EXAMINING THE RELATIONSHIP BETWEEN OCCUPANTS' ENERGY-RELATED BEHAVIORS AND SPATIAL CONTEXTUAL FACTORS USING AN AGENT-BASED MODELING APPROACH

By

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ABSTRACT

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Environmental Design focuses on the interaction among the naturally occurring environment, human-built environment, and humans themselves. Underlying environmental design is energy performance. Energy performance is one of the environmental design aspects that contributes to the sustainability of the built environment. The built environment – or building's –energy performance depends on technical and human factors. Technological factors have been exhaustively studied, not surprising given the length of time building have been around. Human factors, however, while having an impact on buildings' energy performance, have only recently received considerable attention. Human factors, such as occupant behavior, has been identified as one of the factors that contribute to the inconsistencies between predicted and measured energy consumption. And energy consumption and conservation have been concerns for decades. The effect of specific building designs, namely spatial factors, that have on occupants' behavior, have been underestimated in previous research.

The purpose of this research was to examine the relationship between spatial factors and occupants' energy-related behaviors. A survey was conducted to study occupants' behaviors regarding operating windows and adjusting blinds in multifamily residential buildings. The survey was conducted during the three months of both summer and winter. The responses were statistically modeled, and then a preliminary agent-based model was used to simulate occupants' interaction with buildings' systems and predict the resultant energy consumption.

The proposed agent-based model accounted for the occupants' drivers to interact with the environmental systems within a building, such as air quality, thermal, visual, and acoustical conditions. It

defined occupants' needs to control indoor environmental conditions based on spatial factors such as site characteristics, building features, space type, and furniture layout. That is, a good furniture layout (as suggested in this current study) can help people perform more sustainable behaviors. Additionally, occupants would need to achieve a multi-comfort level and may prioritize indoor environmental quality criteria based on their individual preferences. The proposed model also accounted for the psychological factors through utilizing the Theory of Planned Behavior.

The survey results showed that the constructs of the Theory of Planned Behavior could be used to predict occupants' behavior of operating windows and adjusting blinds. It also explained that occupants' beliefs of operating windows and adjusting blinds are consistent across living and sleeping areas. Responses showed that the furniture layout influenced their interaction with windows and blinds. Most occupants indicated that they operate windows to control the indoor temperature and air quality. Some of the occupants mentioned that they prefer to sit close to the window to enjoy natural daylight and outdoor views. However, there was no significant relationship among the occupants' beliefs of operating windows and adjusting blinds, and the site characteristics such as the orientation, and the building features such as the floor level.

The results of the proposed agent-based model simulation showed that occupants' beliefs regarding operating windows and adjusting blinds affect the building's energy consumption. One of the main limitations of this study is collecting subjective data of occupants' behavior of operating windows and adjusting blinds using a survey. Suggestions for future research include incorporating monitoring studies to collect objective data to support the survey results. Future research could also incorporate the proposed agent-based model with building energy simulation software to increase the accuracy and realism of the predicted building energy performance. Designers could benefit from this tool to make informed decisions based on the simulated energy-related occupants' behavior.

This dissertation is dedicated to my husband, Ahmed, and my sons, Yahia, Adam, and Noah.
Thank you for always believing in me.

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CHAPTER ONE:

INTRODUCTION

According to Moore (1984), the research term “environmental design” emerged in the 1950s. Environmental design is interdisciplinary in nature with multiple disciplines contributing to its growth and development. Among their varied interests, environmental design researchers investigated the relationship between the social, natural, and built environments (Moore, 1984). In doing so, environmental design research borrowed theories and principles from its many disciplines, including human ecology. The Human Ecosystem Model, developed by Bubolz, Eicher, and Sontag in 1979, is a theoretical framework that have been applied across disciplines and this is applicable here. Guerin (1992) suggest that the Human Ecosystem Model provided researchers with a visual framework that presents relationships between human beings and their social, natural, and built environments.

While this appears theoretical in nature, environmental design has practical applications. For example, the energy crisis that occurred in the 1970s resulted in a push for the market to find better ways to design, construct, operate, and maintain buildings (Hemsath & Bandhosseini, 2017). Just two decades later, the United Nations' Rio Declaration (UNCED, 1992), argued that sustainable buildings should account for environmental, economic, and social factors comprehensively. From gas crisis to environmental buildings in just twenty years. Of course, the term “green building” emerged, which was an approach that encompassed a broad range of sustainable strategies in the structure design process. It provided standards that assist in delivering high performance and environmentally friendly buildings (US Green Building Council, 2015).

According to US Green Building Council, (2013), there are two major approaches to designing environmentally friendly buildings. The first is a prescriptive path, and the second is a predictive path. The prescriptive approach is based on the green building notion, which is known by engineers and designers as the prescriptive path to high-performance buildings. Different types of green building certifications or rating systems exemplify the prescriptive path. This path allows a design team plan to achieve sustainable criteria during the design process. One important common credit category touched upon in the prescriptive path is the Indoor Environmental Quality (IEQ). IEQ, as will be discussed in greater detail later, is extremely important and warrants some attention now. IEQ refers to thermal comfort, visual comfort, acoustical comfort, and air quality within interior spaces (USGBC, 2019a). Thermal comfort is the outdoor climate, the building systems, and the occupants themselves (Mahdavi & Kumar, 1996). Visual comfort, as the term suggests, is the color temperature of lighting, the reflectance of surfaces, the balance of lighting levels within the field of vision (Anderson, 2014). Acoustical comfort are sound transmission and background noise (Croome, 1977). Indoor air pollution is commonly known. Daily activities, such as cooking, heating, and lighting, are primarily responsible for indoor production of pollutants as well as the building materials and products. Secondary sources are the outdoor to indoor transport of contaminants through building openings (Mitchell et al., 2007; Wallace et al., 2003).

Returning to the two major approaches to designing environmentally friendly buildings, the second approach to achieve high-performance buildings is the predictive path that comprehensively assesses IEQ. This path is based on technological advancement that has led to the development of different design support tools. For example, various types of building performance simulation software were created to mimic the effect of environmental conditions on a virtual building model. Different interfaces of building performance simulation software were designed for different audience groups and simulation purposes. Most building performance simulation software programs included one or more simulation capabilities such as lighting, thermal, acoustical, or airflow. Eventually, these software tools aid designers to predict building performance before the building is being constructed (Anderson, 2014; Hemsath & Bandhosseini, 2017).

Researchers recognized that buildings’ energy performance depends on the deterministic buildings’ physics and the stochastic occupants’ behaviors (Calì et al. ,2016; Fabi et al. 2012; Fujii & Tanimoto, 2004; Hong et al. 2015).; They claim that not adequately considering occupant behavior may result in discrepancies between actual and estimated energy consumption. Therefore, these researchers emphasized the need to study factors that drive occupants’ behavior to interact with buildings’ systems. In addition, they highlighted the importance of developing accurate and realistic occupant behavior models that consider the dynamics of the relationship between multiple factors, including indoor environmental quality, occupant behavior, and building energy performance. Finally, they recommended embedding occupants’ behavior models into building energy performance simulation software to increase its accuracy.

A group of researchers noticed the need for a unified approach to study energy-related occupant-building interaction (Yan et al., 2015). Therefore, a unified technical approach was developed, which consists of three stages: monitoring, modeling, and simulating occupant behavior (Hong et al., 2016). Monitoring encompasses occupant movement and presence as well as adaptive behaviors. Adaptive behaviors are occupants’ interaction with passive and active building systems to control their indoor environmental conditions. Occupants’ interaction with passive building systems includes operating windows and/or adjusting blinds. They also interact with active building systems such as setting thermostats and/or switching artificial lights. Occupants’ adaptive behavior was extensively studied since the early 1950s (Dick & Thomas, 1951) due to their significant influence on buildings’ energy performance. Researchers also examined contextual factors that influence the occupants’ behavior related to controlling indoor environmental conditions. They indicated that interior design is one factor that has a significant impact on occupants’ comfort and thus influences their behavior (Fabi et al., 2012; O'Brien & Gunay 2014; Stazi et al., 2017).

Numerous models on occupant behavior have been developed to capture the dynamic occupant-building interaction (Anderson et al., 2014; Andrews et al., 2011; Haldi & Robinson, 2011). These studies that developed such models are based on intensive monitoring data that establish a relationship between an environmental factor and targeted operations. This current study identified two research frameworks that are designed to standardize the study of the relationships among environmental, behavioral, and built environments. The first represents a systematic framework for energy-related occupant-building interaction. The Drivers, Needs, Actions, and Systems (DNAs) framework is developed based on four components: drivers behind occupant behavior, occupants' needs that buildings should meet, actions that occupants take to restore their comfort, and building systems that the occupants interact with causing a change in the use of building energy (Hong et al., 2015). The second research framework studied the relationships among the users, activities, and spaces. Clearly, this framework was developed to assist the building design team in developing automated efficient space planning (Kim & Fischer, 2014). It is these frameworks the lead to the development of more advance modeling involving the interaction between occupant and building.

Eventually, occupant behavior models were integrated with building performance simulation programs to quantify the impact that the occupant behavior has on the energy performance of buildings (Yan et al., 2015). Agent-Based Modeling (ABM) is one of the methods used to simulate energy-related occupant behaviors and to incorporate it into building energy simulation programs (Hong et al., 2015; Hong et al., 2016). This approach is called co-simulation in which an agent-based model and a building energy simulation software are coupled to run simultaneously and exchange information in real-time. This process has been shown to increase simulation accuracy and reveal emerging phenomena that advances the understanding of building-occupant interaction (Lee & Malkawi, 2013; Lee & Malkawi, 2014).

An ABM is a dynamic computational model that simulates a complex system structure and its processes. In ABM, a system is modeled as a number of autonomous entities known as agents. Agents, environments, and the interactions between them are key elements of ABMs. An agent is equipped with attributes describing its characteristic states, rules guiding its decision making, and actions performed after the decision is made. Modeling the decision-making process is one of the major challenges of ABM. (Ligmann-Zielinska, 2017). Individual behavior has long been studied and from a variety of disciplines. This is not new. But modeling the decision-making process of individuals is relatively new and were developed, in part, based on these studies.

More specifically, Wilson and Dowlatabadi (2007) studied decision-making models related to residential energy use. Some of these models were based on psychological variables, and others emphasized contextual physical factors (Wilson & Dowlatabadi, 2007). Sovacool (2014) proposed that incorporating social science disciplines could contribute to the depth and breadth of energy study research and recommended integrating social sciences with physical sciences into energy research (2015). The theory of Planned Behavior, developed by Ajzen (1985), is a well-established theory in the field of psychology that has been widely adopted by environmental psychology researchers to study environmental behaviors (D'Oca et al., 2017).

According to Ajzen (1985), behavioral intention is the only determinant of actual behavior. Ajzen addressed that behavioral intention could be predicted through three determinants that are attitudes, subjective norms, and perceived behavioral control. However, Ajzen (1985) highlighted that the weight of each of the three determinants varies depending on the behaviors and the population of the study. While intentions can be predicted by attitudes, subjective norms, and perceived behavioral control, these in turn are derived by behavioral beliefs, normative beliefs, and control beliefs. Therefore, the main strength of the Theory of Planned Behavior is that relies on one's relative cognitive development that is essential for realistic human behavior modeling (Fishbein & Ajzen, 2010; Lee & Malkawi, 2014).

Individuals' behavior is important because of the way it interacts with their environment, specifically buildings. There are several researchers who addressed this. For example, Yan et al. (2017) discussed that reducing energy and carbon dioxide emissions in buildings requires interdisciplinary understanding of the occupant-building interaction. D'Oca et al. (2017) introduced an interdisciplinary framework to study energy-related occupant building interaction. Their framework incorporates theories from building physics and social psychology. Using data that validated their framework, they modeled occupant behavior and incorporated it in Building Energy Simulation software (Hong et al., 2018). While this yielded interesting results, occupant-building interaction remains a highly complex problem that needs further investigations.

1.1. Problem Statement

High-quality buildings provide balances among indoor environmental quality, energy performance, and occupants' well-being (Roulet et al., 2005). However, achieving the balances is still challenging because of the complexity and contradictions among these criteria. Regarding energy performance, Green building rating systems and building performance simulation software assist researchers in making sustainable energy-related decisions. However, studies showed that there are still differences between the measured versus the designed energy use intensity (Calì et al., 2016; De Wilde, 2014; Frei et al., 2017). In addition, studies revealed that some green-certified buildings consume more energy than the code baseline (Turner & Frankel, 2008).

There are also issue between energy usage and occupants' comfort. Previous studies relate the inconsistencies between predicted and actual energy consumption to the occupant's behavior (Hong et al., 2016; Hong et al., 2018; Yoshino et al., 2017). It is generally agreed that there are technical performance standards to achieve energy-efficient buildings. Until recently, researchers have given little attention to occupants' behavioral factors (i.e., actions) that might influence the buildings' performance (Calì et al.,2016; Hong et al., 2017; Hong et al., 2018).

Fabi et al. (2012) identified that the way in which occupants operate windows in residential buildings is influenced by contextual factors such as the dwelling type, room type, and room orientation. Stazi et al. (2017) indicated that researchers studied blind use since 1978; however, most of the studies focused on office buildings. O'Brien and Gunay (2014) examined contextual factors that influence the occupants' behavior to control indoor environmental conditions. They indicated that interior design is a factor that has a significant impact on occupants' comfort and thus influences their behavior. In addition, Pereira, and Ramos (2019) indicate that occupants' motivation to interact with building control systems may vary depending on the spatial and environmental parameters. They also recommended investigating occupants' motivations at the compartment scale.

Some unresolved issues have been identified while reviewing different methods of occupant energy-use monitoring and modeling approaches. For example, Yan et al. (2015) argued that contextual factors are often underestimated in occupant behavior monitoring and modeling studies are just reported along with other measured quantities of interest. Therefore, researchers argue that more studies and models are needed to represent the diverse human, environmental, and contextual factors (Hong et al., 2015; Yan et al., 2015).

Energy-related building occupant interaction represents a complex problem that encompasses the relationship among the natural environment, built environments, and occupant behaviors. There was a gap in the literature review in which this research can contribute. One of them is the need to study the underlying reasons behind the occupants' adaptive behavior to control their multi-comfort level, including thermal, visual, acoustical, and air quality. More attention is required for the spatial factors, and occupants' behavior, that were overlooked in previous research.

1.2. Research Goal and Objectives

The goal of this research is to examine the residential occupant adaptive behavior to control indoor environmental conditions with a focus on their interaction with passive building systems such as operating windows and adjusting blinds in summer and winter. This study, thus, examines the influence that spatial factors (such as site characteristics, building features, space type, and furniture layout) have on occupants' behavioral beliefs to operate windows and adjust blinds. This current research incorporates the Theory of Planned Behavior (Ajzen, 1985) as the theoretical background that guides the exploration of occupants' energy-related behaviors (i.e., their decision-making process) based on their beliefs, attitude, subjective norm, perceived behavioral control, and behavioral intention. In addition, this study proposes an agent-based model that represents energy-related occupant behavior. This research contributes to increasing the accuracy and realism of buildings' energy performance prediction by accounting for occupants' behavior. It is expected to provide designers with a framework, and possibly a tool, to inform their decision making at the early stages of the design process.

Specific Objectives

To meet the research goals, this study sets three specific objectives, followed by research hypotheses. The objectives are as follows.

1. To investigate occupants' behavioral beliefs, attitudes, subjective norms, perceived behavioral control, intentions, and behaviors of operating windows and adjusting blinds in different interior spaces in which various activities are taking place using a self-report questionnaire.
2. To model occupant's behavioral intention towards operating windows and adjusting blinds based on their attitude, subjective norm, perceived behavioral control to predict their energy-related behavior through the Theory of Planned Behavior.
3. To simulate occupants' behavior of operating window blinds and adjusting blinds using Agent-Based Modelling (ABM) to explain the different energy use implications resulting from occupants' behaviors in different interior spaces.

1.3. Research Hypotheses

This research uses the Theory of Planned Behavior (Ajzen, 1985) that focuses on occupants' beliefs, attitudes, subjective norms, perceived behavioral control, intentions, and behaviors. The research hypotheses are presented below.

H1: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with spatial factors.

H1a: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with site characteristics

H1b: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with building features

H1c: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with space type

RQ: How occupants' behavioral beliefs of operating windows and adjusting blinds are influenced by furniture location

H2: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with their attitudes towards performing this behavior.

H2a: Occupants' behavioral beliefs of operating windows are associated with their attitudes towards performing this behavior in the living area during the summer.

H2b: Occupants' behavioral beliefs of operating windows are associated with their attitudes towards performing this behavior in the living area during the winter.

H2c: Occupants' behavioral beliefs of adjusting blinds are associated with their attitudes towards performing this behavior in the living area during the summer.

H2d: Occupants' behavioral beliefs of adjusting blinds are associated with their attitudes towards performing this behavior in the living area during the winter.

H2e: Occupants' behavioral beliefs of operating windows are associated with their attitudes towards performing this behavior in the sleeping area during the summer.

H2f: Occupants' behavioral beliefs of operating windows are associated with their attitudes towards performing this behavior in the sleeping area during the winter.

H2g: Occupants' behavioral beliefs of adjusting blinds are associated with their attitudes towards performing this behavior in the sleeping area during the summer.

H2h: Occupants' behavioral beliefs of adjusting blinds are associated with their attitudes towards performing this behavior in the sleeping area during the winter.

H3: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows and adjusting blinds contribute to the explanation of their behavioral intention to perform this behavior.

H3a: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows contribute to the explanation of their behavioral intention to perform this behavior in the living area during the summer.

H3b: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows contribute to the explanation of their behavior to perform this behavior in the living area during the winter.

H3c: Occupants' attitude, subjective norm, and perceived behavioral control towards adjusting blinds contribute to the explanation of their behavioral intention to perform this behavior in the living area during the summer.

H3d: Occupants' attitude, subjective norm, and perceived behavioral control towards adjusting blinds contribute to the explanation of their behavior to perform this behavior in the living area during winter.

H3e: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows contribute to the explanation of their behavioral intention to perform this behavior in the sleeping area during the summer.

H3f: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows contribute to the explanation of their behavior to perform this behavior in the sleeping area during the winter.

H3g: Occupants' attitude, subjective norm, and perceived behavioral control towards adjusting blinds contribute to the explanation of their behavioral intention to perform this behavior in the sleeping area during the summer.

H3h: Occupants' attitude, subjective norm, and perceived behavioral control towards adjusting blinds contribute to the explanation of their behavior to perform this behavior in the sleeping area during the winter.

H4: Occupants' behavioral intention of operating windows and adjusting blinds affect their actual behavior.

H4a: Occupants' behavioral intention of operating windows affects their actual behavior in the living area during the summer.

H4b: Occupants' behavioral intention of adjusting blinds affects their actual behavior in the living area during summer.

H4c: Occupants' behavioral intention of operating windows affects their actual behavior in the sleeping area during the summer.

H4d: Occupants' behavioral intention of adjusting blinds affects their actual behavior in the sleeping area during the summer.

H4e: Occupants' behavioral intention of operating windows affects their actual behavior in the living area during the winter.

H4f: Occupants' behavioral intention of adjusting blinds affects their actual behavior in the living area during the winter.

H4g: Occupants' behavioral intention of operating windows influences their actual behavior in the sleeping area during the winter.

H4h: Occupants' behavioral intention of adjusting blinds affects their actual behavior in the sleeping area during the winter.

H5: Occupants' behavioral beliefs of operating windows and adjusting blinds affect the building's energy consumption.

H5a: Occupants with positive beliefs of operating windows and adjusting blinds consumes less energy than those who have negative beliefs of those behaviors during the summer.

H5b: Occupants with positive beliefs of operating windows and adjusting blinds consumes less energy than those who have negative beliefs of those behaviors during the winter.

1.4. Significance of the Study

The importance of this research lies in studying the influence that the spatial factors have on occupants' energy-related behavior. Occupants' interactions with passive building systems such as operating windows and adjusting blinds have been studied immensely in previous research. However, most of the previous research focuses on studying one behavior at a time. This research suggests that operating windows and adjusting blinds needs to be considered simultaneously to have a more realistic understanding of occupants' behavior. In addition, this research studies and compares occupants' adaptive behaviors in summer and winter seasons to gain a holistic understanding of occupants' adaptive behavior in the long term. A better understanding of occupants' behavior utilizing windows and blinds simultaneously, alternating in winter and summer, can result in financial savings to those who operate buildings, greater anticipated comfort for occupants, and greater conservations for the environment. It can also provide greater insight into research on this topic.

This research utilizes the Theory of Planned Behavior (Ajzen, 1985) as its theoretical background. The Theory of Planned Behavior is well-established in the field of psychology, and it allows researchers to collect data based on a well-constructed questionnaire (Ajzen, 2006). The Theory of Planned Behavior will enable researchers to predict human behavior based on extensive investigation of their beliefs, attitude, subjective norm, perceived behavioral control, and behavioral intention. It considers individual and social factors that influence human decision making.

