with a prediction accuracy of 85.6%. Similarly, most closing actions occur when occupants use their energy-saving knowledge more. However, the closing can also occur when they do not use energy-saving knowledge much and have more awareness of energy-saving benefits. Such a model provides a prediction accuracy of 91.8% with a risk estimate of 17.5%. Our study is the first to evaluate the factors influencing the occupants' door behaviour. Similarly, Deme Belafi, Naspi, et al. (2018) suggested that the adjustment of doors influences energy consumption. For example, if occupants keep doors open in an air-conditioned space, the indoor temperature will fluctuate, and more energy will be required to cool down the space. Future research can further evaluate this behaviour.

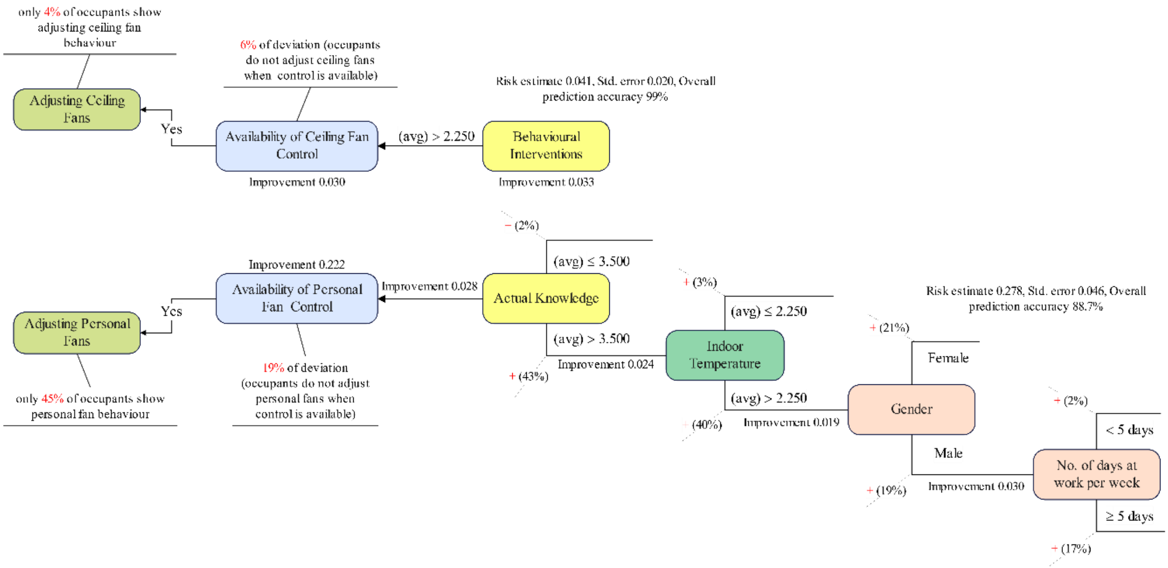


Figure 11.8 The decision-making path diagram of occupants' fan behaviours

The adjusting fan behaviour of occupants was evaluated by considering ceiling fans and personal fans. Figure 11.8 illustrates the decision tree models for these two behaviours. As shown in Figure 11.8, only 4% of occupants adjust ceiling fans, as most of the 99 observations responded that the ceiling fans are unavailable in their workspace or have no control. The prediction accuracy of this model is 99%, with a 4.1% risk estimate. Availability of ceiling fan control is the main predictor, followed by behavioural interventions by the organisation. Regarding personal fans, the study observed that 45% of occupants adjust their fans, and the main predictor is the availability of personal fan control. Other predictors contributing to this behaviour are occupants' actual knowledge, indoor temperature, gender, and the number of days at work per week. These predictors further indicate that occupants should be more aware of energy-saving benefits, perceive that the indoor temperature is discomfort, and work more than five days per week if it is a male. The model has a prediction accuracy of 88.7%; however, the risk estimate is 27.8%. He et al. (2019) identified that indoor or outdoor temperatures are the primary triggers of fan usage, and accordingly, numerous models were established to estimate fan use behaviour in buildings. However, our study highlights the availability of fan control as the primary trigger and the indoor temperature as another essential factor. Other social-psychological factors: behavioural interventions and actual knowledge, and demographic factors: gender and no. of days at work per week, are also important considering the occupants' fan behaviour. Behavioural interventions such as plug strips to turn off the power when the sensor does not detect any occupancy and sending emails to turn off equipment when unoccupied have often been used to reduce plug load profiles, including fans (Acker et al., 2012).

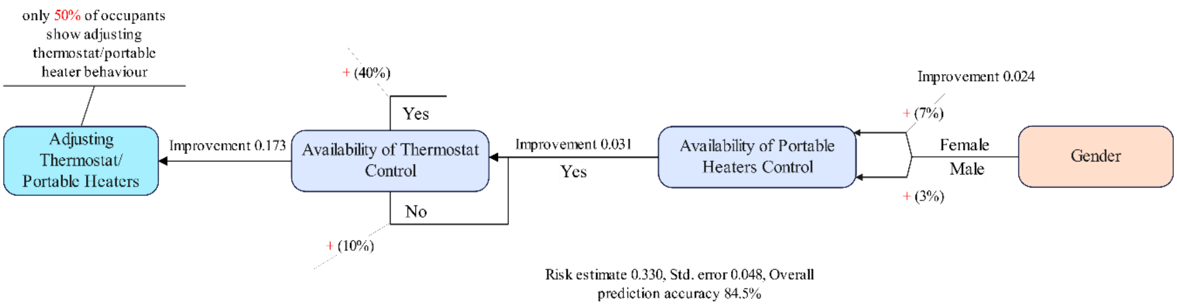


Figure 11.9 The decision-making path diagram of occupants' thermostat/portable heater behaviours

Figure 11.9 indicates the decision tree model for adjusting thermostat/portable heaters behaviour. Like lighting and personal fan behaviour, thermostats and portable heaters show only 50% of occupants' responses. Of the majority, the main predictor of adjusting the thermostat is the availability of thermostat control, while adjusting portable heaters occur when the thermostat control is unavailable, but the occupants can operate a portable heater. Gender is another predictor linked to the availability of control over portable heaters, and most females tend to adjust portable heaters. The prediction accuracy of this model is 84.5%, with a higher risk estimate of 33%. Our study aligns with the findings of Bavaresco et al. (2021), which identified the availability of thermostat control as the primary predictor. Likewise, HVACLearn is an Occupant-Centered Control (OCC) system that Park and Nagy (2020) introduced. It allows building occupants to control the temperature by expressing their thermal sensation as too cold or too hot, making it easier to control and adjust the temperature to their comfort level. Additionally, the same authors highlighted the influence of other factors, frequency of negotiation of control, knowledge to control, IEQ satisfaction, productivity beliefs, and the no. of hours spent in the office. On the other hand, our study highlights the influence of the availability of portable heaters control and gender. Similarly, Sintov et al. examined the gender influence on interactions with thermostat adjustments (Sintov et al., 2019). Their results suggested that women report conflicts while men report agreements and compromises engaging in thermostat adjustments. However, both men and women adjust a thermo-stat on a given day.

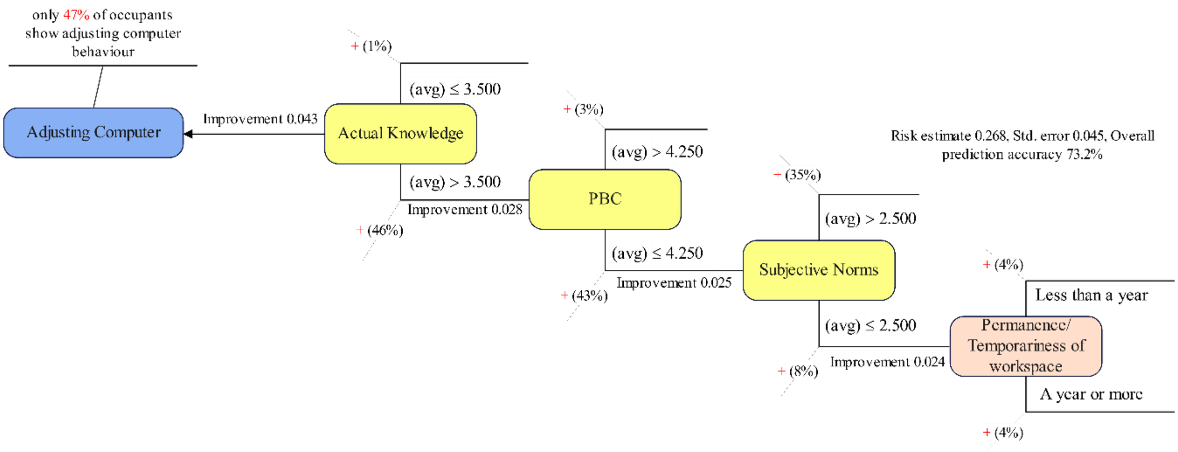


Figure 11.10 The decision-making path diagram of occupants' computer behaviours

Figure 11.10 presents the decision tree analysis of another behaviour, the occupants' computer adjustment behaviour. This behaviour evaluates whether occupants turn off the computers when they leave and put them into sleep mode when unattended for an extended period. The model shows that only 47% of respondents adjust their computers, and the main predictor of this behaviour is the occupants' actual knowledge or awareness of energy-saving benefits. If the occupants have more knowledge of these energy-saving benefits, they tend to adjust the computers more. Other predictors of this behaviour are perceived ease/difficulty in saving energy, pressure from co-workers to save energy and permanence/temporariness of the workspace. The model predicts the behaviour with an accuracy of 73.2%, and the estimated risk is 26.8%. Unlike our study, previous studies highlighted the influence of the behavioural intervention on occupants' computer adjustment and related savings (Zhao et al., 2014). Another factor considered necessary was occupancy schedules (Zhao et al., 2014), whereas Kwong et al. (2014) showed that a plug load of computers after working hours contributes substantially to the energy demand. However, our study highlighted how social-psychological factors primarily influence this behaviour, and the influence of actual knowledge, PBC, and subjective norms was supported by (Li et al., 2019). Research elsewhere supported that PBC and perceived substantial expectations from others about occupant energy-related behaviours increase energy-saving behaviours (Xie et al., 2021).

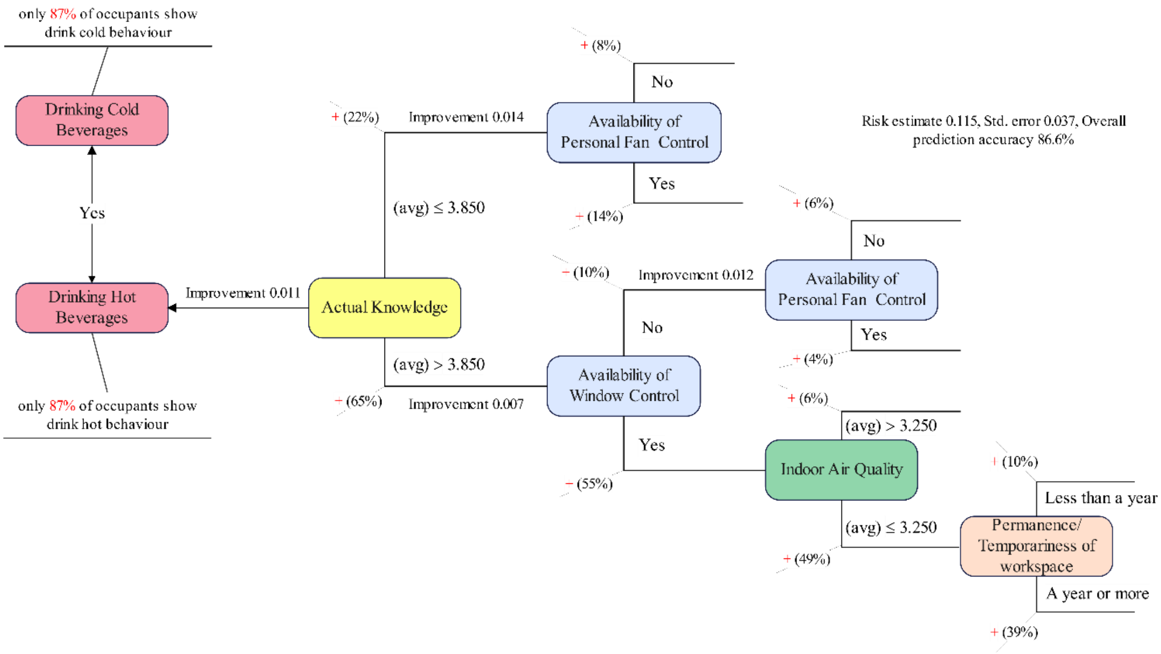


Figure 11.11 The decision-making path diagram of occupants' drinking beverage behaviours

As shown in Figure 11.11, the occupants were evaluated for their behaviour of drinking cold and hot beverages at the workspace. There was 87% of occupants drink beverages during work. Decision tree analysis only provided the model for drinking hot beverages. According to this model, the main predictor is actual knowledge linked to other predictors, availability of personal fan control and window control. The availability of window control is then linked with personal control, indoor air quality, and the permanence/temporariness of the workspace. The majority of behaviour occurs if occupants' knowledge is high, the window control is available, indoor air quality is on the draughty side, and the occupants have been in the same workspace for over a year or more. The model predicts the drinking hot beverages behaviour with an accuracy of 86.6%, and the risk estimate is considerably lower (11.5%). The previous research also has not evaluated this behaviour to a greater extent. However, Deme Belafi, Naspi, et al. (2018) emphasised the importance of including drinking beverage behaviour in the office environment. In a recent study, Rupp et al. (2021) explained the influence of indoor and outdoor air temperature, thermal sensation, and clothing insulation on drinking beverage behaviour along with the other behaviours: windows, thermostats, portable fans, and clothing adjustments. Therefore, our study adds a new set of factors influencing occupants' drinking hot/cold beverage behaviour.

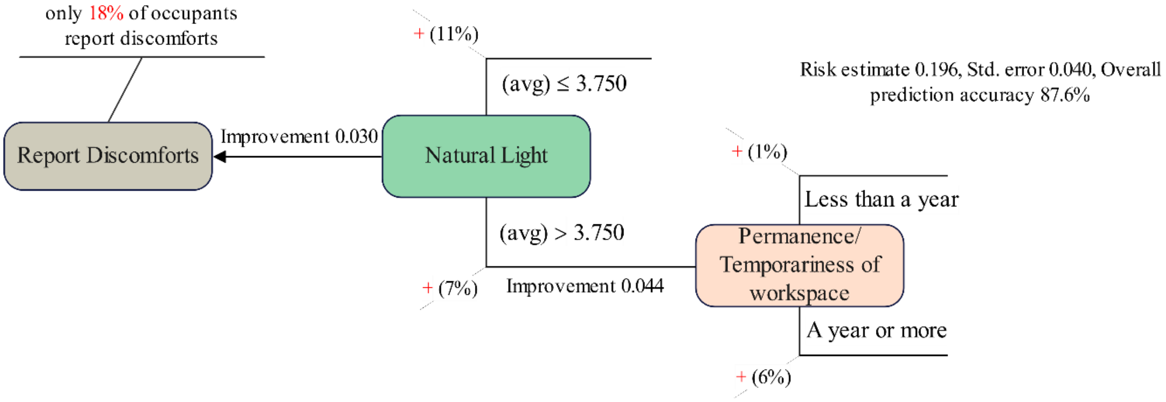


Figure 11.12 The decision-making path diagram of occupants' report discomforts behaviours

The occupants' reporting discomfort behaviour is illustrated in Figure 11.12. However, this behaviour has only an 18% response out of the total observations. Similarly, in their study of tertiary institutional offices, a low response has been reported by (Weerasinghe, Rasheed, et al., 2022a). The main predictor is the natural light which is followed by the permanence/temporariness of the workspace. A majority showcase this behaviour when natural light is dark. However, some feel uneasy with bright natural light even after working in the same space for over a year. The accuracy of this model is 87.6%, and the estimated risk is 19.6%. Although discomfort can be reported on any environmental conditions, most in our selected case study show this behaviour considering the natural light conditions in the workplace. Therefore, this behaviour depends on the building characteristics, IEQ satisfaction, and the occupants' personal and physiological characteristics.

The last behaviour modelled by decision trees is accepting the workspace's current condition and doing nothing. This behaviour was shown by 57% of occupants, where a majority was predicted when the behavioural interventions were lower, had lower pressure from the co-workers to save energy, and had high actual knowledge. The prediction accuracy is 73.2%, with a risk estimate of 26.8%. Accordingly, most accept and do nothing about the existing conditions, while only a small percentage report discomfort. Looking at the influential factors, this behaviour depends on the occupants' social-psychological drivers. In our scenario, the behavioural intervention to save energy from the organisation side is very low, and the occupants tend to accept whatever the conditions in the workspace. This is further influenced by when their co-workers give little attention to energy-saving. However, many occupants aware of energy-saving benefits tend to accept the existing environmental conditions.

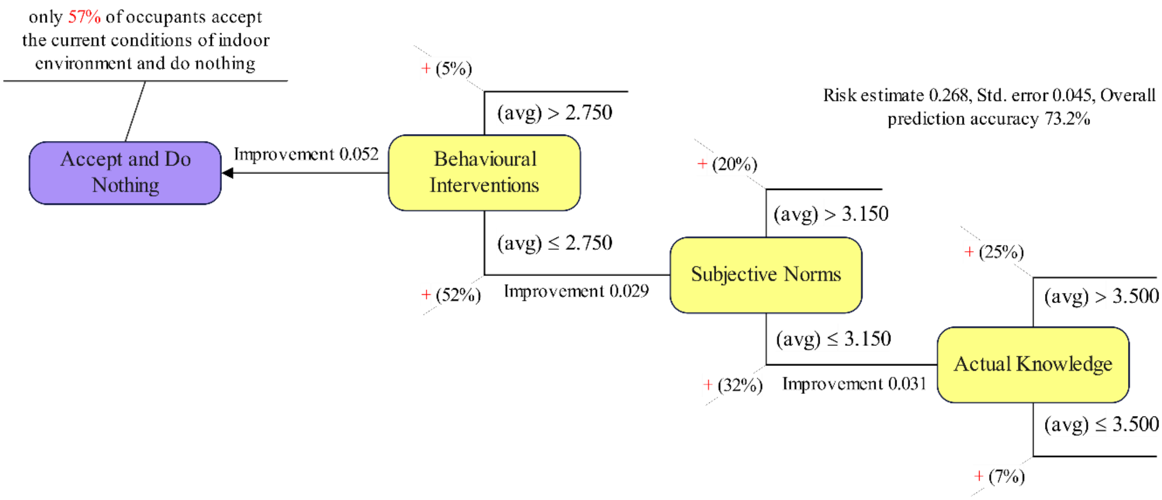


Figure 11.13 The decision-making path diagram of occupants' accept and do nothing behaviours

Overall, our results suggested that the availability of control and the impacts of social-psychological factors are prominent in each behaviour, and the indoor environment-related and demographic factors are also impactful.

11.4.5 Excluded Behaviours from the Analysis

The study also considered two behaviours: adjusting clothing and moving through spaces. However, the analysis did not produce decision tree models for these two behaviours due to the inadequate number of nodes. The occupants who practised these two behaviours were 92% for adjusting clothing and 66% for moving through spaces. In the existing literature, the studies on clothing adjustment are somewhat limited compared to other occupant behaviours. In the recent past, Von Grabe (2020) stated that occupants should dress appropriately for the weather. Highlighting the influence of indoor temperature and local climate, Chen and Chang (2012) studied office buildings with poorly operated air conditioning and mechanical ventilation system in tropical climates. The study exposed how long-term exposure to the hot and humid climate changes occupants' thermal and clothing preferences. Further discussed, introducing a significant amount of cool air into the building might elevate the occupants' clothing adjustments. Unlike the above studies, Mustapa et al. (2016) found that clothing adjustment was inversely related to the outdoor temperature in office buildings. Therefore, this behaviour is not identical due to the influence of other characteristics. For instance, metabolic activity, gender, relative humidity, and air velocity are other factors highlighted in studies (Schiavon & Lee, 2013).

Additionally, occupant presence (i.e., where, when and by whom a building is occupied) often indicates occupants' random walk patterns or moving from one space to another in buildings (Ahn et al., 2017). Similarly, moving through spaces was significantly motivated by occupants' preference to take short breaks during work (Weerasinghe, Rasheed, et al., 2022c). Therefore, it is not easy to estimate accurately. However, the researchers have produced occupancy models for accurate building simulations (Das et al., 2019). Studies suggested incorporating occupant schedules and thermal set points to improve the predictions. Moreover, Das et al. introduced occupancy presence and trajectory data captured by 3D Stereo Vision Cameras for occupant presence and behaviour modelling (Das et al., 2019). This dataset helps to explore the relationships between trajectory and indoor localisation problems related to spatial design layouts of a building.

11.5 Conclusions

The current study evaluated the occupant behaviour decision-making of the New Zealand office building context, considering occupants' perceived IEQ comfort, the availability of control, and the social-psychological impacts on occupant behaviours. The study investigated the influence of these factors on multiple occupant behaviours, including windows, doors, lighting, shades and blinds, fans, thermostats, computers, drinking beverages, adjusting clothing levels, and occupant presence through spaces, to identify the decision-making patterns of occupants. Amongst all behaviours, adjusting windows, doors, shades and blinds, and drinking beverages were mostly practised, while adjusting lighting, personal fans, thermostats/heaters, and computers were moderately practised by occupants. However, a considerably smaller number of occupants practised non-adaptive behaviours like reporting discomfort and accepting and doing nothing about indoor environmental conditions. Although adjusting clothing and moving through spaces are practised by most occupants, the driving factors of these two behaviours were not revealed in the current study.

The study revealed perceived discomfort in temperature, air quality, and natural light while perceived comfort in artificial light and inside and outside noise. However, only the indoor temperature, indoor air quality, natural light, and inside noise parameters were highlighted as most influential towards decision-making on occupant behaviours. Furthermore, the direct relationship between the amount of control available on building appliances and systems and the individual occupant behaviours was identified and highlighted as the main predictor of most behaviours.

Considering the social-psychological factors, the occupants indicated the highest agreement on actual knowledge, accessibility to control, and perceived knowledge, while the lowest was on organisational support. Amongst the nine social-psychological factors considered in the study, actual knowledge and perceived knowledge were related to two or more behaviours, behavioural interventions and subjective norms to two behaviours, and organisational support, personal norms, attitudes, and PBC were linked to only one behaviour. Additionally, the demographic factors are also impactful, and such factors were gender, work duration within the building, no. of days at work per week, and permanence/temporariness of workspace.

The above findings in the current study can enhance future occupant energy monitoring, modelling, and decision-making approaches. Knowing how complex the occupants' decision-making on their behaviours will help building managers (i.e., facilities managers, energy managers) to use this sensitive information to enhance building energy performance, enable more energy feedback to the occupants to raise their awareness, valuable for intelligent environmental control systems loop with eco-feedback, and establish occupant-centric buildings or features. Implications can also enhance the rating tools introduced by the International WELL Building Institute (IWBI) and the National Australian Built Environment Rating System (NABERSNZ) by taking in many complex variables and producing a simple score to inform occupants. The current study is limited to data collected from three selected buildings in one case study. Therefore, the selected case study's energy culture and other characteristics could affect the occupants' behaviours. Accordingly, further research is recommended with increased cases and analyses specific to the different buildings or their characteristics.

Epilogue

This part evaluates the social-psychological effects on energy-related behaviours of office occupants in New Zealand using a modified MOA framework in the first two chapters. The social-psychological constructs of motivation, opportunity and ability are significant. The study further shows these three elements' direct and mediating relationships to energy-related behaviours and their significant influence on adaptive behaviours. It suggests the importance of considering these factors in developing future energy monitoring and decision-making approaches and may have implications for policy in achieving net-zero energy goals.

