A Review of How Occupant Behaviour Determines the Energy Efficiency of Green Buildings: A Case of Office Buildings

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Abstract

In most countries, buildings consume about 50% of the total energy. High energy consumption is still addressed by stakeholders through traditional technical methods, such as design considerations. However, studies suggest that strategic actions achieve a zero net energy or low energy goal depending on the behaviour of building occupants. The objective of this study is to develop methods for modeling and evaluating occupant behaviour in green office buildings. Specifically, this paper aims to present the research questions and hypotheses for the main investigation and to identify the predictors of occupant behaviour in conventional and green buildings based on a literature review. The research found that the behaviour of building occupants in interacting with or using the building, such as using blinds, and curtains, controlling lighting, opening and closing windows, the way they dress, and the temperature of their drinking water to adjust the indoor environment to their needs or tastes, has a strategic impact on the energy performance and consumption of the building. The study also found that the building envelope, building services, natural ventilation, daylighting, artificial lighting, and thermal comfort are the most important predictors of occupant behaviour in green office buildings. User satisfaction with the building depends on user interaction with the building system and the extent of user adaptation and social value systems. It is found that the ontology of positivism and the epistemology of objectivism are the appropriate metaphysical orientations for the main research. The main research includes qualitative and quantitative data. The results suggest that performance surveys, simulations, experiments, case studies, and questionnaires are appropriate for the main research.

Keywords
Thermoregulation, Thermal Comfort, Post-Occupancy Evaluations, Research Design, Malaysia

Introduction
This research is part of ongoing research that looks at the energy management of office buildings in Malaysia by comparing green buildings with conventional buildings. This is a ground-breaking study on green energy modeling that incorporates thermal physiological data to reveal the effects of thermal comfort on human behaviour in the workplace when establishing a baseline model. Buildings have a significant impact on sustainability

objectives. For instance, the building industry consumes raw materials, energy, and water, produces waste, and releases potentially harmful airborne particles into the atmosphere (Olanrewaju & Chong 2021; Guoqing, et al. 2022). To lessen the harmful consequences of buildings on individuals, communities, and the environment, green buildings were developed. Since the start of the green building effort, there are a lot more certified green buildings. The energy estimation of the occupant's behaviour on the building performance is determined by simulation and design concepts. However, this would lead to an energy performance gap between prediction and actual consumption which is up to 300% in some instances (Delzendeh 2017).

The efficiency and quality of installed indoor equipment, occupant interaction, construction assembly details, the climate of the location, and the thermal performance of the building are all factors that influence how much energy a building consumes over its lifetime. There is a need to change construction methods and employ energy-efficient technologies. As compared to other determinants, occupants' behaviour is the most impactful, yet the most difficult to predict because it entails both qualitative and quantitative dimensions. Understanding the efficacy of the current green buildings is necessary to inspire residents, get their comments, and pass them on to the architects and builders (Olanrewaju & Chong 2021; Guoqing, et al. 2022). Despite the importance of this feedback loop, Malaysia has little research on the subject. This study seeks to close this gap by developing systematic methods to measure, model, evaluate, and apply to the occupants' behaviour in green office buildings. To achieve this aim, this paper would provide an answer to the question: "Based on building parameters, occupant parameters, and external parameters, to what extent do conventional office buildings differ from green office buildings?

Ohueri, et al., (2018) stated that a total of 300 green buildings had received certification in Malaysia until March 2017; the majority of these were commercial structures such as offices, malls, airports, and others according to the Green Building Index (GBI). Due to the significance of green office buildings, the Malaysian Government and the Work Department Malaysia (PWD), the Construction Industry Development Board (CIDB), the Ministry of Energy, etc., have developed numerous initiatives and policies. The National Green Technology Policy, the Low Carbon Cities Framework, and green building grading systems are a few of the initiatives that seek to encourage the adoption of energy efficiency practices in the Malaysian construction sector. Various green building rating systems are available, including the Green Performance Assessment System, Penarafan Hijau, Green Real Estate, and GBI.