The Theory of Planned Behavior was also used in this research as part of the proposed agent-based model to represent the psychological aspect of the occupants' decision-making process. In addition, the study adopts the Driver, Needs, Actions, and Systems (DNAS) framework as a basis for the agent-based model conceptual framework. This novel framework was developed as a collaboration among pioneer researchers in the field of energy-related occupant-building interaction in the United States of America and Europe (Hong, D'Oca, Turner, & Taylor-Lange, 2015). Therefore, it will ensure that the research is following the up-to-date knowledge in modeling occupants' behaviors.

This research is guided by the "User, Activity, Space" framework that is designed initially to study occupants' space use behavior (Kim & Fischer, 2014). This study emphasizes the importance of considering spatial factors when studying occupants' behavior. This research also acknowledges that occupants evaluate IEQ simultaneously, as suggested by Barakat in 2015. This research asks occupants to rank the IEQ, and this information is incorporated in the proposed agent-based model.

Finally, this research proposes an agent-based model that accounts for spatial factors such as site characteristics, building features, space type, and furniture layout. It also accounts for environmental factors and considers the occupants' multi-comfort level such as the thermal, visual, acoustical, and air quality criteria. In addition, it considers occupants' behavior of operating windows and adjusting blinds and their influence on the indoor environmental qualities simultaneously to have a more realistic simulation of occupants' behavior. It acknowledges the psychological factors that influence the occupants' decision making. The proposed agent-based model can be developed and integrated with building energy simulation software to provide more accurate buildings' energy performance estimations. Designers can use this potential tool to design spaces that balance between occupants' satisfaction and energy efficiency.

1.5. Definition of Key Terms

ABM -> Agent-based models are a class of computational models for simulating the actions and interactions of autonomous agents that interact with both its environment and other agents by making behavior decisions.

IEQ -> Indoor Environmental Quality refers to the quality of a building's environment about the health and wellbeing of those who occupy space within it and on building's energy consumption. IEQ is determined by many factors, including lighting, air quality, thermal, and acoustical conditions.

CHAPTER TWO:

LITERATURE REVIEW

This chapter reviews basic and applied environmental design research. It utilizes the Human Ecosystem Model as a theoretical framework to classify existing environmental design research. This chapter then provides a literature review of the technical approaches that are used to study energy-related occupant-building interaction. Finally, it reviews different aspects of agent-based modeling of occupant behavior with a focus on the decision-making process that will be further used in the research design and methodology chapter.

2.1. Environmental Design Research

Moore (1984) noted that the systematic study and application of environmental design research started in the 1950s. Environmental design is sometimes also called environment-behavior research (Moore, 1984). It is an interdisciplinary field that involves the study of the mutual interaction between people and their surrounding environments, and its application includes the planning and design of built environments that improve the quality of life of its occupants on the one hand, and the elimination of the negative impacts that the buildings have on the natural environment on the other hand (Moore, 1984).

2.1.1. *Environmental Design Basic Research*

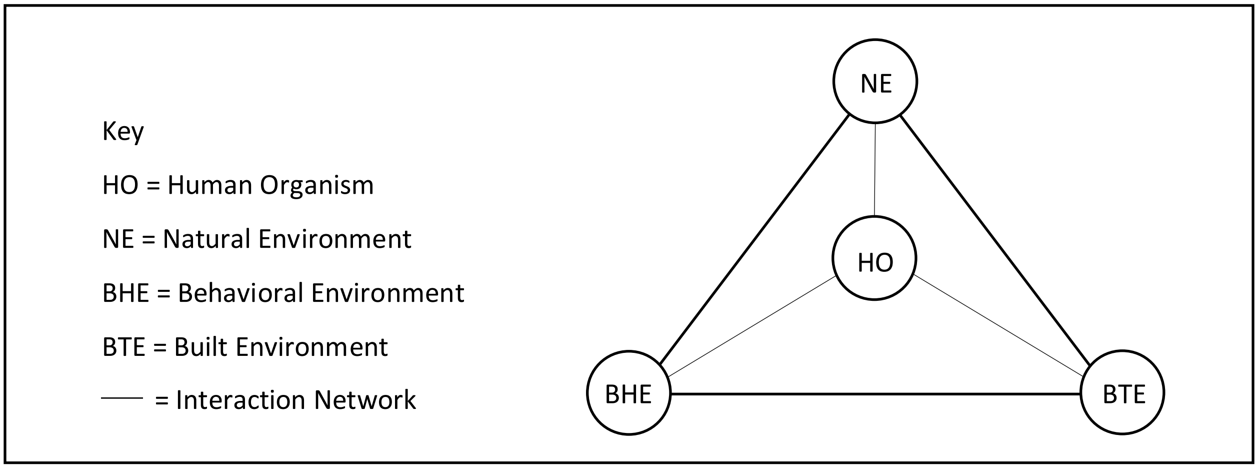
Human ecology is one of the disciplines that contributed to the early development of the theoretical frameworks of environment-behavior research. This is clear when one understands that human ecology is an interdisciplinary field that is concerned with the scientific study of human-environment interaction. More specifically, it involves uncovering the interdependencies between human actions, social systems, and natural and built environments (Westney et al., 1991).

The Human Ecosystem Model proposed by Bubolz, Eicher, and Sontag in 1979 is one of the well-established frameworks that help in analyzing human interaction with natural and built environments. It is an adaptation of a model previously developed by Morrison (1974), and it gives special attention to the spatial dimension in which human beings modify and adjust according to their culture and values. The first construct of the Human Ecosystem Model is the human environed unit, which can represent either one or a group of individuals. The three other constructs represent three different types of environments, yet they are interrelated. They are the natural environment, the human-constructed environment, and the behavioral environment. According to the Human Ecosystem Model, the natural environment is the environment formed by nature. The human-constructed environment is one that is altered or created by humans, and is essential for meeting the biological, physical, social, and phycological needs of humans (Bubolz, Eicher et al., 1979; Guerin, 1992).

A background in human ecology is of great guidance to solve the social and environmental problems addressed by interior designers (Kaup et al., 2007). In 1992, Guerin proposed the adaptation of the Human Ecosystem Model as a framework for interior design research, resulting in the Interior Ecosystem Model. She argues that the Interior Ecosystem Model supports the study of interaction among individual components within a complex system. Guerin (1992) suggests that this framework provides the researcher with a visual model that can be used to identify and organize the variables that measure the construct of interest. Guerin used two research issues as examples of the application of the Interior Ecosystem Model: the interior lighting design and the household energy consumption usage.

Figure 2.1

The Interior Ecosystem Model



Note. Source: Guerin (1992).

Guerin's role was significant in adopting the Human Ecosystem Model and utilizing it in exploring a variety of interior design subjects. The Interior Ecosystem Model helps to identify and organize the variables related to energy consumption in residential buildings and occupant satisfaction in the work environment. In 2000, Yust, Guerin, and Coopet reviewed research since 1975 to study the impact that human behavior in residential buildings has on energy consumption change. This study showed that energy consumption change is affected by weatherization characteristics, comfort levels, homeownership, incentives, and sociodemographic characteristics. These results have confirmed the applicability of the Human Ecosystem Model as a framework to study the interactions between people's social, natural, and built environment and their influence on the energy use behavior change.

2.1.2. *Environmental Design Applied Research*

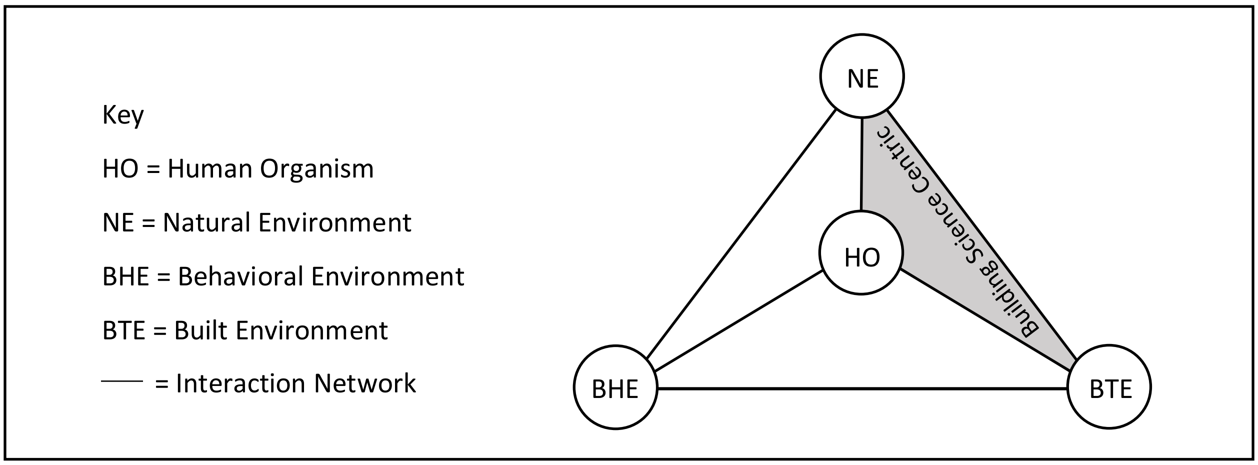
This current research utilizes the Human Ecosystem Framework (Bubolz et al., 1979) to organize the literature review according to the relationship between the human being's social environment, built environment, and natural environment. Accordingly, this study will review previous research that contributes to the environmental design approach through the lens of the Human Ecosystem Model.

2.1.2.1. <u>Natural Environment and Indoor Environment</u>

The Human Ecosystem Model (Bubolz et al., 1979) illustrates that natural and built environments influences one another. This section will review previous research that address the mutual effect between the natural and built environments in terms of energy efficiency.

Figure 2.2

Using the Human Ecosystem Model to Represent the Influence of the Natural Environment on the Built Environment



Note. Adapted from Guerin (1992).

The information compiled from the United States Environmental Protection Agency (EPA, 2016) and the United States Energy Information Administration (EIA, 2017) shows that buildings play a significant role in the global energy consumption and greenhouse gas emissions. According to EIA (2017), end-users in residential buildings contribute 20% of the total U.S. energy consumption. Also, EIA Residential Energy Consumption Survey (RECS, 2015) showed that a considerable amount of energy in U.S homes is used for space heating and cooling systems, ventilation, and lighting.

In 2002, Reinhart studied the effect of interior design on daylight availability in open-plan office spaces. DAYSIM, which is a RADIANCE-based daylighting analysis software, was used in this study. The researcher identified five climatic centers that represented daylight conditions of 186 North American metropolitan areas, including more than 1000 office settings with different configurations. The results showed that electrical energy saving is highly dependent on blind control strategies. Also, peripheral offices allow more electrical energy saving because of the availability of sufficient natural daylight. An external obstruction such as neighboring buildings was not found to impede daylight significantly. On the contrary, it acts as a shading device in the summer. Finally, second-row offices experienced lower daylight availabilities. An insufficient amount of daylight can be enhanced by reducing the heights of the interior partitions and increasing the reflectance of the ceilings in addition to specifying high transmittance glazing for the façade (Reinhart, 2002).

Moving away from residential buildings, in 2007 and 2008, Musau and Steemers studied the effect of space planning on the energy performance of institutional and commercial buildings. They used software (TAS) to create 3D models of buildings and added partitions to create different interior space layouts. Results showed that space planning influenced the space use density, which would, in turn, affect energy performance. It was assumed that different activities would require different indoor environmental conditions. Therefore, the orientation and adjacency of interior spaces were significant determinants of energy consumption and is site-specific. This research also emphasizes that energy variation with space planning is site-specific and may vary according to the building's context (Musau & Steemers, 2007; Musau & Steemers, 2008).

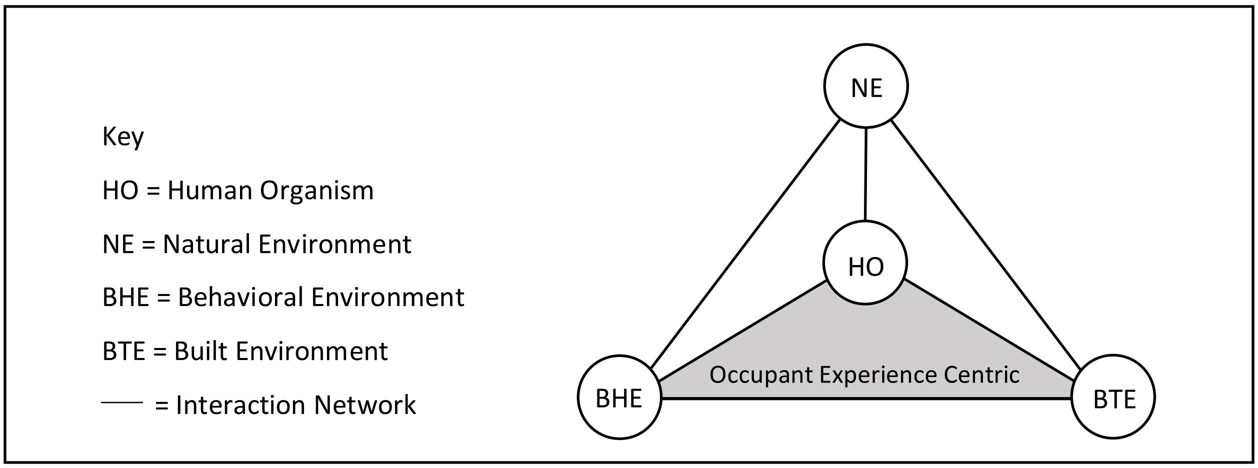
The same researchers used the same software packages from their previous research, but this time focused on ventilation. They studied the effect of space planning, interspatial airflow, and occupancy levels on energy consumption in office buildings. Their study investigated five standard office layouts to calculate the amount of energy that can be saved from proper ventilation. The results showed that space planning and interior porosity had a significant influence on fresh air supply and flow. This study also suggested that the factors behind interior apparatus patterns - such as doors - should be considered in interior space planning to accurately estimate the amount of air supply and flow within each space.

2.1.2.2. Indoor Environmental Quality and Human Comfort

This section will review previous research that addressed the interaction between the built and behavioral environment in terms of indoor environmental quality and occupant's well-being, satisfaction, and performance.

Figure 2.3

Using the Human Ecosystem Model to Represent the Influence of the Built Environment on the Behavioral Environment



Note. Adapted from Guerin (1992).

Time-budget studies conducted in the United States revealed that 30 years ago, people spent almost 90% of their time in different types of indoor environments (NSCEP, 1989). These findings are supported by more recent American time-use surveys (ATUS, 2017), which studied various activities performed by people of different ages in different building types. Therefore, it is generally accepted that indoor environmental quality of interior spaces has a significant impact on occupants' health, wellbeing, comfort, satisfaction, perceived performance, and therefore building performance (Mahdavi, 1998; Peretti & Schiavon, 2011).

Previous researchers believed that building occupants are a valuable source of information when it comes to assessing the indoor environmental quality (IEQ) (Schiavon, 2011). Therefore, many investigators conducted a Post Occupancy Evaluation (POE) to “evaluate the building systematically and rigorously after they have been built and occupied for some time” (Preiser et al.,1988, p.14). The POE takes into consideration the needs, perceptions, and expectations of occupants, operators, and owners of the building. It is also important to mention that POEs differs from other technical evaluations or tests that focus solely on technological aspects and disregards the occupants’ perspective (Federal Facilities Council, 2002; Preiser & Schramm, 1997).

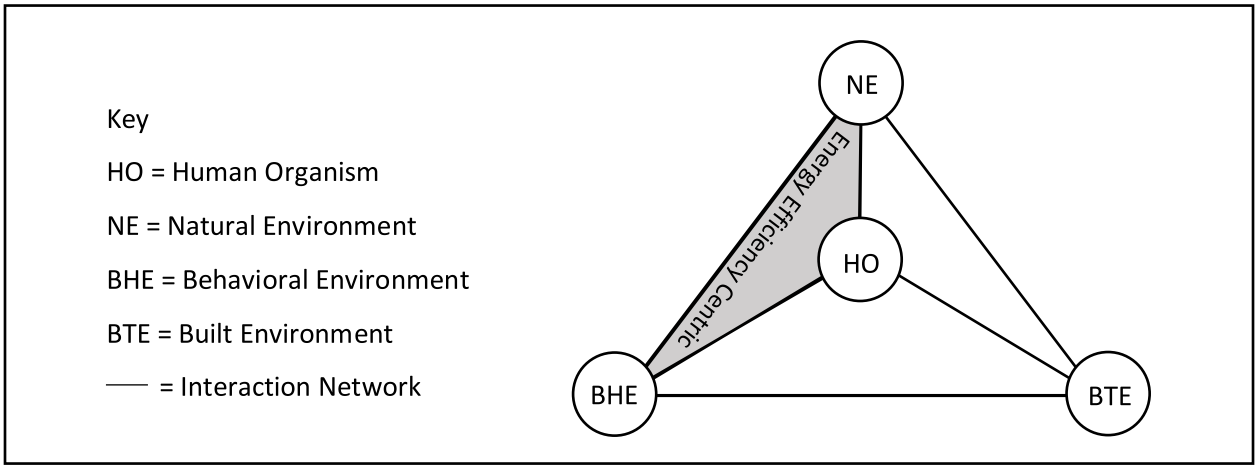
Horr et al. (2016) also addressed IEQ by conducting an extensive literature review on how this impacted occupants’ wellbeing and comfort in office buildings. They considered the year of publication and the impact factor of the journal in which the study was published. Their study revealed that there are conflicts between comfort and wellbeing criteria and energy efficiency goals. Their study additionally discussed acoustical comfort as a challenging criterion that can be compromised for sufficient daylight and natural ventilation, especially in open-plan layouts. It also suggested that the geometry of the plan layout can either eliminate or exacerbate acoustical concerns in interior spaces.

2.1.2.3. Human Behavior and Energy Efficiency

This section reviews previous research that addressed the relationship between occupant behavior and the natural environment in terms of energy depletion and environmentally harmful emissions.

Figure 2.4

Using the Human Ecosystem Model to Represent the Influence of the Human Comfort on The Energy Efficiency



Note. Adapted from Guerin (1992).

Previous studies showed that energy-related occupant behavior influences building energy performance (Yoshino et al., 2017). “Energy-related occupant behavior refers to observable actions or reactions of a person in response to external or internal stimuli, or actions or reactions of a person to adapt to ambient environmental conditions” (Yoshino et al., 2017, p. 26). Other research supported this postulation by showing that there were energy consumption fluctuations among residential units that had the same building configuration (such as orientation, envelope, and systems) (Turner & Frankel, 2008). Additionally, recent studies revealed discrepancies between modeled and measured buildings’ energy performance, which mainly arises from lack of a realistic and accurate representation of space and energy-use behavior (Hong et al., 2017).

Parker, Mills, Rainer, Bourassa, and Homan (2012) compared measured versus predicted energy use for 428 occupied homes at three different locations. Their study showed that the accuracy of physical and operational input data results in a more accurate results than did predicted energy performance. Additionally, Ingle, Moezzi, Lutzenhiser, and Diamond (2014) used a self-report questionnaire to gain insights about the occupants’ highly variable energy-use behavior. The results showed that incorporating occupant behavior improved the accuracy of the model estimates compared to the actual consumption of single-family energy-use. That is, input from occupant behavior, is essential to predicting energy usage. Furthermore, Zhao, McCoy, Du, Agee, and Lu (2017) collected technical and behavioral data from about 300 residential buildings to identify interaction effects between human behavior and building technology. The results of this research indicated a direct correlation between temperature settings in winter and summer. Researchers conclude that energy efficiency is achievable in homes with technological advancement and behavioral plasticity. That is, greater technology coupled with flexible user behavior can result in lower energy consumption.

2.2. Energy-Related Occupant Behavior

Energy-related occupant-building interaction is defined as "human being's unconscious and conscious actions to control the physical parameters of the surrounding built environment based on the comparison of the perceived environment to the sum of past experiences" (Schweiker 2010, p.15). Those actions are caused by adaptive triggers based on the occupants' perception of indoor environmental conditions (Fabi et al., 2012). Wagner et al. (2018) categorized occupants' actions into four types: physiological, individual, environmental, and spatial adjustments. Physiological adjustments are the involuntary action that the human body takes to adapt to a certain situation, such as the thermoregulation process. Individual adjustments include changing clothing or activity level. Environmental adjustments refer to human interaction with different elements in a space to control the indoor environmental conditions (Wagner et al., 2018). Previous research addressed the relation between building components, control systems states such as windows (opening behavior), shading/blinds, heating and cooling (thermostat setpoint), and electrical lighting systems), indoor and outdoor environmental conditions (field sensors, and weather stations), occupant behavior, and energy consumption. Finally, Spatial adjustment refers to the occupants' movement from one space to another (Hong et al., 2017; Wagner et al., 2018). Hong et al. (2017) synthesized that technical approach to study energy-related occupant behavior within a building is described by a three-step methodology, which is monitor, model, and simulate.

2.2.1. *Monitoring Occupant Behavior*

Studies on monitoring are based on extensive data collection to establish a relationship between environmental factors and targeted operation(s). Monitor studies are mainly divided into three methodological approaches, objective field monitoring, subjective self-reporting or questionnaires, and experimental studies (Hong et al., 2017; Wagner et al. (2018). According to Yan et al. (2015), objective field monitoring studies are divided into (a) occupancy and equipment use monitoring and (b) adaptive occupant behavior monitoring. Also, occupants' surveys and interviews are a common method of self-reporting studies. Research on occupant-building interaction started with occupant surveys and interviews to develop an understating of behavioral factors that influence the building energy performance. Occupants surveys and interviews become more informative when paired with data obtained from monitoring devices. Finally, laboratory-based studies are used to assess the occupants' physical and psychological comfort conditions and establish measurements accordingly (Hong et al., 2017).