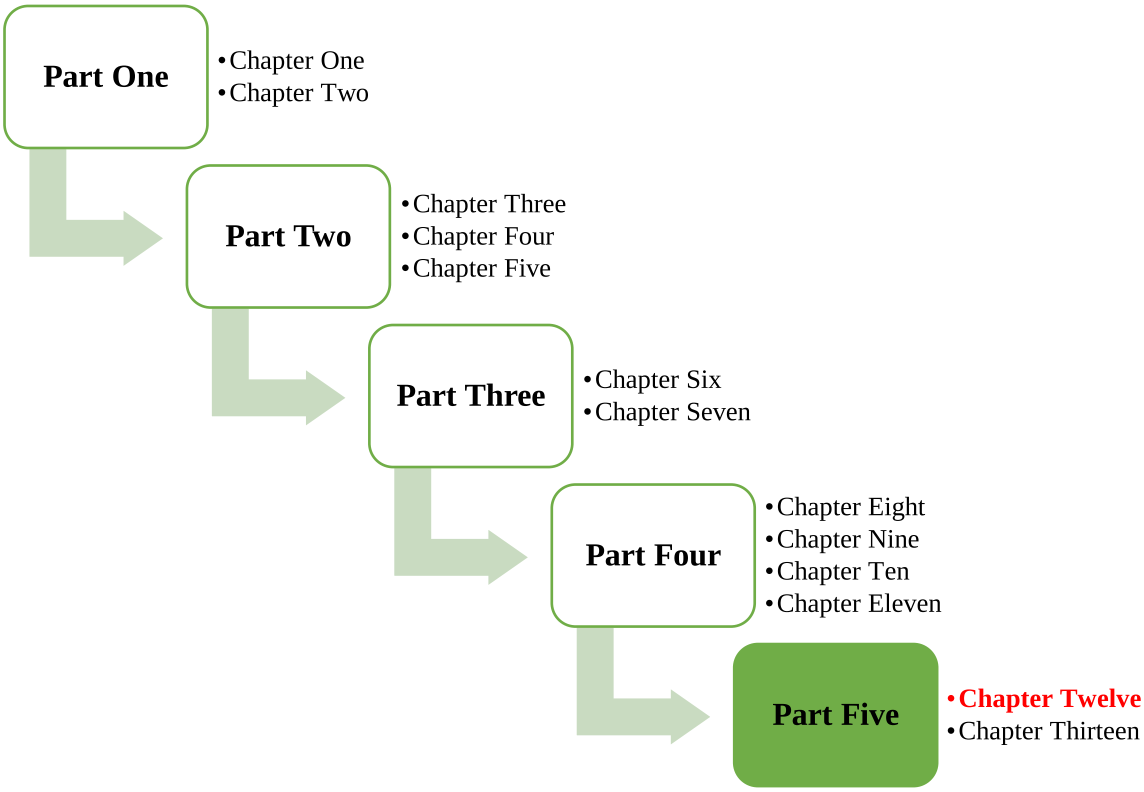
As such, next, it evaluates the influence of occupants' perceived indoor environmental comfort, the availability of control, and the social-psychological impacts on individual behaviours in New Zealand office buildings in chapters 10 and 11. It finds the behaviours that are highly practised, moderately, and had relatively low practised. The study also highlights the most influential factors in the decision-making of occupants, the primary predictor of behaviours, and the highest agreement among the social-psychological factors. This part proposes further research to study the impact of building characteristics and energy culture on occupants' behaviours. The study suggests that modelling each energy behaviour is crucial to improve future energy monitoring, modelling, and decision-making approaches in buildings and enhance the energy performance of office buildings. The next part of the thesis presents the research solution to address these knowledge gaps.

PART 5 – SOLUTION

Prologue

Part five of the thesis develops an ontology for effectively monitoring and collecting occupant energy behaviour-related data to optimise the energy performances of New Zealand office buildings. This part contributes to achieving objective 4. Accordingly, chapter 12 validates the developed occupant energy behaviour ontology for its ability to effective monitoring and collect occupant energy behaviour-related data. Thereby, the chapter contributes to achieving sub-objective 4.1. It presents the design and outline of the ontology, ontology for different occupant behaviours, and the findings of ontology validation in five parameters sufficiency, clarity, coherence, relevance, and applicability. Further, it discusses the ontology's advantages, limitations, and further improvements to propose recommendations to optimise the energy performances of New Zealand office buildings.

The study concludes in Chapter 13 by summarising its findings according to each objective. The chapter highlights the impact of occupant behaviours on the energy consumption of buildings and the significant factors that influence these behaviours. It also provides the theoretical and practical contributions of the study, recommendations for different stakeholders, limitations, and suggestions for future research.


Part One
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• Chapter Thirteen

12.0 Validation of the occupant energy behaviour-ontology for energy performance improvement in New Zealand office buildings

Abstract

Occupant behaviour-related data monitoring and data collection can provide essential feedback to optimise the operational performance of existing buildings and to improve the future designs of buildings. The empirical research emphasises that such data monitoring can support building energy performance contracting and policy-making, intelligent environmental control systems, and energy predictive modelling. However, these potentials are not fully realised due to the lack of data on the dynamic nature of occupant behaviours. Therefore, this study first introduces an occupant energy behaviour-ontology addressing drivers, occupants' preferences and needs, and the pattern of behaviours and then validates the applicability of the proposed ontology for building energy performance simulation and energy and environmental management systems. To validate the developed ontology for energy saving in New Zealand office buildings, SME interviews were conducted with 12 building professionals representing multi-disciplinary building management and control teams. The study found that additional data must be included in the ontology and suggested classifying ontology elements based on building stakeholders for easy understanding and focus. The advantages and barriers identified in the study reveal the industry's perceptions of implementing an ontology, providing insights into potential solutions to overcome challenges. Limitations include the study's reliance on input from subject matter experts and the need for future research to focus on defining monitored variables and educating users. Additionally, the study raised questions about the trade-off between occupant comfort, health, and sustainability that future research should address in more detail.[10]

[10] This chapter is based on the following manuscript under review:

Weerasinghe, A.S., Rotimi, J.O.B., & Rasheed, E.O. (2023). Validation of the occupant energy behaviour-ontology for energy performance improvement in New Zealand office buildings.

12.1 Introduction

The energy performance evaluation in buildings should preferably rely on actual monitoring of the performance variables such as the differences in design and structural parameters, construction quality, building materials used, mechanical installations, and occupant energy behaviours (Calì et al., 2016; D'Oca, Hong, et al., 2018; Fabi et al., 2012). For instance, the energy predictions show a significant gap between the expected and actual energy consumption of a building due to a lack of reliability in such data (Calì et al., 2016; De Wilde, 2014; Fabi et al., 2012). Specifically, occupant behaviours are usually treated as static, deterministic schedules or settings in building energy performance simulation, ignoring their diversified and dynamic nature (Hong et al., 2018). Systematic and continuous monitoring of occupant behaviour-related data can offer feedback for enhancing operational performance and improving future designs (Mahdavi et al., 2018). Furthermore, it can support building energy performance contracting (Mahdavi & Tahmasebi, 2012), energy performance policy and goals (Hong et al., 2017), intelligent environmental monitoring and control systems (Zhu et al., 2022), and model-predictive building systems control (Mahdavi & Taheri, 2017). Therefore, the building stakeholders must look into systematically monitored and high-quality data to enhance the performance and operation of buildings.

As occupant behaviour-related data are limited, energy performance models are often deployed with preliminary observations (Yan et al., 2017). Specifically, the occupant behaviour modelling tools that integrate with energy performance simulation and modelling must consider multiple environmental, physiological, contextual, and social-psychological parameters (Yan et al., 2017). Similarly, Hong et al. (2016) emphasised that technology-driven measures alone do not solve the highly complex problem involving occupant behaviour's impact on energy consumption. Accordingly, researchers have recently given more attention to studying the impacts of social-psychological factors that significantly improve occupant energy behaviour modelling for BPS (Ding et al., 2018). Additionally, occupant actions directly depend on the occupants' comfort requirements and influence overall building performance in building energy consumption and comfort (Wang et al., 2016). Although significant interest has been given to investigating IEQ satisfaction, availability of controls and multi-domain comfort preferences, many potential drivers of occupant behaviours have not yet been fully identified (Bavaresco et al., 2021; Yan et al., 2017). Furthermore, understanding occupant behaviour's influence on the building energy performance is essential from the design stage (He et al., 2021). A simpler model comprising environmental, contextual, and social-psychological parameters enables efficient and reliable decision-making at the initial stage, where the occupant behaviour-related information is still limited (Yan et al., 2017). Although Mahdavi and Taheri (2017) first emphasised the necessity of such an ontology that explicitly and comprehensively captured the dynamic state of occupant behaviours and performance data and introduced an ontology for building monitoring. However, the proposed ontology has a narrow focus on specific social-psychological parameters and the comfort preferences of occupants. Their proposed ontology comprises six basic data categories: occupants, indoor and external environmental conditions, control systems and devices, equipment, and energy flows.

Developing such an ontology focused on specific occupant behaviour drivers, comfort preferences of occupants and patterns of occupant behaviours and validating it with SMEs is the main objective of the current study. The ontology is introduced to develop occupant behaviour tools to integrate with building energy performance simulation. It is also valuable for enhancing energy performance, environmental control systems, and occupant-centric buildings. The ontology comprises the critical findings of a few data collection stages. The first stage was a preliminary study with building occupants, facilities managers, and sustainability managers. The researcher explored the organisational energy culture toward occupant behaviours in this stage and answered questions about perceived comfort preferences, factors influencing occupant behaviours, behaviour impact on energy, and occupant-centric energy culture (Weerasinghe, Rasheed, et al., 2022a, 2022b). In the second stage, the researcher surveyed social-psychological factors influencing occupant behaviours of general office building occupants in New Zealand. Two hundred ninety-four (294) responses were received, and the researcher evaluated the motivation-opportunity-ability (MOA) framework for occupant behaviours (Weerasinghe, Rotimi, et al., 2023). In the final stage, another survey was conducted within a selected case study to explore the decision-making process of occupants leading to their behaviours (Weerasinghe, Rasheed, et al., 2023). The process highlights the pattern of behaviours, occupants' preferences and needs, building-related factors, social-psychological factors, indoor environmental factors, and demographic factors that influence occupant behaviours.

The current study mainly presents the validation results of the proposed ontology based on 12 interviews conducted with SMEs. The forthcoming section presents the proposed ontology and explains the ontology parameters for different occupant behaviours. Section 12.3 discusses the research methods followed in the validation. In section 12.4, the results and findings of the validation are expressed, and section 12.5 discusses the research findings. Finally, section 12.6 presents the conclusion and recommendations of the study.

12.2 Occupant energy behaviour-ontology

12.2.1 Design and outline of the ontology

Ontology is a set of concepts or categories and their properties or relationships in a subject area relevant to modelling a particular domain (Liu & Özsu, 2009), and there is no one methodology for developing ontologies (Noy & McGuinness, 2001). However, the researchers can follow specific guidelines when developing one. In the current research, the researcher followed the steps in Figure 12.1 to develop the occupant energy behaviour ontology. As seen in Figure 12.1, the developed ontology aims to identify the occupant behaviour-related data office buildings need to monitor to improve energy performance. Therefore, the study followed the building monitoring ontology developed by Mahdavi and Taheri (2017). Based on the prior efforts in occupant energy behaviours (Weerasinghe, Rasheed, et al., 2022a, 2022b; Weerasinghe, Rasheed, et al., 2023; Weerasinghe, Rotimi, et al., 2023), the researcher created the essential terms in the ontology, defined the categories and category hierarchy, and defined the relationships of categories. A combination of the development process of the top-down and bottom-up approaches was followed to define the category hierarchy. In this way, the researchers first defined the more salient categories and then generalised and specialised them appropriately (Noy & McGuinness, 2001).

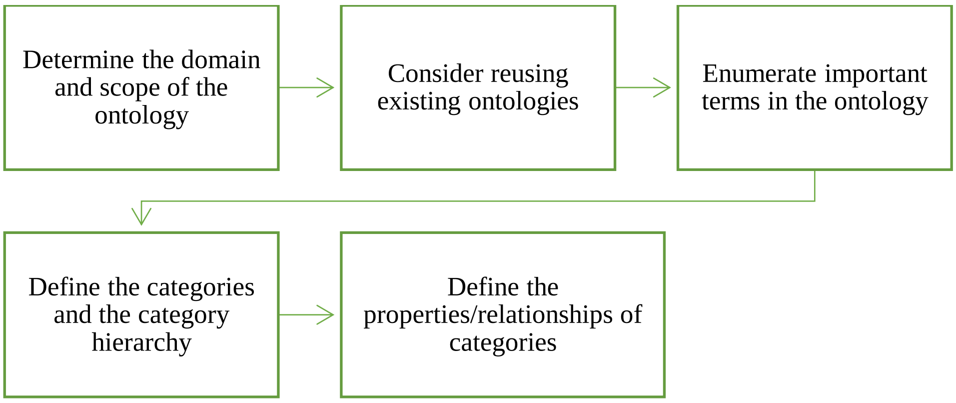


Figure 12.1 Basic steps of developing an ontology

Adapted from Noy and McGuinness (2001)

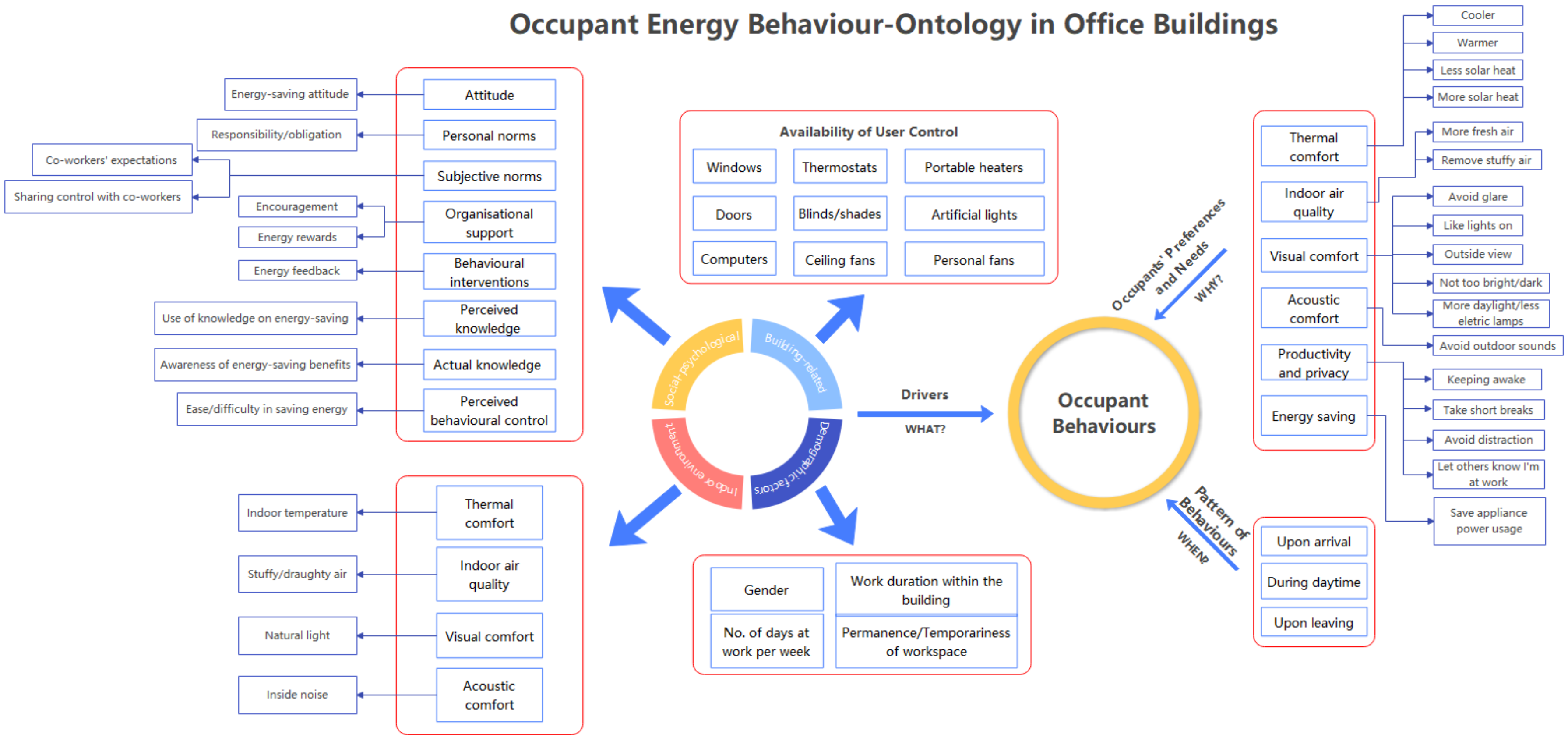


Figure 12.2 Occupant energy behaviour-ontology in office buildings

The proposed ontology is given in Figure 12.2. The ontology elements include data categories, sub-categories, and the corresponding monitored variables to explain occupant behaviours. For example, the following categories, sub-categories, and variables are suggested;

- Data categories – occupant energy behaviours, occupants' preferences and needs, drivers, the pattern of behaviours (middle part)
- Sub-categories – availability of user control, social-psychological factors, demographics, indoor environmental factors: thermal comfort, indoor air quality, visual comfort, acoustic comfort, and others (elements circled in red colour)
- Variables – window control, energy-saving attitude, indoor temperature, gender, upon arrival, cooler, outside view, and others (last elements)

12.2.2 Occupant energy behaviours

Hong et al. (2017) categorised occupant energy behaviours into two main clusters: adaptive and non-adaptive. Adaptive behaviours include adjusting windows, blinds, thermostats, lighting, and plug-ins (personal heaters, fans) to adapt the indoor environment to their preferences. Also include changing clothing levels, drinking hot/cold beverages, and moving through spaces to adapt to their environment (De Dear & Brager, 1998). On the other hand, non-adaptive behaviours include occupant presence, operation of plug-ins and electrical equipment (office and home appliances), reporting complaints regarding discomfort (O'Brien & Gunay, 2014) and accepting the existing indoor environmental conditions when there is no access, awareness, and choice to control comfort (Deuble & de Dear, 2012; Healey, 2013). Accordingly, the authors considered occupant behaviours relating to windows, shades and blinds, lighting, doors, fans, thermostats, portable heaters, and computers in the proposed ontology. Also, consider other behaviours like drinking, adjusting clothes, moving through spaces, reporting discomforts, and accepting and doing nothing.

Ontology sections for these different occupant behaviours are presented in section 12.3. These behaviours must be directly monitored or extracted from corresponding equipment state change data (Mahdavi & Taheri, 2017). However, organisations must consider the technical feasibility and occupants' privacy concerns when collecting such data (Mahdavi et al., 2018). Such behaviours occur when building occupants want to control the environmental factors based on their living spaces and the outside environment (Burger, 2013). Usually, these reactions of occupants are possible when they are in discomfort and trying to create a comfortable environment (Nicol & Humphreys, 2002). According to Bluyssen (2019), the building occupants influence the indoor climate through their presence and adjust building systems and components. Such activities aimed to improve thermal, acoustic, visual, and aesthetic comfort in the indoor environment. Thus, these occupant actions directly depend on the occupants' comfort requirements and influence overall building performance in building energy consumption and comfort (Wang et al., 2016). Likewise, the ontology elements: occupants' preferences and needs and drivers of occupant behaviours are interconnected.

12.2.3 Occupants' preferences and needs

The occupants cope with various sources of multi-domain discomforts at work, and the primary sources include thermal, visual, acoustic, and air quality aspects (Heydarian et al., 2020). Recently, Bavaresco et al. (2021) presented the interrelations between multi-domain comfort preferences with human building interactions like windows, blinds/shades, HVAC, and lighting in office settings. For example, occupants open windows and blinds to let more daylight in, closing them to reduce overheating in summer (Bavaresco et al., 2021). Thus, occupant behaviours depend on comfort or discomfort levels (Ozcelik et al., 2019). As further explained by Ozcelik et al. (2019), occupants initially adjust the shades and blinds under concurrent thermal and visual discomfort, whereas, in no-discomfort situations, they tend to adjust the desk fan first. Accordingly, blinds and shades are adjusted under multi-domain comfort preferences (O'Brien et al., 2013). Additionally, the comfort aspects like indoor air quality and noise level as triggers of window adjustment behaviour are highlighted (Fabi et al., 2012; Haldi & Robinson, 2011). Along these lines, Day et al. (2020) emphasised the need to assess how occupants use different building systems using knowledge of multi-domain comfort stimuli. The assessment of combined effects between comfort preferences and occupant energy behaviours is a ground-breaking approach to modelling occupant behaviour for BPS (Carlucci et al., 2020). Nevertheless, most previous research lacks broader views and has been limited to specific behaviours like window operation and HVAC adjustments (Harputlugil & de Wilde, 2021). The comfort preferences and needs of occupants were identified under the sub-categories of thermal comfort, indoor air quality, visual comfort, acoustic comfort, productivity and privacy, and energy saving in the proposed ontology. These sub-categories include variables relating to both indoor and outdoor environmental conditions. The current study identified these preferences and needs through subjective indoor and outdoor climate evaluation for each behaviour. The subjective assessment of indoor and outdoor environmental conditions based on the occupants' perceptions is crucial, as proven by causal theories in building energy performance evaluation. How these comfort preferences and needs relate to occupant behaviours are illustrated in the Figures in Section 12.3. Accordingly, subjective environmental data from thermal, indoor air, visual, and acoustic conditions are preferable to integrate occupant energy behaviours in building energy performance modelling and simulation.

12.2.4 Drivers

A vast majority of researchers in the occupant behaviour research field classified factors influencing occupant energy behaviour into various categories, such as environmental, building, social, physiological, psychological, and time-related (Bavaresco et al., 2020; D'Oca et al., 2019; Fabi et al., 2012; O'Brien & Gunay, 2014; Peng et al., 2012). Furthermore, it is believed that the design and control of indoor environmental conditions, occupant comfort preferences, and occupant energy behaviours are interconnected. A proper balance between those aspects is significant to reduce the energy wastage due to occupants while realising energy saving potentials of occupants (Weerasinghe, Rasheed, et al., 2021). For example, changes in relative humidity and indoor CO_2 concentration can impact thermal comfort, air quality, energy consumption, and occupants' interactions with buildings. These factors can affect how people feel in a space and impact their behaviour, such as using windows (Andersen et al., 2013; Barthelmes et al., 2017; Calì et al., 2016; Yao & Zhao, 2017).

Accordingly, the current study considered indoor environmental and building-related factors contributing to the "drivers". Sub-categories under the indoor environment were thermal comfort, indoor air quality, visual comfort, and acoustic comfort. Variables contributing to these sub-categories are indoor temperature, stuffy/draughty air, natural light, and inside noise. Additional data concerning the indoor environment, such as artificial lighting, may be required depending on the building systems and configurations. The data relating to these variables can be monitored using sensors (i.e., temperature) and human agents (i.e., subjective evaluation). Moreover, the availability of user control is the one sub-category related to building-related factors. The building energy performance depends on the control characteristics of systems such as windows, doors, thermostats, fans, lights, computers, and others. Therefore, the state of such systems requires monitoring in terms of the occupants' accessibility to these control systems. In some buildings, the occupants can fully or partially control building systems and appliances depending on the building settings and configurations, while some systems and appliances can be controlled only automatically. For example, changes in observed values indicate control events in the context of device states and control set points. Since they can be derived from device state data and related control set-points, these occurrences and actions are implicitly recorded in the monitored state data. However, information about actors (e.g., human initiators, agents, or control software) should be provided alongside information about events or acts (Mahdavi et al., 2018). Several studies have shown that building type and size have a significant impact on occupant behaviour, particularly concerning heating and cooling adjustments in residential buildings (Burgett & Sharp, 2017; Engvall et al., 2014; Yun & Steemers, 2011).

Recent research has shown that social-psychological considerations must be considered when analysing how tenants affect building efficiency and performance (Day & O'Brien, 2017). The New Zealand Energy Culture Framework focuses on business and residential electricity consumer behaviour, considering socio-psychological factors (Stephenson et al., 2015; Stephenson et al., 2010). For instance, a survey was carried out online at 14 universities and research institutes in the US, Europe, China, and Australia by D'Oca et al. (2017). It was considered how inhabitants interacted with building control systems and whether they intended to share controls. Motivational elements, group dynamics, ease and knowledge, and productivity satisfaction are essential considerations. Another study classified subjective characteristics as attitudes (behavioural and normative beliefs), subjective norms like motivational drivers, and PBC, including knowledge controls, ease of sharing, and perceived comfort (Bavaresco et al., 2020). For instance, occupants' upbeat attitudes encourage them to engage in more energy-saving behaviours (Li et al., 2019). These studies also imply that energy research methodologies based solely on objective occupant behaviour parameters can miss important information about subjective occupant behaviour parameters in buildings. Therefore, social-psychological drivers based on Li et al. (2019) MOA framework were considered in the proposed ontology.