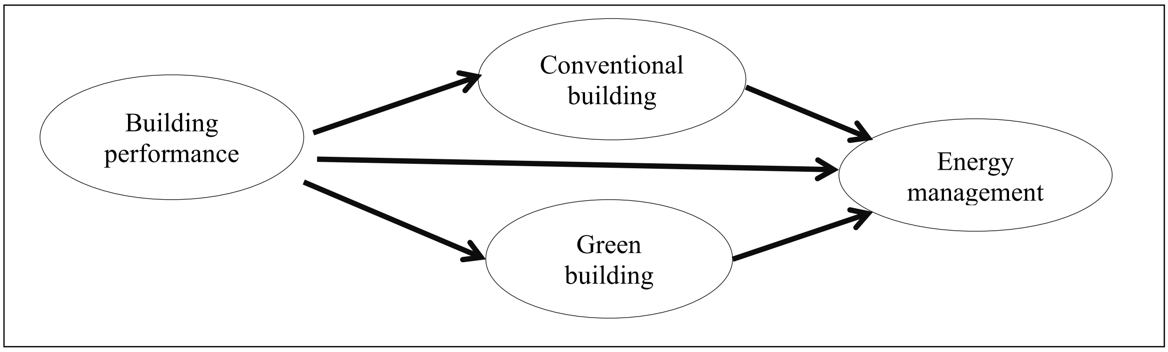

Figure 1. The simplified conceptual model for the analysis of energy management for the research

The GBI is Malaysia's first comprehensive rating system and was created by the Association of Consulting Engineers Malaysia and the Malaysian Institute of Architects to help Malaysia achieve its sustainable development objectives. GBI evaluates the environmental design and performance of green buildings in Malaysia based on six primary criteria—sustainable site planning and management, materials and resources, water efficiency, indoor environment quality, innovation, and energy efficiency. The performance of green office buildings is compared with that of conventional office buildings based on building performance factors. Figure 1 displays a simplified conceptual model for the research. The research would examine the relationship between the carbon footprint and greenhouse gas (GHG) comfort index in office buildings with human behaviour toward the development of a baseline model.

2. Background and conceptual framework

According to previous research, one of the primary industries with a substantial impact on the SDGs is the built environment sector (Biggart 2013; Olanrewaju, et al. 2019; Spiegel & Meadows 2010). According to reports, buildings utilize more than 40 percent of the total of the world's energy, 15 percent of the world's freshwater, 50

% of the fluorocarbons released, 40 % of the materials created for landfills, 25 % of the wood collected, and 45 % of the energy used for operations (Wood 2009 & Olanrewaju, et al. 2018). Office buildings use a significant profile of energy on daily basis. For instance, office buildings account for around 20% of all energy used by buildings. This energy is mostly utilized for lighting, refrigeration, ventilation cooling, computers, office equipment, water heating, space heating, and other services.

Therefore, several million metric tonnes of CO^2 will be saved if the office building is built, operated, and planned to use less energy and water while reducing carbon emissions (Olanrewaju & Chong 2021, Nugradi 2022). Studies show that occupants of green buildings are happier and more satisfied than those of conventional buildings (Symonds et al. 2019; Aminuddin et al. 2012; Li et al. 2018; Meyer 2019). The advantages of green buildings include less waste production, higher interior environmental quality, increased productivity, lighting, acoustic management, thermal comfort, and general occupant well-being. A global temperature increase has been recorded in recent years, and it is expected to be on the rise in the upcoming decades. In tandem with the global temperature increase, human behaviour was found to be shifting towards more aggressive, especially in increasing the emission of carbon dioxide in buildings. Utilizing the beneficial advancements in equipment energy efficiency that contribute to overall energy performance is crucial for reducing carbon emissions. The efficiency of the heating and hot water systems, the output of any solar energy equipment, reduced conduction and ventilation, additional internal heat, solar input, and other factors all affect a building's energy performance, which is expressed in terms of energy consumption.