2.2.1.1. Occupancy and Equipment Use Monitoring

Identifying occupant's presence and their numbers have been studied using a variety of methods, including motion detectors, different types of sensors, cameras, and mobile devices. Also, different types of plug-level meters are available to detect equipment plug load (except HVAC) (Hong et al., 2017). Wagner et al. (2018) classified technologies that focus on detecting occupants' presence, including those that are used to monitor occupants' interaction with the built environment into six major categories: image-based, threshold and mechanical, motion sensing, radio-based, human-in-the-loop, and consumption sensing.

2.2.1.2. Adaptive Occupant Behavior Monitoring

Major adaptive occupant behaviors include operating windows, adjusting blinds, using doors, switching lights, and adjusting the thermostat (Hong, 2017). Threshold and mechanical sensing are one of the approaches that detect the change of a state of a building component, such as a door or a window opening or closing when occupants interact with them. Examples in this category include reed contacts, door badges, piezoelectric mats, and IR beams (Wagner et al., 2018). In addition, self-report methods such as surveys are sometimes used solely or paired with objective monitoring using one of the techniques mentioned above (Hong, 2017). Monitoring adaptive occupant behavior allows researchers to identify drivers that motivate occupants to perform a certain behavior (Fabi et al., 2012; Stazi et al., 2017; Van Den Wymelenberg, 2012). Accordingly, empirically- derived occupant models can be developed and incorporated with building energy simulation software to predict the effect of occupant behavior on the buildings' energy performance (Gilani et al., 2016). Examples of monitoring studies that were conducted in the residential sector that focused on monitoring occupants' behavior of operating windows and adjusting blinds are presented in Table 2.1 and Table 2.2.

Table 2.1

Summary of Literature Review of Occupants' Window Use Behavior

Paper	Sample	Method	Findings
Dubrul (1988)	Residential Buildings	Questionnaires and observations	The behavior of opening and closing windows is influenced by the building characteristics such as the type of dwelling (single house or apartment), orientation and type of the room (bedroom, living room or kitchen).
Erhorn (1988)	24 identical flats in Germany	Window and door sensors	Windows were opened more frequently in bedrooms for ventilation and they stayed opened for longer times compared to other areas of the flats.
Dick & Thomas (1951)	15 houses	Measurement	The number of open windows is mostly related to the outdoor temperature.
Brundrett (1977)	123 houses in England	Recording weather data, observation, and interviews	The temperature is an important explanatory variable for the occupant's behavior of opening of windows.
Dubrul (1988)	Residential Buildings	Questionnaires and observations	Residents tend to close the windows at wind speeds above 8 m/s.
Erhorn (1988)	24 flats with identical ground plans	Measurement	The duration in which the windows stay opened in summer is more than in winter.
Johnson & Long (2005).	1100 residences X two visits per residence	72 2-hour survey sessions	The residents are more likely to open the windows during the time of session visit; high population or housing density; window air conditioning (AC) units; absence of AC; a large number of doors; and wind speed above two mph.

Table 2.1 (cont'd)

Paper	Sample	Method	Findings
Andersen et al. (2009)	993/summer and 636/winter Danish dwellings	questionnaire survey	The behavior of opening windows is strongly related to the outdoor temperature.
Andersen et al. (2011)	10 rented apartments and 5 privately-owned single-family houses	A questionnaire survey and measurement	The most influencing variables in determining the probability of operating windows were outdoor temperature, indoor temperature, and the indoor CO^2 concentration. The survey results showed that the most common action performed by residents when feeling thermal discomfort were to adjust clothing, adjust heating set-point, and to operate windows.
Calì et al. (2016)	5 rooms of the 60 apartments located in the buildings	Monitored data (measured each minute)	The time of the day and the amount of the carbon dioxide concentration were the two most common drivers to open windows. The outdoor temperature and the time of the day were the two main drivers to close the windows.
Dubrul (1988)	Residential Buildings	Questionnaires and observations	Residents considered the presence of children when opening the windows.
Andersen et al. (2009)	Danish Dwellings	questionnaire survey	The window opening behavior was influenced by the interaction between occupants' gender and perceived illumination.
Guerra-Santin & Itard (2010)	Households in the Netherlands	Household survey	The behavior of operating windows was influenced by the age of the residents.

Table 2.2

Summary of Literature Review of Occupants' Blind Use Behavior

Paper	Sample	Method	Findings
Foster & Oreszczyn (2001)	three buildings in both summer and winter	monitored data	Results showed that there is a weak relationship between orientation and window occlusion. Also, occupants' behavior of adjusting blinds were not related to solar availability.
Veitch et al. (2013)	455 households in detached homes in Canada	A survey	Occupants indicated that the main reasons for closing blinds were privacy, security, eliminating glare, and keeping the house cool in summer. They also mentioned that their drivers for opening blinds were increasing daylight, accessing outdoor views, and providing light to plants. During the winter, blinds were opened to let in solar heat.
Bennet et al. (2014)	One high-rise building located in Ottawa, Canada	A field study	Residential occupants have different schedule of adjusting blinds compared to occupants of office buildings. The time of the day and the weekday were significant factors that influenced the occupants' behavior of adjusting shades. In addition, the orientation, and the status of the sky conditions such as cloudiness or sunniness had an impact on the occupants' decision to operated shades.
Pereira & Ramos (2019)	One apartment in Portugal was studied for one year	External sensors and daily journals	Different drivers were found to influence the occupants' behavior of adjusting blinds such as the building compartment and season of the year.

2.2.2. *Modeling Occupant Behavior*

Based on monitoring data, implicit and explicit behavioral models are developed to predict the probability of occupant behavior with building systems, that can affect both space and energy use of a building (Cha & Kim, 2015; Cha et al., 2017; Hong et al., 2017). Numerous occupant behavior models have been developed to capture dynamic occupant-building interaction. Some of these models were developed to study the energy-use behaviors, while others study space-use behavior.

2.2.2.1. <u>Energy-Use Behavior Modeling</u>

Some energy-use occupant behavior models were developed and incorporated in building energy simulation to increase the accuracy of predicted energy performance. To achieve this goal, models must balance between practicality and accuracy. Accordingly, Melfi et al. (2011) classified model resolution into three categories: first, a temporal resolution, which refers to the timing in which the events are modeled (e.g., days, hours, minutes, or seconds); second, a spatial resolution, which refers to the physical scale in which the occupant's behavior is modeled (e.g., building, floor, zone, or room); and third, an occupancy resolution, which refers to characteristics that describe the presence of the occupants (e.g., occupancy, number, identity, or activity) (Hong et al., 2015).

A number of researchers investigated energy-related occupant behavior and its impact on building energy performance. Different methodologies and techniques to investigate the factors that influence occupant behavior have emerged. Literature shows several cognitive-behavioral frameworks that capture the stochastic and reactive nature of human cognition and behavior. For example, the need-action-event process was used to describe the relationship between the human “inside world” and the contextual environment “outside world.” However, none of these frameworks focused on energy-related human-building interaction (Hong et al., 2017). Hong et al. (2015) developed the DNAs (driver-need-action-system) framework based on the correlation identified in previous human-building interaction research to standardize a way to quantify energy use associated with occupant behavior.

According to the DNAs framework, the driver is the outdoor environmental conditions that stimulate energy-related occupant behavior. And behavior is based on need. Need is identified as the physical and non-physical requirements of the human inside the world to achieve satisfaction with their surrounding environment. Physical needs can be summarized, according to IEQ, as indoor air quality, acoustical, thermal, and visual comfort (USGBC, 2019a). While nonphysical needs vary depending on personal and cultural preferences, the specific actions represent the interaction between the human's indoor and outdoor world to achieve environmental comfort. Systems may simply be building components, equipment, or mechanisms in which the occupants interact (control) to reach or maintain comfort and satisfaction with their surrounding environment (Hong et al., 2015).

The Drivers, Needs, Action, and system framework aims to standardize a method to study energy use associated with occupant behaviors and thus facilitate its efficient incorporation in building performance simulation tools (Hong et al., 2015). In 2017, D'Oca et al. integrated the DNAs system ontology with theories from the social psychology discipline such as the social cognitive theory and the theory of planned behavior. This interdisciplinary framework is intended to investigate energy related occupant-building interaction in office spaces.

2.2.2.2. Space-Use Behavior Modeling

The space-use analysis determines the amount and frequency (or rate) of space utilization. The space-use analysis becomes more realistic and efficient for planning the space-use of a building when simultaneously considering the attributes of the users, space, and activities in the programming phase. The space-use analysis gained increased attention because of sustainability concerns such as underutilized space and the resulting waste of energy. This present a conundrum for building managers. On the one hand, every added square footage requires more budget and consumes more energy. On the other hand, the building is expected to support specific activities without compromising the occupant's satisfaction (Kim et al., 2013).

Kim, Rajagopal, Fischer, and Kam (2013) developed a knowledge-based framework to formalize (or systemize) the relationship between the different and complex perspectives of the user, space, and activities. This framework was meant to provide consistent, transparent, and efficient prediction, documentation, and communication of space-use among design team members and clients. Accordingly, this framework allows the design team members and clients to make better-informed design decisions based on solid data. Kim et al. (2013) reviewed previous space-use analysis frameworks and user activity (or behavior) models to cover the three perspectives of space, activity, and user, and integrated them in their automated space-use analysis framework.

As an initial step towards improved space-use analysis, Cha and Kim (2014) developed a conceptual framework for the indoor spatial choice model. This framework is based on the random utility theory that was explained by McFadden in 1974. The framework, developed by Cha and Kim (2014), suggests that occupants select spaces with specific attributes based on their preferences to maximize one's utility. Cha and Kim (2014) considered four main data sets when developing an indoor spatial choice model. The first two sets are spatial information and activity and user profiles. These two required data sets are provided by the architect in the design planning phase. The third data set is comprised of a set of attributes that are relative to the indoor spatial choice. Although some attributes are used to determine spatial choice in certain types of buildings, more attributes need to be researched and generalized to apply to spatial choice models of different types of buildings. Finally, two statistical methods can be used to collect data. They are stated and revealed preference methods. Where the stated preference method is based on an actual choice situation and revealed, the preferred method, is based on hypothetical choice situations.

2.2.3. ***Simulating Occupant Behavior***

Researchers simulated occupant behaviors to predict the impact of occupant behaviors on building energy performance and leverage the IEQ (Hong et al., 2017). For example, Barakat and Khoury

(2016) studied the effect of occupants' multi-comfort, including thermal, visual, acoustical, and air quality on the buildings' energy performance. They implemented their model to examine the effect of the occupant behavior on energy-use. In addition, Hajj-Hassan and Khoury (2018) developed a simulation environment to simultaneously study parametric building design and diverse occupant behavior. Another study conducted by Gilani et al. in 2017, incorporated empirically driven occupant behavior models in the process of building design and code compliance.

2.2.3.1. Schedule-Based Approach

In the building energy simulation domain, since occupancy has a significant impact on building performance, the DNAs framework is implemented further into the form of an XML (Extensible Markup Language) to provide interoperability between occupant behavior and building energy models (Hong et al., 2015). Following the previous step, Hong et al. (2016) utilized the DNAs ontology and the obXML (Occupant Behavior - XML) schema to develop an occupant behavior modeling tool that allows co-simulation with building energy modeling programs. In 2018, Chen et al. developed an agent-based occupancy simulator to capture the stocastic presence and movement of occupants in buildings. In this scenario, each occupant and space are explicilty represented to simulate the spatial and temporal diversity of occupants.

2.2.3.2. Utilization-Based Approach

In the space planning domain, it is a challenging process for designers and engineers to optimize a design solution that accounts for users' space preferences. It is challenging to optimize space use due to the complex (multicriteria) interactions between the user, activity, and space (Cha et al., 2017; Cha & Kim, 2015). For this reason, occupancy prediction studies incorporated agent-based modeling into the study of the stochastic occupant-building interaction). One of these examples is the agent-based space-use prediction simulation (ASUPS) (Cha & Kim, 2015). The ASUPS system provides designers with individual level space-use information over time in a building based on spatial choice behavior. The inputs of this framework are the building's information model, users' profiles, and space preference data. It provides designers with detailed space-use information as an output (Cha & Kim, 2015).

2.3. Agent-Based Modelling of Occupant Behavior

When one studies models, they can be viewed as natural or contrived. Agend-Based Modeling (ABM) is an example of contrived models (Thompson & Derr, 2009). ABMS is a simple digital representation of complex systems. It is a computational modeling approach in which heterogeneous agents represent individuals. Agents are equipped with decision rules that drive their behavior, and they are situated in a shared, spatially explicit, environment. They interact with each other, and with the environment where they are present, to achieve their objectives. As a result of those interactions, some macroscale (properties) phenomena appear at the systems level. ABM focuses on individuals' behaviors and is capable of modeling dynamic human-environment processes. Therefore, ABM allows computational experimentation using artificial societies and environments. It enables researchers to study the quantitative and qualitative system-level changes (Heppenstall et al., 2010; Ligmann-Zielinska, 2010).

Modeling ontologies can comprise almost everything that exists in the designed artificial world, including contents (entities and relationships), spatial and temporal structure, rules of behavior (physics), and logic (axioms and rules of inference) (Ligmann-Zielinska, 2017). ABM consists of system structure integrated with dynamic processes of agents and environments. Agents are defined by attributes that describe their characteristics, behavioral rules that guide their decision making, and actions that are performed based on their decisions. The agent's cognitive frameworks determine the level of reality of the agent's behavior. Agents include reactive who ignore previous experience, proactive who are attentive and can take the initiative, elaborate who depend on their memory, and deliberative who are equipped with personality (Ligmann-Zielinska, 2017).

Agents' decision making is implemented in ABM using a variety of different approaches. The mathematical approach is commonly used due to its ease of implementation. One of its simplest, but not realistic, methods utilize a random number generator to select a set of predefined choices (Crooks et al., 2018). Another, more realistic mathematical approach, employs rule-based systems which operate based on if-then conational statements. These models utilize different forms of utility functions that attach a weight to a choice. Utility functions can be used to represent a rational decision, which assumes that individuals have complete information (Crooks et al., 2018; Ligmann-Zielinska, 2010). A refined approach uses bounded rationality, which suggests that individuals have limited knowledge and resources. In this sense, decision-making heuristics can be either random, satisfier, ordered, or hybrid choice (Ligmann-Zielinska, 2010). In this proposed research, satisfier heuristics is the most reasonable choice since agents, in this case, select the alternative that is "good enough" concerning a threshold value of a selected criterion.

Some features distinguish ABM among others. Below are the most important features of ABM (Crooks et al., 2018; Gilbert, 2008):

1. Ontological Correspondence: The ontology of ABM resembles the real system that is being modeled. It is considered an advantage when it comes to designing and analyzing the model if compared to an equation-based model, for example.
2. Autonomy: Agents have full control of their decision making.
3. Heterogeneous agents: The way agents are programmed allows them to operate based on their individual attributes, behavioral rules, and actions.
4. Explicit Environment Representation: Agents exist and operate in a shared space, which can be an explicit representation of a physical environment or an abstract one.
5. Agent Interactions: Agents interact with each other and their environment to achieve their goals. Agent-to-agent interaction is a distinguishing feature of ABM. It can be as simple as transferring data

from one agent to the other or as complicated as the passing of messages composed in language. Also, agents can be reactive, proactivity, elaborate, or deliberative. Accordingly, agents can respond to changes in the environment according to the level of their cognitive modeling.

6. Bounded Rationality: Like humans, agents have knowledge that is specific to their context. They also have limited cognitive capabilities and time, which constrains their ability to optimize utility when making decisions.
7. Learning: ABM can simulate learning at individual and social levels. Agents can learn from their previous experiences. They can also learn through sharing experiences with other agents.
8. Emergence: Micro-level agent choices lead to emerging macro-level patterns.

2.3.1. *Agent-Based Models in Social Sciences*

Agent-based models are frequently used in social sciences. ABI is a computational method in which computer programs represent processes in a way that mimics its presence in real systems. This program takes some form of input (independent variables) and creates outputs (dependent variables) (Gilbert, 2008).

Despite the advantages of experimental studies, it is often utilized in social sciences due to being impossible or undesirable to perform. ABM enables researchers to experiment on virtual human systems without having to worry about difficulties or ethical concerns. ABM allows simulating a variety of circumstances with different inputs and analyzing the outputs. Experimentation with ABM enable the researcher to identify macro-level regularities that had been previously unsuspected and explain the reason for these using programmed interactions and behaviors (Gilbert, 2008).

ABM have been used to experiment on the collective human behavior during an emergency evacuation in different types of buildings. For example, Ha and Lykotrafitis (2012) employed a system of self-moving particles whose motion is determined through a social force model. This research studied the multi-room or the multi-floor with a focus on the size of the room door and the size of the main exit on influencing the evacuation time. Another evacuation experiment using ABM was conducted by Duan, Fan, Meng, and Qiu (2013). They compared the performance of two different interior layouts of an emporium in terms of decreasing the traveling speed during an evacuation. Similarly, Liu, Du, and Issa (2014) integrated a game engine with Building Information Modelling to provide a 3D visualization to study the effect of spatial configuration on human behavior during an evacuation process.

Constructing the proper cognitive model is the most challenging aspect of ABMs due to human beings' complex process of thinking and decision making (Crooks et al., 2018; Ligmann-Zielinska, 2010). Balke and Gilbert (2014) distinguish agents' architectures into five dimensions: first, the cognitive dimension that ranges for production-system architectures to psychologically and neurologically inspired approaches; second, the social dimension that assumes that individuals can perceive and respond to social network relations and concepts; and the last three dimensions consider the ability of agents to express social norm consideration, represent their affective states explicitly and the level at which they learn.

2.3.2. *Human Behavior in Agent-Based Models*

The study of human behavior started fewer than 150 years ago. However, progress can be described as slow due to the complexity of the human mind. Early concepts assumed that humans' brains were like computers and that they can be explained in computational terms (e.g., input, processes, and output) (Pinker, 2002).

One of the misconceptions of human behavior is that it operates in a random manner. Studies showed that people could not make random decisions even if they intended to do so. Human behavior may appear to be random or inconsistent because they have preferences; they consider the consequences of their decisions and have memory in which previous choices are stored (Heppenstall et al., 2011). That is, it is difficult to predict human behavior.

In ABM, modeling human behavior follows a system architecture that supports the cognitive model that drives behavior. There are several cognitive approaches to this architecture, with the first being a mathematical approach which simplifies the decision-making process (production-rule system architecture). The second are conceptual frameworks that are based on general and abstract (psychological approach). The third are research tools in which cognitive models of specific tasks are implemented within these cognitive architectures (neurological approach) (Balke, & Gilbert, 2014; Heppenstall et al., 2011).

The choice of the proper cognitive approach depends on the research question. For example, Klabunde and Willekens (2016) argued that the Theory of Planned Behavior could be used to model decision processes and social networks. The Theory of Planned Behavior is a well-established behavioral theory in the field of psychology, and it is an extension of the Theory of Reasoned Action (Ajzen & Fishbein, 1980; Fishbein & Ajzen,1975). This current research will adopt the Theory of Planned Behavior, which is the most recent development of the work of Fishbein & Ajzen that was published in 2010.

2.4. Theory of Planned Behavior

Fishbein and Ajzen have been studying the prediction and change in behavior approach jointly and individually for more than 45 years before they presented their Theory of Planned Behavior. First, in 1975, Fishbein proposed that intentions precede behaviors, in which intentions are a function of the sum of behavioral beliefs weighted by outcome evaluations. This determines the attitude explained in the equation below and the normative beliefs weighted by the motivation to comply.

$$A \alpha \sum b_i e_i \tag{1}$$

A – attitude towards a behavior

bi – the strength of the belief that the behavior has an attribute i

ei - evaluation of the attribute i

In their first book that was published in 1975, Fishbein and Ajzen introduced the normative construct as analogous to the attitude construct. The formula below explains that the sum of the normative beliefs weighted by the motivation to comply determines the subjective norm.

$N_I \alpha \sum n_i m_i$ (2)

N – subjective norm towards a behavior

n_i – the subjective normative belief about referent *i*

m_i - motivation to comply with referent *i*

Fishbein and Ajzen introduced the Theory of Reasoned Action (TRA) in their second book that they published in 1980. In this theory, they explicitly included background factors and argued that those influence an individual's behavioral and normative beliefs and thus indirectly influence behavior. They also developed a set of procedures to elicit salient behavioral and normative beliefs and to measure the theory's constructs. As Ajzen continued to test and refine the theory, he recognized that not all behaviors are under complete volitional control. Therefore, he introduced the Theory of Planned Behavior (TPB) as an extension to the TRA. He suggested adding a third construct, which is the perceived behavioral control. The function below explains that the perceived behavioral control is assumed to be a function of the sum of underlying control beliefs weighted by the power of control factors.