Demographic factors identified in the ontology are gender, work duration within the building, number of days at work per week, and permanence/temporariness of the workspace. The sub-categories under the social-psychological factors were identified, referring to the MOA framework developed by Li et al. (2019). Accordingly, motivation (M) measures an occupant's concern over individual energy consumption and their behaviour involving saving energy. Opportunity (O) measures the occupants' accessibility to information related to energy conservation and environmental and interpersonal factors influencing their energy-saving intentions. Ability (A) is how occupants interpret energy-saving behaviour information based on their knowledge of energy use, impacts, and consequences. Accordingly, ontology drivers are [1] Indoor environmental factors, [2] Availability of user control, [3] Social-psychological factors, and [4] Demographics.

Depending on the resolution and coverage of the planned applications, more information on the occupants may be needed. This includes information about the characteristics or states of the occupants (i.e., physiology, activity, and clothing) and attitudinal data, including subjective feeling, perception, and appraisal. The human agent in these situations could be considered the sensor, for instance, subjective characterisations of indoor environmental conditions provided through thermal sensation and thermal comfort scales (Mahdavi et al., 2018). Also, nominal and ordinal data can be quantifiable by mapping them to numerical values, which can then be subjected to statistical operations in energy simulations.

12.2.5 Pattern of behaviours

Based on an investigation of human behaviour in residential buildings, Peng et al. (2012) defined time-related factors, such as activities repeated within specific time intervals, and random factors, such as behaviours depending on unknowable, non-quantifiable elements. Based on Peng et al.'s study findings, Stazi et al. (2017) examined the behaviours of building occupants and identified the primary motivators behind those behaviours, classified as environmental and time-related stimuli. For instance, several methods have been employed to assess the frequency of window openings, and it has been discovered that the frequency increases during particular times as time-related aspects are also crucial factors in occupants' interaction with building systems and appliances, the ontology considered the occupants' pattern of behaviours upon arrival, during the day, and upon leaving.

12.3 Ontology for different occupant behaviours

The proposed ontology can accommodate multiple occupant behaviours such as adjusting windows, shades and blinds, lighting, doors, fans, thermostats, portable heaters, and computers, drinking beverages, adjusting clothes, moving through spaces, reporting discomforts, and accepting and doing nothing. Figure 12.3 to Figure 12.14 provide each of these ontologies.

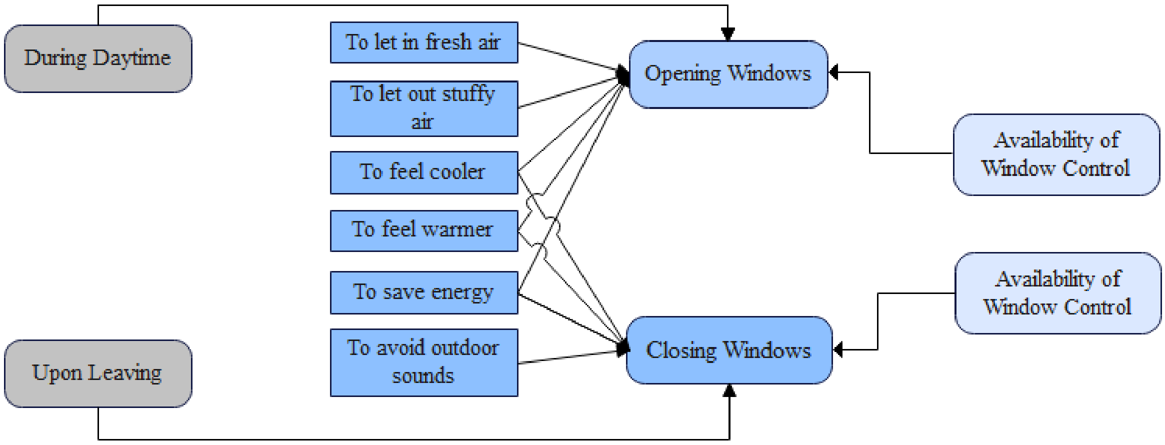


Figure 12.3 Ontology of occupants' window behaviour

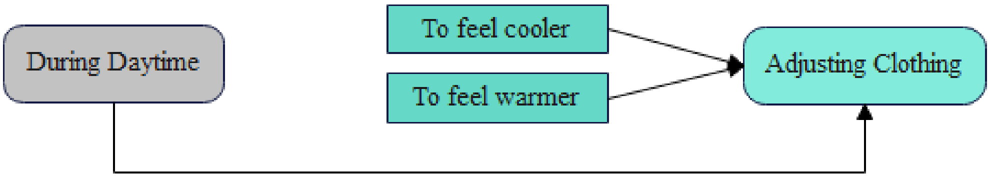


Figure 12.4 Ontology for occupants' adjusting clothing behaviour

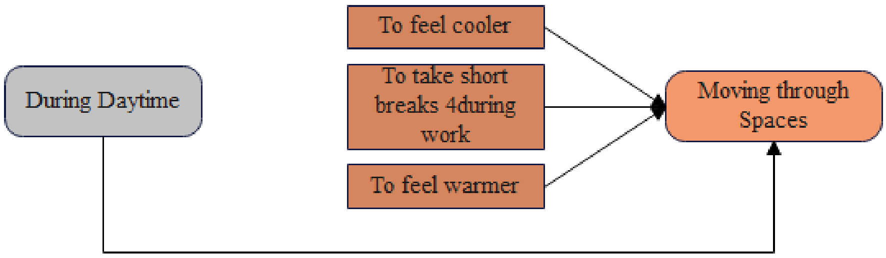


Figure 12.5 Ontology for occupants' moving through spaces behaviour

Figure 12.6 Ontology for occupants' reporting discomforts behaviour

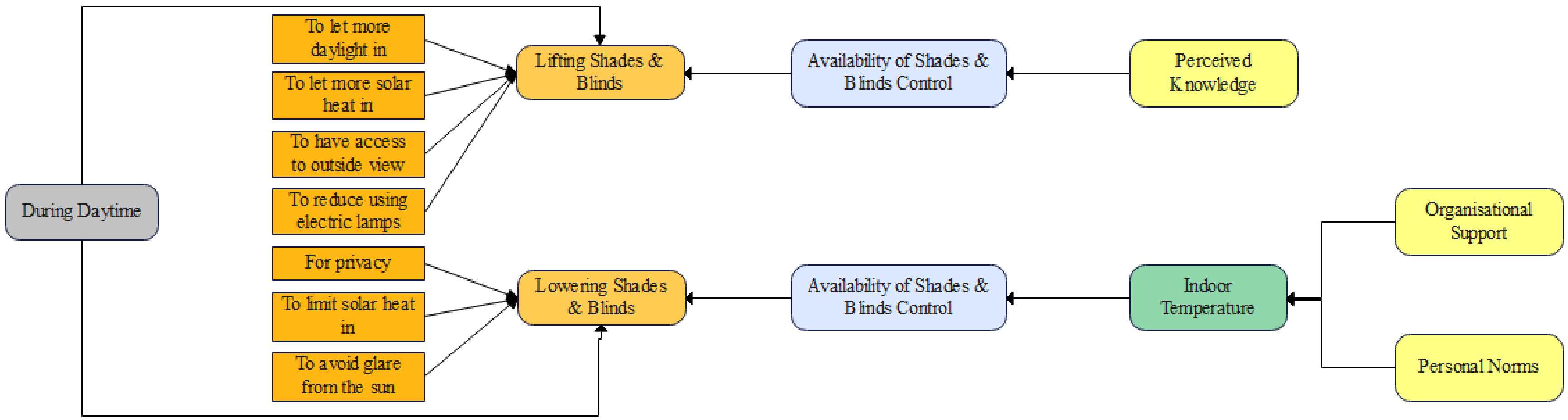


Figure 12.7 Ontology of occupants' shades and blinds behaviour

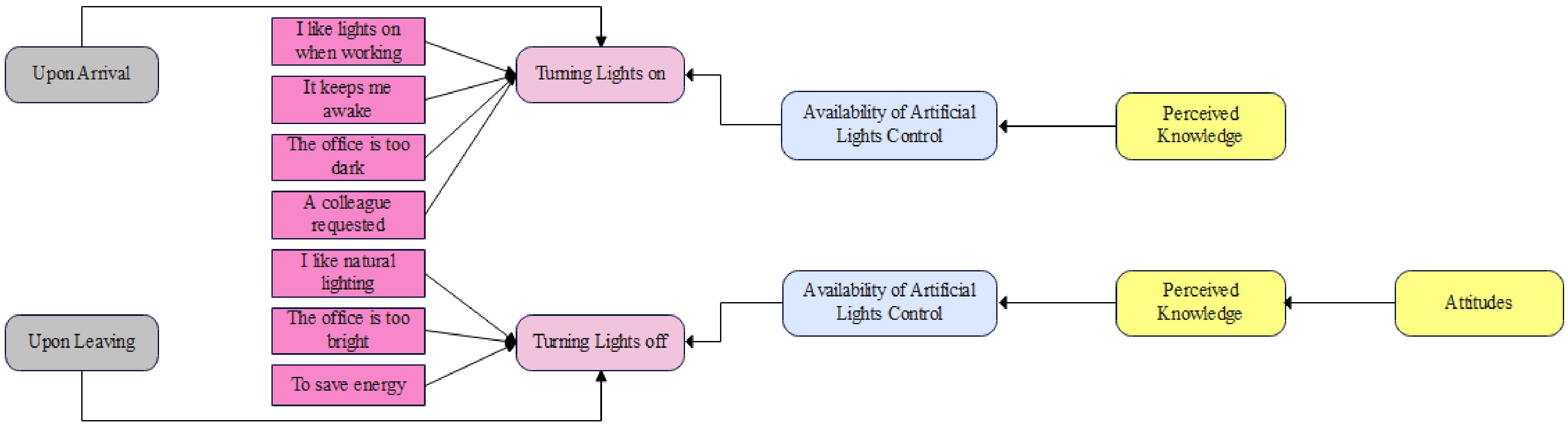


Figure 12.8 Ontology of occupants' lighting behaviour

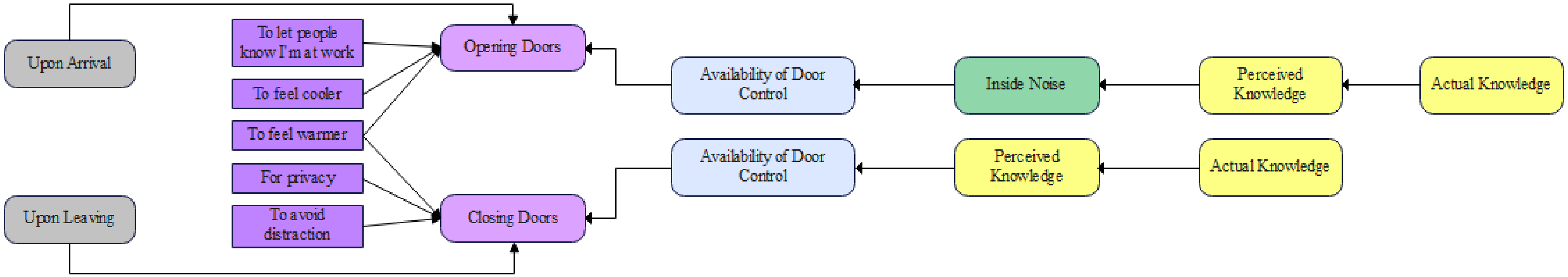


Figure 12.9 Ontology for occupants' door behaviour

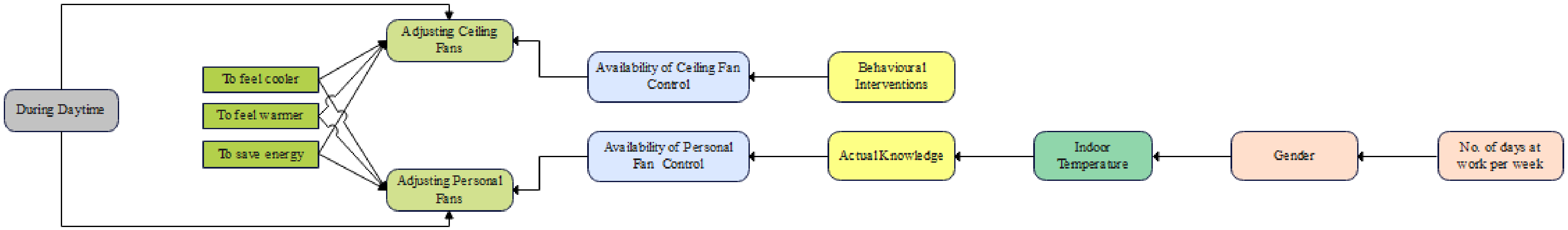


Figure 12.10 Ontology for occupants' fan behaviour

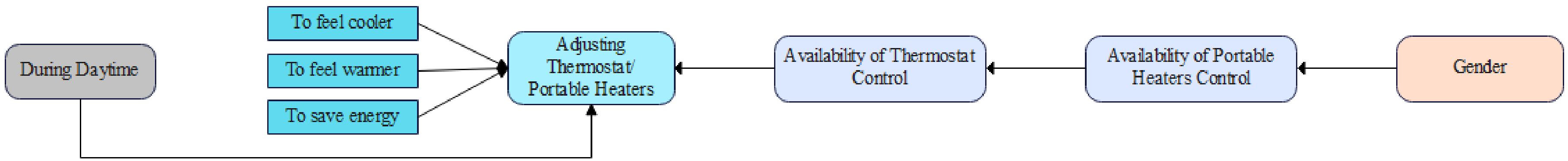


Figure 12.11 Ontology for occupants' thermostat/ portable heaters behaviour

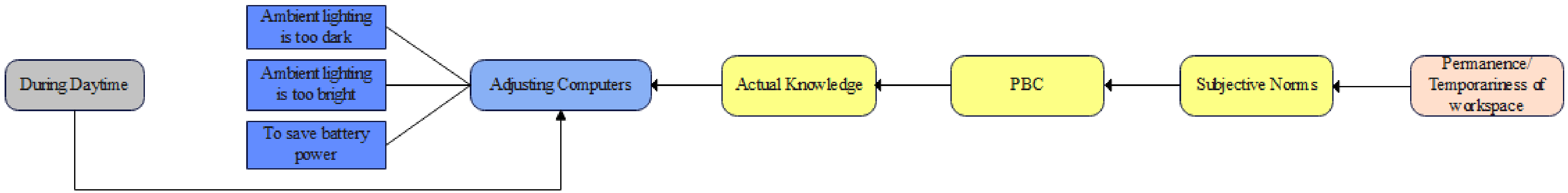


Figure 12.12 Ontology for occupants' computer behaviour

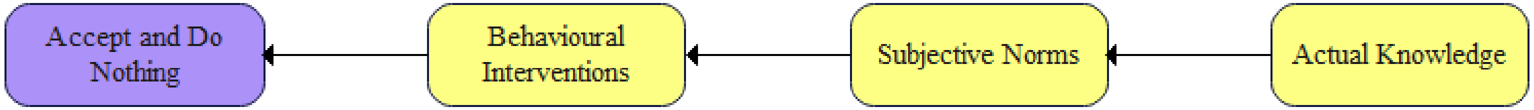


Figure 12.13 Ontology for occupants accept and doing nothing behaviour

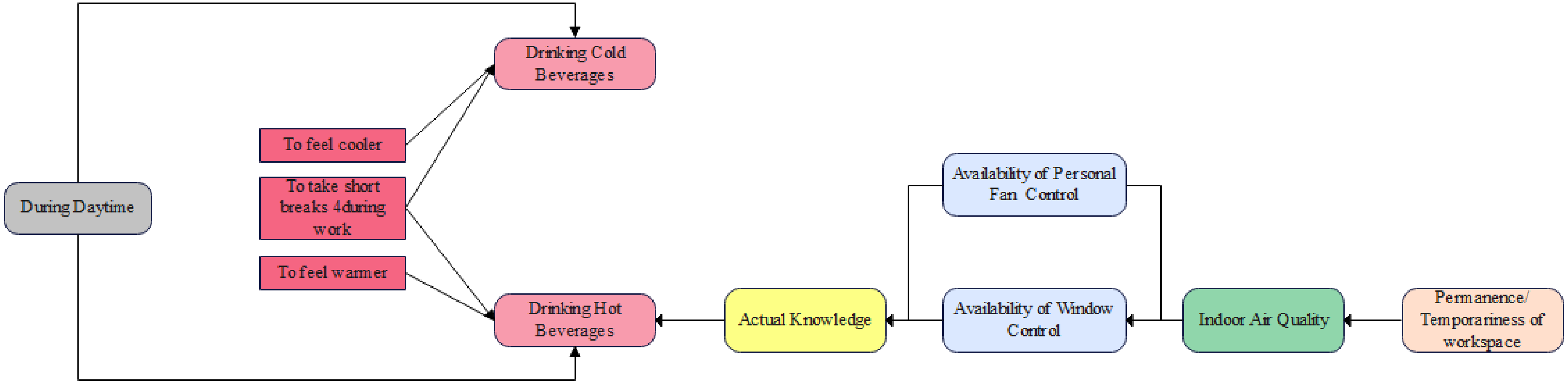


Figure 12.14 Ontology for occupants' drinking beverages behaviour

12.4 Research methods

This study aims to validate an occupant energy behaviour-ontology to develop occupant behaviour tools to integrate with building energy performance simulation. The ontology ensures better monitoring of occupant behaviour-related data and efficient energy performance in office buildings. The study adopted an SME approach to validate the proposed ontology. SMEs have an extensive understanding of a particular subject or topic due to their abilities, knowledge, and experience in that field (Hopkins & Unger, 2017; Lavin et al., 2007). SMEs are frequently employed in research because of their deep subject knowledge and skill, which enables them to offer fresh perspectives on a given topic or subject (Ford & Wood, 1992; Truxillo et al., 2004). An SME must be an authority on the topic, possess the exceptional skill, have the capacity for critical and analytical thought, and provide correct information (Marshall, 1996; Tremblay, 2003). The SMEs should be able to respond to interview questions confidently and willingly due to their extensive expertise or formal education in the field (Lavin et al., 2007; Marshall, 1996). The SME was selected as the best method for gathering data because it offers participants limitless opportunities to share ideas based on their expertise. Utilising SMEs is a fair and cost-effective strategy for finishing qualitative research projects on schedule and within budget while encouraging the emergence of new views (Marshall, 1996). Additionally, the SMEs support the investigation of the usefulness and applicability of the created ontology to increase energy efficiency in New Zealand office buildings. The SMEs approach enables the chosen participants to enquire about further clarification and specifics.

12.4.1 Data collection and analysis

The sample of SMEs was selected using snowball sampling. All of them were experts in areas that could contribute to improving the content, procedural, and wording aspects of the ontology. Invitation letters, ontology, and questionnaires were emailed to participants, and online meetings were scheduled after their acceptance. The invitation letter contained information on the main objective of this study, the research process, the interview procedure and how to respond and assured the experts of the confidentiality of their data. For the experts to evaluate a certain number of items, the amount of information and its presentation is essential (Pedrosa et al., 2013). Therefore, these aspects were all taken into account. The invitations were sent to 15 participants; only 12 agreed to participate. The process took two months, October and November 2022, from participant identification to sending invitations and holding the last participant interview. The participants gave their informed consent over the online questionnaire setup in the Qualtrics platform, and their participation was voluntary.

The experts assessed the ontology online during the meeting, while the researcher was always available to answer any unclear information. The time taken by the participants to answer the questionnaire ranged from 30 to 45 minutes. The questionnaire for validating the ontology consisted of participant background (i.e., job role, age, work experience, the field of expertise), introduction to occupant behaviour-ontology, validation of proposed ontology (i.e., sufficiency, clarity, coherence, relevance, applicability), and further evaluation of the ontology (i.e., advantages, likely barriers, any improvements). The items validating the proposed ontology were adapted from the framework for assessing content validity through experts (Escobar-Pérez & Cuervo-Martínez, 2008), adding the fifth item, "applicability." The items were encoded on a seven-point Likert scale (1–Strongly disagree/Extremely useless, 7–Strongly agree/Extremely useful) response to measure the applicability of ontology. Table 12.1 presents the categories and indicators SMEs used to validate the proposed ontology. The quantitative data collected were descriptively analysed to evaluate the respondents' agreement on the occupant energy behaviour ontology, while qualitative data collected from the open-ended questions were analysed using manual content analysis.

Table 12.1 Categories and indicators used by SMEs to validate the proposed ontology

Category	Code	Indicators
Sufficiency	S1	The variables and sub-categories are sufficient to explain each data category of the ontology
	S2	The variables and sub-categories express some aspects of the data categories but do not represent them fully
	S3	A few variables and sub-categories must be added in order to understand the occupant behaviours fully
Clarity	C1	The ontology elements are clear, with appropriate semantics and syntax
	C2	The ontology elements require several modifications or an extensive modification in terms of meaning or word order
	C3	Some elements of the ontology require very precise modifications
Coherence	Co1	The ontology elements are entirely related to the occupant behaviours
	Co2	The ontology elements have an indirect/moderate relationship to the occupant behaviours
	Co3	The ontology elements bear no rational relationship to the occupant behaviours
Relevance	R1	The elements are very relevant and should be included when developing occupant behaviour models/tools to integrate with building energy performance simulation

	R2	The elements are somewhat relevant, but other elements are more relevant when developing occupant behaviour models/tools to integrate with building energy performance simulation
	R3	The removal of any element would not affect the development of occupant behaviour models/tools to integrate with building energy performance simulation
Applicability	A1	How useful do you think this ontology is for building managers (i.e., facilities managers, energy managers) to enhance building energy performance
	A2	How useful do you think this ontology is for building managers to use in environmental control systems
	A3	How useful do you think this ontology is for building managers to establish occupant-centric buildings

Adapted from Escobar-Pérez & Cuervo-Martínez (2008)

Twelve SMEs were selected for validation using snowball sampling, and an overview of these participants is included in Table 12.2. The experts come in different work positions, experience and age levels, and fields of expertise. Table 12.2 is arranged as per SMEs' work experience levels. 33% of the selected experts have more than 20 years of experience, 42% have 11–20 years of experience, and 25% with 1–10 years of experience. The selected experts come from the senior or executive level (E01, E05), mid-level management (E03, E06, E08), and first-level management (E02, E04, E07, E09, E10, E11, E12). There were 25% of experts aged between 55–64, 17% between 45–54, 33% between 35–44, and 25% aged between 25–34.

The experts were presented with a list of fields of expertise and asked to rate their expertise on a five-point Likert scale (1-Not knowledgeable at all, 2-Slightly knowledgeable, 3-Moderately knowledgeable, 4-Very knowledgeable, 5-Extremely knowledgeable). The fields rated 4 and 5 were included in the table. All the participants have expert knowledge of one or a few fields relating to this research: energy, emissions, building design and operation, environmental control, user comfort, and simulation/modelling.

12.5 Validation of ontology

When validating the proposed ontology, the experts were first asked to rate the ontology based on the given criteria. The researcher also recorded any comments they raised while rating the ontology. Next, they were asked to comment on the advantages, likely barriers, and other improvements to the proposed ontology. The following criteria were used to rate the ontology;

- Sufficiency—The information presented in the ontology suffice to express the occupant behaviours
- Clarity—The elements in the ontology can be understood easily
- Coherence—The ontology elements are logically related to the occupant energy behaviours
- Relevance—The ontology is essential
- Applicability—The possible applications of the ontology

A seven-point Likert scale was used in the rating, including SD-strongly disagree, D-disagree, SoD-Somewhat disagree, NAD-Neither agree nor disagree, SoA-Somewhat agree, A-Agree, SA-Strongly agree. Regarding applicability, the Likert scale is EU-Extremely useless, MU-Moderately useless, SU-Slightly useless, NU-Neither useful nor useless, SU1-Slightly useful, MU1-Moderately useful 7, and EU1-Extremely useful.