Several international green rating tools (BREEAM, LEED, GreenStar, Green Building Index, and Green Mark) suggest that the level of the energy performance of a building can be identified based on several criteria of a structure, such as thermal performance of the building envelope, air conditioning system, building envelope, natural ventilation, daylighting, artificial lighting, lifts, and escalators, energy efficiency practices and features, and renewable energy. To assess various types or categories of efficiency alternatives and determine the entire cost of energy consumption of buildings, energy modeling is used to anticipate energy consumption, energy cost, comfort index, heat transfer, carbon footprint, and carbon emission. Besides that, energy modeling can be used to simulate human behavioural changes, and the alternation needs to be made based on the simulation results. As such, it is highly warranted to use energy modeling to predict human behavioural changes and suggest the alternations that need to be made to make the working environment more conducive. Therefore, a comparative building simulation analysis will be carried out in this research study between a conventional and a green building to identify the relationship between these two buildings in terms of energy consumption, comfort index, carbon dioxide (CO^2), and heat transfer. Literature in this space is, however, very scanty and just growing. Figure 2 provides a visualization of the network of authorship by country.

According to the size of the nodes, the country with the most overall connection strengths is shown in the network of authorship by countries depicted in the figure. There are 145 links overall, with 420 total link strengths, as shown in the figure. With 490 documents and 213 total links, Malaysia has the highest total link strength among the top 15 countries, followed by the United Kingdom with 52 documents and 89 total links, Japan with 42 documents and 56 total links, Australia with 22 documents and 50 total links, Singapore with 16 documents and 41 total links, Thailand with 8 documents and 35 total links, South Korea with 6 documents and 29 total link strength, followed by Hong Kong with 5 documents and 24 total link strength, United State with 19 documents and 23 total link strength, South Ireland with 5 documents and 17 total link strength and Philippines with 7 documents and 17 total link strength. South Africa obtained the least in the list with 6 documents and 16 total link strengths. The majority of Malaysia-related documents, however, are not based on academic works.

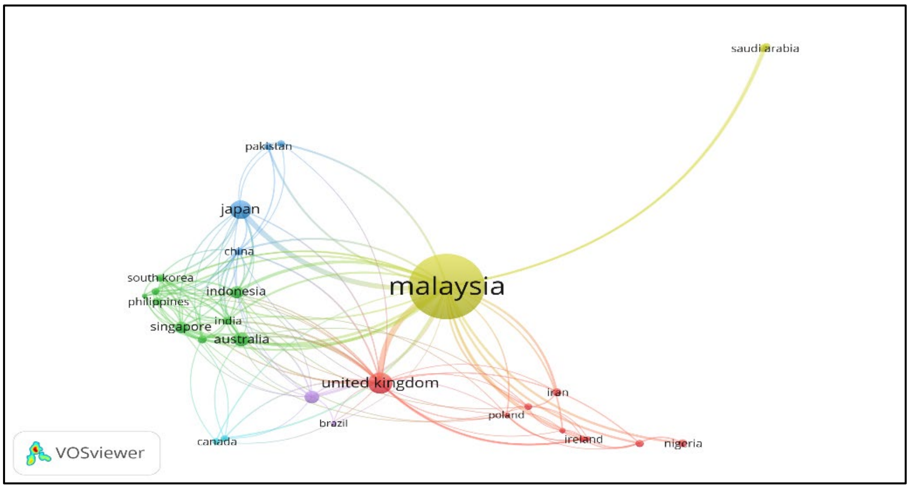

Figure 2. Country co-authorship network

In addition, the few articles/documents only mention the Green Office and Malaysia in particular in passing. For instance, in a search in the ScienceDirect database using the following keywords thermoregulation, thermal comfort, green building, post-occupancy evaluations, and office buildings, Malaysia returned 152 related articles. All the searches on the online databases were conducted on 25 October 2022. Generally, upon entering the keywords, the titles of the results generated will be examined, and only after that will the abstract and conclusion of the relevant articles be read further. If the abstract and conclusion contain relevant information, the article will be considered further. In the articles, emphasis is placed on the presence of 'green office buildings" and 'Malaysia, and only after that will the abstract and conclusion of the relevant articles be read further. If the abstract and conclusion contain relevant information, the article will be considered further. In the articles, emphasis is placed on the presence of "green office buildings" and "Malaysia." Upon completion of this exercise, it was inferred that empirical research on green office buildings is required in Malaysia to spur the demand for green buildings and to provide guidance to the building industry.