$PCB \alpha \sum c_i p_i$ (3)

PCB – perceived behavioral control towards a behavior

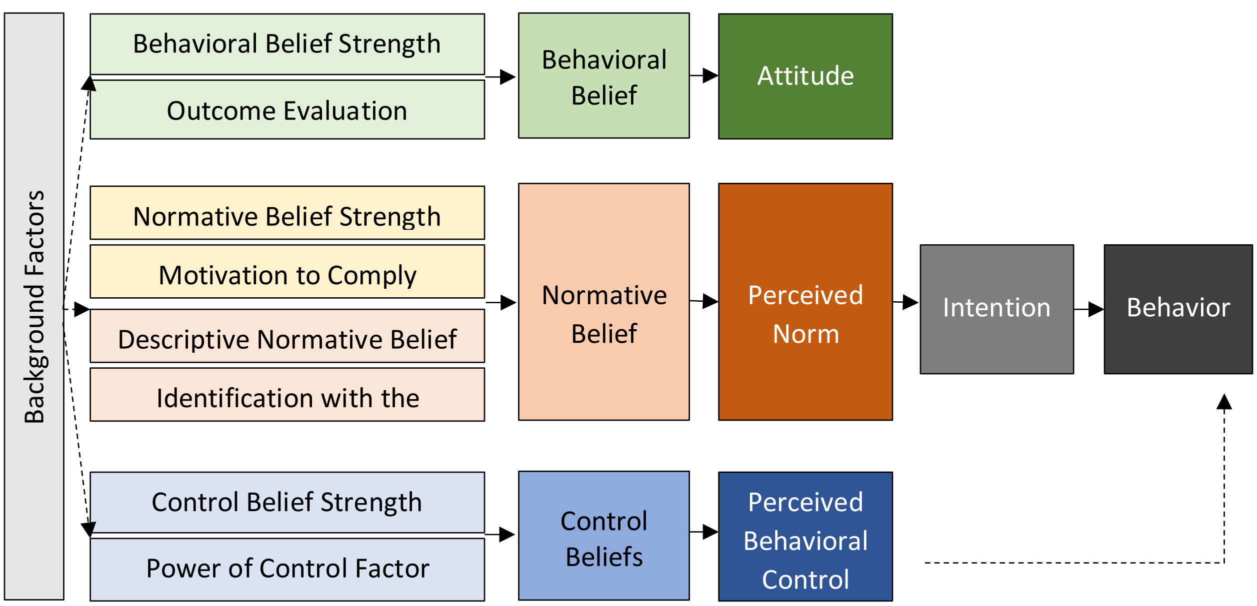
c_i – the belief that the control factor *i* will be present

p_i - the power of factor *i* to facilitate or impede the performance of the behavior

In 2010, Fishbein and Ajzen provided an updated outline of their theory of behavioral prediction. They highlighted the importance of a clear identification of the behavior of interest. The researchers assumed that human behavior is guided by the beliefs that people hold about the behavior under consideration. Accordingly, they distinguished three kinds of beliefs. First, behavioral beliefs are the individual's beliefs about the positive or negatives outcomes that they might experience if they performed the behavior. These outcome expectancies are assumed to determine the individual's attitude towards a behavior, that is, the individual's evaluation of the outcome of the behavior in question. Second, normative beliefs are formed by people about whether essential people in their lives will approve or disapprove of this behavior, in addition to whether these significant people also perform the behavior. The sum of the injunctive and descriptive normative beliefs determines the subjective norm. The subjective norm refers to the perceived social pressure to adopt or not adopt the behavior in question. Third, control beliefs are about personal and environmental factors that can facilitate or impede their attempts to carry out the behavior. The control beliefs determine the perceived behavioral control about the behavior in question.

Figure 2.5

Schematic Presentation of the Theory of Planned Behavior



Note. Source: Fishbein & Ajzen (2010).

Fishbein and Ajzen (2010) declared that background factors influence an individual's beliefs. The beliefs, in turn, provide detailed information that guides people's decisions to perform or not to perform the behavior of interest. The three types of beliefs - behavioral, normative, and control beliefs - determine the attitudes, subjective norms, and perceived behavioral control, respectively. Each of these have a relative weight that is expected to vary from one person to the other, and from one behavior to another. In their aggregate, the three constructs lead to behavioral intentions, which are explained as the readiness to perform a behavior. Then the intention determines the likelihood of performing the behavior. The Theory of Planned Behavior postulates that the intention is the best predictor of behavior, but it is important to consider behavioral control. Therefore, it suggests assessing the actual behavioral control (such as relevant skills and barriers) to improve behavioral prediction. However, perceived behavioral control can be used as a proxy if the actual behavioral control measurement is not possible (Fishbein & Ajzen, 2010).

The reasoned action does not assume that people always engage in rational behaviors. It includes both deliberative and spontaneous decision making. Deliberative decision making happens when people are confronted with a new or important situation, while people engage in spontaneous decision making when performing a familiar or unimportant behavior (Fishbein & Ajzen, 2010). When a behavior is repeated many times in a stable context, it becomes a habit. In 2000, Fishbein and Ajzen argued that in the case of habitual behavior, the intention is activated with minimal conscious effort or attention (spontaneously). In addition, existing evidence shows that the predictive validity of intentions does not decline for habitual behaviors.

According to Fishbein and Ajzen (2010), the behavior is defined in terms of four elements: the action performed, the target at which the action is directed, the context in which it is performed, and the time at which it is performed. Therefore, from their perspective, a change in one of the defining elements in the behavior constitutes a change in the behavior itself.

In addition, Fishbein and Ajzen (2010) clarified that each of a behavior's four elements can be defined at various levels of generality or specificity. However, they argue that the research that studies an extremely narrowly defined behavior will be of little theoretical or empirical significance. They warn that this is often the case in laboratory experiments, where a certain behavior on a specific target is measured in the same context and time. However, when one or more of the behavior elements is expanded, observing the behavior becomes unrealistic or unaffordable in terms of money and time.

While it is possible to observe a single behavior, observing a behavioral category is impossible. Therefore, social sciences often adopt the self-reports of behaviors rather than direct observations. It is also important to ensure that all participants have the same understanding of the behavioral category that matches the investigator's definition. Therefore, Fishbein and Ajzen (2010) point out that the researcher should provide a clear definition of the category of behavior in question when using a self-report survey to assess the behavior. For some behavioral categories, it is necessary to provide representative examples of the specific activities that define the category.

The behavioral criterion can be in the form of dichotomies, frequencies, or magnitudes. The dichotomy is when a behavior is performed or not performed, while frequency measures how often a behavior was performed, and magnitude measures the amount in which the behavior was performed. Fishbein and Ajzen (2010) indicate that different frequencies or magnitudes define different action elements and thus constitute different behaviors. In practice, it is almost impossible to explain every behavioral frequency or magnitude. However, in some cases, the investigator is interested in behavioral quantity or frequency, which can be used to redefine the behavior in terms of a dichotomy.

2.5. Summary of Literature Review

The literature review started by discussing environmental design research through shedding light on two of its two main branches, which are basic and applied research. Basic research is mainly about creating theories, and the Human Ecosystem Model developed by Bubolz, Eicher, and Sontag in 1979 is a great example of representing the relationship between the human, natural, and built environment. This researcher used this framework and its simplified visual representation developed by

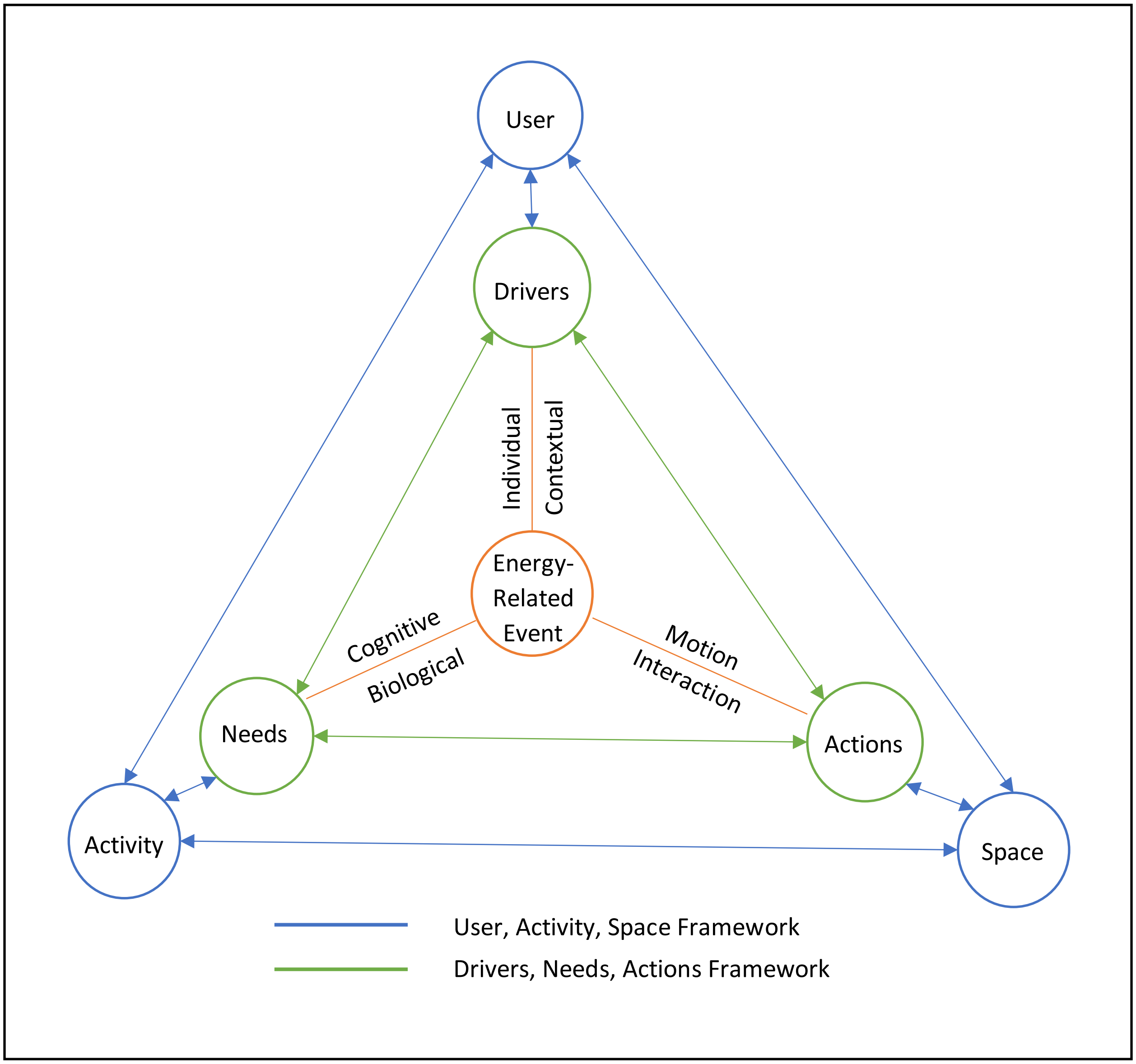
Guerin in 1992 as a guide to classify the existing literature. Three main areas of research were identified, which are building science-centric, occupant experience-centric, and energy efficiency centric. The building science section focused on studying the mutual impact between natural and built environment. Accordingly, research in this area is focused on determining indoor environmental conditions and the prediction of energy consumption using different Building Energy Simulation (BES) software. Unfortunately, this section of the literature gives little attention to human behavior. The occupant experience is mainly dedicated to studying their satisfaction with the indoor built environmental conditions. Most of the research in this area takes the form of Post Occupancy Evaluation (POE) studies. This research reveals the occupants' perception of indoor environmental conditions and how it affects their health and wellbeing. The energy efficiency-centric research discussed in the last section explains the influence that the diverse occupant behaviors have on the energy performance of the buildings. It reveals that occupant behavior is one of the main contributors to the discrepancies between the predicted and real measured energy performance in buildings.

In this research, the first section of the literature review shows three fragmented areas of research. The second part of the literature review starts by discussing an initiative that pioneer researchers in the field of high-performance buildings took to standardize a technical approach to study energy-related occupant interaction. Two main frameworks were highlighted due to their significance in the field of studying energy-related occupant building interaction, and they are the Drivers, Needs, Actions, and Systems (DNAs) framework (Hong et al., 2015) and the User, Activity, and Space framework (Kim & Fischer, 2014). Both frameworks can be incorporated with agent-based modeling to quantify the influence that the occupant behavior has on buildings' energy performance.

This researcher suggests that combining the two approaches results in a holistic conceptual framework to study the energy-related occupant behavior using agent-based modeling with a focus on behavioral, environmental, and contextual factors.

Figure 2.6

Proposed Occupant-Building Interaction Framework



CHAPTER THREE:

RESEARCH DESIGN AND METHODOLOGY

3.1. Introduction

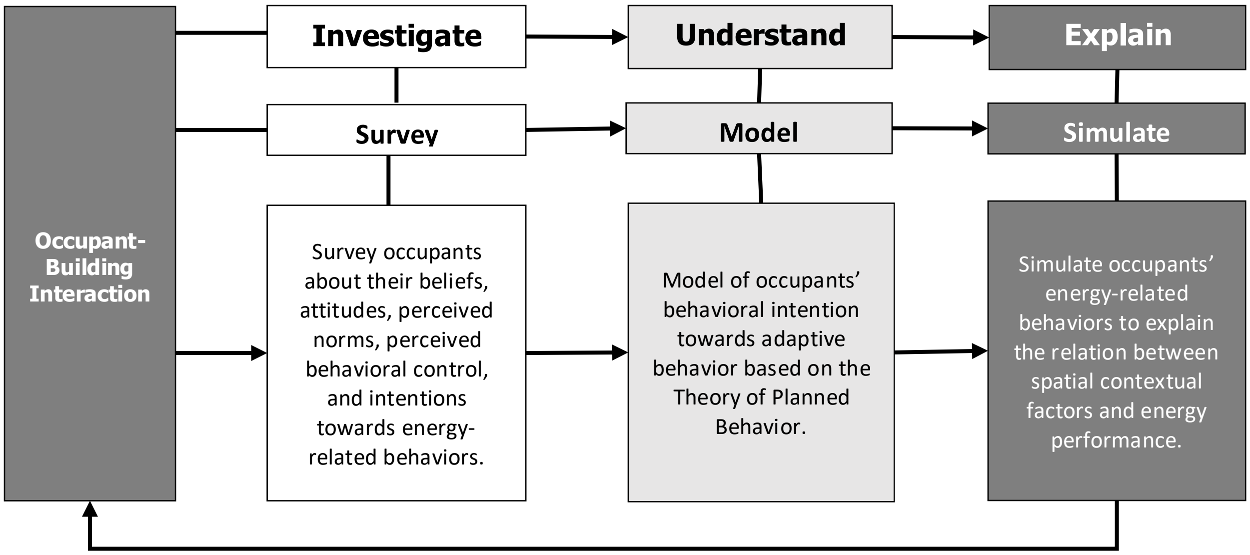
This study is a correlational research that started with a field survey to collect and analyze quantitative data about occupants' energy-related behaviors. Data collection and analysis followed the research framework proposed in Figure 3.1. The study utilized a self-reporting questionnaire that was designed following the Theory of Planned Behavior (Fishbein & Ajzen, 2010). The researcher examined the occupants' behaviors of operating the windows and adjusting the blinds to control indoor environmental conditions.

The study focused on the living area and the sleeping area due to the vastly different types of activities that takes place in each of these spaces. This study targeted residents of three multifamily buildings located in East Lansing, Michigan. This survey measured the same unit of analysis in summer and winter to compare the occupants' energy-related behaviors in two different seasons. The researcher analyzed the occupants' energy-related behaviors based on the buildings' spatial contextual factors such as the space type, orientation, floor level, and outdoor views.

The questionnaire results were then used to develop a statistical model to predict occupants' behaviors of operating windows and adjusting blinds. The occupant's' actual energy-related behavioral patterns were used as the input for an agent-based model that was designed based on the Divers, Needs, Actions, and Systems Framework (Hong et al., 2015). The agent-based model simulation was used to explain occupants' energy-related behaviors and explore its relation to the building's energy performance.

Figure 3.1

Research Framework



3.2. Survey Design

A field survey approach was chosen to gain a better understanding of occupant behavior, from which the investigator can draw more accurate inferences about the factors that drive that behavior. This approach also provides an economical and rapid turnaround in the data collection (Creswell, 2014; Wagner, 2018). The survey design encompassed four stages: measurement, sampling, data collection, and data analysis. Additionally, establishing research validity and reliability will be mentioned.

3.2.1. *Measurement*

The questionnaire used is the Theory of Planned Behavior (TPB) by Ajzen (2006), presented in APPENDIX B. The TBP questionnaire has been used by many researchers in multiple fields, which already established the reliability and validity of the instrument. The self-report measure takes the form of a 7-point Likert-type scale, where participants are asked to indicate the degree to which they agree or disagree with each statement, ranging from 1 (strongly disagree) to 7 (strongly agree). Each item measures one of the constructs of the Theory of Planned Behavior, namely beliefs, attitudes, norms, perceived control, intention, and behavior.

Fishbein and Ajzen (2010) emphasized the importance of describing the behavior under study based on four criteria: action, target, context, and time. Table 3.1 shows the behaviors investigated in this research. The occupants' energy-related behaviors to control indoor environmental conditions is the focus of this study. The researcher specified two actions to study: operating windows and adjusting blinds. Occupants' behavior may change from one space to the other; therefore, the actions of the operating window and adjusting blinds were studied in two different contexts, sleeping area and living area. Finally, the survey was conducted two times to account for the change of occupants' behaviors during different seasons. Table 3.1 shows the detailed description of the behaviors under study.

Table 3.1

Detailed Description of the Behaviors Under Study

Behavior	Action	Target	Context	Time
Occupants'	Operating	Windows	Sleeping Area	Winter Daytime
Energy-Related Behaviors to Control	Adjusting	Blinds		
Indoor Environmental	Turning	Lights		
Conditions	Setting	Thermostat	Living Area	Summer Daytime

In addition, the questionnaire included a set of items that are meant to indicate general characteristics of the occupants, such as demographic and socioeconomic characteristics. It also included some items that are designed to gather information about the characteristics of the apartments. Additionally, a set of items was used to collect subjective data about occupants' energy-related behaviors.

This research with MSU study ID STUDY00002932 has been determined to be exempt under 45 CFR 46.104(d) 2i on July 2nd, 2019 (see APPENDIX).

3.2.2. ***Sampling***

1) Unit of analysis

The unit of analysis for this study a multifamily residential building located at East Lansing, Michigan, where a total of three buildings were used. Each building consists of four occupiable stories above the ground level, as shown in Figure 3.2. Each building has 63 apartments. The total number of apartment units in the complex is 189. Each apartment is the one or two-bedroom apartment. The apartments had virtually identical layouts. According to the 2009 International Energy Conservation Code (IECC), Ingham County is within the climate zone 5. Figure 5 shows the average climate in East Lansing based on data reported by over 4,000 weather stations.

Figure 3.2

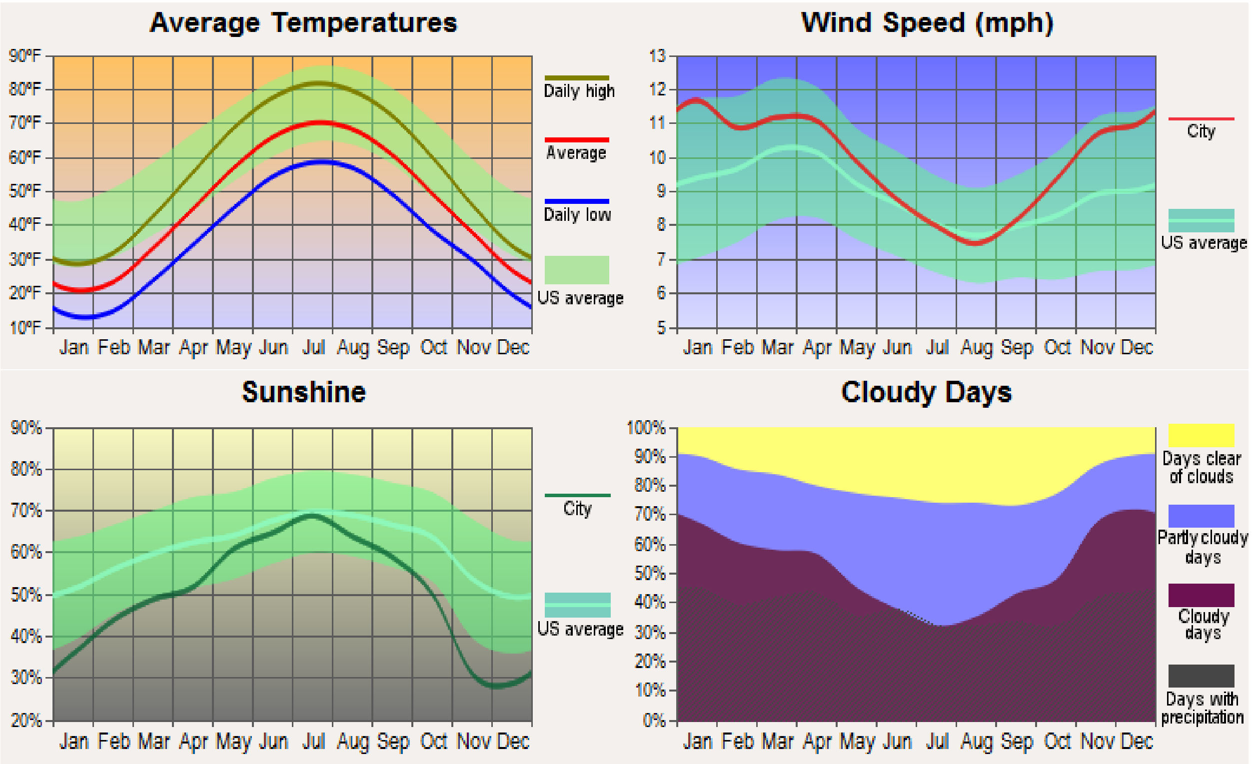
Multifamily Residential Buildings Studied in this Research

Note. Source: MSU (2016).