12.5.1 Sufficiency

Table 12.3 summarises the SMEs' ratings on the sufficiency of the ontology elements to explain occupant behaviours. The sufficiency measurements include three sub-criteria focusing on the ability of ontology sub-categories' sufficiency in explaining the main data categories of the ontology (i.e., occupant energy behaviours, occupants' preferences and needs, drivers, and the pattern of behaviours). Specifically, S1 states they are sufficient, S2 states they only express some aspects, and S3 states that the ontology lacks some variables and sub-categories. The researcher added these three statements to understand whether the current ontology can express what it intended to. All the SMEs agreed that the variables and sub-categories are sufficient to explain each ontology data category, with 25% indicating somewhat agreement. E11 added that the ontology elements are sufficient and consolidated well, and the elements could bring down even further. An interviewee further explained that:

> *"The ontology got all the variables and sub-categories that are sufficient to explain, and every one of these points raises another argument, which means this research must be exciting" (E03).*

Table 12.2 Participants profile

Interviewees	Work Position	Work Experiences (Years)	Age	Field of Expertise
E01	Managing Director	More than 20 years	55 - 64	Building systems and technology, intelligent operations, and environmental control systems, Building design and architecture, Energy consumption and conservation, Indoor environment and user comfort, Occupant-centred building controls, Zero carbon buildings
E02	Facilities Services Manager	More than 20 years	55 - 64	Building systems and technology, intelligent operations and environmental control systems, Occupant-centred building controls
E03	Head of Technical Services	More than 20 years	45 - 54	Building design and architecture, Energy consumption and conservation, Indoor environment and user comfort, Building systems and technology, intelligent operations and environmental control systems, Occupant-centred building controls, Building performance simulation and energy modelling, Occupant behaviour monitoring and modelling
E04	Energy Transition Programme Manager	More than 20 years	35 - 44	Sustainable Development Goals (SDGs), GHG emissions, Energy consumption and conservation
E05	Director of Sustainability	11 - 20 years	55 - 64	SDGs, GHG emissions, Zero carbon buildings, Building design and architecture, Energy consumption and conservation, Indoor environment and user comfort
E06	Senior Facilities Specialist	11 - 20 years	35 - 44	Energy consumption and conservation, Indoor environment and user comfort, Building systems and technology, intelligent operations, and environmental control systems
E07	Project Engineer	11 - 20 years	35 - 44	Zero carbon buildings, Building design and architecture, Energy consumption and conservation, Building systems and technology, intelligent operations, and environmental control systems, Building performance simulation and energy modelling
E08	Lead Engineer - Sustainability	11 - 20 years	35 - 44	GHG emissions, Zero carbon buildings, Building design and architecture, Energy consumption and conservation, Indoor environment and user comfort, Occupant behaviour monitoring and modelling, Building performance simulation and energy modelling
E09	Business Development Manager - Existing Buildings	11 - 20 years	25 - 34	SDGs, GHG emissions, Zero carbon buildings, Building design and architecture, Energy consumption and conservation, Indoor environment and user comfort

E10	Facilities Services Manager	1 - 10 years	45 - 54	Energy consumption and conservation, Indoor environment and user comfort, Building systems and technology, intelligent operations and environmental control systems, Occupant-centred building controls
E11	Engineer	1 - 10 years	25 - 34	SDGs, GHG emissions, Zero carbon buildings, Building design and architecture, Energy consumption and conservation, Indoor environment and user comfort, Building performance simulation and energy modelling
E12	Assistant Manager - Engineering Facilities	1 - 10 years	25 - 34	GHG emissions, Zero carbon buildings, Energy consumption and conservation, Indoor environment and user comfort, Building systems and technology, intelligent operations, and environmental control systems

Table 12.3 Sufficiency of the ontology

Statement		SD	D	SoD	NAD	SoA	A	SA
S1	The variables and sub-categories are sufficient to explain each data category of the ontology	0	0	0	0	25.0%	66.7%	8.3%
S2	The variables and sub-categories express some aspects of the data categories but do not represent them fully	0	16.7%	16.7%	25.0%	25.0%	16.7%	0
S3	A few variables and sub-categories must be added in order to understand the occupant behaviours fully	8.3%	16.7%	16.7%	8.3%	16.7%	33.3%	0

However, regarding S2 and S3, a majority agreed instead of disagreeing. 41.7% agreed that the variables and sub-categories express some aspects of the data categories but do not represent them fully, while 50% agreed that a few variables and sub-categories must be added to understand the occupant behaviours fully. For instance, the interviewees (E01 and E02) highlighted the importance of considering indoor noise levels relating to the occupant preferences category in the ontology. As E01 explained:

> *"A missing ingredient under "Occupant Preferences" is Indoor noise levels – it refers only to Avoiding Outdoor sounds. Indoor noise is mentioned under the Indoor Environment section, which is true, but it also impacts Occupant Preferences. While excluding Outdoor sounds is important, from our experience, most acoustic issues arise from Indoor issues such as noisy air conditioning equipment, crosstalk issues, reverberation levels etc."*

Another factor highlighted by the interviewees (E01 and E05) was that the culture within an organisation could also play its part. E01 further explained that *"if a lousy culture exists, then most people may feel somewhat negative about their surroundings, so they are more likely to complain and less likely to engage with energy or IAQ initiatives that rely on people's participation. The converse is true."* Like culture, another vital factor added by E02 was space utilisation by the occupants. The interviewee, E05, further explained that autonomy and space are much more limited for people in shared spaces than private rooms. Also, the complexity of the space depends on the size of the organisation (i.e., small or large). *"That might be an interesting factor to consider including in the ontology"*. However, the factors like indoor noise level preferences and office type (i.e., private rooms, shared space, open-plan office) were considered in the statistical analysis before developing the ontology, and these factors were eliminated in the analysis.

E05 and E07 also raised the importance of educating the people and including this element in the ontology. As the buildings are designed to suit a particular audience best, the occupants should be educated about the capabilities of the building. E05 further explained that *"a building manager might do better sitting down and talking with people and getting a sense of the whole"*. As the interviewees further explained, a human being is complex and has all these layers that need to be somehow able to be responded to, and it will be feasible depending on the building type (i.e., tenant or leased building, owner-occupied buildings). Looking at these views of the experts, there is a possibility that ontology elements can be further broken down depending on such building characteristics.

On another note, some experts (E09 and E12) suggested including physical environmental factors: humidity and CO_2 levels, and physiological factors: metabolic rates, clothing types of the occupants, and different postures and activities (i.e., sitting, standing or walking). Nevertheless, these factors are objective and need measurements, and occupants are usually not knowledgeable about these factors. As the ontology elements were obtained through occupant surveys, these elements were not included, but they are necessary for building monitoring and modelling to improve building energy performance. Four interviewees expressed neutral views (E01, E02, and E06, and E12) regarding S2 and S3 statements.

12.5.2 Clarity

Table 12.4 Clarity of the ontology

Statement		SD	D	SoD	NAD	SoA	A	SA
C1	The ontology elements are clear, with appropriate semantics and syntax	0	8.3%	8.3%	8.3%	25.0%	41.7%	8.3%
C2	The ontology elements require several modifications or an extensive modification in terms of meaning or word order	0	41.7%	41.7%	0	16.7%	0	0
C3	Some elements of the ontology require very precise modifications	0	33.3%	0	33.3%	25.0%	8.3%	0

Table 12.4 presents the SMEs' ratings on the clarity of the ontology elements. This measurement also includes three sub-criteria evaluating whether ontology elements are easy to understand. Accordingly, the C1 statement evaluates whether elements are clear and have

used correct semantics and syntax. In other measures, C2 states that these elements require some modifications in meaning or word order, while C3 states that the ontology elements require precise modifications. As seen in Table 4, 75% of respondents agreed that the ontology elements are clear with appropriate semantics and syntax, including 25% indicating somewhat agreement. Interviewees E01 to E08 and E10 to E12 were the experts who agreed that the ontology elements are clear with appropriate semantics and syntax. Considering C2, a majority, 83.4%, indicated disagreement, while for the C3 measure, an equal percentage (33.3%) of agreement and disagreement were received. Accordingly, the required modifications were suggested by the experts.

Considering modifications, E08 suggested classifying the factors based on the organisation's size (i.e., small, medium, and large office) and factoring in the real-time probability of each potential driver. Thereby the drivers will be changed. Another interviewee (E11) suggested dividing categories based on their importance for FMs, end users, and designers. The ontology will be more simplified if such changes are carried out. Furthermore, the interviewees (E06, E05, and E11) expressed that just looking at the ontology is not enough to understand the ontology fully. It would have been more accessible for people if someone had explained the specific connectivity of the elements like the researcher did in the beginning. Also, the other precise modifications suggested by E01 and E12 were highlighted regarding evaluating the sufficiency of elements. However, four interviewees expressed neutral views (E02, E06, E07, and E09) regarding C1 and C3 statements.

12.5.3 Coherence

Table 12.5 Coherence of the ontology

Statement		SD	D	SoD	NAD	SoA	A	SA
Co1	The ontology elements are entirely related to the occupant behaviours	0	0	8.3%	16.7%	16.7%	50.0%	8.3%
Co2	The ontology elements have an indirect/moderate relationship to the occupant behaviours	8.3%	16.7%	8.3%	25.0%	25.0%	16.7%	0
Co3	The ontology elements bear no rational relationship to the occupant behaviours	33.3%	50.0%	8.3%	8.3%	0	0	0

The SMEs' ratings on the coherence of the ontology elements to explain occupant behaviours are given in Table 12.5. The three sub-criteria evaluate whether the ontology elements are logically related to the occupant energy behaviours. The C01, Co2, and Co3 statements measure the relationship of ontology elements to occupant behaviour in three levels: entirely related, indirect/moderately related, and not related. Based on the ratings of the experts, 75% of them agreed with the statement that the ontology elements are entirely related to occupant behaviours. On the other hand, 41.7% indicated that these ontology elements have an indirect/moderate relationship with occupant behaviours. However, a majority, 83.3% of experts, disagreed with the statement that the ontology elements bear no rational relationship to occupant behaviours.

One interviewee (E05) disagreed with the statement that the ontology elements are entirely related to the occupant behaviours, based on the fact that the ontology elements are also helpful in improving the occupants' comfort, health, and productivity aspects. Also, they agreed that the ontology elements have an indirect/moderate relationship to the occupant behaviours for the same reason. Another set of interviewees (E03, E08, E09, and E12) agreed about the indirect/moderate relationship of ontology elements to occupant behaviours depending on the different building characteristics. For instance, E09 explained that control over building systems and appliances could be limited in some office spaces depending on the building size and type. In such a situation, occupants cannot perform many behaviours.

"If you give control to occupants to adjust the thermostat based on their preferences, people might turn it up and turn it down numerous times. Some people like a slightly warm environment, while others may like a slightly cold one. Thus, the environment is always too warm and cold for everyone. Accordingly, many offices completely remove the human factor and move to smart controls."

E03 further explained that "the more dominating personality and the organisation will take over and then create resentment." E08 opined that energy feedback could loop back to behaviour interventions with building systems and start educating them. E09 added that the pattern of behaviours is also linked with other factors like building occupancy patterns, building operation time, last person to leave the space, arrival/departure of housekeeping staff, and facilities operations, which are logical to explain in the ontology. However, two interviewees (E06 and E09) expressed neutral views regarding the Co1 statement, the interviewees: E01, E04, and E07 had neutral views on the Co2 statement, and one interviewee (E07) expressed neutral views regarding the Co3 statement.

12.5.4 Relevance

Table 12.6 Relevance of the ontology

Statement		SD	D	SoD	NAD	SoA	A	SA
R1	The elements are very relevant and should be included when developing occupant behaviour models/tools to integrate with building energy performance simulation	0	8.3%	0	8.3%	8.3%	66.7%	8.3%
R2	The elements are somewhat relevant, but other elements are more relevant when developing occupant behaviour models/tools to integrate with building energy performance simulation	0	25.0%	16.7%	16.7%	33.3%	8.3%	0
R3	The removal of any element would not affect the development of occupant behaviour models/tools to integrate with building energy performance simulation	8.3%	25.0%	41.7%	8.3%	8.3%	8.3%	0

Considering the proposed ontology's relevance or importance in developing occupant behaviour models/tools to integrate with building energy performance simulation, Table 12.6 summarises the corresponding responses on the three sub-criteria. Specifically, R1 states that the elements are relevant for fulfilling the above purpose, and R2 states that the elements included in the ontology are somewhat relevant. However, other elements are more relevant and not included in the ontology, and R3 states that removing any element would not affect it significantly. Accordingly, 91.7% of the SMEs agreed that the elements are relevant and should be included when developing occupant behaviour models/tools to integrate with building energy performance simulation. Considering R2, an equal percentage (41.7%) of agreement and disagreement were received, while a majority, 75%, indicated disagreement with the C3 measure.

Except for E11, all other interviewees agreed that the ontology elements are relevant and should be included when developing occupant behaviour models/tools to integrate with building energy performance simulation. The interviewees: E02, E05, E06, E07, E09, and E12, had agreed that the elements are only somewhat relevant and others are more relevant when developing occupant behaviour models/tools to integrate with building energy performance simulation. Furthermore, E11 and E07 agreed that removing any element would not affect the development of occupant behaviour models/tools to integrate with building energy performance simulation. For instance, E09 explained the reasons for his view. According to him, the ontology should also include the shift work arrangements of the regular and temporary occupants.

> *"You would have different shifts of people coming in and out all the time, and the lights were generally all on. Then there are also times when housekeeping staff comes, and they might turn on all the lights and turn them off when they leave."*

Likewise, many of these elements depend on how the building has been designed and operated. In some buildings, there is limited influence by the occupants' behaviours, and those directly related factors need to be considered for energy performance simulation. For example, *"occupants cannot change some aspects of the building, like the orientation of the building, the spaces to take short breaks, lighting, and all the other things relating directly to a building that is now built and set up."*

E07 emphasised that they would conduct energy modelling around the design stage, giving them the parameters of total energy consumption and the optimum maximum and minimum temperatures they want to operate the building. Their base energy model would be justified through the modelling, allowing them to run the building for a year or two before they have enough data to justify the model. Therefore, using occupants' behaviour to reduce the carbon targets for an existing building usually comes later at the operation stage. As someone having good experience in energy simulations, E11 added that:

> *"The inputs of building energy performance would be building fabric, the internal gains of a building which might come into play with building occupancy, like how often people turn the lights off multiplied by the actual wattage of the lighting, the hours the building is used, and the hours the equipment used to get the building to acceptable temperature level for comfort."*

E11 argued that the current energy simulations do not consider the factor of occupant behaviour except for a few turning on/off activities and thus could not agree with its relevance in energy performance simulation. In terms of occupants' comfort, however, there are other building performance tools (i.e., WELL Building Standard). Some interviewees (E04, E06, E07, E11) had neutral views on the three statements.

12.5.5 Applicability

Table 12.7 Applicability of the ontology

Statement		EU	MU	SU	NU	SU1	MU1	EU1
A1	How useful do you think this ontology is for building managers (i.e., facilities managers, energy managers) to enhance building energy performance	0	0	0	8.3%	25.0%	33.3%	33.3%
A2	How useful do you think this ontology is for building managers to use in environmental control systems	0	8.3%	0	0	41.7%	16.7%	33.3%
A3	How useful do you think this ontology is for building managers to establish occupant-centric buildings	0	0	0	0	25.0%	33.3%	41.7%

At last, the experts were asked to rate the applicability of ontology in different applications. There were three applications considered, such as the usefulness of ontology for building managers to enhance building energy performance (A1), to use in environmental control systems (A2), and to establish occupant-centric buildings (A3). The researcher expected that all the experts would see the importance of the proposed ontology in these applications. Likewise, a majority agreed with all three statements. Notably, 91.7% of experts indicated that the proposed ontology is useful in A1 and A2 statements, while only 8.3% differed. Considering the R3 statement, all the experts indicated that the proposed ontology is useful for building managers to establish occupant-centric buildings.

Most interviewees, except E03, have indicated that the proposed ontology is useful for building managers (i.e., facilities managers and energy managers) to enhance building energy performance, use in environmental control systems, and establish occupant-centric buildings. For instance, E09 pointed out that the ontology information is useful for facilities managers to focus on where energy wastage could occur. The existing BMS provide facilities managers with critical feedback when something goes wrong (i.e., water leak, light and HVAC were left on). Thus, ontology provides knowledge to expand these trigger points. Another interviewee, E10, explained that ontology is potentially useful depending on what the building managers try to achieve. In a building where building managers deliver a standard approach, ontology elements have a considerable variance and are probably more relevant than the design parameters of the building. However, looking at how the building manager would deal with the different occupant preferences for environmental user control is essential. What facilities managers practice is taking a relatively cautious view of occupant feedback. According to E08, ontology is also applicable in leased buildings. The building managers can conduct occupant surveys considering the ontology elements to evaluate user comfortability in the building space. If the results reveal that most occupants are in discomfort and their occupant behaviours lead to excessive energy, they can decide not to renew the lease for the next term. E03 had a somewhat different view of the proposed ontology in that she expressed that the ontology is only useful for new facilities managers.

> *"Nevertheless, anyone who spent time in this space would quickly know. Within the first six months of working, they would have had a complaint about or dealt with any one of these things. However, it would be useful if the building manages to establish occupant-centric buildings, but they will quickly understand that it is a utopia they cannot have because of cost barriers.*"

12.5.6 Advantages, barriers, and further improvements of the Ontology

At the end of the validation, the experts were required to provide their opinions on the main advantages of the proposed ontology to the existing occupant energy monitoring, modelling, and decision-making approaches. They had to give feedback on the possible obstacles to implementing the proposed ontology and suggest ways to enhance its content. These were presented as open-ended questions to evaluate the ontology further. Based on the answers given by the experts, Tables 12.8 to 12.10 summarise the advantages, barriers, and further improvements of the ontology.

As seen in Table 12.8, the experts highlighted advantages relating to energy and other aspects. Accordingly, the proposed ontology mainly contributes to educating and promoting energy-efficient behaviours (E10 and E12) and improving communication between managers and occupants (E04 and E10), which involves both occupants and managers. Other advantages are mainly for the building managers, owners, and policymakers regarding energy efficiency. For instance, the ontology provides a more holistic and cultural understanding of the relationship between the technical and the occupants in a building (E05), which may lead to better scheduling of equipment and systems (E04), understanding the trade-offs between energy and comfort (E05), develop strategies to reduce energy consumption (E11), and save energy costs (E04). The ontology also acts as a guide to data/information for energy efficiency (E09). For example, E05 explained that:

"The ontology raises issues that are often marginalised because of a focus on technical solutions over the needs and perspectives of occupants. This can be valuable for policymakers as it helps to address issues related to human-building interactions and how those interactions can impact energy performance. However, it is important to note that there may not be a direct relationship between energy efficiency and occupant comfort, as occupants may prioritise their physical comfort over energy efficiency. The ontology can help to highlight these trade-offs and enable policymakers to make informed decisions that balance energy efficiency with other factors."

Other advantages highlighted are mainly relating to occupant comfort (E01, E02, E05, E07, and E12), IAQ (E01, E05, E06, E07, and E12), and sustainability (E01 and E05). As E01 explained:

"Energy efficiency in buildings cannot be achieved without factors such as occupant comfort, building health, and sustainability. The ontology diagram is a comprehensive way to approach these complex and interrelated subjects."

What E01 meant by complex and interrelated subjects is thermal comfort influenced by factors such as mean radiant temperature, relative humidity, direct solar radiation, stratification, and IAQ, which is essential for building health and occupant comfort. However, these factors are rarely measured, making achieving optimal thermal comfort and IAQ in buildings challenging. Furthermore, E08 and E11 support the ontology's ability to guide the qualitative and quantitative measurements.

Table 12.9 presents the likely barriers to the implementation of the proposed ontology. Most interviewees (E01, E02, E03, E06, and E11) highlighted that finances could be a barrier, as many building owners may not see a compelling financial incentive or return on investment for improving energy efficiency through occupant behaviours as opposed to technical solutions. E05 further supported that *"technical solutions are often seen as neat, but when applied in real-world situations, the complexity of human behaviour can make it challenging to achieve optimal outcomes. This is particularly true in energy efficiency, where human behaviour can significantly impact energy consumption."*

Table 12.8 Main advantages of the ontology

Advantages		E01	E02	E03	E04	E05	E06	E07	E08	E09	E10	E11	E12
1	Educating and promoting energy-efficient behaviour										✓		✓
2	Improve communication between managers and occupants				✓						✓		
3	Provide a more holistic and cultural understanding of the relationship between the technical and the occupants in a building					✓							
4	Enable better scheduling of equipment and systems				✓								
5	Valuable for policymakers to understand the trade-offs between energy and comfort					✓							
6	A guide to data/information for energy efficiency									✓			
7	Building owners and managers can develop strategies to reduce energy consumption											✓	
8	Save energy costs				✓								
9	Potential integration into occupant comfort	✓	✓			✓		✓					✓
10	Potential integration into building health and IAQ	✓				✓	✓	✓					✓
11	Potential integration into sustainability	✓				✓							
12	Helpful in developing easy-to-complete survey tools for occupants								✓				
13	Potential for consolidating data on occupant comfort and the qualitative and quantitative measurements in the industry											✓	

Table 12.9 Likely barriers to the ontology

Barriers		E01	E02	E03	E04	E05	E06	E07	E08	E09	E10	E11	E12
1	Building owners may not see compelling financial incentives or return on investment	✓	✓	✓			✓					✓	
2	Translating the complexity of the Ontology into simple terms for an average building occupant	✓			✓				✓	✓			✓
3	Organisational facilities management and business strategies		✓				✓				✓		

4	Resistance to change (i.e., occupants, leadership)		✓				✓						
5	Pre-defined building standards										✓		✓
6	Overrate technical solutions and underrate occupant behaviours					✓							✓
7	Opposing forces of energy and building health	✓											
8	Lack of intervention/stimulation by the government	✓											
9	Lack of professional talents and awareness						✓						
10	Organisational energy policy and carbon reporting							✓					

Table 12.10 Further improvements in the ontology

Improvements		**E01**	**E02**	**E03**	**E04**	**E05**	**E06**	**E07**	**E08**	**E09**	**E10**	**E11**	**E12**
1	Space utilisation		✓			✓					✓		
2	Cultural influence	✓				✓							
3	Noise parameter	✓	✓										
4	Education and awareness				✓			✓					
5	Occupants' needs and actual energy requirements			✓									
6	CO_2 levels									✓			✓
7	User interfaces for lived experiences					✓							
8	Factor in the real-time probability								✓				
9	Classification of office size								✓				
10	More relationships and feedback loops									✓			
11	Classification on stakeholders											✓	
12	Occupant postures												✓
13	Humidity									✓			
14	Metabolic rates and clothing types of the occupants												✓

E05 also explained that it is crucial to understand occupant behaviour's role in energy consumption and to design solutions considering occupant behaviours to overcome this barrier. Possible solutions are involving users in the design process, providing education and incentives to promote energy-efficient behaviour, and designing buildings and systems that are easy to use and understand.

Another barrier highlighted by many experts (E01, E04, E08, E09, and E12) is the complexity of the ontology of building energy performance, and the trade-offs between occupant comfort, health, and sustainability can be difficult for building occupants to understand. As EO1, E03, and E09 suggested, tools like the WELL Building Standard (by International WELL Building Institute [IWBI]) and the National Australian Built Environment Rating System (NABERSNZ) can help by providing simple scores to inform occupants. At the same time, professionals can use underlying data to make adjustments.

The existing organisational facilities management and business strategies are also barriers to implementing such an ontology (E02, E06, and E10). For example, E10 explained, *"Changing service delivery to meet occupants' requests will be challenging as personalised changes may only be possible in an intelligent building."* Adding to that resistance to change by both occupants and the leadership (E02 and E06), lack of professional talents and awareness (E06), and organisational energy policy and carbon reporting (E07) are other barriers. Also another barrier is pre-defined building standards (E10 and E12). For example, E12 further explained that *"building or facilities managers operate their facilities as per the pre-defined standards, which may cause facilities managers not to give much attention towards the occupant behaviours".* E01 expression is also relevant at this end that explains there is also often a tension between energy efficiency and IAQ, with the optimal setting varying depending on the building and location. As E01 proposed, government interventions can help address these organisational barriers in countries like Australia and Singapore. *"However, New Zealand is still behind in building performance" (E01).*

As seen in Table 12.10, the experts also suggested further improvements to the proposed ontology. Some of these factors were also discussed under the "sufficiency" category. Therefore, the researcher only explained the additional improvements suggested by the expert. One such improvement suggested by E03 is including the information relating to actual energy requirements of occupants' needs in the ontology. Another interviewee (E09) suggested including more relationships and feedback loops between the ontology elements.

Similarly, E05 recommended including more elements to capture the occupants' lived experiences. The expert pointed out that the proposed ontology does not fully capture the complexity of the lived experience of being in an office building. Thus, she recommended considering the emotional and subjective aspects of the experience. However, E03 emphasised that the feedback is only useful if the information is used, responded to and implemented.

12.6 Discussion

The study validated an occupant energy behaviour-ontology's usefulness in developing occupant behaviour tools to integrate with building energy performance simulation. The ontology consisted of variables relating to the drivers influencing occupant behaviours, occupant comfort preferences, and patterns of behaviours. The validation evaluates the proposed ontology's sufficiency, clarity, coherence, relevance, and applicability and highlights further improvements, advantages, and barriers.