2.1 Workplace environmental behaviour

Employee involvement in workplace environmental behaviour, workplace green behaviour, or workplace pro-environmental behaviour results in improvements to the sustainability of the environment. These behaviours cover both in-role and out-of-role actions related to sustainable business strategies (Parida, 2020).

2.2 Occupant energy behaviours

According to Grover (2019), an occupant's energy behaviour is described as their interaction with the building's systems to achieve the desired level of personal comfort inside spaces. The term "behaviour" refers to "observable actions or reactions of a person in response to external or internal stimuli, or respectively actions or reactions of a person to adapt to ambient environmental conditions, such as temperature, indoor air quality, or sunlight. Building parameters (climate conditions, building typology and functions, architectural environment design, space layout, and maintenance) and occupant characteristic parameters (state of occupants like presence or absence in space, socio-economic and sense of ownership) can be used to classify the factors that occupant energy behaviour in a building to achieve the design comfort and satisfaction. Any modification to these variables may result in unwanted occupants interacting with the environment.

Experts have identified two key aspects of occupant behaviour that influence a building's performance for energy use and comfort: adaptive behaviour, and non-adaptive behaviour. When occupants take steps to customize the indoor environment to suit their wants or tastes, such as interacting with the building envelope (such as windows, blinds, and shades), control systems, and other factors (i.e., thermostats set points, fans, radiator valves). Inhabitants can also modify their layers of attire to better fit their surroundings. An action, such as opening a window, falls under the category of non-adaptive behaviour. Non-adaptive behaviour relates to the outcome, such as the location of an opened window. These are the results of measurable triggers, such as indoor building and space conditions, but occupant contextual factors also have an effect. Both passive and active effects of occupants on a building's energy usage can be observed. The occupancy section of an energy simulation tool can consider the passive effects of metabolic heat generated by a given occupancy pattern, but it is impossible to predict their active behaviour when it comes to interacting with control systems and building components like openings, adjustments to blinds, and the use of electrical appliances.

According to Nia et al. (2022), occupants' behaviour regarding energy is influenced by their comfort, particularly their thermal comfort. Physiological adaptation, psychological adaptation, and behavioural adaptation are the three categories into which human behaviour can be divided. These three adaptations are influenced by the regional climate, social environment, and cultural practices. The primary mechanism by which people modify their surroundings or themselves to maintain thermal comfort is behavioural adaptation. People alter their appearance or conduct in other ways, such as posture or activity, to alleviate discomfort by opening windows, pulling curtains, or moving to a more comfortable position, people alter their surroundings to maintain thermal comfort. Utilizing mechanical devices like fans, heaters, and air conditioners are instances of adaptive behaviour. For instance, the results of Bonte and Thellier's case study on an office indicate that changing the set-point temperature, the blinds, and the lights is the key behaviour that affects overall energy use. In addition, altering the set-point temperature, wearing warm clothing, and closing the curtains are the primary thermal comfort behaviours.

Prafitasiwi and Rohman (2019) confirmed that in social psychology, the fact that several factors, including attitudes toward conduct, perceived behaviour control, subjective norm, and intention, can affect how people behave can often lead to complexity. Due to their complexity, social factors have turned into one of the main obstacles to attaining sustainable building, according to several academic studies. The behaviour of building occupants, however, plays a crucial part in whether energy savings are successful. One of the elements that have the biggest impact on energy consumption in the building sector is social variables including behaviour, way of life, and culture. Energy-saving refers to consumer energy consumption decision-making strategies used to cut down on energy use. Changes in building occupants' energy-saving behaviour can reduce electricity use by up to 10%.