The unit of analysis is considered a geographical representative of multi-family residential buildings because there are different apartment orientations (north, south, east, and west). In addition, some apartments are facing a lawn area while others are facing a parking lot, and this represents different surrounding site conditions that might influence the occupants' behaviors. The buildings also have four floor levels and are geographically located in Michigan which, as shown in Figure 3.3, experiences low temperature during the winter and high temperature during the summer.

Figure 3.3

The Average Climate in East Lansing based on Data Reported by over 4,000 Weather Stations



Note. Source: City Data (2019).

2) Population of study

The population of interest was occupants of the three multifamily residential buildings. These buildings are designed and constructed to be occupied by families of Michigan State University's undergraduate and graduate students. Family housing is designated for the students enrolled in degree-granting programs which are (MSU, 2016; MSU 2018). The eligibility criteria for family housing are:

- Single students with dependent children and relatives,
- Legally married, with or without dependent children and relatives, or,
- Domestic partners, with or without dependent children and relatives

The population of study is considered representative because occupants can be undergraduate or graduate students which includes diverse age and income. Students can also be domestic or international students, which contributes to the diversity in race, ethnic, cultural backgrounds.

3) Sample frame

The three multifamily residential buildings that were selected had a total of 189 apartments. The research will target all heads of households who were occupying the three multifamily residential buildings since the total number of households is fewer than 200 (PSU 2014). In addition, the participants will be asked to forward the survey to their family members to expand the pool of participants by the snowballing technique.

4) Sample size calculations

The sample size influences the external (inferential statistical) and the internal validity of the study (Wagner et al., 2018). The following steps were followed to determine the appropriate sample size for external validity, as shown in Table 3.2. (Creswell, 2014; PSU 2014):

a. Determine the size of the population of interest: The three multifamily residential buildings have a total of 189 apartments with 189 heads of household who will receive an invitation to participate in the survey.

b. Determine the desired precision of results: Confidence intervals are a function of sampling error (standard error). A five percent margin of error indicates a willingness to accept an estimate within +/- 5 of the given value.

c. Determine the confidence level for this margin of error: This study assumes a 95% confidence level, identifying the risk of 1 in 20 that actual error is larger than the margin of error (greater than 5%).

d. Estimate the degree of variability: Since the variability is too difficult to estimate, the researcher assumed that the population is divided 70%-30% on the attribute being measured.

e. Estimate the response rate: Dillman (2000) argues that a 75% response rate can be obtained through "The Tailored Design Method," which incorporates internet and mail surveys.

Table 3.2

Requirements to Calculate the Sample Size

Where:	Inputs:
n = final sample size required	n= 186
N = population size	N = 189
P = variance in population	P = 0.3
A = precision	A = 5%
Z = confidence level	Z = 1.96 for 95% confidence
R = Estimated Response rate	R= 0.5 based on Dillman 2000
This produces a base sample size of 93 survey participants required in the study	

Note. This table was produced based on the sampling calculation available in APPENDIX A.

Finally, APPENDIX A was used to determine the sample size based on the requirements showed in Table 3.2.

3.2.3. *Data Collection*

This researcher contacted the Michigan State University's Registrar's Office to contact students who were residents of the buildings under study. Michigan State University cannot provide personally identifiable information such as email addresses to protect the privacy of students. However, the Registrar's Office can send out emails to students on behalf of the research team. Also, due to Family

Educational Rights and Privacy Act (FERPA), some students apply restrictions on their profile, so the Registrar's office was not able to reach out to the whole population of the study.

Therefore, the researcher adopted the mixed-mode survey design suggested by Dillman, Smyth, and Christian (2014) to increase the response rate while maintaining low levels or errors while also reducing survey costs. In this research, the single-mode survey (in this research online) was not expected to cover the population of interest. Therefore, using the mixed mode helped reduce the coverage error. Also, offering a second mode (in this research, paper-based) to non-respondents reduced the non-response error by encouraging responses from people who did not participate using the initial mode.

The online questionnaire was designed using Qualtrics software. The researcher submitted a data request to the Registrar's Office to send the link to the standardized online survey to students on her behalf. The researcher sent the subject line, message body, and contact information for the research team that the email came from, as shown in APPENDIX B. All responses and questions were redirected to this email. Dillman, Smyth, and Christian (2014) recommended to follow up with survey reminders. The first online reminder was sent to residents one week after the initial invitation. The second online reminder was sent two weeks after the first reminder, as shown in APPENDIX C. All online reminders were sent to occupants through the Registrar's Office.

After four weeks, a paper-based survey was sent to all the non-respondents through their mailboxes located at the 1855 Place Community Service Center. The push-to-web approach was used in which a URL and a QR code were added to the paper-based survey to allow respondents to take the online version of the survey. This method is recommended to reduce human error that might arise when coding and inserting data (Dillman, Smyth, & Christian, 2014). A sample of the paper-based survey can be found in APPENDIX B. One week later, a postcard was delivered to the non-respondents through their mailboxes, as shown in APPENDIX F. It took about 12 weeks to complete all rounds of data collection.

The researcher followed the guidelines provided by Dillman, Smyth, and Christian (2014) for designing a questionnaire to minimize measurement differences across survey modes. First, the same visual format, question format, and wording were used. Also, the researcher accounted for the differences in apartment layouts. Web technology was used to determine which floor plan to display to the respondent based on their response to a previous filtering question. On the other hand, ten versions of the paper-based surveys were designed. Each one had a floor plan that matches the number of the apartment that it was sent to.

In addition, the respondents were offered a $5 Amazon gift card for completing the questionnaire. The questionnaire had a question that asked respondents if they wished to receive the incentive or not. Respondents who chose to receive the incentive were directed to another website where they were asked to share the email or physical address where the gift card should be sent.

3.2.4. *Data Analysis Plan*

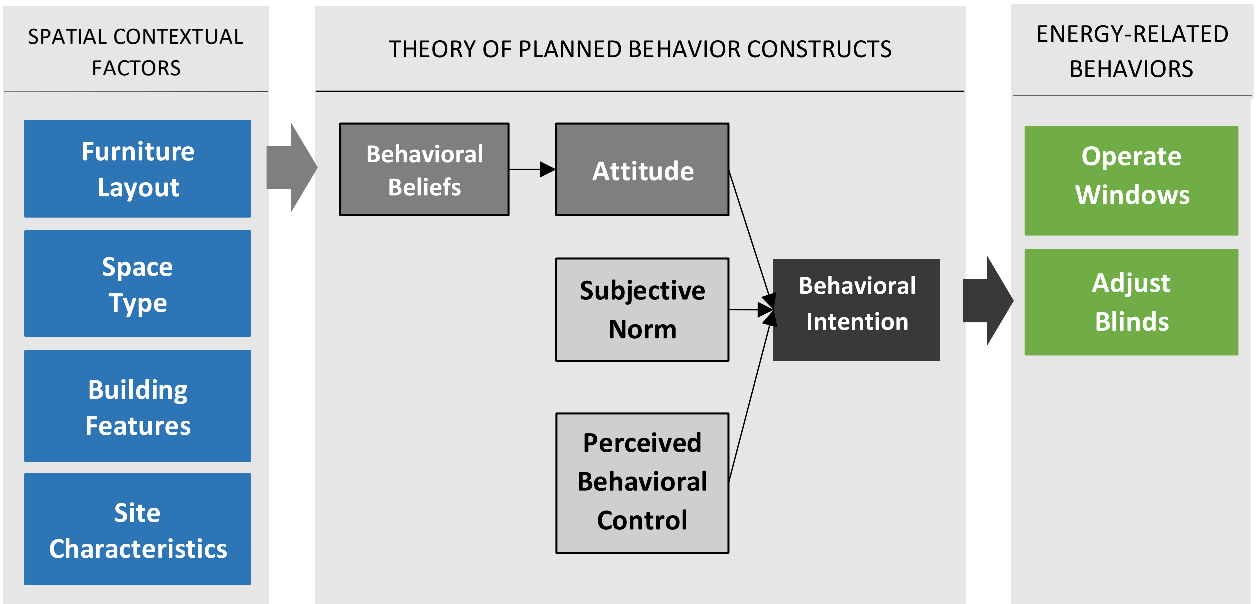
1) Variables

This study considered variables in three stages, as shown in Figure 3.4. In the first stage, the independent variables were the occupants' behavioral beliefs about spatial contextual factors (location, space type, outdoor views, floor level, and orientation), while the dependent variable is the occupants' attitude towards operating windows and adjusting blinds. In the second stage, the independent variables were the occupants' attitude, subjective norm, and perceived behavioral control, while the dependent variable was the occupants' behavioral intention towards operating windows and adjusting blinds. In the third stage, the independent variable was the occupants' behavioral intention, while the dependent variables was the occupants' behavior of operating windows and adjusting blinds.

In addition, demographic characteristics, socioeconomic factors, housing characteristics, and other energy-related behaviors were used for classification and comparison purposes.

Figure 3.4

Variables of the Study



2) Reporting the number of respondents

The first step of the data analysis was to identify the non-valid responses by reporting the numbers and percentages of respondents and non-respondents (Creswell, 2014). Some respondents did not answer the main set of questions related to the Theory of Planned Behavior. So, these two types were considered as non-valid response and were eliminated from the data set.

3) Response bias

The researcher did not restrict the number of times a household could take the survey because the number of adults varies. This resulted in some occupants taking the survey twice. Duplicated responses having the same IP address and responses within a period of fewer than 15 minutes were excluded (Hong et al., 2018).

4) Descriptive analysis

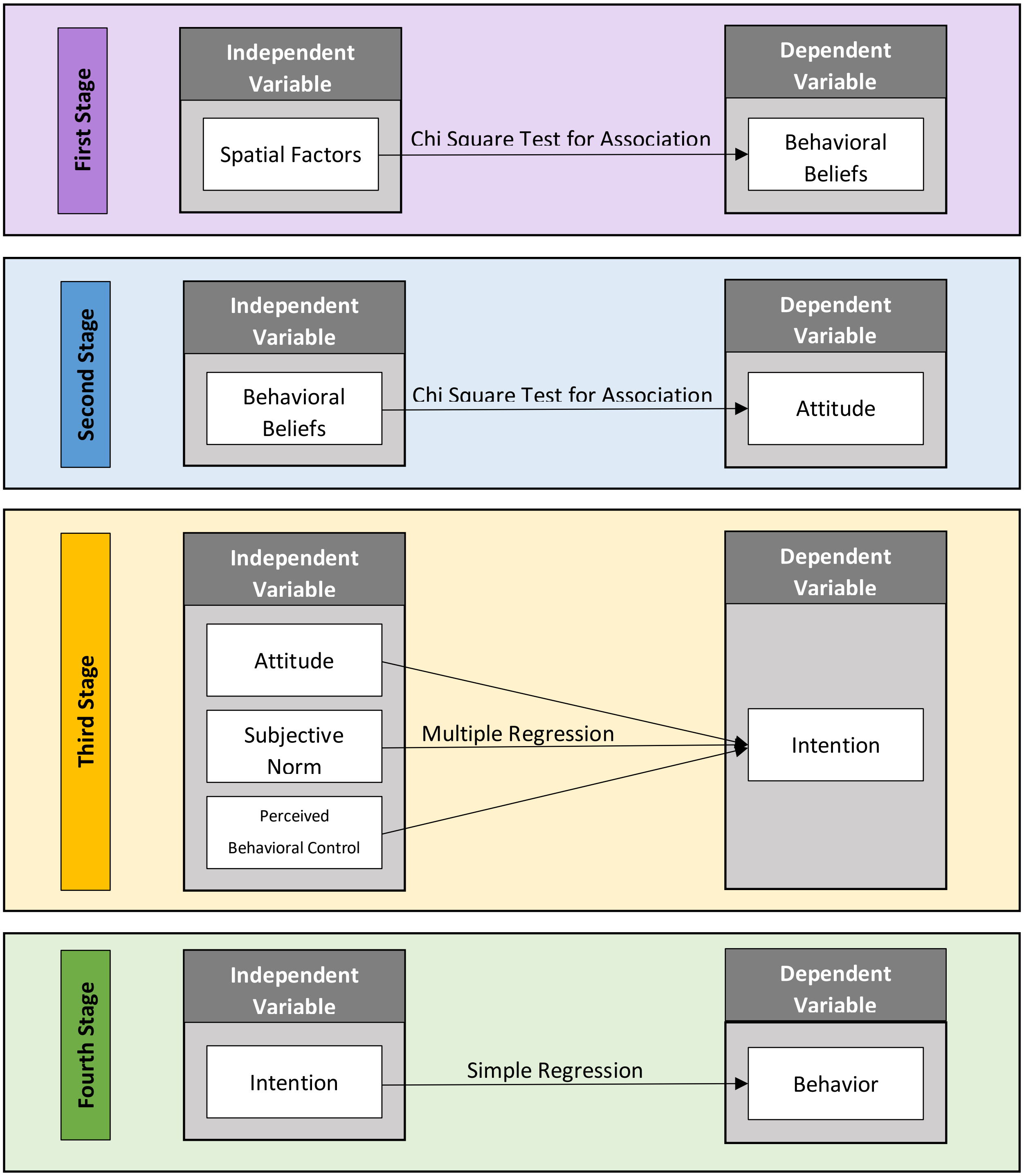
Descriptive statistics, including frequency and percentage, were applied to sort the general characteristics of the respondents, such as demographic, socioeconomic, housing, and energy-related factors. Descriptive statistics were also used to compare the results of the summer versus the winter surveys.

5) Inferential analysis

First, a Chi-Square for association test was run to measure the relationship between occupants' behavioral beliefs and attitudes. Then, multiple regression was performed to estimate the beta-weight coefficient of three independent variables, which are the attitude, subjective norms, and perceived behavioral control on an outcome variable, which is the behavioral intention. Finally, a linear regression analysis was conducted to measure the relationship between behavioral intention and actual behavior.

Figure 3.5

Four Stages of Analysis and the Independent and Dependent Variables of Each Stage



6) Hypothesis testing

The hypothesis testing is a measure of the lack of fit between the measured data and the inverse of the hypothesis known as the null hypothesis. Statisticians have agreed on standard key parameters for hypothesis testing, which are: levels of confidence and statistical power (Bordens, & Abbott, 2002). In the energy and buildings field, 80% statistical power and 95% confidence is cited, which means that the cut off for the p-value is an alpha of 0.05 (Wagner et al., 2018). The *p-value* is a value between 0 and 1, and it determines the significance of the results. In this case, if the p-value is less than 0.05, this indicates statistically significant evidence against the null hypothesis. Thus, the proposed null hypothesis will be rejected and vice versa.

3.2.5. *Reliability and Validity*

Reliability and Validity are concepts used to evaluate the quality of the research. Reliability refers to the consistency of the measure, while validity refers to the accuracy of the measurement (Schutt, 2018).

To ensure the reliability of the measurement, the direct items (reflective indicators) designed to assess the TPB constructs (attitude, subjective norms, perceived behavioral control, intention, and behavior) were constructed following established guidelines that are provided by Ajzen in 2006. The measurement used in this research was designed to investigate the behavior of occupants in the living area and the sleeping area. So, the researcher decided to use a single-item scale for each construct to reduce the cognitive burden on respondents. As far as internal consistency, there is evidence indicating acceptable reliability values for single-item scales (Fuchs & Diamantopoulos, 2009). Finally, the survey was administered with consistent dates and modes to eliminate errors caused by carelessness in administration or scoring (Creswell, 2014).

To establish construct validity to assess the validity of the questionnaire used in this research, this process incorporated procedures such as content validity, convergent and divergent validity, and criterion validity (Messick, 1980; Wainer & Braun, 2013). The behaviors under study were described based on the recommendations of Fishbein & Ajzen (2010). The behaviors were described based on the action, target, context, and time. For example, the occupants perform an action which is operating a window which is the target in a specific context, which in one of the cases is the sleeping area. The research focused on behaviors during the daytime, and in two different seasons which are summer and winter. The behaviors under study were described in Table 3.1 to ensure content validity. In addition, a seven-point Likert scale was used to collect data about the main constructs of the Theory of planned Behavior as suggested by Ajzen (2006).

Internal validity is the ability of the research design to adequately test the exact hypothesis, in which the research findings should be correctly attributed to the interventions being tested (Campbell & Stanley, 1963; Wagner et al., 2018). In a correlational design, this means that changes in the value of the dependent variable relate solely to changes in the value of the independent variable (Bordens & Abbott, 2002). Confounding variables are one of the threats to internal validity, especially in correlational research design. Campbell and Stanley (1963) identified seven sources of confounding that might cause a threat to internal validity: history, maturation, testing, instrumentation, statistical regression, biased selection of subjects, and experimental morality (Bordens & Abbott, 2002).

In this research, occupants were asked to answer background questions about demographics and socioeconomic characteristics. The survey was distributed among all potential participants to eliminate any preexisting bias such as age or nationality due to the small number of the targeted households (fewer than 200).

The “history” confounding effect might pose a threat to the internal validity of self-reports (Bordens & Abbott, 2002; Fishbein& Ajzen, 2011). For instance, respondents may not be able to recall their past behaviors. Recently performed behaviors are easier to recall than those that were performed a long time ago. Therefore, this study administered the self-report questionnaire in summer and winter, respectively. This way, occupants were asked to respond to the survey according to their current energy-related behaviors regarding window blinds.

Since the buildings are rentable, the investigator included one questionnaire item that asked if the respondent changed the apartment that he is living in since the last survey. This way, the investigator can depict some events that might have occurred between the two observations, such as the change in the respondent or the type and location of the apartment that was occupied before.

The external validity of a study can be determined by the degree to which the results can be considered to apply to similar _but not identical _ research settings, units of analysis, and samples in which the data was initially obtained. It is the underlying mechanisms of human behavior that can be generalized rather than the specific findings (Bordens & Abbott, 2002; Mook, 1983; Wagner et al., 2018).

Campbell and Stanley (1963) identified a list of factors that might affect external validity: reactive testing, the interaction between subject selection, biases, and independent variable, reactive effects of experimental arrangements, and multiple-treatment interference.

The research subjects, residents of the MSU family housing, are undergraduate or graduate students. They can be domestic or international students. Therefore, the effects observed may be generalized to the bigger population. Additionally, the reactive effects of experimental arrangement are eliminated in this study because the participants will be asked to give information about behavior that they do in their everyday life in their natural setting, which is the apartment that they live in.

In addition, respondents may provide inaccurate responses due to self-representation concerns. In the case of this research, occupants may choose to give a false response about their window and blind use behavior to pretend that they support socially favorable behaviors such as sustainability. Therefore, self-representation is a potential bias that should be eliminated. This kind of bias can be reduced in this research by ensuring the confidentiality of their responses and exemplifying the positive impact that this study is expected to have in improving the energy performance of the residential building and thus reducing energy bills, as shown in the survey's cover letter in APPENDIX B.

It is challenging to maintain high internal and external validity throughout the same research as their criteria might conflict. This research follows the applied research that is concerned with applying results to real-world problems. Therefore, in the research design, the investigator attempted to enhance external validity while maintaining a reasonable degree of internal validity.

3.2.6. *Pilot Study*

As recommended by Zeisel (1984), a pilot study was conducted to check the manageability of the survey, the duration, and face validity. The pilot sample consisted of 10 participants who were asked to respond to the questionnaire on May 27th, 2019. The participants were a convenience sample and were residents of the buildings used in this study. The pilot study helped determine the clarity of the questionnaire wording and the comprehensibility of the questionnaire items. The questionnaire was revised based on the conclusions from the pilot study to eliminate any potential problems and maximize the quality of information. Some of the occupant's comments included repeated items. Also, some respondents thought that introducing images helped them understand the questions and they suggested placing them at the beginning of the questionnaire.

3.3. Constructing the Agent-Based Model

Constructing an agent-based model is comprised of three main phases: conceptual, modeling, and evaluation. The conceptual phase is divided into preparation and design. In the preparation phase, the researcher identified the research questions and objectives, then decide on the first design decision regarding the abstraction level of the model depending on its purpose and function. In the modeling phase, the model is conducted by using Anylogic Simulation Software version 8.5.2, which was released in January 2020. The final phase of model construction is the evaluation phase, where verification, validation, sensitivity analysis, and calibration take place (Crooks et al., 2018).

3.3.1. *Conceptual Phase*

The conceptual phase is the first step in constructing the ABM, and it consists of two subphases, which are preparation and design. In the preparation phase, the ABM modeler defines the objectives of the research and the level of abstraction that best fits the purpose of the model. While in the design phase, the modeler decides on which components are crucial to the research problem-solving in addition to defining the interactions between agents and their environment. This is in addition to identifying the appropriate decision behavioral rule and necessary data.