The experts suggested that the ontology could benefit from including additional data elements and classifying the ontology elements considering building characteristics. In terms of adding more data elements to the ontology, the organisational culture is highlighted as an essential consideration that should be included in the ontology. Similarly, the cultural factors that drive energy behaviours were expressed in previous studies. For example, the "energy cultures framework" suggests that energy cultures are shaped by the interactions of norms, practices, and material culture (Stephenson et al., 2015; Stephenson et al., 2010). However, these parameters are influenced by external factors beyond individuals' control, and further application and testing are needed to fully explore the usefulness of such parameters for understanding energy behaviours (Stephenson et al., 2015). The current study specified the influence of personal norms, subjective norms, organisational support and encouragement, and energy feedback on occupant energy behaviours. However, for a better representation of energy cultures, the ontology could also consider material culture representing available technologies, building regulations, energy rating systems, and others (Stephenson et al., 2010) that need to be carefully characterised or measured to be included in the ontology as building occupants may or may not know how these parameters influence energy behaviours.

Also, the validation highlighted the inclusion of physical environmental factors, such as indoor noise levels, humidity and CO_2 levels, and physiological factors, like metabolic rates and clothing types of occupants, to further improve the ontology. All of these factors were highlighted as necessary in empirical research. Specifically, the ontology considers indoor noise as a physical environmental driver of occupant energy behaviours, while the validation suggested it should also be considered under occupant preferences. Similarly, noise levels are considered triggers of window adjustment behaviour (Fabi et al., 2012; Haldi & Robinson, 2011). Also, studies have shown that changes in relative humidity can affect thermal comfort, air quality, and energy consumption (Barthelmes et al., 2017; Yao & Zhao, 2017). Additionally, indoor CO_2 concentration significantly affects occupants' interactions with buildings, particularly regarding window usage (Andersen et al., 2013; Calì et al., 2016). Information on the characteristics and states of occupants, such as physiology, activity, and clothing, can provide a more comprehensive understanding of how occupants interact with and experience the building environment (Mahdavi et al., 2018)**.** These objective measurements of building performance factors are necessary for monitoring and modelling to improve building energy performance. However, obtaining this data through occupant surveys may not provide accurate or complete information, as occupants may not know about these factors or accurately report their perceptions. Therefore, it is vital to supplement occupant survey data with objective measurements to understand building performance comprehensively and then include these in the ontology.

Another additional factor suggested in the study is space utilisation by occupants based on the office types (i.e., private, shared, open-plan) and organisational sizes (i.e., small, medium, large) to be included in the ontology. Additionally, the ontology elements can be further broken down depending on these building characteristics, as the relationship between the ontology elements and the occupant behaviours can vary depending on such characteristics. The building type (Engvall et al., 2014; Yun & Steemers, 2011) and building size (Burgett & Sharp, 2017) were often considered for their significant influence on occupant behaviours (i.e., heating and cooling adjustments) in residential buildings. The other building and contextual characteristics, such as building occupancy patterns, building operation time, and facilities operations (Peng et al., 2012; Stazi et al., 2017), are logical to explain in the ontology, and many of these elements depend on how the building has been designed and operated. The ontology classification based on their importance for facilities managers, occupants, and building designers is a novel finding that emerged through validation. The careful alignment between multi-disciplinary teams is often lacking in empirical research in this direction. Similarly, including more elements to capture the complexity of the lived experience of being in an office building and including more relationships and feedback loops between the elements are also crucial to improve building energy performance. However, the feedback provided by the ontology needs to be responded to and implemented.

In summary, the proposed ontology helps enhance building energy performance and environmental control systems and establish occupant-centric buildings. Therefore, the current study's findings support existing research conclusions in the field. Collecting and analysing building occupants' behaviour data can provide valuable insights for improving building performance and design (Mahdavi et al., 2018). This data can be used to support energy performance contracting (Mahdavi & Tahmasebi, 2012), energy policies and goals (Hong et al., 2017), environmental monitoring and control systems (Zhu et al., 2022), and model-predictive building systems control (Mahdavi & Taheri, 2017). Additionally, the ontology information is helpful for facilities managers to focus on where energy wastage could occur, and it is potentially useful depending on what the building managers try to achieve. For example, ontology could help new facilities managers get familiar with the building. Furthermore, the advantages of ontology include improving communication between managers and occupants, providing a more holistic and cultural understanding of the relationship between the buildings' technical systems and the occupants, acting as a guide to data/information for energy efficiency, and educating and promoting energy-efficient behaviours among occupants. The ontology could also benefit factors such as occupant comfort, indoor air quality and sustainability. Specifically, the ontology is applicable in leased buildings, and that building managers can conduct occupant surveys considering the ontology elements to evaluate user comfortability in the building space.

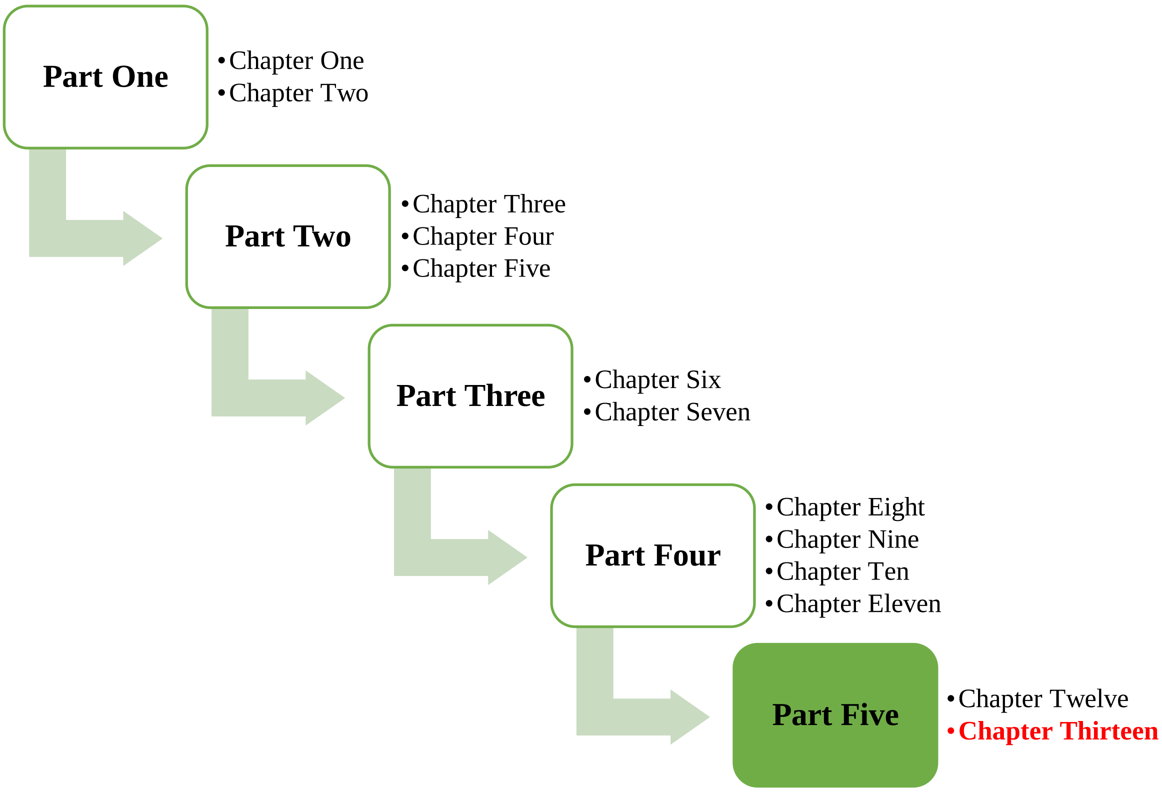
There are several barriers to implementing the proposed ontology in building energy performance. Finances are a significant barrier, as many building owners may not see a compelling financial incentive or return on investment for improving energy efficiency through occupant behaviours instead of technical solutions. Occupant actions are directly influenced by their comfort requirements and significantly impact overall building performance regarding energy consumption and comfort (Wang et al., 2016). The complexity of the ontology was another barrier, as the trade-offs between occupant comfort, health, and sustainability can be difficult for building occupants to understand. However, the limited availability of data on occupant behaviour makes it necessary to use energy performance models based on preliminary observations. Occupant behaviour modelling tools that integrate with energy performance simulation and modelling must consider multiple environmental, physiological, contextual, and social-psychological factors (Yan et al., 2017). Existing organisational facilities management and business strategies, resistance to change by occupants and leadership, lack of professional talents and awareness, and pre-defined building standards are also identified as barriers. Nevertheless, technology-driven measures alone are insufficient to address the complex problem of the impact of occupant behaviour on energy consumption (Hong et al., 2016). Understanding the impact of occupant behaviour on building energy performance is essential from the design stage (He et al., 2021). As most energy modellers do not consider the factor of occupant behaviours in current energy simulations, the government interventions and tools like the WELL Building Standard and the NABERSNZ can help address these barriers.

12.7 Conclusion

This study validated an ontology for modelling occupant energy behaviour to develop tools that can be integrated with building energy performance simulation. The ontology is designed to improve the monitoring of occupant behaviour data and promote efficient energy performance in office buildings. The study used an SME approach to validate the proposed ontology. This approach involves obtaining feedback and input from experts in the field to ensure that the ontology accurately represents the relevant concepts and relationships in the domain of occupant energy behaviour and building energy performance. The study's findings revealed that additional data must be included in the ontology and the advantages, barriers, and potential improvements related to the ontology. This includes additional data that can be included in the ontology to provide a more accurate representation of how occupant behaviours and energy impacts may vary depending on physical environmental, physiological, and building characteristics. Also, the study suggested classifying the ontology elements based on the different building stakeholders for easy understanding and focus. The SMEs' feedback helped identify these areas for improvement and how to enhance the ontology to serve the intended purpose better.

Furthermore, the advantages and barriers identified in the study reveal how the industry perceives the implementation of an ontology and the challenges they may face when implementing such a concept. It also provides insights into the solutions they offer to overcome these challenges. The advantages of using an ontology, such as increased accuracy and data representation consistency, can help improve the overall performance of building energy simulation and automation systems. Barriers, on the other hand, can include the cost and complexity of implementation, as well as the need for specialised knowledge and skills to use the ontology effectively. Identifying these advantages and barriers can help organisations to make informed decisions about whether or not to implement an ontology and how to best go about doing so.

The findings of this study may not be generalised to a global context, but they can be applied to other countries that do not currently consider the impact of occupant behaviour in their energy simulations, specifically in the context of office buildings in New Zealand. However, as a limitation, this study relied solely on input from subject matter experts to validate the developed ontology, and future research should consider using a mix of quantitative research methods. Additionally, the study could be repeated with a more significant number of experts and with more defined criteria for selecting experts. Furthermore, future research should focus on clearly defining the nature of the monitored variables regarding their values, associated sources, and potential actors, as the existing empirical research identified this as a need. Since educating ontology users was also highlighted, future research should focus on developing a step-by-step approach for educating users, considering their existing knowledge and providing specific guidelines or training. Additionally, questions about the trade-off between occupant comfort, health, and sustainability were raised during the study, and future research should address this issue in more detail.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13.0 Conclusion and recommendations

The research study has successfully achieved its objectives, which were centred around the development of an occupant energy behaviour-related ontology for optimising energy performance in New Zealand office buildings. The key findings and conclusions from each objective have been summarised in the preceding section (Section 13.1). Objective 1 of the study was successfully accomplished by identifying the prevalent occupant energy behaviours and their significant drivers in New Zealand and international contexts. The study reveals the interrelated nature of these behaviours and emphasises the importance of considering the social-psychological factors alongside physical and contextual aspects. Objective 2 involved analysing how organisations rationalise occupants' energy behaviours and comfort preferences in New Zealand office buildings. The study provides valuable insights into the perceptions of building managers and occupants, highlighting the significance of implementing energy-saving improvements that involve occupants in decision-making processes. Objective 3 focused on evaluating how occupants perceive decision-making regarding their energy behaviours in New Zealand office buildings. The study sheds light on the impact of social-psychological factors on occupant energy-saving behaviours and emphasises the need for building managers to consider subjective norms and behavioural interventions to encourage energy-efficient practices. Objective 4 culminated in the development of an occupant behaviour ontology for effective monitoring and collection of occupant energy behaviour-related data. This ontology provides a comprehensive understanding of factors influencing occupant energy behaviours, which can be valuable for energy modelers, policymakers, building managers, and building users.

The study has made several significant contributions to the field of building energy optimisation in Section 13.2. The development of the occupant energy behaviour ontology stands out as a major theoretical contribution, providing valuable insights into occupant behaviour-related data that need to be monitored and collected. The study also highlights the significance of considering social-psychological drivers in achieving energy reduction goals and balancing energy efficiency with occupant comfort.

Based on the research findings and conclusions, several recommendations are offered to different stakeholders involved in New Zealand office buildings in Section 13.3. Energy modelers are recommended to incorporate occupant behaviour-related data into their simulations to improve accuracy. They should consider the decision-making models provided for each behaviour type and make non-quantitative variables quantifiable for energy modelling purposes. Policymakers are encouraged to define clear goals for monitoring occupant energy behaviours and adopt an interdisciplinary approach involving experts from various fields. The study also suggests utilising modern technology such as the Internet of Things (IoT) for data collection and integrating social-psychological factors into building design and operation. Building managers are advised to prioritise occupant comfort and engagement in energy-saving efforts and involve occupants in decision-making processes through open communication. Implementing interventions such as rewards, energy feedback, and user control can encourage energy-efficient behaviours among occupants. Building occupants are recommended to actively participate in awareness and education programs to increase their awareness about energy usage and benefits of energy-efficient behaviours. They should take occupant surveys seriously and provide feedback to improve indoor environmental conditions.

The study also acknowledges certain limitations in Section 13.4, such as the sample size and representativeness of the survey data, potential subjective interpretations in ontology development, and limited generalisability due to the New Zealand context. Future research can address these limitations to improve the study's scope and impact. Accordingly, the study identifies several avenues for future research in Section 13.5, including incorporating diverse perspectives in ontology development, conducting longitudinal studies, exploring causal relationships between social-psychological factors and occupant behaviours, and addressing trade-offs between occupant comfort, health, and sustainability. In conclusion, this research contributes valuable insights into occupant energy behaviour in New Zealand office buildings, emphasising the importance of considering both technical and social-psychological aspects in building design and operation. The developed occupant energy behaviour ontology provides a roadmap for further research and implementation to optimise energy performance and enhance occupants' comfort and well-being. By addressing the identified limitations and pursuing future research directions, the field can continue to advance towards more sustainable and energy-efficient buildings.

13.1 Achievement of research objectives

The primary focus of this study is to develop an occupant energy behaviour-related ontology that could enhance data monitoring and collection to optimise the energy performance of New Zealand office buildings. To achieve this goal, the study developed four research objectives, and a summary of how each objective was achieved is outlined in the following subsections.

13.1.1 Objective 1 –To identify the prevalent occupant energy behaviours and the significant drivers that influence these behaviours in the New Zealand and international contexts

Objective one was achieved in Chapters Three to Five of this thesis. In Chapter Three, the study reviewed previous research to identify the occupant energy behaviours and drivers influencing occupant behaviours based on IEQ parameters. The study found that most existing research focuses on specific actions occupants take to adapt to the indoor environment, such as operating plug-ins, opening/closing windows, turning lighting on/off, adjusting thermostats, and lowering blinds. These behaviours are identified as significant contributors to building energy consumption. Non-adaptive behaviours were also highlighted, such as the occupants' presence and reporting discomfort. However, many studies focus on a single energy behaviour and do not consider the interrelated nature of these behaviours. The study also found that most existing research focuses on physical environmental, and contextual factors, while physiological, social, psychological, and time-related factors are rarely considered. Therefore, the study recommends that it is crucial to consider IEQ parameters and all the significant, influential factors to recognise the dynamic nature of prevalent occupant energy behaviours.

Due to the limited focus on social-psychological factors and the highlighted importance of these factors in the recent research, the study conducted a systematic literature review in chapter 4 to determine the patterns or trends of previous research on social-psychological drivers of occupant energy behaviours in buildings. The review aimed to comprehensively understand current knowledge on the social-psychological factors that influence occupant behaviours. The review identified gaps in existing research and guided future research on occupant behaviours. The review suggests that an integrated framework, such as the modified MOA framework, can be used to systematically investigate the factors that influence occupant energy behaviours in office environments. However, further research is needed to validate the effectiveness of this framework in promoting energy behaviours among occupants. Accordingly, the MOA framework is purported to apply in understanding the social-psychological aspects of occupant energy behaviours and to evaluate the behavioural intentions of occupants in New Zealand office buildings.

Based on the review findings, Chapter Five sought to conceptualise the relationships between indoor environmental conditions, comfort preferences, and occupant behaviours to improve building energy performance. Results showed a similarity in the satisfaction rating by the occupant across private, shared, and open-plan offices in terms of visual comfort and furniture arrangement. However, there were variations in satisfaction with thermal comfort, ventilation, acoustic comfort, and access to lighting control, depending on the type of office. The study identified dominant behaviours and comfort preferences and found that the occupants interact with windows and doors, drink hot/cold beverages, and adjust clothing to satisfy individual IAQ and thermal comfort preferences. The findings suggest that IAQ and thermal comfort are more important to building occupants than visual and acoustic preferences. Architects, designers, and building managers can use this information to create buildings that prioritise occupant comfort and develop more effective energy efficiency strategies that consider the dynamic nature of occupants' energy behaviours and preferences.

13.1.2 Objective 2 – To analyse how organisations rationalise occupants' energy behaviours and comfort preferences in New Zealand office buildings

Chapters Six and Seven in the thesis contributed to achieving objective two of this research presenting the preliminary study findings. In Chapter Six, the study discussed the perceptions of building managers and occupants regarding the impact of occupant behaviours on energy use in buildings. The study identified a set of theoretical perspectives that outlines the perceived indoor environmental discomfort and building managers' responsibility as per occupants' perceptions. The study also identified environmental, contextual, and social-psychology aspects influencing occupant behaviours, impacts of occupants on building energy, and the degree of knowledge and awareness, authority, and decision-making of occupants as per the views of building managers. Based on these theoretical perspectives, the study recognised that implementing energy-saving improvements like automation and management systems is at the forefront of building managers' thinking. These technological improvements can limit the occupants' control over building systems and lead to dissatisfaction while the energy impacts of occupant behaviours continue. Accordingly, the study supported building managers in understanding occupants' discomforts, energy impacts, and social-psychology influence on individual behaviours, thereby contributing to informed decision-making. The study highlighted the significance of building managers in preparing occupant-centred energy policies and contributed to the multi-disciplinary approaches involved in research in this field.

In Chapter Seven, the study evaluated the relationships between user comfort preferences, occupant energy behaviours, and drivers in office settings. The survey approach synthesises the literature on comfort preferences, occupant behaviours, and environmental, building, and social-psychological factors as an extension to the conceptual study in Chapter Five. It also added significant knowledge on occupant behaviours in office settings based on the occupants' multi-domain comfort preferences. The study found that the primary sources of IEQ discomfort were related to thermal and air quality and that occupants' satisfaction with IEQ correlated with their comfort preferences. The study used a binary logistic regression analysis which showed that occupants' perceived user control satisfaction is the main driver for increasing window actions, and no other independent variable showed a statistically significant association with other behaviours. This chapter is a preliminary attempt to predict occupant behaviours based on the above variables. These findings support the achievement of objective two while supporting the discrepancies between the building managers' approach to occupant energy behaviours and comfort preferences and how occupants perceive the indoor environment.

13.1.3 Objective 3 – To evaluate how occupants perceive decision-making regarding their energy behaviours in New Zealand office buildings

Objective three of the study was achieved in Chapters Eight to Eleven. Chapters Eight and Nine are related where these analysed the general occupancy survey data collected from 294 office occupants in New Zealand. Similarly, Chapters Ten and Eleven analysed the data collected from 99 office occupants from a New Zealand tertiary office building case.

The effects of social-psychological factors on occupant energy behaviours are recently brought to attention by empirical studies and suggested further analysis through social-psychological theories. Accordingly, in Chapter Eight, the study presents social-psychological insights into occupant energy behaviours among office building occupants in New Zealand, applying a modified MOA framework. It focuses on user control availability, occupants' energy behaviours, and relevant social-psychological effects, and each analysed based on the demographic groups representing gender, age, ethnicity, and region. The study descriptively found that occupants mainly adjust to the indoor environment while indicating attitude, personal norms, and actual and perceived knowledge to save energy. In addition, organisational support and behavioural intervention are needed to encourage energy-saving behaviours, which is currently lacking in the office setting in New Zealand. Chapter Nine extensively analyses the social-psychological effects on occupant energy behaviours in New Zealand offices using statistical methods. The study found that attitudes, personal norms, subjective norms, organisational support, behavioural intervention, accessibility to user control, PBC, and perceived and actual knowledge were significant social-psychological factors influencing occupants' motivation, opportunity and ability to save energy. However, motivation has a relationship that is mediated by opportunity and ability. The study also found that these social-psychological factors influenced adaptive behaviours like adjusting appliances, and clothing, drinking beverages, and moving through spaces.

Chapter Ten explored the link between IEQ beliefs, user control, comfort preferences, and time-related patterns of occupant behaviours. This study is unique in that it examined a wide range of behaviours related to windows, doors, lighting, shades, blinds, fans, thermostats, computers, drinking beverages, adjusting clothing, and moving through spaces, whereas previous studies have been limited to examining a few behaviours at a time. Furthermore, in this chapter, the findings from the earlier chapters are brought together to analyse the influence of diverse factors on these individual occupant behaviours. The study found that those occupant behaviours are motivated by their comfort preferences and other subjective factors. The dominant comfort preferences and subjective factors are linked to each behaviour. Furthering the analysis in Chapter Ten, Chapter Eleven evaluated the decision-making patterns of occupants in New Zealand office buildings regarding IEQ comfort, availability of control, and demographic and social-psychological factors influencing their behaviours. The study investigated the impact of these factors on multiple behaviours, as stated in Chapter Ten. The results showed that adjusting windows, doors, shades and blinds, and drinking beverages were the most frequently practised behaviours, while adjusting lighting, personal fans, thermostats/heaters, and computers were moderately practised by the occupants. However, fewer occupants reported discomfort or did nothing about indoor environmental conditions. The study found that the availability of control on building appliances and systems was the main predictor of most behaviours and that demographic factors such as gender, work duration within the building, and days at work per week are also important. The influence of the previously identified IEQ comfort-related, and social-psychological factors differ for each behaviour. The study suggests that modelling each energy behaviour is vital to enhance the energy performance of office buildings.

13.1.4 Objective 4 – To develop an ontology for the effective monitoring and collection of occupant energy behaviour-related data to optimise the energy performances of New Zealand office buildings

Based on the findings from Chapters Eight to Eleven, the study developed an occupant behaviour ontology for effectively monitoring and collecting occupant energy behaviour-related data. Accordingly, objective four was achieved by developing the occupant energy behaviour ontology in section 12.2 while validating the ontology and proposing recommendations to optimise energy performances in office buildings in New Zealand in section 12.5. It used an SME approach to obtain expert feedback and input to ensure the ontology's accuracy. The validation of the proposed ontology evaluated its sufficiency, clarity, coherence, relevance, and applicability and found areas for improvement, advantages, and barriers. The findings showed that the ontology needs additional data and should be classified based on building characteristics and stakeholder types. The study also identified advantages and barriers to implementing an ontology and suggested recommendations to overcome these barriers. Further recommendations for building stakeholders are suggested in subsequent section 13.3.

13.2 Research Contributions

This research makes several significant contributions that were absent from earlier research projects. The main contributions made by this study to the corpus of knowledge are outlined in this section.

13.2.1 Theoretical contribution

The main theoretical contribution of this study lies in the development of an occupant energy behaviour ontology, which goes beyond the existing literature and offers a holistic framework for optimising energy performance in buildings. Unlike traditional approaches that focus solely on technological improvements, this ontology acknowledges the role of building occupants and their comfort preferences in achieving energy reduction goals. It offers insights into the factors influencing occupants' energy-related decisions, helping stakeholders make informed decisions that prioritise both energy efficiency and occupant comfort.