2.3 Requirements of environmental behaviour in green buildings

Every structure functions either explicitly or implicitly by how its occupants act and react, and similarly, green buildings' total environmental advantages depend on occupant behaviour. The effective use of these resources is largely determined by specific human behaviour. The technical and cost-effective solutions offered by green buildings are, however, constrained by particular cognitive and behavioural difficulties, for instance, while people are inside a building, they may conserve energy. Another instance is when people use artificial light sources instead of the natural daylighting that the building was intended for to maximize their comfort. These examples are part of the behavioural issues that affect building occupants and materially alter the effectiveness of green structures. Residents' lack of interaction with the green aspects of green buildings is frequently impacted by their ignorance of the buildings. Some researchers tend to use occupant responses in which they rate their satisfaction through behavioural feedback to develop their comprehension of these challenges.

There is a strong likelihood that occupant perceptions and, consequently, behaviour, will be very varied and unexpected. This is the main area of concern, and designers frequently lament their inability to manage each occupant's behaviour to attain high environmental quality. From this angle, there is controversy surrounding the occupant-oriented design methodology, particularly when it appears that some occupants' preferences and demands may not be taken into account by designers. Employees are more stressed when they don't have control over or responsibility for the setting in which they work. As a result, their work performance, including productivity and well-being, may be most impacted. This line of thinking suggests that for employees to contribute to and create value for organizations, their environmental behaviour at work should take into account both in-role and extra-role performance. However, the organization's initiatives and policies have a significant impact on employee behaviours that predict performance (Parida 2020).

2.4 Performance measurement of green buildings

Measuring the operational performance of green buildings is the most often used method of performance evaluation. A well-liked technique used by academics to gather information on the operational efficiency of buildings is post-occupancy evaluation (POE). The Post-Occupancy Evaluation (POE) technique has been used to contrast efficiency with the necessary standards based on the interactions and perceptions of the occupants with the buildings. A tactical instrument for assessing the project's efficacy is the POE of a green building. Numerous techniques, including questionnaires, interviews, role plays, and case analysis, can be used to evaluate the occupier. Getting input from the building's occupants is the main focus of this process. Topics covered include energy usage, indoor air quality, mobility inside the building, the type and level of maintenance, noises, and artificial lighting. Depending on the structure type and the purpose of the evaluation, different information is needed on a POE form (Olanrewaju & Chong 2021). Humans have huge and constantly changing demands. Building designers must therefore comprehend the behavioural sciences, which study the interactions between users and the built environment. Environmental factors that affect an office setting's inhabitants' productivity and mental health, such as temperature, noise, and air quality, are categorized as the main stressors. By engaging in thermoregulation and behavioural adaptation within the constraints of thermal stress and physical activity, thermal comfort can be preserved. The comfort is brought on by temperature, humidity, wind speed, and radiation (Huang, et al. 2015; Ainun, et al. 2022).

Thermal comfort is a crucial component of enclosed spaces since it reflects how pleasant building occupants are. There are two main approaches to determining thermal comfort, namely analytical and adaptive approaches. The energy performance of a building depends on several determinants, including the thermal performance of the building envelope; location weather; air conditioning system; natural ventilation, daylighting; artificial lighting; lifts and escalators; building typology; space layout; maintenance; gender, age, employment, family size; household size; level of education; awareness of energy profile; occupant weight; mental health; marital status; type of building; method of construction; use of the building; class of buildings (i.e. conventional or green buildings) (Olanrewaju et al. 2019; Alfakih & Kalyoncuoglu 2022). Weighing all of the aforementioned factors that affect how people behave. As of right now, no direct research has been published on the energy modeling technique utilized to ascertain how temperature fluctuations affect human behaviour. Delzendeh et al. (2017) stated that according to the post-occupancy energy use project analysis, there was a significant difference in the total energy consumption between two flats in the same building block because of different occupant behaviours, such as varying levels of presence in a building, varying occupancy levels, and variations in the occupants' thermal preferences. The occupant preferences and human behaviour were major factors in the discrepancy between expected and actual building energy performance. The most ignored factor that "might not be included as part of the energy design" along the continuum of design, building, operation, and maintenance is occupant behaviour (Melo et al. 2019; Farooq et al. 2021).