1) Preparation phase

The goal of the proposed model is to simulate the energy-related occupant behavior in multifamily residential buildings. This model focused on energy-related behaviors that relate to the indoor environmental quality criteria: thermal comfort, visual comfort, acoustical comfort, and air quality. Two behaviors were chosen to be modeled: 1) operating windows and 2) adjusting blinds. These two interactions that the occupants have with interior elements were modeled concerning buildings' spatial contextual factors such as the orientation, floor level, outdoor views, and space type. The objective of this model was to study the impact of the occupants' beliefs towards operating windows and adjusting blinds on the buildings' energy use.

The proposed model explained the different energy use implications resulting from occupants' behaviors in different interior spaces. Therefore, the energy-related behaviors were quantified into an energy metric. Simulating energy-use in this model will be represented in the abstract form of "increase" or "decrease." Realistic calculations were not used, as the rationale behind this ABM is to examine the relationship between occupants' behaviors and contextual building factors and how this relationship influences the buildings' energy-use, and not to predict the energy use accurately.

2) Design phase

Structure: The proposed conceptual model consists of seven basic building blocks, as shown in Figure 3.6. One of the main parts of the conceptual model is the agent who represents the occupants of the residential apartment. Another part is the indoor environmental conditions of the residential apartment that represents the drivers of the occupants' behaviors and they include lighting, views, acoustics, air quality, and temperature. The Needs of the occupants are also represented in the conceptual model, and they are divided into individual factors such as indoor environmental quality preferences, and the spatial contextual factors such as orientation, outdoor views, floor level, space type, and location. The drivers and needs of the occupants determine their interaction with the Buildings' systems as suggested by the Drivers, Needs, Actions, and Systems framework (Hong et al.,2015). This model studied the occupants' behaviors of operating windows, adjusting blinds, setting thermostats, and switching the artificial lighting. The occupant-building interaction results in energy consumption, which is the output of this model. Finally, the proposed model accounts for the physiological factors in addition to the physiological factors. Therefore, part of the agent decision making is based on the three constructs of the Theory of Planned Behavior, which are attitude, subjective norm, and perceived behavioral control.

Relationship: The functional connection between the occupant's intentions and predicted behavior is represented using a multiple regression equation:

$$y = \text{constant} + b_1x_1 + b_2x_2 + b_3x_3 + e \quad (4)$$

Where y is the predicted criterion score.

Constant is the y-intercept.

B_1, B_2, and B_3 are the regression weights associated with the predictors.

X_1, X_2, and X_3 are the values of the predictors' attitude, subjective norm, and perceived behavioral control, respectively.

Process: The event operating over time and space in this model is operating the windows and adjusting the blinds. This process changes the indoor conditions in the modeled target system.

Boundary (Conditions): The thermal, lighting, acoustics, air quality conditions are constraints on the values of model variables reflecting different comfort levels of occupants, and they will trigger the occupants to make a specific behavior.

Time: The model simulates occupant behavior from 6:00 a.m. to 6:00 p.m. for the months of January and July to compare the occupants' behavior in winter versus summer.

Constant: It is the quantity that does not vary in the system under the study and in the case of this model, it is the explicit environment which is the apartment, including the windows and blinds. Also, the number of occupants (agent instances) is fixed.

Parameter: these are the quantities that will vary across cases but will stay constant in every case being modeled. In the proposed model, the parameters are the occupant's beliefs, attitudes, subjective norm, perceived behavioral control, which determines the occupants' behavioral intention.

Variable: The variables are the quantities that vary within the model. In this model, they are the environmental conditions that change over time and influences the indoor environment quality (IEQ) such as air temperature, carbon dioxide concentration, outdoor noise, and daylighting. Also, the building systems status such as blind, window, thermostat, and artificial light statuses are going to change according to the occupant's behavior.

Figure 3.6

Conceptual Framework of Adaptive Occupant Behavior in ABM

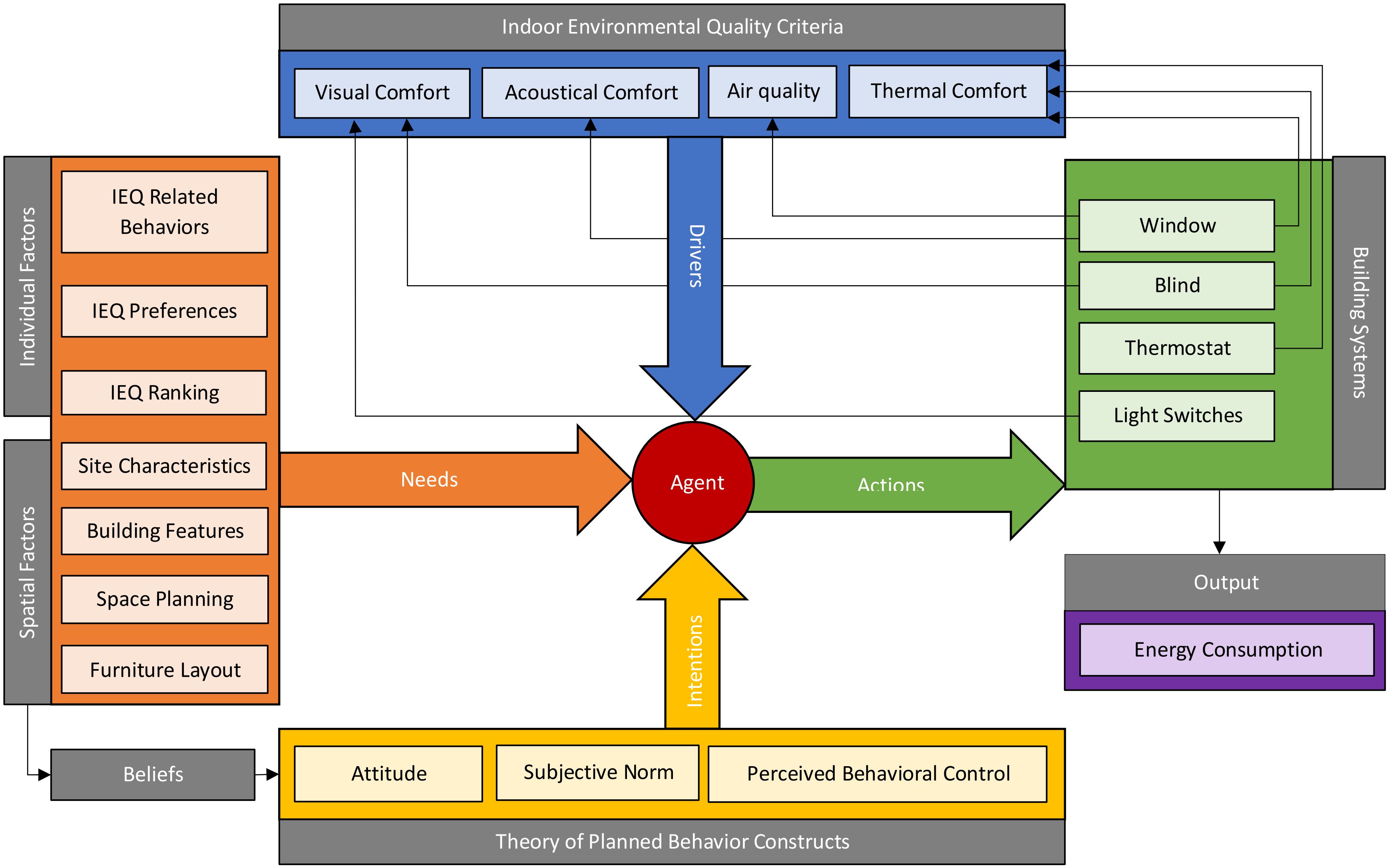
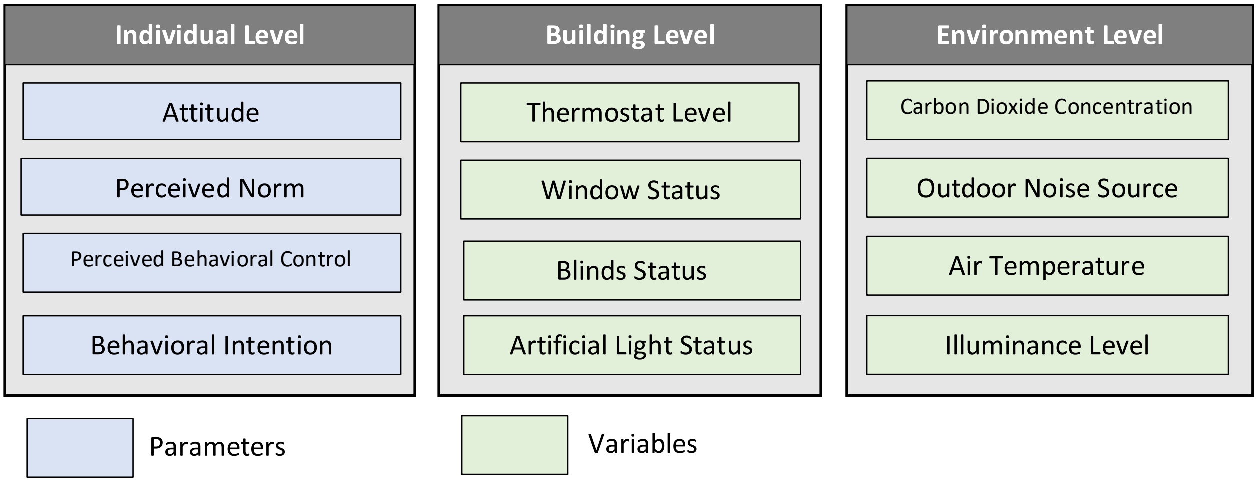


Figure 3.7

Model Parameters and Variables



3.3.2. *Modeling Phase*

In this phase, the modeler identified and arranged the components of the proposed agent-based model as follows:

a) Agent

In agent-based modeling, the agent is implemented using the object-oriented programming paradigm based on the concept of "objects." These objects contain data in the form of attributes and methods. The attributes are used to describe the agent, including its memory, while the methods dictate the agent's behavior (Ligmann-Zielinska, 2018). In this model, the agent represents the occupants of residential apartments. Their attributes were identified based on the two behaviors under study: operating windows and adjusting blinds; and they were guided by the constructs of the Theory of Planned Behavior, as shown in Figure 3.6.

Figure 3.8

Agent's Attributes Arranged According to the Theory of Planned Behavior

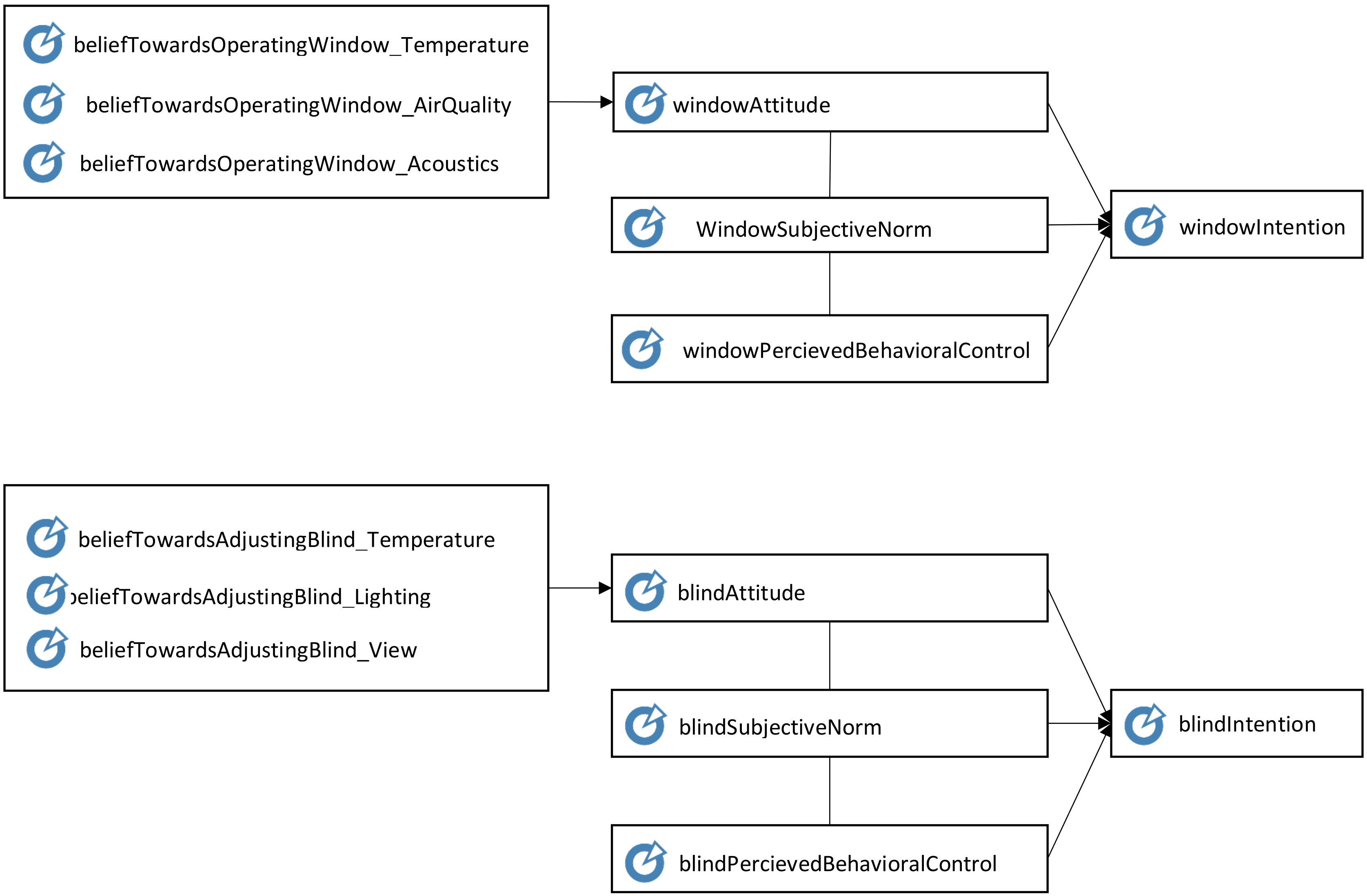
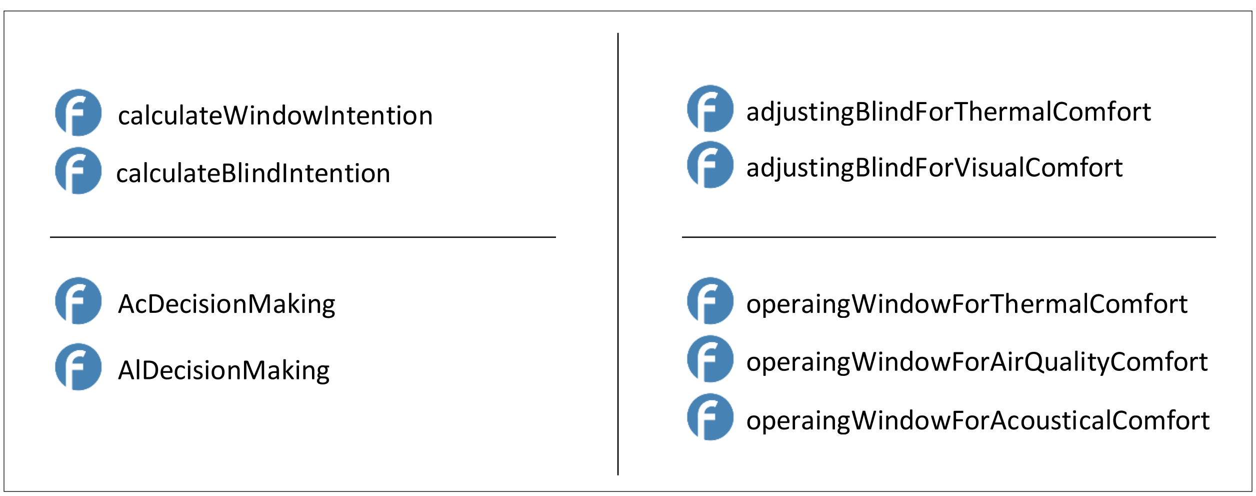


Figure 3.6 shows the agent's attributes, that are related to the two behaviors being studied, are operating windows and adjusting blinds. The agent's beliefs were identified based on the impact that the two behaviors have on indoor environmental quality. Operating windows can influence the indoor temperature, air quality, and acoustics. Adjusting blinds can influence the indoor temperature, daylight, and outdoor views. Two more attributes were identified: the ranking of each of the indoor environmental quality criteria, and the preferred temperature. The preferred lighting, air quality, and acoustics levels were defined based on previous research and are common across all instances of the agent.

The methods used to determine the agent's behavior used in this model are decision rules in the form of IF-THEN/ condition-action statements. Figure 3.9 shows the different methods that were used in this model. The first set of methods calculate the agent's intention based on their attitude, subjective norm, and perceived behavioral control attributed defined earlier. The other three sets of methods are the agent's decision rules to operate windows, adjust blinds, adjust the thermostat, and/or turn on the artificial light.

Figure 3.9

The Agent's Methods that Determines their Behavior

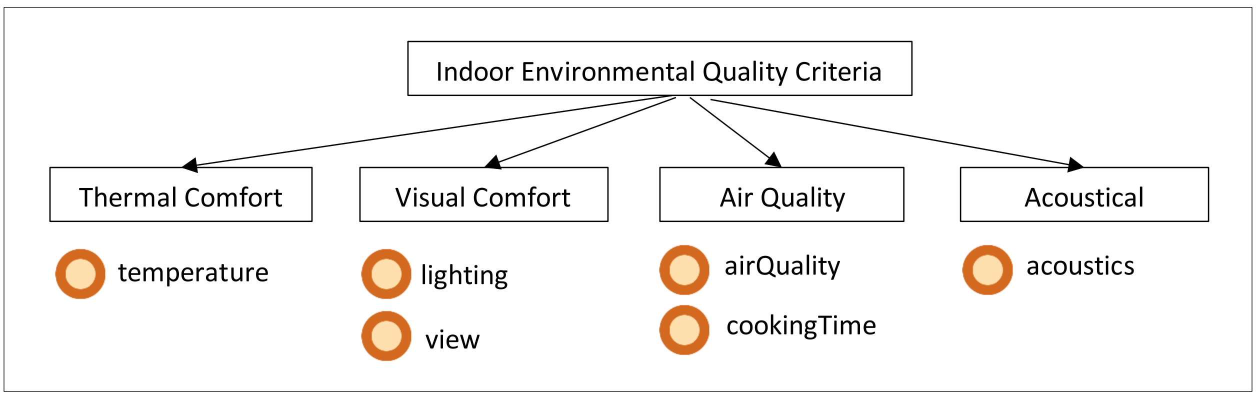


b) Environment

The environment is anything outside the agent (Ligmann-Zielinska, 2018). In this model, the environment is the continuous physical space, which is the residential apartment that the agent occupies. The environment is accessible to the agent. The agent can obtain complete, accurate, and up-to-date information on the environment. The indoor characteristics of the environment were identified based on the indoor environmental qualities, and they are 1) temperature, 2) lighting, 3) view, 4) acoustics, and 6) air quality, as shown in Figure 3.10.

Figure 3.10

Indoor Characteristics of the Environment



The environment in this model is dynamic. Its characteristics changes based on the model time. Three dynamic parameters were created to store the values of the hours, days, and months as shown in Figure 3.11. These dynamic variables were used to access the information in the excel files to update the environment characteristics, as shown in Figure 3.12. The temperature and sky conditions information were obtained from the Local Climatological Data (LCD) that were downloaded from the National Centers for Environmental Information (NCEI) for Lansing Capital City Airport Station. The weather data used was from January 2019 to January 2020.

Figure 3.11

Model Time Counters

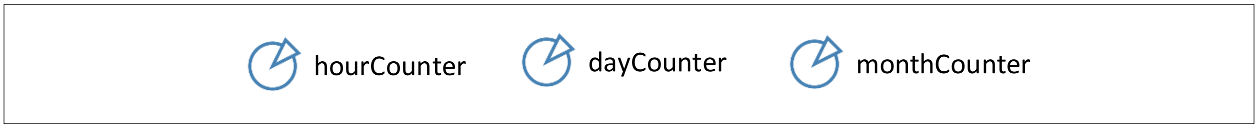
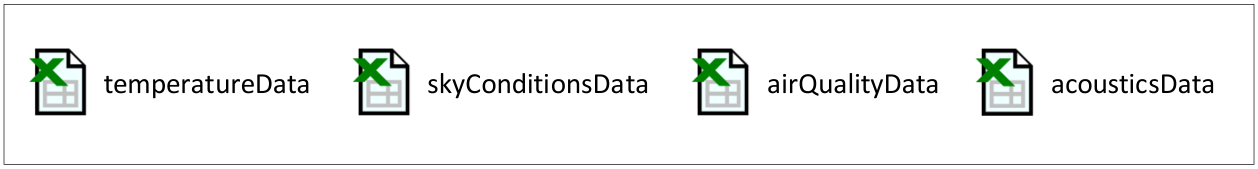


Figure 3.12

Excel Files Used to Update the State of the Environment



The environment involves stochasticity in the form of uncertain states of the hourly temperature, amount of daylight, air quality, and acoustics. The hourly dry bulb temperature obtained from the Local Climatological Data (LCD) was adjusted, as shown in Table 3.3, to reflect the indoor temperature. The sky conditions obtained from the Local Climatological Data (LCD) for Lansing Capital City Airport Station were used as shown in Table 3.4.