By providing insights into occupants' perspectives on IEQ beliefs and user control availability, the ontology bridges the gap between technical aspects and human-building interactions. Moreover, the systematic review conducted as part of the study uncovers the applicability of social-psychological theories in different building settings, enhancing the study’s depth and ensuring that it is well-researched. The ontology also addresses the areas for improvement, advantages, and barriers to establishing a better occupant energy behaviour tool, making it a valuable theoretical contribution to the body of knowledge.

As highlighted in the recommendations and future research section, the occupant energy behaviour ontology serves as a roadmap for further investigation and advancements in the field. It opens up opportunities for exploring diverse perspectives, conducting longitudinal studies, and understanding the causal relationships between social-psychological factors and occupant behaviours. By addressing the identified limitations and pursuing future research directions, the study’s theoretical contributions can lead to continued advancements in sustainable and energy-efficient building practices.

While the study focuses on New Zealand office buildings, the theoretical contributions of the occupant energy behaviour ontology can have broader transferability and applicability. The insights gained from this research can inform building practices and energy optimisation strategies not only in New Zealand but also in other regions and building types globally. By considering occupant behaviour-related data and social-psychological drivers, stakeholders in different contexts can tailor their energy-saving efforts effectively and achieve better energy performance outcomes.

In conclusion, the theoretical contributions of this research extend beyond the existing literature and encompass a comprehensive understanding of occupant energy behaviours in buildings. The occupant energy behaviour ontology offers valuable insights into the interplay between technical and social-psychological aspects, providing a roadmap for further research and implementation to optimise energy performance while enhancing occupant comfort and well-being. Through its transferability and applicability, the study’s findings can contribute to more sustainable and energy-efficient building practices on a broader scale.

13.2.2 Contribution to industry

The proposed ontology in section 12.2 mainly focuses on educating and promoting energy-efficient behaviour and improving communication between managers and occupants in a building. It provides a holistic understanding of the relationship between the technical and the occupants, leading to better equipment scheduling, reducing energy consumption, and saving energy costs. The ontology acts as a guide for data/information for energy efficiency. Furthermore, ontology improves occupant comfort, IAQ, and sustainability. The study highlights the need for building managers to prioritise occupant comfort and engagement in their energy-saving efforts rather than relying solely on technological improvements. Various factors influence complex and interrelated subjects like thermal comfort and IAQ and are essential for building health and occupant comfort. The ontology's ability to guide qualitative and quantitative measurements addresses the challenge of achieving optimal thermal comfort and IAQ in buildings due to a lack of measurement. By incorporating the insights from the study into their decision-making process, building managers can drive change in occupant behaviour and achieve their energy reduction goals. The findings can also inform intelligent environmental control systems with eco-feedback and help establish occupant-centric buildings. The study's implications can enhance building ratings, such as WELL Building Standard and NABERSNZ, by considering complex variables and providing a simple score for occupants.

Another key contribution from the study is the impact of social-psychological factors on occupant energy-saving behaviour. The study highlights the importance of considering subjective norms, organisational support, and behavioural interventions in encouraging energy-saving behaviours among occupants. The findings suggest that these interventions can increase occupants' perceived ability and control, leading to a more positive attitude towards energy-saving. The study also proposes an MOA information model that can be used by building managers and energy modellers for improved energy monitoring and decision-making. Integrating social-psychological factors into building design and operation can lead to improved energy reduction goals. The information gathered at the building level can also be used to support net zero carbon and energy targets at a policy level.

13.3 Recommendations

Based on the findings and conclusions of the research, the following recommendations can be made to the different stakeholders involved in office buildings to optimise the energy performance of their buildings.

13.3.1 Recommendations to energy modellers

This study presents a comprehensive ontology for understanding and monitoring occupant energy behaviours. It outlines the data needed to be collected and monitored, areas for improvement, advantages, and barriers to establish a better occupant energy behaviour tool. During the ontology validation, the SMEs emphasised the importance of conducting energy modelling during the design stage to determine total energy consumption and ideal temperature range. Energy modelling validates the base energy model and requires a year or two of data before it can be justified. Occupant behaviour is typically considered at the operation stage and is not included in most energy simulations, which primarily focus on building fabric, internal gains, lighting wattage, hours of use, and heating/cooling equipment. However, empirical research in this direction argues the importance of incorporating occupant energy behaviour-related data in energy modelling and simulations to overcome the discrepancies between predicted and actual energy. However, as most energy modellers do not consider the factor of occupant behaviours in current energy simulations, the current study recommends using the information guided by this ontology alongside the existing data for their energy calculations to improve accuracy.

The energy modellers can specifically consider the occupants' decision-making models provided for each behaviour type (refer to section 12.3). However, some variables are not quantitatively measured (i.e., nominal and ordinal data), and the energy modellers could make them quantifiable by mapping their values to a set of numerical values, which then can be subjected to energy modelling and simulations (refer to section 12.2). Furthermore, in building automation, changes in control devices, equipment, and settings may be initiated by agents like human operators or automated systems (refer to section 12.2). Ideally, the monitoring system should be able to distinguish the responsible agent for each state change. This requires tracking the source of each change, whether a human operator or an automated system initiated it. Building monitoring can involve technical sensors, meters, and occupants' feedback. The latter can include subjective evaluations of the indoor climate, usually gathered through interviews or surveys. Such feedback can offer valuable insights into occupants' perceived comfort levels, informing building management decisions.

13.3.2 Recommendations to policymakers

The ontology addresses non-technical aspects of building design, focusing on human-building interactions and their effect on energy performance. It is valuable for policymakers as it sheds light on trade-offs between energy efficiency and occupant comfort, allowing for informed decisions that balance both factors. The study recommends that policymakers define clear goals and objectives for monitoring and collecting occupant energy behaviour data, adopt an interdisciplinary approach involving experts from fields such as facilities management, energy management, and IEQ consultants, and utilise modern technology such as the IoT devices and cloud-based data platforms for data collection. Understanding the subjective aspects of occupants can lead to more effective building design and management that addresses their comfort and energy performance needs. This can result in higher satisfaction levels, improved IAQ, and reduced energy consumption. The policymakers could consider government interventions and tools like the WELL Building Standard and the NABERSNZ that can help address the current limitations of establishing occupant-centric buildings (refer to section 12.5). Finally, knowing how social-psychological constructs influence occupants' decision-making or behaviours will facilitate the choice of advanced building design and technologies to achieve energy reduction goals. Considering energy reduction goals, the study recommends incorporating the occupant behaviour component to achieve the energy targets for commercial, residential, and transport sectors as set by EECA and MBIE in New Zealand (refer to section 1.3).

13.3.3 Recommendations to building managers

Building managers (i.e., facilities, energy, maintenance, and operational managers) play a crucial role in recognising the impact of occupants' comfort on energy strategies. The barriers to implementing an ontology for occupant energy behaviour include existing facilities management and business strategies, resistance to change, pre-defined building standards, and lack of awareness. The building managers can be involved and take measures to mitigate these barriers and acquire the approval of the top management when necessary. The study shows that building managers need to balance the priorities of energy efficiency, occupant comfort, and cost considerations. They must understand the occupants' perspectives on indoor environment quality, comfort preferences, and energy behaviours, as social-psychological factors influence these. Involving occupants in the decision-making process through open communication can better understand their needs and behaviours and help managers effectively tailor their energy reduction strategies. The study recommends that building managers provide occupants access to their energy usage data and educate them on how to interpret it and create a culture of conservation by promoting energy-efficient behaviours and attitudes among occupants (refer to section 12.5).

The study emphasises the importance of integrating these views and making energy-saving improvements like automation and management systems that involve occupants and make them responsible for energy conservation. Building managers can use different interventions to encourage energy-saving behaviours, such as rewards, energy feedback, user control, and authority around occupants' workspace, which are more effective than just awareness (refer to section 6.6). If offered incentives or rewards for occupants who adopt energy-efficient practices, they would be encouraged to save more energy. Instead of individual rewards, building managers could consider group-based rewards or incentives where energy savings are attributed to the building or floor as a whole. This approach encourages collaboration among occupants to work collectively towards energy-saving goals.

Furthermore, providing regular feedback to occupants on their energy usage would encourage them to change their behaviours. The building managers must encourage occupants to actively reduce their energy usage by providing them with practical tips and tools. By considering occupant engagement and feedback, building managers can tailor their energy reduction strategies to better align with the needs and behaviours of building users. For instance, building managers can implement energy-efficient technologies, such as smart lighting systems, to make it easier for occupants to adopt energy-efficient behaviours. This can lead to higher buy-in and success in meeting energy reduction targets. The diversity of occupants in commercial buildings does present challenges in changing energy behaviour. However, building managers can overcome these challenges with a thoughtful and multifaceted approach that considers the unique needs of the occupants. By combining automation with behaviour change strategies and fostering a culture of energy awareness, significant progress can be made in achieving energy savings and sustainability goals

The proposed ontology in section 12.2 is useful for building managers to enhance building energy performance and efficiency. It provides knowledge to expand trigger points, improves communication between managers and occupants, and acts as a guide to data/information for energy efficiency. The ontology information helps identify energy wastage and can help new building managers get familiar with the building. It also applies to leased buildings where building managers can conduct occupant surveys to evaluate user comfort and make informed decisions. The ontology elements have considerable variance and are potentially more relevant than the building design parameters. Technology alone is not enough to address the issue, and a design stage understanding of the impact of occupant behaviour is essential (refer to section 12.5).

13.3.4 Recommendations for building users

The perspectives of building occupants significantly contributed to developing the occupant energy behaviour ontology. The findings highlight that the occupants' behaviours are motivated by their IEQ beliefs, comfort preferences, and social-psychological factors that are subjective to the building occupants (refer to section 11.4). The occupants showcased their motivation (i.e., energy-saving attitudes, responsibility/obligation to save energy) and ability (i.e., perceived ease or difficulty in saving energy, use of knowledge on energy-saving, the ability to perform energy-related behaviours) (refer to section 9.5). However, the building managers revealed that the occupants need to be educated about how buildings operate and maintain as per the pre-defined building standards. Therefore, the occupants must actively participate in awareness and education programmes to increase their awareness about energy usage, its impact, and the benefits of energy-efficient behaviours. Furthermore, the occupants highlighted a lack of behavioural interventions such as energy feedback and rewards by organisations. However, when the organisation provides regular feedback and offers occupants incentives or rewards for their energy usage, they must take these positively and actively engage in fostering a culture of conservation, adopting energy-efficient practices. Additionally, it was highlighted that occupants might be conservative in evaluating the perceived IEQ satisfaction and control. Thus, the study recommends that the occupants take those surveys seriously and provide information to improve indoor environmental conditions.

13.4 Research limitations

Firstly, the survey sample consisted of building occupants, while facilities and energy professionals were interviewed during grounded theory and SME analysis. This study collected preliminary data from October 2020 to January 2021, the general survey from July to November 2021, and the survey of occupants in the selected case study from August 2021 to January 2022. During all these periods, the countrywide lockdowns affected the data collection due to the Covid 19 pandemic in New Zealand. Although the sample size is satisfactory for most data analyses, the analysis in Chapter Eleven may be limited due to the lack of data at that stage. Initially, the researcher planned to collect data from a few cases targeting a much larger sample size, and this has been limited to a single case and current sample size of 99 building occupants due to the travel restrictions and lack of restricted contact with building occupants. In addition, some participants from the selected samples may work from home when filling out the online questionnaire, which could have influenced the reported values.

Secondly, the proposed ontology may be limited by the subjective interpretations of the occupants and building managers involved in its development and may not accurately reflect the perspectives of all stakeholders in the field. Moreover, the study relied solely on SMEs input to validate the developed ontology, and they could interpret the ontology bound by their own experience and existing company policies.

Thirdly, the proposed ontology's applications will be limited to the New Zealand context as the data collection is primarily based on New Zealand offices. As a result, the research findings may be limited in their generalisation. However, the knowledge can be applied to other research areas, such as creating ontologies for buildings in New Zealand or other countries using the same methodology. The collection of more expansion of the database to include other forms of office buildings will permit more generalisations. Furthermore, the proposed ontology is based on current office building knowledge and may not account for new developments or changes in the field, and regular updates are necessary to ensure its relevance and accuracy.

13.5 Future research

This study has significant academic and industry implications but also has limitations, and future research is needed to address these limitations. The current study relied on interviews with building experts and self-reported surveys from occupants for data collection. When using interviews for data collection, the study only used building experts such as facilities managers, engineers, and sustainability managers. To address this issue, a diverse range of perspectives should be considered and incorporated into ontology development. Therefore, future studies can collect data from multi-disciplinary teams involving external consultants, architects, energy modellers, and government officials. In chapter 11, the limitations include a narrow focus on a single case, tertiary office buildings in New Zealand and the energy culture and other unique characteristics of the case study may impact the occupants' behaviours. Future research should include multiple cases, different types of office buildings and countries.

The study results are generally limited due to the purposive sample used, which may not accurately represent the broader office population. The impact of environmental and building-related factors on occupant energy-related behaviours was not measured and could introduce biases. Future studies should consider controlling for these external factors. Additionally, the current study is cross-sectional and based on a self-reported survey of occupants in several organisations (specific to the chapter 9 analysis). People often overrate their energy-saving intentions in self-reports due to societal expectations. Therefore, future research could use field observation alongside in-person surveys to monitor the actual occupant energy-related behaviours and individual energy consumption data over time.

Further research is needed to understand the causal relationship between social-psychological factors and occupant behaviours concerning energy use. A theoretical framework is needed to explore the impact of social-psychological factors on energy-related behaviours. The study used only one indicator for some constructs, and future research should consider using multiple indicators to measure the impact of these factors on the outcome.

Also, the actual occupant energy-related behaviour and individual energy consumption data over time can be monitor in future research. In large organisations, directly monitoring individual energy consumption can be challenging. However, several alternative strategies can still be employed to foster energy efficiency and conservation. These approaches include group-level monitoring, organisation-wide energy-saving campaigns and competitions, installing sub-meters for specific equipment or areas, conducting regular surveys to understand employees' energy-related behaviour and preferences, and performing periodic energy audits.

Future research in the developed ontology should focus on clearly defining the nature of the monitored variables in terms of their values, associated sources, and potential actors, as identified by existing empirical research. Given the importance of educating ontology users, future research should develop a step-by-step approach for educating users, considering their prior knowledge and providing specific guidelines or training. Furthermore, during the study, questions about the trade-off between occupant comfort, health, and sustainability were raised, and future research should address this issue in greater depth.

Epilogue

This part of the research has demonstrated how the final objective of the study was achieved. The study developed and validated an occupant behaviour ontology for monitoring energy behaviour data in office buildings in New Zealand. The validation of the proposed ontology evaluates its accuracy and recommends areas for improvement, advantages, and barriers. The study also suggests recommendations for overcoming the barriers to implementing the proposed ontology within the conclusion chapter. Based on the findings and conclusions of the research, the study gave recommendations for different stakeholders in NZ office buildings, such as energy modellers, policymakers, building managers, and building occupants, to optimise the energy performance of their buildings. The chapter provided insights into the importance of understanding and managing occupant behaviours to improve building energy efficiency. The findings of this research inform building design, management, and operation and contribute to the development of energy-saving policies and programs. Due to a lack of research on such issues in the New Zealand building sector, a systematic approach is required to facilitate effective monitoring and collection of energy behaviour data in New Zealand office buildings. This research study addressed this gap by comprehensively examining the core concepts relating to occupant behaviours and their interrelationships. An ontology can also be concluded as the study's final accomplishment to be used for future research in New Zealand, which needs additional investigation to define the nature of the monitored variables in terms of their values, associated sources, and potential actors based on the building and culture-specific characteristics.

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Appendix

Appendix A

Table A1 Theoretical approach to latent and observed variables

Latent variables/ Constructs	Observed variables/Indicators	Sources
Attitude	At1 - Saving energy at work is important to me	(Du & Pan, 2021b; Xuan Liu et al., 2021; Si et al., 2022; Xie et al., 2021)
Personal norms	PN1 - I feel responsible at to save energy	(Du & Pan, 2021b; Gao et al., 2017; Xuan Liu et al., 2021; Zierler et al., 2017)
Subjective norms	SN1 - My co-workers expect me to save energy at the workplace	(Xuan Liu et al., 2021; Nie et al., 2019; Si et al., 2022; Xie et al., 2021)
	SN2 - Most of my co-workers expect me to turn off electrical appliances	
	SN3 - Sharing control over building systems with my co-workers is easy	
Organisational support	OS1 - My company encourages employees to save energy	(Tan et al., 2017; Unsworth et al., 2013; Xie et al., 2021; Zierler et al., 2017)
	OS2 - My company rewards employees for saving energy	
Behavioural interventions	BI1 - The feedback on individual energy use by our building management team is important for me to change my energy-driven behaviour	(Kamilaris et al., 2015; Kim et al., 2022; Mulville, 2017)
	BI2 - Our building management team often sends energy use reports	
Accessibility to control (AC)	AC1 - I have personal control over most of the appliances (windows, doors, blinds, thermostat, lights, heaters, fans, computers) in my workspace	(D'Oca et al., 2017; Li et al., 2019; Xiaoqi Liu et al., 2021)
Perceived behavioural control	PBC1 - Saving energy during work is entirely within my control	(Dalvi-Esfahani et al., 2020; Gao et al., 2017; Xuan Liu et al., 2021; Xie et al., 2021; Zierler et al., 2017)
	PBC2 - Actions I take to save energy depending on my comfort preferences	
Actual knowledge	AK1 - I am aware that reducing energy use will reduce cost	(Xie et al., 2021; Yadav & Pathak, 2016; Zierler et al., 2017)
	AK2 - I am aware that reducing energy use will reduce emissions	
	AK3 - I am aware that reducing energy use will improve my organisation’s image/reputation	
Perceived knowledge	PK1 - I often close windows, turn off the lights, heaters, fans, computers, etc., whenever I leave the office, and unplug appliances when not in use	(Gao et al., 2017; Gunay et al., 2016; Li et al., 2019)
	PK2 - If I feel slightly cold at the workplace, I would put on another layer of clothing instead of using the heater	

	PK3 - If I feel slightly warm at the workplace, I would adjust my clothing level instead of using the air conditioner	
Non-adaptive behaviours	NAB1 - I often report discomforts related to indoor environmental quality (IEQ)	(Gunay et al., 2016; Hong et al., 2017)
	NAB2 - I am willing to accept and do nothing about the existing indoor environmental conditions	
Adaptive behaviours	AB1 - I often adjust building appliances to satisfy my comfort preferences	(Gunay et al., 2016; Hong et al., 2017)
	AB2 - I often adjust myself to the environmental conditions at my workspace by adjusting clothing, drinking hot/cold beverage, and moving through spaces	

Table A2 Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.151	18.868	18.868	4.151	18.868	18.868
2	2.431	11.052	29.920			
3	2.263	10.286	40.206			
4	1.803	8.194	48.400			
5	1.223	5.559	53.959			
6	1.134	5.153	59.112			
7	1.019	4.632	63.745			
8	0.908	4.128	67.873			
9	0.806	3.664	71.537			
10	0.783	3.559	75.097			
11	0.730	3.319	78.416			
12	0.687	3.123	81.539			
13	0.619	2.815	84.354			
14	0.564	2.564	86.917			
15	0.515	2.339	89.256			
16	0.439	1.995	91.251			
17	0.377	1.716	92.966			
18	0.351	1.595	94.561			
19	0.343	1.559	96.120			
20	0.313	1.421	97.541			
21	0.294	1.336	98.877			
22	0.247	1.123	100.000			
Extraction Method: Principal Component Analysis.						

Table A3 Cross loadings of the indicators

	AB	NAB	AC	AK	At	BI	OS	PBC	PK	PN	SN
AB1	0.973	-0.000	0.554	0.031	0.037	0.043	0.064	0.342	0.339	0.075	0.274
AB2	0.337	0.100	-0.002	0.043	0.073	0.042	-0.004	0.018	0.322	0.034	0.040
NAB1	0.042	0.938	-0.069	0.065	-0.001	0.189	0.129	-0.067	-0.043	-0.003	0.077

NAB2_R	-0.042	0.479	-0.020	0.073	-0.049	0.055	-0.002	-0.097	0.013	-0.043	0.018
AC1	0.524	-0.069	1.000	0.058	0.045	-0.032	0.070	0.415	0.298	0.099	0.306
AK1	0.058	-0.027	0.119	0.584	0.391	0.039	0.067	-0.016	0.254	0.375	0.115
AK2	0.018	0.039	0.038	0.735	0.354	0.045	0.032	-0.038	0.190	0.320	0.067
AK3	0.042	0.089	0.057	0.955	0.396	0.343	0.268	0.079	0.070	0.369	0.213
At1	0.052	-0.019	0.045	0.432	1.000	0.228	0.217	0.019	0.169	0.726	0.235
BI1	0.055	0.143	-0.012	0.269	0.302	0.780	0.341	0.151	0.098	0.344	0.241
BI2	0.024	0.147	-0.038	0.168	0.047	0.766	0.577	0.163	-0.100	0.055	0.225
OS1	0.047	0.099	0.096	0.224	0.249	0.454	0.868	0.172	0.027	0.281	0.441
OS2	0.056	0.099	0.029	0.163	0.132	0.576	0.879	0.226	-0.016	0.168	0.363
PBC1	0.272	-0.003	0.388	0.167	0.071	0.250	0.287	0.774	0.180	0.177	0.370
PBC2	0.242	-0.141	0.262	-0.086	-0.040	0.070	0.074	0.790	0.125	0.025	0.174
PK1	0.408	0.002	0.355	0.102	0.186	0.013	0.010	0.262	0.883	0.238	0.258
PK2	0.144	-0.074	-0.008	0.040	0.043	-0.021	0.041	-0.042	0.571	0.038	0.018
PK3	0.121	-0.057	0.072	0.115	0.037	-0.015	-0.059	-0.008	0.531	0.044	0.053
PN1	0.079	-0.017	0.099	0.399	0.726	0.261	0.256	0.128	0.212	1.000	0.286
SN1	0.143	0.120	0.186	0.266	0.329	0.299	0.503	0.257	0.124	0.388	0.699
SN2	0.168	0.069	0.106	0.041	0.159	0.164	0.244	0.195	0.225	0.144	0.730
SN3	0.259	0.001	0.342	0.128	0.079	0.214	0.300	0.300	0.150	0.141	0.776

Table A4. Covariance matrix of higher-order constructs

Constructs	Occupant Behaviours	Motivation	Opportunity	Ability
Occupant Behaviours	1.000	0.069	0.437	0.401
Motivation	0.069	1.000	0.297	0.380
Opportunity	0.437	0.297	1.000	0.481
Ability	0.401	0.380	0.481	1.000

Table A5: Covariance matrix of latent variables

	AB	NAB	AC	AK	At	BI	OS	PBC	PK	PN	SN
AB	1.000	0.010	0.525	0.037	0.052	0.052	0.059	0.328	0.397	0.079	0.268
NAB	0.010	1.000	-0.064	0.092	-0.028	0.175	0.098	-0.106	-0.026	-0.025	0.069
AC	0.525	-0.064	1.000	0.054	0.045	-0.031	0.072	0.413	0.299	0.099	0.306
AK	0.037	0.092	0.054	1.000	0.428	0.277	0.213	0.041	0.121	0.394	0.184
At	0.052	-0.028	0.045	0.428	1.000	0.235	0.220	0.017	0.170	0.726	0.235
BI	0.052	0.175	-0.031	0.277	0.235	1.000	0.581	0.200	0.006	0.269	0.302
OS	0.059	0.098	0.072	0.213	0.220	0.581	1.000	0.225	0.007	0.259	0.462
PBC	0.328	-0.106	0.413	0.041	0.017	0.200	0.225	1.000	0.194	0.126	0.344
PK	0.397	-0.026	0.299	0.121	0.170	0.006	0.007	0.194	1.000	0.212	0.223
PN	0.079	-0.025	0.099	0.394	0.726	0.269	0.259	0.126	0.212	1.000	0.286
SN	0.268	0.069	0.306	0.184	0.235	0.302	0.462	0.344	0.223	0.286	1.000