Parida (2020) argued that due to its current structure, the POE is unable to take into account the occupants' social, psychological, and behavioural factors that may affect how well a building performs overall. Although it may appear at first glance that technical factors have a significant influence on behaviour, environmental literacy needs to be addressed if green building techniques are to be adopted. This is because it takes behavioural sustainability as well as technological sustainability to comprehend and assess crucial performance in green buildings. A disengagement from technical measurements of a structure may reveal significant physiological, social, and behavioural difficulties among building occupants. It is necessary to move away from the physical environment and focus more on the social backdrop that shapes human behaviour rather than the actions of the inhabitants. Concerning green building design, management has the opportunity to demonstrate both their knowledge of green buildings and their comprehension of the effects that these structures have on inhabitants' behaviour. This human factors viewpoint offers a fresh look at recent studies on post-occupancy evaluation (POE).

3. Proposed research methodology

There is a paucity of research that examines the epistemology and ontology of the inhabitants' behaviour, although scholars have started to think about the methods to investigate occupant behaviour in green buildings. Hence, the first question is: what is the building's occupant behavior? A building is an enclosure, either permanent or temporary, in which activities are performed or outside of it. Human behaviour is defined as a person's actions (and reactions), activities, or processes and reactions. These actions, activities, and processes are typically initiated in response to situations or agents that may be induced internally or externally (Olanrewaju et al. 2015). Building occupant behaviour refers to how occupants search for, use, and evaluate the building's performance to derive and increase their comfort, productivity, and satisfaction in the building (Olanrewaju, et al. 2015). Occupant behaviour in buildings entails occupant interactions with the building systems and the adaptation of the occupants (e.g., changing clothing, and having hot or cold drinks) (Yan et al. 2017). Comfort and climate control are critical components of maintaining productivity in an office building. Energy management seeks desirable comfort while reducing energy consumption to reduce operational costs and reduce its impact on sustainability. Therefore, the first step in determining where to make cuts is to examine energy usage within a building. How occupants use energy depends on their behaviour. Climate control, lighting, and water usage are the primary approaches to reducing energy consumption in office buildings. The research is partitioned into phases as follows:

3.1 Phase 1

Energy modeling analysis will be conducted in the two (2) selected office buildings, which are green office buildings and conventional office buildings with similar dimensions and features for comparison. Schedule data for 12 months for each of the buildings would be obtained from the building management (e.g., maintenance organizations) for simulation using IESVE software. The heat movement in the building and the thermal equilibrium attained in the prescribed space will be visualized using the simulation results. By simulating the room temperature at various temperatures, energy modeling analysis will be utilized to track the carbon dioxide emissions and energy consumption for the allocated space. Designing the area for a comfortable working environment and maximizing energy use in the buildings will be done using the IESVE results. Several predominant elements will be tested using energy modeling, namely, Model IT, Suncast, Macroflo, Apache Sim calculation, and VE Compliance.

3.2 Phase 2

Heat transfer into the building would be analyzed using a thermocouple meter. Various points inside the designated space would be fitted with thermocouple wire to record the temperature over the experimental period. Data from the external of the building will also be recorded as the supporting parameters to improve data reliability because the data collection process will be collected for 12 months for each of the selected buildings. For the average value, at least two readings would be taken. Deviation from the normal condition, such as continuous rainy days and dry days, would be recorded for the extreme condition evaluation. At the same time, the human body temperature of the person occupying the space and office equipment would be recorded using a digital thermometer. The difference between the human body temperature and the closed space would be analyzed to determine the effect of heat transfer in the closed space. Simultaneously, computational fluid dynamics (CFD) would be used to simulate the heat flow into the designated space. The dimensions of the space would be specified and drawn using Solidworks©. The data obtained through the simulation would be evaluated together with the real-time data. Data validation would be performed to verify the model used in CFD.