The sky conditions were used as indicators of the amount of daylight. The value of the air quality variable depends on the apartment orientation and the amount of cooking that the occupants perform. This model assumes that the residential apartments being modeled are smoke-free in compliance with Michigan State University's policy. The value of the acoustics depends on the outdoor surrounding environment. In this research, the modeled apartments are either overlooking a parking lot or a green area.

Table 3.3

Adjustment Made by the Researcher to the Temperature to be Used in the Model

Hourly Dry Bulb Temperature Range	Adjusted Hourly Dry Bulb Temperature
-20F to -16F	65F
-15F to -11F	66F
-10F to -6F	67F
-5F to -1F	68F
0F to 4F	69F
5F to 9F	70F
10F to 14F	71F
15F to 19F	72F
20F to 24F	73F
25F to 29F	74F
30F to 34F	75F
35F to 39F	76F
40F to 44F	77F
45F to 49F	78F
50F to 54F	79F
55F to 59F	80F
60F to 64F	81F
65F to 69F	82F
70F to 74F	83F
75F to 79F	84F
80F to 84F	85F

Table 3.4

Sky Conditions Used in the Model

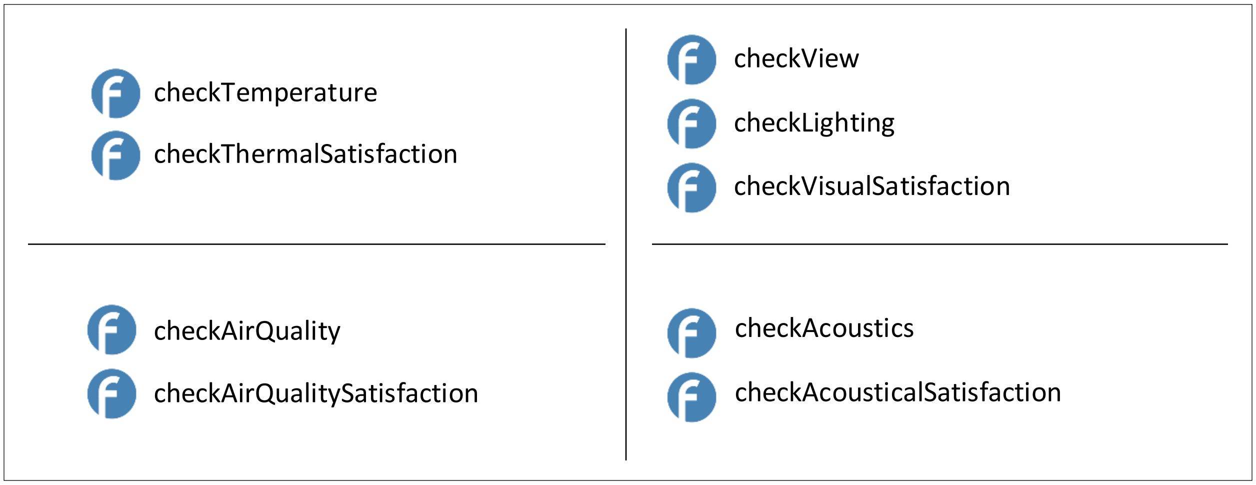
#	Cloud Cover Term	Nomenclature	Meaning	Suggested Illumination Level
1	Clear	CLR	0% of the sky is covered by clouds	300
2	Few	FEW	10% - 20% of the sky is covered by clouds	270
3	Scattered/Partly Cloudy	SCT	20%-50% of the sky is covered by clouds	190
4	Broken/Mostly Cloudy	BKN	50%-90% of the sky is covered by clouds	60
5	Overcast	OVC	>90% of the sky is covered by clouds	20

c) Interactions

The model to be implemented incorporates agent-environment interaction in the form of a cyclic loop. This interaction starts with the agent who collects information about the environment. Based on this information, the agent takes an action that modifies the status of the environment if needed. The researcher wrote different functions to allow the agent to collect information about the environment status, as shown in Figure 3.13.

Figure 3.13

Functions that Allows the Agent to Collect Information about the Environment Status



The model to be implemented assumed that the agent would interact with the environment to control the indoor environmental conditions with the following actions 1) operate window, 2) adjust blind, 3) set thermostat, and/or 4) turn artificial light on/off. Four variables were created to store the updated values namely widowStaus, blindStatus, airConditionStatus, and artificialLightStatus, as shown in Figure 3.14.

Figure 3.14

Variables to Store the Updated Environmental Conditions Statuses

The model to be implemented suggested that the agent interacts with elements of the environment to control indoor environmental conditions according to his/her beliefs of the advantages and disadvantages of a behavior. A group of functions was written as decision rules for the agent's behavior, as shown in Figure 3.15.

Figure 3.15

Functions that Determine the Agent's Interaction with Windows and Blinds

- adjustingBlindForVisualComfort
- adjustingBlindForThermalComfort
- operatingWindowForThermalComfort
- operatingWindowForAirQualityComfort
- operatingWindowForAcousticalComfort

In addition to the decision rules that determine the interaction with building systems passive elements such as windows and blinds, the model also considered interaction with active building systems such as thermostats to control the indoor temperature and light switches to control the amount of artificial light, as shown in Table 3.5.

Figure 3.16

Functions that Determine the Agent's Interaction with Thermostats and Switches

- AcDecisionMaking
- AlDecisionMaking

Finally, two functions were written to turn off the air conditioner/heater and the artificial light switches if they were on, to allow the agent to evaluate the indoor environmental conditions continuously.

Table 3.5

Nomenclature Applied to the Parameters and Variables of the Agent-Based Model

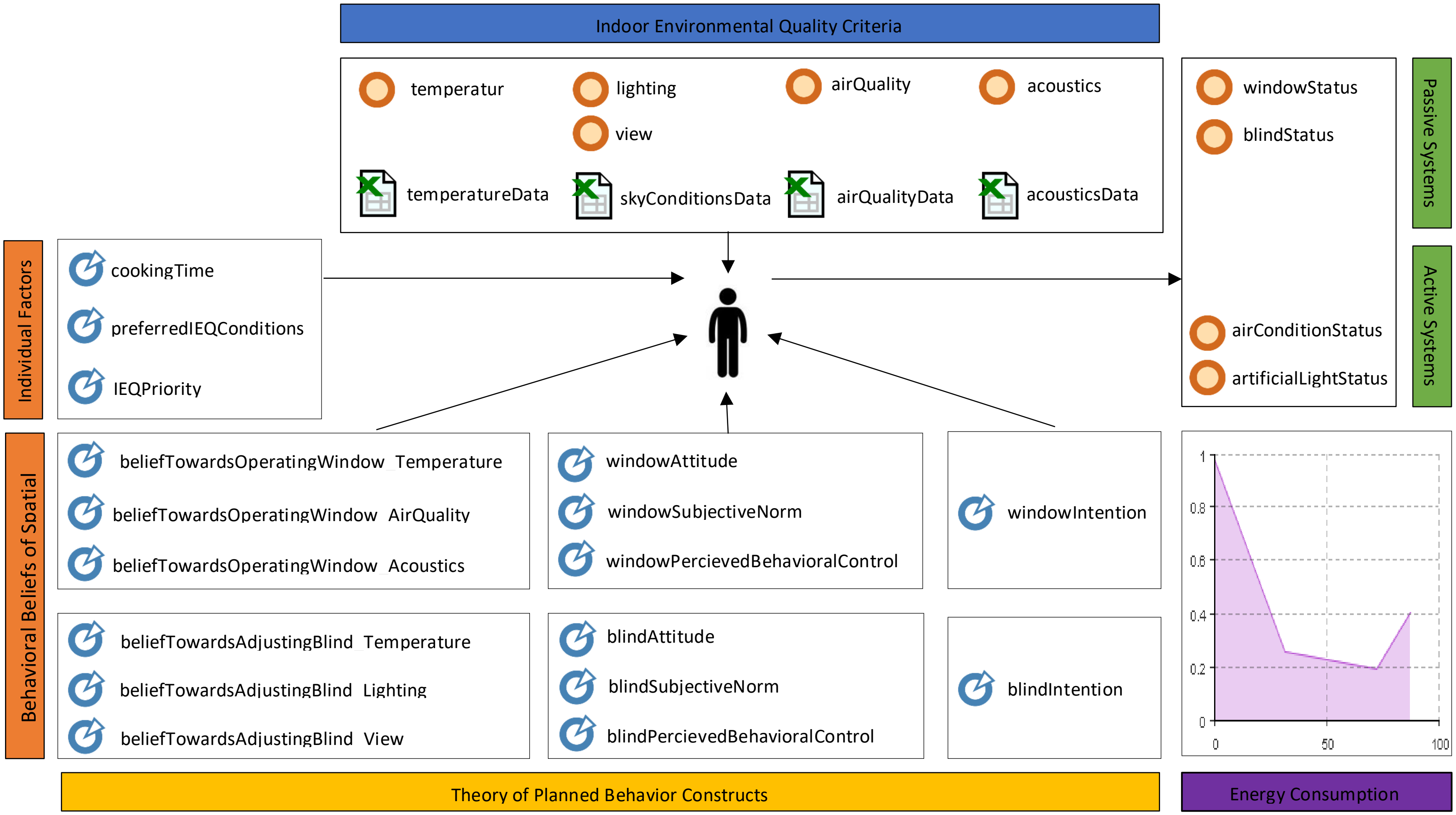
Building Systems		Affected Parameters	Possible Status
Passive Systems	Window	• Air temperature (°C)	Open/Close
	Blind	• Horizontal illuminance level (lx) • Air temperature (°C)	Open/Close
Active Systems	AC	• Air temperature (°C)	On/Off
	Lights	• Horizontal illuminance level (lx)	On/Off

d) Time

The model time is like the calendar dates for the months of July 2020 and January 2020. The model time units are minutes.

Figure 3.17

Proposed Adaptive Occupant Behavior Agent-Based Model

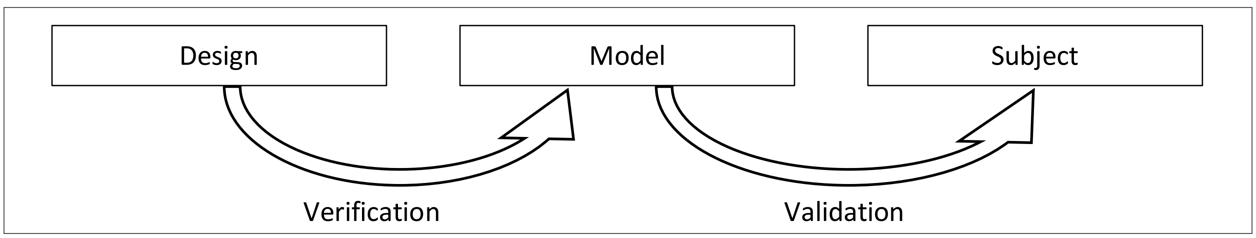


3.3.3. *Evaluation Phase*

The evaluation phase involves model verification and validation, as described in Figure 3.18. Model verification is the process of checking that the implemented model reflects the conceptual model. It is checking whether the model is right. Model validation is the process of comparing the computational results to real-world results to examine if the model can be generalized. It is checking whether the modeler built the right model (Ligmann-Zielinska, 2018).

Figure 3.18

Model Evaluation Steps



1) Model verification

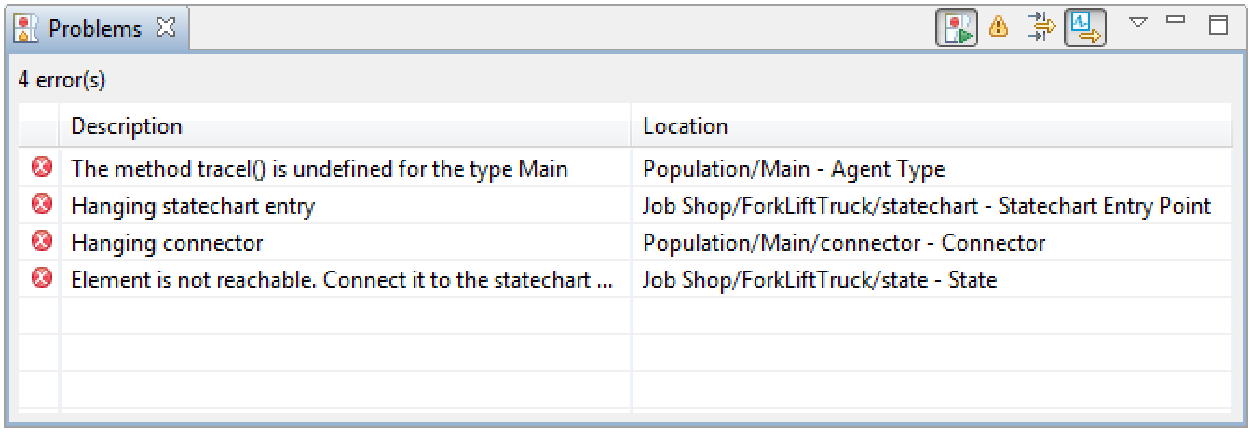
Verification (like internal validity) is the first stage in model evaluation. It can be defined as verifying that the implemented model corresponds to the conceptual designed model (Crooks et al., 2018; Ligmann-Zielinska, 2010). This research will utilize AnyLogic, which is a simulation modeling software tool developed by the AnyLogic Company (Anylogic, 2020). AnyLogic includes a graphical modeling language which consists of state and action charts. The language also includes low-level modeling constructions (variables, equations, parameters, events, etc.), presentation shapes (lines, polylines, ovals, etc.), analysis facilities (datasets, histograms, plots), connectivity tools, standard images, and experiments frameworks. The graphical modeling language reduces the risk of coding errors. However, the Java code can be used when needed (Borshchev, 2013).

a) Code debugging

AnyLogic supports “on-the-fly” checking of types, parameters, and diagram syntax. The errors found during code generation and compilation are displayed in the problems view. For each error, the problems view displays description and location, as shown in Figure 3.19 (Anylogic Help, 2020).

Figure 3.19

The Problems View



Note. Source: Anylogic Help (2020).

b) Logic examination

The Anylogic state charts were examined to verify that the programming logic functions as described in the conceptual model.

c) Unit test

The unit test verified whether each unit of the model works as designed. Most attributes were assigned with deterministic values to verify the unit functionality. Multiple runs were used to verify that the unit was worked as intended.

2) Model validation

The main purpose of model validation, according to Crooks et al. (2018) is to “demonstrate that the model is sufficiently accurate given the context of the system that it is attempting to simulate.” Literature shows different approaches to validation, one of which is to test if the model can reproduce similar outputs (Oberkampf et al.,2004). Banks (1998) discussed subjective and objective validation techniques. This study adopted the input and output validation proposed by Sargent (2010).

a) Input validation

Input validation aims to ensure that the model inputs are accurate and are based on reasonable assumptions that reflect reality. The conceptual model proposed in this study is comprised of four main building blocks, as shown in Figure 3.8 and discussed below.

- Indoor environmental quality criteria validation

The proposed model assumes that occupants' drivers to interact with building systems are summarized in the indoor environmental quality (IEQ) criteria proposed by USGBC (2019a), which are thermal comfort, visual comfort (including the amount of daylight and outdoor views), air quality, and acoustical comfort.

- Individual and spatial factors validation

The researcher identified two types of occupants' needs based on previous studies: individual needs and needs related to the spatial factors. Individual needs were based on the ANSI/ASHRAE Standard 55-2017 and other previous studies that studied indoor environmental quality parameters in residential buildings such as Lai et al. research in 2009. Spatial factors were derived from the IEQ criteria and supported by the empirical data collected in the two surveys conducted in this research.

- Theory of Planned Behavior constructs validation

The decision-making process proposed in this model is based on the Theory of Planned Behavior (Ajzen, 1985) shown in Figure 2.5. This research conducted two surveys to collect empirical data of occupants' beliefs, attitudes, subjective norms, perceived behavioral control, intention, and behavior of operating windows and adjusting blinds in residential apartments. Chi-square was used to study the association between occupants' beliefs and behaviors. Multiple Linear regression was used to study the occupants' attitude, subjective norm, and perceived behavioral control as predictors of occupants' behavior. Finally, simple linear regression models were used to study the relationship between occupants' intention and behavior. Detailed results and analysis were discussed in Chapter Four.

- Building systems validation

The proposed model focused on studying occupants' interaction with passive building systems such as windows and blinds. It also considered occupants' interaction with active building systems such as HVAC and artificial light controls. The researcher acknowledges that there are other building systems that influence building energy performance. However, the mentioned systems were selected because they are more commonly used to control indoor environmental condition, and thus have a significant impact on the buildings' energy performance as suggested by Stazi et al. (2017)

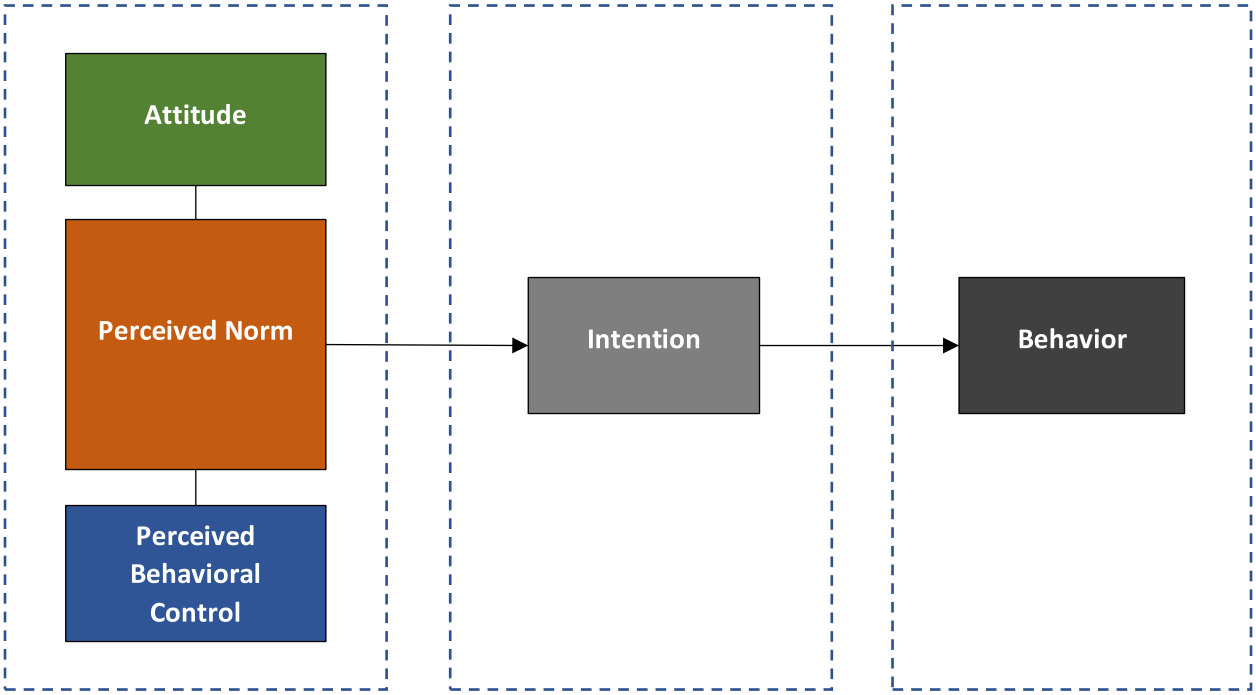
a) Output validation

Output validation aims to ensure that the proposed model generates results like observed data given rational inputs. This research conducted a survey during the summer and the winter to learn about occupants' interaction with building systems. The data collected based on the Theory of Planned Behavior can be represented in the form of three layers, as shown in Figure 3.20. Each layer of data was used as an input for the proposed model, and the output was compared.

A multiple regression model was used to predict the occupants' intention based on their attitude, subjective norm, and perceived behavioral control. In addition, a simple regression model was used to predict the occupants' behavior based on their intention. Detailed analysis and results are in chapter four.