Table A6 Covariance matrix of observed (original) indicators

	AB1	AB2	NAB1	NAB2_R	At1	PN1	AK1	AK2	AK3	PK1	PK2	PK3	AC1	BI1	BI2	OS1	OS2	PBC1	PBC2	SN1	SN2	SN3
AB1	1.000	0.111	0.010	-0.027	0.037	0.075	0.047	-0.001	0.040	0.400	0.046	0.032	0.554	0.042	0.025	0.045	0.066	0.279	0.257	0.152	0.168	0.262
AB2	0.111	1.000	0.141	-0.071	0.073	0.034	0.060	0.081	0.019	0.126	0.431	0.390	-0.002	0.065	0.000	0.019	-0.026	0.033	-0.004	-0.007	0.041	0.045
NAB1	0.010	0.141	1.000	0.145	-0.001	-0.003	-0.020	0.012	0.077	-0.008	-0.068	-0.070	-0.069	0.135	0.159	0.102	0.123	-0.004	-0.099	0.096	0.072	0.020
NAB2_R	-0.027	-0.071	0.145	1.000	-0.049	-0.043	-0.027	0.080	0.059	0.025	-0.038	0.015	-0.020	0.066	0.019	0.025	-0.028	0.002	-0.151	0.101	0.016	-0.049
At1	0.037	0.073	-0.001	-0.049	1.000	0.726	0.391	0.354	0.396	0.186	0.043	0.037	0.045	0.302	0.047	0.249	0.132	0.071	-0.040	0.329	0.159	0.079
PN1	0.075	0.034	-0.003	-0.043	0.726	1.000	0.375	0.320	0.369	0.238	0.038	0.044	0.099	0.344	0.055	0.281	0.168	0.177	0.025	0.388	0.144	0.141
AK1	0.047	0.060	-0.020	-0.027	0.391	0.375	1.000	0.662	0.452	0.253	0.095	0.101	0.119	0.145	-0.088	0.150	-0.029	-0.002	-0.022	0.137	0.021	0.096
AK2	-0.001	0.081	0.012	0.080	0.354	0.320	0.662	1.000	0.500	0.182	0.056	0.118	0.038	0.100	-0.032	0.099	-0.040	0.002	-0.060	0.079	-0.015	0.076
AK3	0.040	0.019	0.077	0.059	0.396	0.369	0.452	0.500	1.000	0.049	0.026	0.095	0.057	0.300	0.230	0.243	0.226	0.212	-0.084	0.305	0.059	0.130
PK1	0.400	0.126	-0.008	0.025	0.186	0.238	0.253	0.182	0.049	1.000	0.174	0.149	0.355	0.092	-0.074	0.006	0.011	0.188	0.221	0.113	0.241	0.207
PK2	0.046	0.431	-0.068	-0.038	0.043	0.038	0.095	0.056	0.026	0.174	1.000	0.572	-0.008	0.029	-0.063	0.098	-0.024	0.041	-0.105	0.091	0.031	-0.053
PK3	0.032	0.390	-0.070	0.015	0.037	0.044	0.101	0.118	0.095	0.149	0.572	1.000	0.072	0.067	-0.093	-0.028	-0.074	0.073	-0.084	0.031	0.098	0.002
AC1	0.554	-0.002	-0.069	-0.020	0.045	0.099	0.119	0.038	0.057	0.355	-0.008	0.072	1.000	-0.012	-0.038	0.096	0.029	0.388	0.262	0.186	0.106	0.342
BI1	0.042	0.065	0.135	0.066	0.302	0.344	0.145	0.100	0.300	0.092	0.029	0.067	-0.012	1.000	0.196	0.318	0.279	0.201	0.037	0.231	0.161	0.155
BI2	0.025	0.000	0.159	0.019	0.047	0.055	-0.088	-0.032	0.230	-0.074	-0.063	-0.093	-0.038	0.196	1.000	0.386	0.616	0.186	0.072	0.232	0.093	0.175
OS1	0.045	0.019	0.102	0.025	0.249	0.281	0.150	0.099	0.243	0.006	0.098	-0.028	0.096	0.318	0.386	1.000	0.526	0.228	0.045	0.486	0.210	0.303
OS2	0.066	-0.026	0.123	-0.028	0.132	0.168	-0.029	-0.040	0.226	0.011	-0.024	-0.074	0.029	0.279	0.616	0.526	1.000	0.272	0.084	0.395	0.215	0.223
PBC1	0.279	0.033	-0.004	0.002	0.071	0.177	-0.002	0.002	0.212	0.188	0.041	0.073	0.388	0.201	0.186	0.228	0.272	1.000	0.223	0.338	0.213	0.275
PBC2	0.257	-0.004	-0.099	-0.151	-0.040	0.025	-0.022	-0.060	-0.084	0.221	-0.105	-0.084	0.262	0.037	0.072	0.045	0.084	0.223	1.000	0.069	0.094	0.195
SN1	0.152	-0.007	0.096	0.101	0.329	0.388	0.137	0.079	0.305	0.113	0.091	0.031	0.186	0.231	0.232	0.486	0.395	0.338	0.069	1.000	0.425	0.256
SN2	0.168	0.041	0.072	0.016	0.159	0.144	0.021	-0.015	0.059	0.241	0.031	0.098	0.106	0.161	0.093	0.210	0.215	0.213	0.094	0.425	1.000	0.287
SN3	0.262	0.045	0.020	-0.049	0.079	0.141	0.096	0.076	0.130	0.207	-0.053	0.002	0.342	0.155	0.175	0.303	0.223	0.275	0.195	0.256	0.287	1.000

Appendix B

Table B1 Factors influencing window opening and closing

Source	Influential/Driving Factors	Type of Building		
		Office	Residential	Other
(Deme Belafi, Naspi, et al., 2018)	Outdoor temperatures			School
	Indoor air quality			
(Park & Choi, 2019)	Indoor and outdoor air temperature		✓	
	Indoor relative humidity			
	CO_2 concentration			
	Season			
	Occupancy			
	Time of the day			

Table B2 Factors influencing lowering/lifting shading and blinds

Source	Influential/Driving Factors	Type of Building		
		Office	Residential	Other
(Bavaresco & Ghisi, 2018)	Solar radiation	✓		
	Building orientation			
(Gunay et al., 2017)	Workplane illuminance	✓		
	Glare sensitivity			
	Outdoor view			

Table B3 Factors influencing turning lighting on/off

Source	Influential/Driving Factors	Type of Building		
		Office	Residential	Other
(Park et al., 2019)	Occupancy	✓		
	Workplace illuminance			
	Lighting state			
(Norouziasl et al., 2019)	Occupancy	✓		
	No. of occupants			

Table B4 Factors influencing use of plug-ins

Source	Plugins			Influential/Driving Factors	Type of Building	
	Fans	Thermostat	Computers		Office	Residential
(He et al., 2019)	✓			Indoor and outdoor temperature		
(Acker et al., 2012)	✓		✓	Behavioural intervention	✓	
(Park & Nagy, 2020)		✓		Indoor air temperature	✓	
				Occupancy		
				Thermal vote		
(Sintov et al., 2019)		✓		Gender		✓

(Zhao et al., 2014)	✓	✓	✓	Occupancy schedules	✓	
(Kwong et al., 2014)			✓	Working hours	✓	

Table B5 Factors influencing drinking hot/cold beverages

Source	Influential/Driving Factors	Type of Building		
		Office	Residential	Other
(Rupp et al., 2021)	Indoor and outdoor air temperature			
	Thermal sensation	✓		
	Clothing insulation			

Table B6 Factors influencing adjusting clothing

Source	Influential/ Driving Factors	Type of Building		
		Office	Residential	Other
(von Grabe, 2020)	Thermal perception	✓		
(Chen & Chang, 2012)	Indoor temperature	✓		
	Local climate			
(Mustapa et al., 2016)	Outdoor air temperature			University
(Schiavon & Lee, 2013)	Outdoor air temperatures			
	Relative humidity			
	Indoor operative temperature	✓		
	Air velocity			
	Metabolic activity			

Table B7 Factors influencing occupant presence.

Source	Influential/Driving Factors	Type of Building		
		Office	Residential	Other
(Ahn et al., 2017)	Random walk patterns			Laboratories and reading rooms at universities
(Das et al., 2019)	Spatial design layouts			✓

Appendix C

Preliminary interview guideline

School of Built Environment
Massey University, Auckland
Private Bag 102904
North Shore
Auckland 0745
New Zealand

The impacts of occupant behaviours on energy consumption in New Zealand office buildings

INFORMATION SHEET

My name is Achini Weerasinghe, a PhD student at the School of Built Environment, Massey University. I am undertaking a PhD research project that focuses on the Impact of Occupant Behaviour on Energy Consumption of Office Buildings in New Zealand. This research aims to achieve energy reduction targets in commercial office buildings based on occupant energy behaviour and factors influencing occupant behaviour.

I wish to invite property and facilities management professionals to take part in an interview to describe the occupant behaviours and factors influencing energy-driven occupant behaviours in New Zealand office buildings.

The interview guideline is structured into four (04) main sections including questions related to participants' background, energy-driven occupant behaviours, and factors influencing energy-driven occupant behaviours, the impact of occupant behaviours on energy consumption, and the achievement of energy reduction targets in New Zealand office buildings. It should take no longer than 30 minutes to answer and discuss the questions.

The research participants' written consent is required for the interview to be audio-recorded. All discussions will be transcribed and will be treated in strict confidence and only used for academic purposes. Results will not be published in any form that allows the identification of individuals or organisations.

This project has been evaluated by peer review and judged to be low risk. The Ethics notification number for this project is 4000022597 and the low-risk notification is valid for a maximum of three years effective from May 2020.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher, please contact Prof. Craig Johnson, Director – Ethics, telephone 063569099 ext 85271, email: C.B.Johnson@massey.ac.nz

STATEMENT OF CONSENT

If you wish to participate in this study, please read the following carefully and sign in the space provided

- I am voluntarily taking part in this project. I understand that I do not have to take part, and I can stop and withdraw my consent at any time up to three weeks from today.
- I have read the Information Sheet.
- I understand that the data I provide is confidential and that I will not be identified in any publications of findings from this research without my permission.
- I have been able to ask any questions I might have, and I understand that I am free to contact the researcher with any questions I may have in the future.

Signature:		**Date:**	

If you have any queries, please contact;

Researcher's Name and Contact Details
Achini Weerasinghe, PhD student,
School of Built Environment
Email:A.Weerasinghe@massey.ac.nz
Phone: +64 22 459 3569

Supervisor's Name and Contact Details
A/Prof James Rotimi
Academic Dean, Construction
School of Built Environment
Email: J.Rotimi@massey.ac.nz

The impacts of occupant behaviours on energy consumption in New Zealand office buildings

Section 1 – Background

This information relates to the participant's background.

Please note: We ask about gender and age because these are relevant to. Issues about privacy are addressed in the Statement of Consent Form and Information Sheet.

1. Job role: …………………………………………………………………….

2. Your gender?

   Male ☐ Female ☐

3. Your age?

   Below 30 ☐ 30 or above 30 ☐

4. Years of Experience (Please tick the relevant category of experience):

   Less than a year ☐ 1 – 10 years ☐

   11 – 20 years ☐ More than 20 years ☐

5. How long have you worked in this organisation/building?

   Less than a year ☐ A year or more ☐

Section 2 – Energy-driven occupant behaviours and factors influencing occupant behaviours in office buildings in New Zealand

This section asks how occupants behave in a way that affects the energy consumption of your office building and factors/drivers affecting different occupant behaviours of your workspace that affects the building energy consumption.

Table 1: Occupant Behaviours in Buildings

Type of behaviour		**Occupant Behaviour**
Adaptive Behaviours	To adapt the indoor environment to their needs or preferences	Opening/closing windows
		Opening/closing doors
		Lowering/lift blinds

		Adjusting thermostats
		Turning lighting on/off
		Operation of plug-ins (e.g. personal heaters, fans, and electrical systems for space heating/cooling)
	To adapt themselves to their environment	Adjusting clothing
		Drinking hot/cold beverage
		Moving through spaces
Non-adaptive behaviours	These behaviours do not adapt themselves or adjust the indoor environment	Occupant presence and absence in different areas/rooms
		Reporting discomfort to the building management
		Inaction - accepting the existing indoor environmental conditions when there is no access, awareness, and choice to control comfort
		Operation of plug-in and electrical equipment (e.g. office and kitchen appliances)

1. Do you think occupants behave (adaptive behaviours) to reach the desired level of comfort when there is a problem with comfort in their work environment in this building?

2. Referring to Table 1, which behaviours are prominent and more frequent in this building?

Occupant Behaviours	**Never**	**Rarely**	**Sometimes**	**Often**	**Always**
Open/close windows	☐	☐	☐	☐	☐
Open/close external doors	☐	☐	☐	☐	☐
Open/close internal doors	☐	☐	☐	☐	☐
Adjust shades and blinds	☐	☐	☐	☐	☐
Adjust thermostats	☐	☐	☐	☐	☐
Turn lights on/off	☐	☐	☐	☐	☐
Adjust clothing	☐	☐	☐	☐	☐
Drink hot/cold beverage	☐	☐	☐	☐	☐
Adjust personal heaters	☐	☐	☐	☐	☐
Adjust portable/ceiling fans	☐	☐	☐	☐	☐
Adjust room air conditioning unit	☐	☐	☐	☐	☐
Turn off the computer monitor	☐	☐	☐	☐	☐
Adjust computer screen brightness	☐	☐	☐	☐	☐
Moving through spaces	☐	☐	☐	☐	☐
Report discomfort	☐	☐	☐	☐	☐

3. Do you think their actions are determined by which factors (physical environmental, physiological, psychological, contextual, social, and time-related factors)?

4. How often do occupants complain about the quality of the temperature, ventilation air, lighting, and noise of the building?

5. Do you have a yearly record of the complaint by the occupants that you could provide me with?

6. How often do the building systems and technologies, equipment, and appliances, and building elements cause problems for building occupants? How was the problem solved?

7. What are the standard levels of thermal comfort (temperature), indoor air quality (ventilation, CO_2 level), lighting comfort (lux level), and noise comfort (dBA level) that you maintained in this building?

Section 3 – Impact of occupant behaviours on energy consumption in New Zealand's commercial buildings

This section asks about the degree of impact of occupant behaviours on the energy consumption of New Zealand's Commercial Buildings.

1. How would you describe your organisation's commitment to building energy efficiency?
2. What is the current energy performance status of this building?
3. How does it differ from the design stage to the operational stage?
4. What are the common causes of energy consumption to exceed?
5. How would you describe the influence of occupant behaviours on the energy consumption of this Building?

Section 4 – Achievement of energy reduction targets in New Zealand's commercial buildings

This section asks about the effect of occupant behaviours on achieving energy reduction targets in New Zealand's Commercial Buildings.

1. Could you please explain what strategies (technology and management) are used to reduce energy use in heating and cooling, lighting, and plug load systems?
2. Are these strategies did not work well or difficult to deal with?
3. Are these technologies required constant maintenance?
4. What strategies are occupant centric?
5. Does your organisation have further planning to improve energy efficiency performance?
6. Do you think control of occupant behaviours helps to achieve energy reduction targets in this building?
7. Do you think it is possible to control the effect of those different factors on occupant behaviours? Which factors are easily controllable?
8. Which energy reduction targets could be introduced into your building in a way that would overcome the impact of occupant behaviours on the energy consumption of this building?

I highly appreciate your valuable time to answer this interview!!

Preliminary survey

Pilot Study – Questionnaire Survey

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

STATEMENT OF CONSENT

The impacts of occupant behaviours on energy consumption in New Zealand office buildings

If you wish to participate in this study, please read the following carefully and sign in the space provided

- I am voluntarily taking part in this project. I understand that I do not have to take part, and I can stop and withdraw my consent at any time up to three weeks from today.
- I have read the Information Sheet.
- I understand that the data I provide is confidential and that I will not be identified in any publications of findings from this research without my permission.
- I have been able to ask any questions I might have, and I understand that I am free to contact the researcher with any questions I may have in the future.

Signature:		**Date:**	

If you have any queries, please contact;

Researcher's Name and Contact Details
Achini Weerasinghe, PhD student,
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Email: A.Weerasinghe@massey.ac.nz
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School of Built Environment

Massey University, Auckland
Private Bag 102904
North Shore
Auckland 0745
New Zealand

INFORMATION SHEET

Researcher Introduction

My name is Achini Weerasinghe, a PhD student at the School of Built Environment, Massey University. I am undertaking a PhD research project that focuses on the Impact of Occupant Behaviour on Energy Consumption of Office Buildings in New Zealand. This research aims to achieve energy reduction targets in commercial office buildings based on occupant energy behaviour and factors influencing occupant behaviour.

Project Invitation

I wish to invite building occupants, property, and facilities managers to take part in a questionnaire survey to describe the occupant behaviours and factors influencing energy-driven occupant behaviours in New Zealand office buildings.

Survey Procedure

The questionnaire is structured into four (04) main sections including questions related to participants' background, IEQ of workspace, energy-driven occupant behviours, and factors influencing energy-driven occupant behviours in New Zealand office buildings. Both close-ended and open-ended questions that allow further discussions are included in the questionnaire. Therefore, it should take no longer than 30 minutes to answer and discuss the questions.

Ethics Notification

This project has been evaluated by peer review and judged to be low risk. The Ethics notification number for this project is 4000022597 and the low-risk notification is valid for a maximum of three years effective from May 2020.

Thank you for your time and your kind support!

The impacts of occupant behaviours on energy consumption in New Zealand office buildings

Section 1 – Background

This information relates to the participant's background.

Please note: We ask about gender, age, and ethnicity because these are relevant to people's actions in buildings. Issues about privacy are addressed in the Statement of Consent Form and Information Sheet.

Email [ ]

Department/Building [ ]

Occupation [ ]

Please tick

What is your Gender? Male ☐ ☐ Female

Your age? Under 25 ☐ ☐ 25 - 34; 35 - 44 ☐ ☐ 45 - 54; Above 55 ☐

Your ethnicity? European ☐ ☐ Māori; Asian ☐ ☐ Pacific People; Africans ☐ ☐ Other

How long have you been in New Zealand? Less than a year ☐ ☐ 11 – 20 years; 1 – 10 years ☐ ☐ more than 20 years

Please tick

Is this building your normal base? Yes ☐ ☐ No

If No, which is? [ ]

Is your office or normal work area....?

Private room ☐ ☐ Public area (i.e. reception, office lobby)

Room shared by 5 others or less than ☐ ☐ Other

Open plan office with separate workstations shared by more than 5 others ☐

Other (Please specify) [ ]

Which of the following best describes the location of your workspace in this building?

Close to a window within 5 feet ☐ ☐ Close to an exterior wall within 5 feet

Centre of the office ☐

Other (Please specify) [ ]

How long have you worked in this building? Less than a year ☐ ☐ A year or more

Please tick

How long have you worked in your present work area? Less than a year ☐ ☐ A year or more

Have you ever had to move your workstation because of discomfort within the building? Yes ☐ ☐ No

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

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 on a computer screen? [ ]

Section 2 - Indoor Environmental Quality (IEQ)

This section asks how comfortable you find the indoor working environment of your building in both winter and summer.

Thermal Comfort and Indoor Air Quality (IAQ)

How would you describe typical working conditions in your normal work area in WINTER? If you have not worked here in Winter, then please leave these questions blank and just complete the questions in Summer.

Temperature in Winter

Please tick your rating on each scale

Uncomfortable	1	2	3	4	5	6	7	Comfortable
Too hot	1	2	3	4	5	6	7	Too cold

Ventilation and Air in Winter

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

Overall Thermal and Ventilation in Winter

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

How would you describe typical working conditions in your normal work area in SUMMER? If you have not worked here in Summer, then please leave these questions blank and just complete the questions in Winter.

Temperature in Summer

Please tick your rating on each scale

Uncomfortable	1	2	3	4	5	6	7	Comfortable
Too hot	1	2	3	4	5	6	7	Too cold

Ventilation and Air in Summer

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

Overall Thermal and Ventilation in Summer

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

Comments about any issue(s) you may experience with the Temperature and Air Quality in your work area

Visual Comfort

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

Overall Lighting

Please tick your rating on each scale

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

Comments about overall lighting conditions

Acoustic Comfort

How would you describe noise in your normal work area?

Noise

Unsatisfactory	1	2	3	4	5	6	7	Satisfactory

Please estimate how you are affected by unwanted interruptions

Not at all	1	2	3	4	5	6	7	Very often

Comments about the impact of unwanted interruptions, noise, and its sources

Section 3 - Energy-driven Occupant Behaviours

This section asks how occupants behave in a way that affects the energy consumption of your office building.

How much control do you personally have over the following building systems and appliances, of your working environment?

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

Are the windows, shades, and blinds being operable within your normal work area?

Yes ☐ ☐ No

Which of the following adjustments do you personally exercise in your work area? (Check all that apply)

Open/close windows	☐	Adjust personal heaters	☐
Open/close external doors	☐	Adjust portable/ceiling fans	☐
Open/close internal doors	☐	Adjust room air conditioning unit	☐
Adjust shades and blinds	☐	Turn off the computer monitor	☐
Adjust thermostats	☐	Adjust computer screen brightness	☐
Turn lights on/off	☐	Moving through spaces	☐
Adjust clothing	☐	Report discomfort	☐
Drink hot/cold beverage	☐	None of the above	☐

What other adjustments do you exercise?

By exercising the adjustments mentioned in question 2, which of the following changes do you expect in your work area? (Check all that apply)

To feel cooler	☐	To increase artificial lighting	☐
To feel warmer	☐	To avoid glare	☐
To increase air movement	☐	To experience the variety of the outdoor climate	☐
To air freshness	☐	To have access to outside view	☐
To let in fresh air	☐	To save energy	☐
To hear outdoor sounds	☐	To follow management guidelines	☐
To avoid outdoor sounds	☐	To feel healthier	☐
To increase daylighting	☐	Other	☐

Other (Please specify)

How confident are you that your adjustments will have the desired effect?

Please tick your rating on each scale

Very unsure	1	2	3	4	5	6	7	Very sure

How often do you make above adjustments in your work area? (Please tick)

Please tick your rating on each scale

Never	1	2	3	4	5	6	7	Very often

How likely is that you will make such adjustments during the winter/summer?

Please tick your rating on each scale

Winter	Extremely unlikely	1	2	3	4	5	6	7	Extremely likely
Summer	Extremely unlikely	1	2	3	4	5	6	7	Extremely likely

During the day, when natural light is adequate, do you switch any lights on?

Yes ☐ ☐ No

If Yes please specify the reason

During the sundown, when glare is high from the sun, do you lower the blinds?

Yes ☐ ☐ No

What would be required from you to change your behaviour (above personal adjustments)?

Please give brief details

Section 4 – Factors Influencing Energy-Driven Occupant Behaviours

Occupants vary in comfort preferences, satisfaction, and indoor environment feelings due to many factors: physical environmental, physiological, psychological, contextual, social, and time-related factors. This section asks the factors/drivers affecting different occupant behaviours of your workspace that affects the building energy consumption.

Building management encourages me to be more energy efficient.......

Please tick your rating on each scale

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

If Agree, please give examples

The feedback on individual energy use by building management is important for me to change my behaviour........

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Building management often sends energy use feedbacks...

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Doing something positive for the environment is desirable.......

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Saving energy at work is important to me.............

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

What actions I take to save energy depends on my comfort needs and preferences.............

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Closing windows, turning off the lights, heaters, fans, etc., whenever I leave the office, and unplugging appliances when not in use can save energy....

Please tick your rating on each scale

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

If I feel slightly cold at the workplace, I can try to put on another layer of clothing rather than use a personal heater...

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

Arrangement of workstation furniture and equipment (i.e. desk, chair, footrest, telephone, document holder and printer, etc.) help to satisfy my visual demands (i.e. lighting and glare) ....

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

I change my behviours to increase my performance/ productivity.......

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

If you have any other comments that you would like to make about any aspect of your work environment, or general comments, please note them here.

Additional comments....

Thank you for your help!

I highly appreciate your valuable time to answer this questionnaire.

General survey

The impacts of occupant behaviours on energy consumption in New Zealand office buildings

INFORMATION SHEET

This project is being carried out by Achini Shanika Weerasinghe as a requirement for the award of a Doctor of Philosophy degree, under the supervision of Dr. James Rotimi.

The research aims to develop a model for factors influencing energy-driven occupant behaviours for the effective integration in achieving energy reduction targets in New Zealand office buildings through two surveys targeting general office building occupants from all over New Zealand and another set of occupants from three office buildings.

You are invited to participate in this survey as a building occupant who has knowledge on energy-driven occupant behaviours that may influence energy consumption in New Zealand office buildings. It will be highly appreciated if you can fill out the attached questionnaire and supply any additional information which you may find useful based on your experience. You are assured of strict confidentiality in the research process and in subsequent publications.

The questionnaire is structured into Three (03) main sections including questions related to participants' background, energy-driven occupant behaviours, and factors influencing energy-driven occupant behaviours in New Zealand office buildings. You are free to ask the researcher not to use any of the information you have given. It should take no longer than 10 minutes to answer.