3.3 Phase 3

Office occupants' feedback on thermal comfort will be recorded by administering a set of survey questionnaires to the occupants in the buildings. The survey would involve occupants that have used the office building for more than 6 months. This is to allow the survey to be used on the occupants' experience rather than perception. The questionnaire aims to identify the comfort level of each of the occupants since every individual has a different level of comfortability in different sets of temperatures. Approximately 300 occupants will be selected randomly to participate in this survey. Questionnaires based on the American Society of Heating, Refrigerating, and Air-Conditioning (ASHRAE) seven-point thermal sensation scale will be conducted simultaneously with the heat transfer analysis session. The parameters on the survey questionnaire forms are related to internal room temperature, humidity, air movement, radiant temperature, noise, metabolic rate, and clothing insulation. All the obtained data will be analyzed using SmartPLS. Data obtained from the questionnaires will be used to verify and validate the data on the comfort index results generated by IES software.

3.4 Phase 4

Findings from energy modeling, heat transfer, and questionnaires will be used in proposing new designs for conventional office buildings with green features. The proposed designs will be designed using SketchUp, 3-D Modelling Software Version 8, and AutoCAD Software and Solutions. The software enables us to visualize the proposed design on energy saving, which is embedded with green building concepts. The proposed design could be adopted in conventional office buildings in the future. A 3-D printer will be used in presenting the proposed models. One office building (green building) with the highest specifications and another office building (conventional building) with the lowest specifications in terms of energy saving will help to create a new baseline model which integrates conventional office buildings with green office buildings. 3-D printing will also be used to visualize the model for clearer understanding.

From the foregoing, the following hypotheses were formulated to be tested:
H1: The increment in the number of humans in the office building is expected to increase the heat production
H2: Heat production in the office buildings would increase humidity and temperature which makes heat stress to be higher
H3: Hot temperature induces antisocial and pro-social behaviour

Similarly, the following objectives were formulated to be achieved:
Objective(s)
OBJ I: To elucidate the relationship between energy consumption, comfort index, carbon dioxide, and heat transfer between green office buildings and conventional office buildings.
OBJ II: To determine the influence of human behaviour based on simulation results and survey results.
OBJ III: To develop a new proposed model for an existing conventional office building with green features.

Similarly, answers would be provided to the following questions:
QI: What are the relationships between energy consumption, comfort index, and carbon dioxide (CO^2), and how heat transfer will be conducted between the green office building and conventional office building?
QII: How human behaviour will influence the stimulation result (comfort index) and survey result?
QIII: How to develop a proposed model for an existing conventional office building?

From the foregoing, the following hypotheses were formulated to be tested:
H1: The increase in the number of humans in the office building is expected to increase heat production.

H2: Heat production in office buildings would increase humidity and temperature, which makes heat stress higher.
H3: Hot temperatures induce antisocial and prosocial behaviour.
Similarly, the following objectives were formulated to be achieved:
OBJ I: To elucidate the relationship between energy consumption, comfort index, carbon dioxide, and heat transfer between green office buildings and conventional office buildings.
OBJ II: To determine the influence of human behaviour based on simulation results and survey results
OBJ III: To develop a new proposed model for an existing conventional office building with green features.
Similarly, answers would be provided to the following questions:
QI: What are the relationships between energy consumption, comfort index, and carbon dioxide, and how heat transfer will be conducted between green office buildings and conventional office buildings?
QII: How will human behaviour affect the stimulation outcome (comfort index) and survey outcome?
QIII: How to develop a proposed model for an existing conventional office building?

The research design that is suitable for a topic like this is the cross-sectional survey and simulation/experimental research. This involves the analysis of data collected from surveys and simulation results. Figure 3 displays the research flow chart. As may be seen, the research 'commences with a qualitative inquiry into the performance of green buildings.

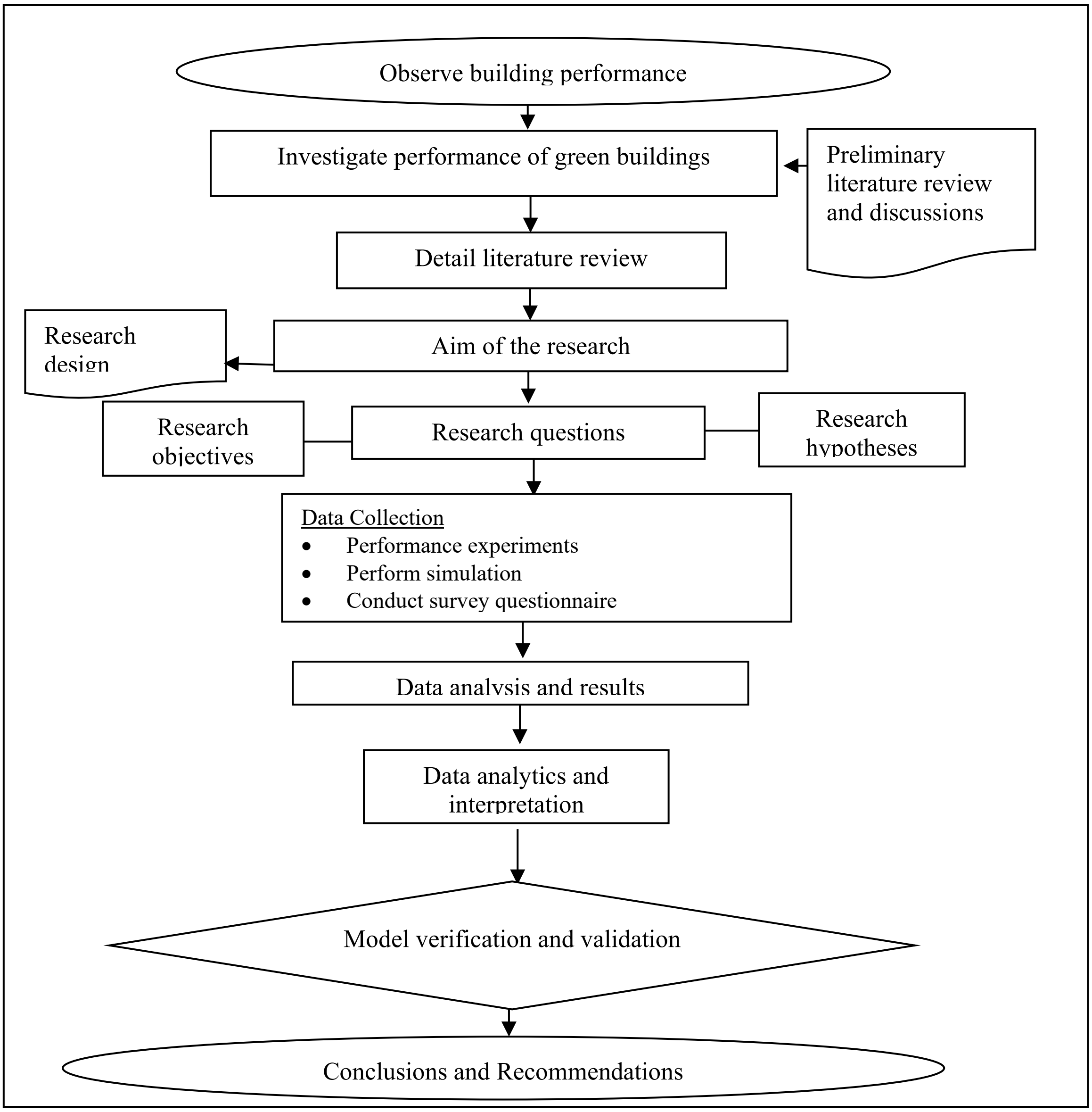

Figure 3. Research Process

4. Conclusion and further research

Even though research on this topic is increasing, it is still in its infancy. Most of the extant studies are based on literature reviews or sponsored studies. The list of what the researchers think to be the reality of energy management in office buildings will include many superfluous constructs while leaving out many vital constructs if this is not the case. The research design for the main research was presented. This research argued for multiple techniques of data collection to predict the model performance of the buildings. Occupant behaviour has a significant impact on the building's energy consumption. To increase office occupant productivity and satisfaction and to maximize the building's energy performance, there is a need to model the energy performance of the buildings using multiple approaches of the survey, simulation, case study, and experiments. In particular, occupant behaviour is not assimilated into the building energy management model.

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