The Ethics notification number for this project is 4000022597 and the low-risk notification is valid for a maximum of three years effective from May 2020. If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher, please contact Prof. Craig Johnson, Director – Ethics, telephone 063569099 ext 85271, email: C.B.Johnson@massey.ac.nz

STATEMENT OF CONSENT

I have read and understood the description of the above-named project. Therefore, I agree to participate in the study, and I consent to any publications of findings from the study with the understanding that data I provide is confidential.

I understand that I may withdraw my consent, including any information I have provided from the study at any time up to three weeks from today.

Signature:		**Date:**	

If any queries arise, please contact:

Researcher's Name and Contact Details
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Supervisor's Name and Contact Details
Dr. James O. B. Rotimi
School of Built Environment
Massey University, Auckland
Email: J.Rotimi@massey.ac.nz

The impacts of occupant behaviours on energy consumption in New Zealand office buildings

Section 1 – Background Information

This information relates to the participant's background.

Please note: We ask about gender, age, and ethnicity because these are relevant to people's actions in buildings. Issues about privacy are addressed in the Statement of Consent Form and Information Sheet.

1. Please state your job [ ]
2. What is your Gender?

Male ☐ Female ☐ Other ☐ Prefer not to answer ☐

3. What is your age range?

Under 30 ☐ 30 or Above 30 ☐

4. How do you describe your ethnicity?

NZ European ☐ Māori/Pacific Islander ☐ Asian ☐ African/ African American ☐

Other (Please specify) ☐ [ ]

5. How long have you been in New Zealand?

Less than a year ☐ 1 – 10 years ☐ 11 – 20 years ☐ More than 20 years ☐

6. What is the highest level of education you have achieved?

Master's degree or above ☐ Bachelor's degree ☐ Highschool ☐

Other (Please specify) ☐ [ ]

7. What is your employment status?

Full-time ☐ Unemployed ☐ Part-time ☐ Unable to work ☐

Contract/Temporary ☐ Other (Please specify) ☐ [ ]

8. How long have you worked in your current workspace?

Less than a year ☐ A year or more ☐

9. What is your primary language?

English	☐	Other (Please specify)	☐	

10. Please choose the region your office is in:

Northland	☐	Manawatu-Whanganui	☐	Auckland	☐	Wellington	☐	Taranaki	☐
Waikato	☐	Nelson-Tasman	☐	West Coast	☐	Otago	☐	Hawkes Bay	☐
Gisborne	☐	Bay of Plenty	☐	Marlborough	☐	Canterbury	☐	Southland	☐

Section 2 – Energy-driven occupant behaviours and factors influencing in New Zealand's Office Buildings

Occupants vary in comfort preferences, satisfaction, and indoor environment feelings due to many factors: physiological, psychological, and social factors. This section asks the factors/drivers affecting different occupant behaviours at your workspace that impacts on the building energy consumption.

1. Please give your agreement on following statements.

Statement	**Strongly Disagree**	**Somewhat Disagree**	**Undecided**	**Somewhat Agree**	**Strongly Agree**
I am comfortable with the environmental conditions at my workspace	☐	☐	☐	☐	☐
I often report discomforts related to indoor environmental quality (IEQ) to the building management	☐	☐	☐	☐	☐
I have personal control over most of the appliances (windows, doors, blinds, thermostat, lights, heaters, fans, computers) at my workspace	☐	☐	☐	☐	☐
I often adjust building appliances to satisfy my comfort preferences	☐	☐	☐	☐	☐
I often adjust myself to the environmental conditions at my workspace by adjusting clothing, drinking hot/cold beverage, and moving through spaces	☐	☐	☐	☐	☐
I am willing to accept and do nothing about the existing indoor environmental conditions at my workspace…..	☐	☐	☐	☐	☐
Saving energy at work is important to me	☐	☐	☐	☐	☐
I feel responsible/obliged to save energy at work	☐	☐	☐	☐	☐
I am aware that reducing energy use at my workspace……….					

Will reduce energy cost	☐	☐	☐	☐	☐
Will reduce carbon emissions	☐	☐	☐	☐	☐
Will improve my organisation' s image/reputation	☐	☐	☐	☐	☐
Saving energy during work is entirely within my control	☐	☐	☐	☐	☐
What actions I take to save energy depends on my comfort needs and preferences	☐	☐	☐	☐	☐
I often close windows, turn off the lights, heaters, fans, computers etc., whenever I leave the office, and unplug appliances when not in use	☐	☐	☐	☐	☐
If I feel slightly cold at the workplace, I can put on another layer of clothing instead of using the heater	☐	☐	☐	☐	☐
If I feel slightly warm at the workplace, I can adjust my clothing level instead of using the air conditioner	☐	☐	☐	☐	☐
Arrangement of workstation furniture and equipment (i.e. desk, chair, footrest, telephone, document holder and printer, etc.) help to satisfy my visual demands (i.e. lighting and glare)	☐	☐	☐	☐	☐
My co-workers expect me to save energy at work	☐	☐	☐	☐	☐
Sharing control over building systems with my co-workers is easy	☐	☐	☐	☐	☐
Most of my co-workers expect me to turn off electrical appliances when leaving	☐	☐	☐	☐	☐
The feedback on individual energy use by our building management team is important for me to change my energy-driven behaviour	☐	☐	☐	☐	☐
My company encourages employees to save energy	☐	☐	☐	☐	☐
My company rewards employees for saving energy	☐	☐	☐	☐	☐
Our building management team often sends energy use reports to employees	☐	☐	☐	☐	☐

Thank you for your help! I highly appreciate your valuable time to answer this questionnaire.

Case study survey

The impacts of occupant behaviours on energy consumption in New Zealand office buildings

INFORMATION SHEET

This project is being carried out by Achini Shanika Weerasinghe as a requirement for the award of a Doctor of Philosophy degree under the supervision of Dr. James Rotimi.

The research aims to develop a model for factors influencing energy-driven occupant behaviours for the effective integration in achieving energy reduction targets in New Zealand office buildings through a survey targeting general office building occupants from all over New Zealand and surveying another set of occupants from three office buildings.

You are invited to participate in this survey as a building occupant who knows energy-driven occupant behaviours that may influence energy consumption in New Zealand office buildings. It would be highly appreciated if you can fill out the attached questionnaire and supply any additional information which you may find helpful based on your experience. You are assured of strict confidentiality in the research process and subsequent publications.

The questionnaire is structured into four main sections, including questions related to participants' background, satisfaction with Indoor Environmental Quality (IEQ), energy-driven occupant behaviours, and factors influencing energy-driven occupant behaviours in New Zealand office buildings. You are free to ask the researcher not to use any of the information you have given. It should take no longer than 15 minutes to answer.

The Ethics notification number for this project is 4000022597, and the low-risk notification is valid for a maximum of three years, effective from May 2020. If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher, please get in touch with Prof. Craig Johnson, Director – Ethics, telephone 063569099 ext 85271, email: C.B.Johnson@massey.ac.nz

STATEMENT OF CONSENT

I have read and understood the description of the above-named project. Therefore, I agree to participate in the study, and I consent to any publications of findings from the study with the understanding that data I provide is confidential.

I understand that I may withdraw my consent, including any information I have provided from the study at any time up to three weeks from today.

Signature:		**Date:**	

If any queries arise, please contact:

Researcher's Name and Contact Details

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Supervisor's Name and Contact Details

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The impacts of occupant behaviours on energy consumption in New Zealand office buildings

Section 1 – Background Information

This information relates to the participant's background.

Please note: We ask about gender, age, and ethnicity because these are relevant to people's actions in buildings. Issues about privacy are addressed in the Statement of Consent Form and Information Sheet.

1. Please state your job
2. Please state your department/building
3. What is your Gender?

Male ☐ Female ☐ Other ☐ Prefer not to answer ☐

4. What is your age range?

Under 30 ☐ 30 or Above 30 ☐

5. How do you describe your ethnicity?

NZ European ☐ Māori/Pacific Islander ☐ Asian ☐ African/ African American ☐

Other (Please specify) ☐

6. What is your primary language?

English ☐ Other (Please specify) ☐

7. How long have you been in New Zealand?

Less than a year ☐ 1 – 10 years ☐ 11 – 20 years ☐ More than 20 years ☐

8. What is the highest level of education you have achieved?

Master's degree or above ☐ Bachelor's degree ☐ Highschool ☐

Other (Please specify) ☐

9. What is your employment status?

Full-time ☐ Part-time ☐ Contract/Temporary ☐

Other (Please specify) ☐ [ ]

10. Would you consider yourself to have a disability?

Yes ☐ No ☐

11. How would you best describe the location of your workspace in the office building?

Close to a window within 5 feet	☐	Close to an exterior wall within 5 feet	☐
Close to an interior wall within 5 feet	☐	Centre of the office	☐
Other (Please specify)	☐	[ ]	

12. Is your workspace ….?

Enclosed office, private	☐	Enclosed office shared with other people	☐
Cubicles with high partitions (about 5 or more feet high)	☐	Cubicles with low partitions (lower than 5 feet high)	☐
Open-plan office with no partitions (just desks)	☐	Other (Please specify) [ ]	

13. In which area of the building is your workspace located?

North-facing ☐ East-facing ☐ West-facing ☐ South-facing ☐

14. How long have you worked in this building?

Less than a year ☐ A year or more ☐

15. How long have you worked in your present workspace?

Less than a year ☐ A year or more ☐

16. In a normal working week, how many days do you spend in the workspace?

Less than 5 days ☐ 5 days or more ☐

17. On a normal working day, what is your starting time and finishing time?

6 am – 2 am ☐ 7 am – 3 pm ☐ 8 am – 4 pm ☐ 9 am – 5 pm ☐

Other (Please specify) ☐ [ ]

18. On a normal working day, how many hours do you spend working with a computer screen (VDU)?

Less than 8 hours ☐ 8 hours or more ☐

Section 2 – Indoor Environmental Quality (IEQ) of New Zealand's Office Buildings

This section asks how comfortable you find the indoor working environment of your office building in both winter and summer.

1. How would you best describe your clothing level during the winter and summer seasons?

Clothing Level	Winter	Summer
Short-sleeve tops	☐	☐
Long sleeve tops	☐	☐
Short pants	☐	☐
Long pants	☐	☐
Thermal inners	☐	☐
Sweatshirts	☐	☐
Sweatpants	☐	☐
Beanie	☐	☐
Scarf	☐	☐
Gloves	☐	☐
Light jackets or coats	☐	☐
Heavy jackets or coats	☐	☐
Closed-toe shoes	☐	☐
Open toe shoes	☐	☐
Other (Please specify)		
	☐	☐
	☐	☐

2. Have you ever had to move your workstation because of discomfort with environmental conditions in your office?

   Yes ☐

   No ☐

   No, but I want to ☐

3. What are the sources of discomforts that you experience in your workspace during the winter season? (You may select answers from the given scale)

Discomfort	Winter				
	1	2	3	4	5
Temperature	Too cold	Cold	Neutral	Hot	Too hot
	☐	☐	☐	☐	☐
Air quality	Too stuffy	Stuffy	Neutral	Windy	Too windy
	☐	☐	☐	☐	☐
Lighting	Too dark	Dark	Neutral	Bright	Too bright

Natural light	☐	☐	☐	☐	☐
Artificial light	☐	☐	☐	☐	☐
Noise	Too quiet	Quiet	Neutral	Noisy	Too noisy
Inside noise	☐	☐	☐	☐	☐
Outside noise	☐	☐	☐	☐	☐

4. What are the sources of discomforts that you experience in your workspace during the summer season? (You may select answers from the given scale)

Discomfort	**Summer**				
	1	**2**	**3**	**4**	**5**
Temperature	Too cold	Cold	Neutral	Hot	To hot
	☐	☐	☐	☐	☐
Air quality	Too stuffy	Stuffy	Neutral	Windy	Too windy
	☐	☐	☐	☐	☐
Lighting	Too dark	Dark	Neutral	Bright	Too bright
Natural light	☐	☐	☐	☐	☐
Artificial light	☐	☐	☐	☐	☐
Noise	Too quiet	Quiet	Neutral	Noisy	Too noisy
Inside noise	☐	☐	☐	☐	☐
Outside noise	☐	☐	☐	☐	☐

Section 3 – Energy-driven occupant behaviours in New Zealand's Office Buildings

This section asks how you behave in a way that affects the energy consumption of your office building.

1. How much personal control do you have over the following appliances of your work environment?

Appliance	**Not Available**	**No control**	**Somewhat control**	**Full control**
Windows	☐	☐	☐	☐
Doors	☐	☐	☐	☐
Blinds/shades	☐	☐	☐	☐
Thermostat (heat/cool pump)	☐	☐	☐	☐
Artificial lights (Electric lamps)	☐	☐	☐	☐
Portable heaters	☐	☐	☐	☐
Personal fans	☐	☐	☐	☐
Ceiling fans	☐	☐	☐	☐
Computer (sleep mode/brightness)	☐	☐	☐	☐

2. Please state "why" and "when" you adjust the above-mentioned appliances (question 1) in your workspace? Please skip any adjustments relating to appliances that are not available or you do not have control over.

Adjustments	**Why?**	**When?**	
		Summer	**Winter**
	To feel cooler	☐	☐

Opening Windows	To feel warmer	☐	☐
	To let in fresh air	☐	☐
	To let out stuffy air	☐	☐
	To save energy	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Closing windows	To feel cooler	☐	☐
	To feel warmer	☐	☐
	To avoid outdoor sounds	☐	☐
	To save energy	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Lifting shades and blinds	To let more daylight in	☐	☐
	To let more solar heat in	☐	☐
	To have access to outside view	☐	☐
	To reduce using electric lamps	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Lowering shades and blinds	For privacy	☐	☐
	To limit solar heat in	☐	☐
	To avoid glare from the sun	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Adjusting thermostat	To feel cooler	☐	☐
	To feel warmer	☐	☐
	To save energy	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Turning lights on	I like lights on when working	☐	☐
	It keeps me awake	☐	☐
	The office is too dark	☐	☐
	A colleague requested	☐	☐

	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Turning lights off	I like natural lighting	☐	☐
	The office is too bright	☐	☐
	To save energy	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Opening doors	To feel cooler	☐	☐
	To feel warmer	☐	☐
	To let people know I'm at work	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Closing Doors	To feel warmer	☐	☐
	To avoid distraction	☐	☐
	For privacy	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Adjusting ceiling fan	To feel cooler	☐	☐
	To save energy	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Adjusting portable fan	To feel cooler	☐	☐
	To save energy	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Adjusting computer brightness	To save energy	☐	☐
	To reduce the brightness	☐	☐
	To increase the brightness	☐	☐

	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Adjusting clothing level	To feel cooler	☐	☐
	To feel warmer	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Drinking cold beverages	To feel cooler	☐	☐
	To take short breaks during work	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Drinking hot beverages	To feel warmer	☐	☐
	To take short breaks during work	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐
Moving through spaces	To feel cooler	☐	☐
	To feel warmer	☐	☐
	To take short breaks during work	☐	☐
	Upon arrival	☐	☐
	Upon leaving	☐	☐
	During daytime	☐	☐
	Other (Please specify)		
		☐	☐
		☐	☐

3. How confident are you that your previous selections will have the desired comfort effects?

Vey unsure	Unsure	Somewhat sure	Sure	Very sure
1	2	3	4	5
☐	☐	☐	☐	☐

4. How often do you turn off the following appliances when not in use to save energy at your workspace?

Appliance	Never	Rarely	Sometimes	Very Often	Always
	1	2	3	4	5

Heat/cool pump	☐	☐	☐	☐	☐
Portable heater	☐	☐	☐	☐	☐
Personal fan	☐	☐	☐	☐	☐
Ceiling fan	☐	☐	☐	☐	☐
Lights	☐	☐	☐	☐	☐
Computers (off/sleep mode)	☐	☐	☐	☐	☐

5. How often do you report discomforts related to indoor environmental quality (IEQ) to the building management?

Never	Rarely	Sometimes	Most of the time	Always
1	2	3	4	5
☐	☐	☐	☐	☐

6. I am willing to accept and do nothing about the existing indoor environmental conditions at my workspace…..

Extremely unlikely	Somewhat unlikely	Neither likely nor unlikely	Somewhat likely	Extremely likely
1	2	3	4	5
☐	☐	☐	☐	☐

7. What would be required for you to change how you adjust your work environment in your office?

Section 4 – Factors influencing energy-driven occupant behaviours in New Zealand's Office Buildings

Occupants vary in comfort preferences, satisfaction, and indoor environment feelings due to many factors: physiological, psychological, and social factors. This section asks the factors/drivers affecting different occupant behaviours at your workspace that impacts on the building energy consumption.

1. Please give your agreement on the following statements.

Statement	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
	1	**2**	**3**	**4**	**5**
Saving energy at work is important to me	☐	☐	☐	☐	☐
I feel responsible/obliged to save energy at work	☐	☐	☐	☐	☐
I am aware that reducing energy use at my workplace……….					
Will reduce energy cost	☐	☐	☐	☐	☐
Will reduce carbon emissions	☐	☐	☐	☐	☐
Will improve my organisation' s image/reputation	☐	☐	☐	☐	☐
Saving energy during work is entirely within my control	☐	☐	☐	☐	☐
What actions I take to save energy depends on my comfort needs and preferences	☐	☐	☐	☐	☐

I am aware that closing windows, turning off the lights, heaters, fans, etc., whenever I leave the office, and unplugging appliances when not in use can save energy	☐	☐	☐	☐	☐
If I feel slightly cold at the workplace, I would put on another layer of clothing instead of using the heater	☐	☐	☐	☐	☐
If I feel slightly warm at the workplace, I would adjust my clothing level instead of using the air conditioner	☐	☐	☐	☐	☐
Arrangement of workstation furniture and equipment (i.e. desk, chair, footrest, telephone, document holder and printer, etc.) help to satisfy my visual demands (i.e. lighting and glare)	☐	☐	☐	☐	☐
My co-workers expect me to save energy at work	☐	☐	☐	☐	☐
Sharing control over building systems with my co-workers is easy	☐	☐	☐	☐	☐
Most of my co-workers expect me to turn off electrical appliances when leaving	☐	☐	☐	☐	☐
The feedback on individual energy use by our building management team is important for me to change my energy-driven behaviour	☐	☐	☐	☐	☐
My company encourages employees to save energy	☐	☐	☐	☐	☐
My company rewards employees for saving energy	☐	☐	☐	☐	☐
Our building management team often sends energy use reports to employees	☐	☐	☐	☐	☐

2. If you have any other comments that you would like to make about the energy use of your work environment or general comments, please note them here.

Thank you for your help! I highly appreciate your valuable time to answer this questionnaire.

Appendix D

Statement of contribution doctorate with publications/manuscripts

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STATEMENT OF CONTRIBUTION
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We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Achini Shanika Weerasinghe
Name and title of main supervisor:	Professor James O.B. Rotimi
In which chapter is the manuscript/published work?	Chapter 3
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

The candidate has written the original draft of manuscript including conceptualisation, methodology, analysis, visualisation, and editing.

Please select one of the following three options:

(●) **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

Weerasinghe, A. S., Rasheed, E., & Bamidele Rotimi, J. O. (2020). Occupant energy behaviours – A review of indoor environmental quality (IEQ) and influential factors. In A. Ghaffarianhoseini et al. (Eds.) Proceedings of the 54th International Conference of Architectural Science Association (pp. 805 – 814), ANZAScA.

( ) **The manuscript is currently under review for publication**

Please provide the name of the journal:

( ) **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

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Student name:	Achini Shanika Weerasinghe
Name and title of main supervisor:	Professor James O.B. Rotimi
In which chapter is the manuscript/published work?	Chapter 4
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

The candidate has written the original draft of manuscript including conceptualisation, methodology, analysis, visualisation, and editing.

Please select one of the following three options:

○ **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

◉ **The manuscript is currently under review for publication**

Please provide the name of the journal:

Energy Research & Social Science

○ **It is intended that the manuscript will be published, but it has not yet been submitted to a journal**

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Student name:	Achini Shanika Weerasinghe
Name and title of main supervisor:	Professor James O.B. Rotimi
In which chapter is the manuscript/published work?	Chapter 5
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

The candidate has written the original draft of manuscript including conceptualisation, methodology, data collection and analysis, visualisation, and editing.

Please select one of the following three options:

◉ **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

Weerasinghe, A.S., Rasheed, E.O. and Rotimi, J.O.B. (2021). A Dilemma Between Building Indoor Environment Preferences and Occupant Energy Behaviours. In: L. Scott & C. J. Neilson (Eds.) Proceedings of the 37th Annual ARCOM Conference (pp. 794-803), Association of Researchers in Construction Management.

○ **The manuscript is currently under review for publication**

Please provide the name of the journal:

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Student name:	Achini Shanika Weerasinghe
Name and title of main supervisor:	Professor James O.B. Rotimi
In which chapter is the manuscript/published work?	Chapter 6
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

The candidate has written the original draft of manuscript including conceptualisation, methodology, data collection and analysis, visualisation, and editing.

Please select one of the following three options:

(●) **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

Weerasinghe, A.S., Rasheed, E.O., & Rotimi, J.O.B. (2022), A Facilities Management Approach to Rationalising Occupants' Energy Behaviours [Article]. Facilities, 40(11/12), https://doi.org/10.1108/F-02-2022-0025

( ) **The manuscript is currently under review for publication**

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Student name:	Achini Shanika Weerasinghe
Name and title of main supervisor:	Professor James O.B. Rotimi
In which chapter is the manuscript/published work?	Chapter 7
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

The candidate has written the original draft of manuscript including conceptualisation, methodology, data collection and analysis, visualisation, and editing.

Please select one of the following three options:

(●) **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

Weerasinghe, A.S., Rasheed, E.O., & Rotimi, J.O.B. (2022), Environmental and socio-psychological drivers of building users' behaviours: A case study of tertiary institutional offices in Auckland, Journal of Facilities Management [Article]. EarlyCite, https://doi.org/10.1108/JFM-01-2022-0011

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Student name:	Achini Shanika Weerasinghe
Name and title of main supervisor:	Professor James O.B. Rotimi
In which chapter is the manuscript/published work?	Chapter 8
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

The candidate has written the original draft of manuscript including conceptualisation, methodology, data collection and analysis, visualisation, and editing.

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Please provide the full reference of the research output:

Weerasinghe, A.S., Rasheed, E.O. and Rotimi, J.O.B. (2022). Social-psychological insights into energy-saving behaviours: An occupant survey in New Zealand. In K. Panuwatwanich et al. Proceedings of the 12th International Conference on Engineering, Project, and Production Management (EPPM2022) (pp. 9/1-9/12)

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In which chapter is the manuscript/published work?	Chapter 9
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

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Please provide the full reference of the research output:

Weerasinghe, A. S., Rotimi, J. O. B., & Rasheed, E. O. (2023). Modelling of underlying social psychological effects on occupant energy-related behaviours [Article]. Building and Environment, 231, 110055. https://doi.org/https://doi.org/10.1016/j.buildenv.2023.110055

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Name and title of main supervisor:	Professor James O.B. Rotimi
In which chapter is the manuscript/published work?	Chapter 10
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

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  Weerasinghe, A.S., Rasheed, E.O. and Rotimi, J.O.B. (2022). Self-rated Motivational Drivers for Occupant Behaviours: A Case Study of Tertiary Office Buildings. In S. Perera & M. Hardie (Eds.) Proceedings of the 45th Australasian Universities Building Education Association (AUBEA) Conference (pp. 995-1004), Western Sydney

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Name and title of main supervisor:	Professor James O.B. Rotimi
In which chapter is the manuscript/published work?	Chapter 11
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

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Please select one of the following three options:

(●) **The manuscript/published work is published or in press**

Please provide the full reference of the research output:

Weerasinghe, A.S., Rasheed, E.O., & Rotimi, J.O.B. (2023), Occupants' decision-making of their energy behaviours in office environments: A case of New Zealand [Article]. Sustainability, 2023, 15, 2305. https://doi.org/10.3390/su15032305

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Student name:	Achini Shanika Weerasinghe
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In which chapter is the manuscript/published work?	Chapter 12
What percentage of the manuscript/published work was contributed by the student?	80%

Describe the contribution that the student has made to the manuscript/published work:

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Please select one of the following three options:

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Please provide the full reference of the research output:

◉ **The manuscript is currently under review for publication**

Please provide the name of the journal:

Journal of building performance simulation

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