Figure 3.20

Constructs of the Theory of Planned Behavior



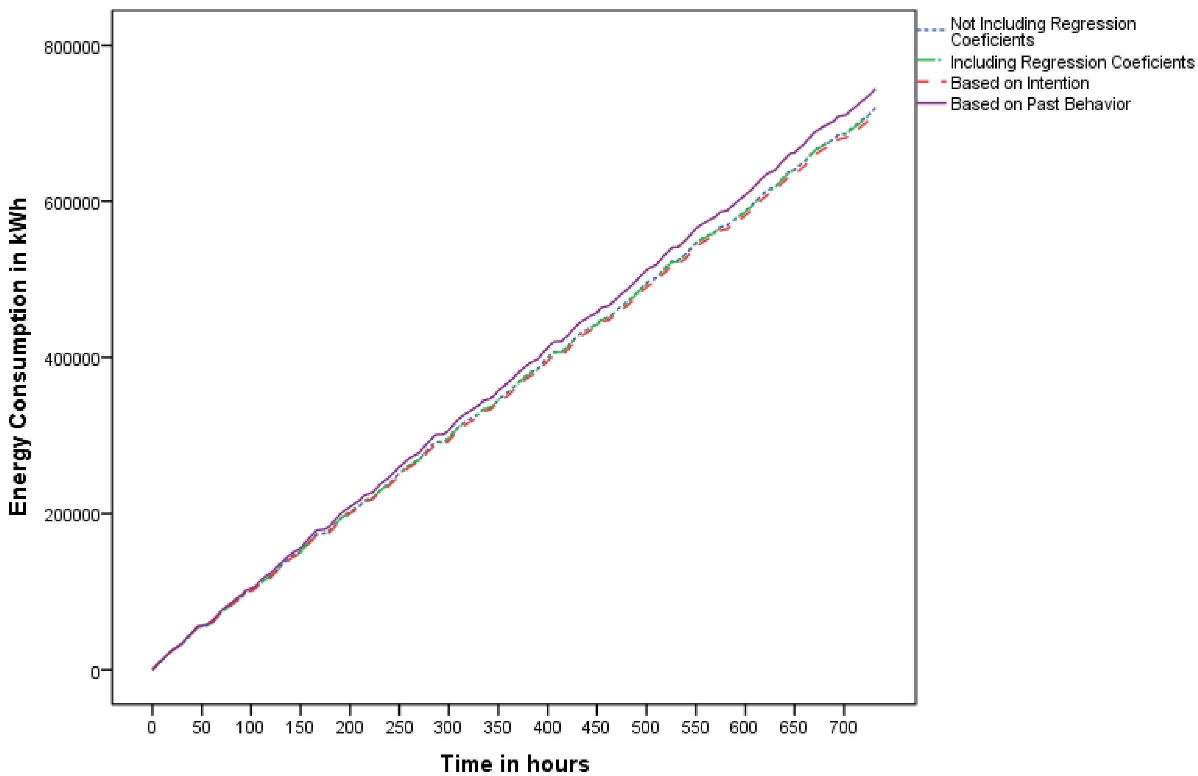
Note. Source: Adapted form Fishbein & Ajzen (2010).

- Output Validation Based on Data Collected from Summer Survey

The four lines shown in Figure 3.21 represents the four outputs of the model. The line graph shows that the output based on the occupants' attitude, subjective norm, and perceived behavioral control is almost like the output based on the occupants' intention. It also shows that the output based on occupants' behavior is the same as the output based on the occupants' attitude, subjective norm, and perceived behavioral control, but without including the regression coefficients.

Figure 3.21

Predicted Energy Consumption Based on the Summer Survey Responses

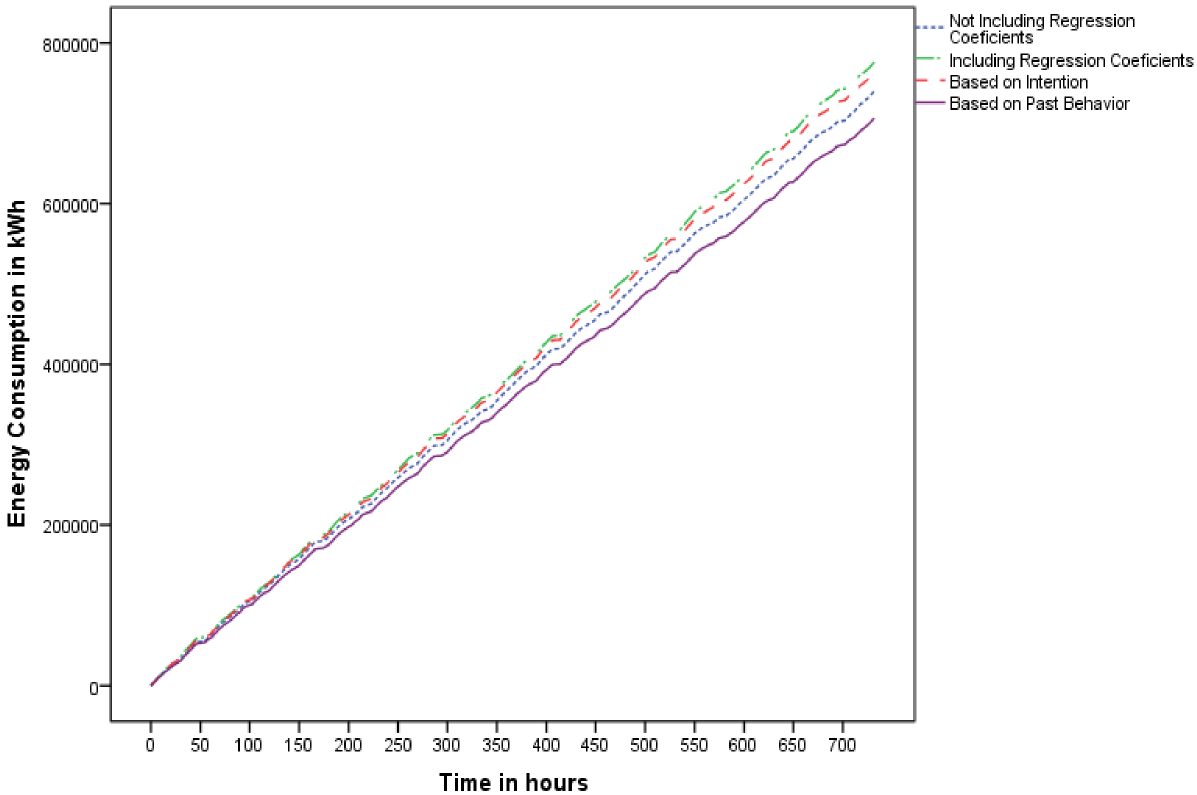


- Output validation based on data collected from winter survey

The four lines shown in Figure 3.22 represents the four outputs of the model. The line graph shows that the output based on the occupants' attitude, subjective norm, and perceived behavioral control is almost like the output based on the occupants' intention. It also shows that the output based on occupants' behavior is close to the output based on the occupants' attitude, subjective norm, and perceived behavioral control, but without including the regression coefficients.

Figure 3.22

Predicted Energy Consumption Based on the Winter Survey Responses



3.4. Summary of Research Design and Methodology

This research adopted the correlational research design. A survey was designed and conducted to collect data about energy-related occupant-building interaction and, in particular, occupants' behaviors of operating windows and adjusting blinds. The questionnaire adopted the Theory of Planned Behavior constructs to investigate those behaviors. In addition, the questionnaire included items that asked about occupants' demographic, socioeconomic, housing, and energy-related characteristics. Also, a proposed agent-based model was proposed in this chapter. First, a conceptual model was designed which included environmental, individual, and spatial factors that influences the occupants' energy-related behaviors. Then, a detailed description of the modelling phase was provided using the Anylogic simulation software. Finally, an initial evaluation of the proposed proof of concept was conducted which included model verification and validation.

CHAPTER FOUR:

ANALYSIS AND FINDINGS FROM THE OCCUPANT SURVEY

4.1. General Characteristics of Respondents

The preceding chapters addressed the overview of this study, the relevant literature, and the methods used to carry out this research. This chapter presents the results of those methods.

Specifically, this chapter first addresses the general characteristics of the respondents, including: 1) demographic characteristics such as gender, age, race, ethnicity, number of adults in household, number of children in household, and marital status of the occupants; 2) socioeconomic characteristics such as educational attainment, employment status, average household income, and affiliation to MSU; 3) housing characteristics such as apartment type, number of bedrooms, apartment orientation, and floor level and 4) energy-related characteristics such as type of cloths, time spent cooking, preferred temperature, and activity level.

4.1.1. *Demographic Characteristics*

A total number of 131 responses were collected in the summer of 2019. A total of 104 responses were considered valid and were used in the statistical analysis. Table 4.1. shows that fewer than half, 40.8%, of the respondents were male leaving 55.3% female. A total number of 101 responses were collected from the occupants in winter 2019.

A total number of 120 responses were collected in the summer of 2019. A total number of 101 were considered valid and were used in the statistical analysis. Table 4.1 shows that only 43.6% of the respondents were male, and 55.4% were female. A total number of 101 responses collected from the occupants in winter 2019.

Table 4.1

Survey Respondents' Gender

Gender	Summer Survey		Winter Survey	
	n	%	n	%
Prefer not to answer	4	3.9	1	1.0
Male	42	40.8	44	43.6
Female	57	55.3	56	55.4

The age of the respondents was categorized into five groups. Table 4.2 shows the ages of the respondents of both the summer and winter surveys. Results showed that in summer, most of respondents, over 60%, were between the ages of 25-34. About one-quarter of respondents, 24.3%, were ages 35-44, clearly indicating that the vast majority of respondents are past their college years and approaching middle age. Similar results can be found for winter 2019. Most respondents were between the ages of 25-34. However, 18-24-year-olds almost double in percentage, apparently replacing those aged 35-44, whose numbers dropped dramatically.

Table 4.2

Survey Respondents' Age

Age	Summer Survey		Winter Survey	
	n	%	n	%
Prefer not to answer	2	1.9	1	1.0
18-24 years old	11	10.7	19	18.8
25-34 years old	64	62.1	60	59.4
35-44 years old	25	24.3	17	16.8
55-64 years old	1	1.0	4	4.0

Table 4.3 shows that respondents of summer and winter surveys were divided into five ethnic groups. Surprisingly, more than one-half of the respondents for both summer and winter, 55.3% and 51.5%, respectively, are Asian or Asian American. The next larger responding group, representing less

than one-quarter of the respondents, is White or Caucasian or European American at 24.3% and 23.8% for summer and winter, respectively. There is no other group in the double-digits, either numerically or in percentage. The results suggest that the racial makeup of the respondents may not reflect the great East Lansing area.

Table 4.3

Survey Respondents' Race and Ethnicity

Race and Ethnicity	Summer Survey		Winter Survey	
	n	%	n	%
Prefer not to answer	4	3.9	4	4.0
American Indian or Alaska Native or Indigenous or First Nations	1	1.0	1	1.0
Asian or Asian American	57	55.3	52	51.5
Black or African American	5	4.9	4	4.0
Native Hawaiian or Pacific Islander	0	0.0	1	1.0
White or Caucasian or European American	25	24.3	24	23.8
Arab or Middle Eastern	5	4.9	9	8.9
Latin American or Hispanic	4	3.9	3	3.0
African	1	1.0	2	2.0
Mixed	1	1.0	1	1.0

The number of adults and children in a household and the marital status of the respondents were investigated to understand the demographic characteristics further. Table 4.4 demonstrates the vast majority of the households consists of two adults at 84.6 %, and just 8.7% consisted of three adults, 5.8% consisted of one adult, and 1.0% consisted of five adults. Also, Table 4.5 reveals that 56.3% of the households had no children, 26.0% had one child, 12.5% had two children, and 5.2% had three children.

Table 4.4

Number of Adults in the Survey Respondents' Household

Number of Adults in the Household	Summer Survey		Winter Survey	
	n	%	n	%
One Adult	6	5.8	6	5.9
Two Adults	88	84.6	88	87.1
Three Adults	9	8.7	6	5.9
Five Adults	1	1.0	1	1.0

Table 4.5

Number of Children in the Survey Respondents' Household

Number of Children in the Household	Summer Survey		Winter Survey	
	n	%	n	%
No Children	54	56.3	60	59.4
One Child	25	26.0	21	20.8
Two Children	12	12.5	14	13.9
Three Children	5	5.2	6	5.9

When it comes to marital status, as seen in Table 4.6, 95.1% of the respondents are married or have a domestic partner. The remainder, 4.9%, are single.

Table 4.6

Survey Respondents' Marital Status

Marital Status	Summer Survey		Winter Survey	
	n	%	n	%
Prefer not to answer	0	0.0	3	3.0
Single	5	4.9	8	8.1
Married or domestic partnership	97	95.1	87	87.9
Separated	0	0.0	1	1.0

4.1.2. *Socioeconomic Characteristics*

Regarding education, Table 4.7 indicates that almost two-thirds of the summer respondents (65%) have a bachelor's or master's degree. Only 17.5% have a professional or doctoral degree, and fewer than 17% have an associate degree or less of education. The winter respondents are virtually identical, with the exception of those with professional or doctoral degrees. Winter respondents are slightly more educated in these areas, at 17.5% to 14.9%, respectively.

Table 4.7

Survey Respondents' Highest Education Degree

Highest Education Degree	Summer Survey		Winter Survey	
	n	%	n	%
Prefer not to answer	1	1.0	0	0.0
High school degree or equivalent (e.g. GED)	5	4.9	4	4.0
Some college, no degree	7	6.8	10	9.9
Associate degree (e.g. AA, AS)	5	4.9	4	4.0
Bachelor's degree (e.g. BA, BS)	20	19.4	24	23.8
Master's degree (e.g. MA, MS, MEd)	47	45.6	44	43.6
Professional degree (e.g. MD, DDS, DVM)	4	3.9	2	2.0
Doctorate (e.g. PhD, EdD)	14	13.6	13	12.9

Table 4.8 indicates that about two-thirds, or 63.7%, of the summer respondents indicated they were MSU students while about one-third, or 32.4%, were a spouse or domestic partner. Similar results are found for winter respondents, although there are a slightly higher percentage of MSU students (71.7%) and a corresponding lower percentage of spouse or domestic partner (25.3%).

Table 4.8

Survey Respondents' Affiliation to MSU

Affiliation to MSU	Summer Survey		Winter Survey	
	n	%	n	%
Prefer not to answer	2	2.0	1	1.0
MSU student yourself	65	63.7	71	71.7
Spouse or domestic partner of MSU student	33	32.4	25	25.3
Child of MSU student	1	1.0	0	0.0
Relative of MSU student	0	0.0	2	2.0
MSU Staff	1	1.0	0	0.0

Respondents were asked to answer a question about their current employment status. Some of them had a primary and a secondary employment. For primary employment, as displayed in Table 4.9, the plurality of summer respondents, 38.8%, indicated "graduate student" as their means of employment. Almost one-fifth, or 19.4%, indicated part-time employment, which could be consistent with a graduate assistantship. Full-time employment was indicated by just 15.5% of respondents. However, if a graduate student thinks of him/herself as a graduate student or a part-time employee, or combined as a full-time employee, it would be equal 73.7% or a bit more than those who identify as "MSU Student." The results were similar for winter respondents, with the exceptions of full-time employment which dropped to 9.9% and part-time employment which rose to 27.7%. Table 4.10 displays the results for respondents who indicated secondary employment.

Table 4.9

Survey Respondents' Primary Employment Status

Primary Employment Status	Summer Survey		Winter Survey	
	n	%	n	%
Prefer not to answer	2	1.9	2	2.0
Employed full time (40 or more hours per week)	16	15.5	10	9.9
Employed part-time (up to 39 hours per week)	20	19.4	28	27.7
Unemployed and currently looking for work	4	3.9	4	4.0
Unemployed and not currently looking for work	10	9.7	5	5.0
Undergraduate student	5	4.9	9	8.9
Graduate student	40	38.8	36	35.6
Homemaker	3	2.9	5	5.0
Unable to work	3	2.9	2	2.0

Table 4.10

Survey Respondents' Secondary Employment Status

Secondary Employment Status	Summer Survey		Winter Survey	
	n	%	n	%
Employed part-time (up to 39 hours per week)	1	7.1	1	5.6
Unemployed and not currently looking for work	1	7.1	0	0.0
Undergraduate student	2	14.3	6	33.3
Graduate student	6	42.9	10	55.6
Homemaker	2	14.3	1	5.6
Unable to work	2	14.3	0	0.0

The average income for about half of both summer and winter respondents, shown in **Error! Not a valid bookmark self-reference.** falls between $12,001 – $36,000. For summer respondents, 50.5% indicate income within that range, while 55% of winter respondents report that same range of income.

Table 4.11

Survey Respondents' Average Household Income

Average Household Income	Summer Survey		Winter Survey	
	n	%	n	%
Prefer not to answer	14	13.6	13	13.0
$ 1- $ 12,000	10	9.7	12	12.0
$ 12,001- $ 24,000	32	31.1	34	34.0
$ 24,001- $ 36,000	20	19.4	21	21.0
$ 36,001- $ 48,000	7	6.8	5	5.0
$ 48,001- $ 60,00	10	9.7	10	10.0
$ 60,001- $ 72,000	5	4.9	2	2.0
$ 72,001- $ 84,000	2	1.9	1	1.0
$ 96,000 or more	3	2.9	2	2.0

4.1.3. *Housing Characteristics*

Michigan State University's family housing buildings have different types of apartments. For this research, the apartment types were classified according to their location. Table 4.12 shows that 46.2% of the summer survey respondents occupied apartments overlooking the parking lot, 26.0% occupied apartments overlooking the green area, 19.2% occupied corner apartments overlooking the green area, and 8.7% occupied corner apartments overlooking the parking lot.

Table 4.12 shows that 40.6% of the winter survey respondents occupied apartments overlooking the parking lot, 33.7% occupied apartments overlooking the green area, 12.9% occupied corner apartments overlooking the green area, and 12.9% occupied corner apartments overlooking the parking lot.

Table 4.12

Survey Respondents' Apartment Type

Apartment Type	Summer Survey		Winter Survey	
	n	%	n	%
Apartment overlooking the green area	27	26.0	34	33.7
Apartment overlooking the parking lot	48	46.2	41	40.6
Corner apartment overlooking the green area	20	19.2	13	12.9
Corner apartment overlooking the parking lot	9	8.7	13	12.9

The regular and corner apartments that are overlooking the parking lot have a north orientation, and the regular and corner apartments that are overlooking the green area have a south orientation. Therefore, Table 4.13 shows that 54.8% of the summer survey respondents occupied an apartment with a north orientation, and 45.2% of the respondents occupied an apartment with a south orientation. Also, Table 4.13 shows that 53.5% of the winter survey respondents occupied an apartment with a north orientation and 46.5% of the respondents occupied an apartment with a south orientation.

Table 4.13

Survey Respondents' Apartment Orientation

Apartment Orientation	Summer Survey		Winter Survey	
	n	%	n	%
North	57	54.8	54	53.5
South	47	45.2	47	46.5

Apartments were also classified according to the number of bedrooms. Table 4.14 shows that 72.1% of the summer survey respondents occupied two-bedroom apartments, while 27.9% of them occupied one-bedroom apartments. It also shows that 68.3% of the winter survey respondents occupied two-bedroom apartments, while 31.7% of them occupied one-bedroom apartments.

Table 4.14

Survey Respondents' Number of Bedrooms

Number of Bedrooms	Summer Survey		Winter Survey	
	n	%	n	%
One Bedroom	29	27.9	32	31.7
Two Bedrooms	75	72.1	69	68.3

Additionally, the floor level in which each apartment is located was recorded. According to Table 4.15, 31.7% of the summer survey respondents occupied apartments on the second floor, 27.9% occupied apartments on the third floor, 22.1% occupied apartments on the fourth floor, and 18.3% occupied apartments on the first floor. Also, Table 4.15 shows that 36.6% of the summer survey respondents occupied apartments on the second floor, 28.7% occupied apartments on the third floor, 17.8% occupied apartments on the fourth floor, and 16.8% occupied apartments on the first floor.

Table 4.15

Survey Respondents' Floor Level

Floor Level	Summer Survey		Winter Survey	
	n	%	n	%
First Floor	19	18.3	17	16.8
Second Floor	33	31.7	37	36.6
Third Floor	29	27.9	29	28.7
Fourth Floor	23	22.1	18	17.8

The three buildings started operating since Fall 2016, so occupants were asked to share the time when they first moved into these buildings. Table 4.16 shows there are no dominant themes regarding when respondents first moved into the building. However, it does appear that the most common times, all between 20% - 30.7%, are Fall 2016, Fall 2018, and Fall 2018, for both summer and winter respondents. It is not surprising that fall is the most commonly occurring time for moving into student housing given that most academic programs start in the fall semester. Once in their apartments, the vast majority, as indicated in Table 4.17, do not move to a different apartment.

Table 4.16

Date in Which Survey Respondents' Moved into their Current Apartment

Time Move into Apartment	Summer Survey		Winter Survey	
	n	%	n	%
Fall 2016	21	20.2	21	20.8
Spring 2017	3	2.9	1	1.0
Summer 2017	3	2.9	2	2.0
Fall 2017	21	20.2	18	17.8
Spring 2018	7	6.7	2	2.0
Summer 2018	4	3.8	2	2.0
Fall 2018	29	27.9	31	30.7
Spring 2019	4	3.8	0	0.0
Fall 2019	12	11.5	20	19.8
Spring 2020	0	0.0	4	4.0

Table 4.17

Number of Survey Respondents' who Changed Apartment Since July 2019

Change Apartment Since July 2019	Summer Survey		Winter Survey	
	n	%	n	%
No	83	79.8	71	70.3
Yes	21	20.2	30	29.7

4.1.4. *Energy-Related Characteristics*

Some of the survey questions were designed to capture the energy-related behavior of occupants. For example, Table 4.18 reveals that a range of temperatures were enjoyed, but the most preferred temperatures for both summer and winter survey respondents were 70, 72, and 75 Fahrenheit.

Table 4.18

Survey Respondents' Preferred Temperature

Preferred Temperature	Summer Survey		Winter Survey	
	n	%	n	%
65F	0	0.0	3	3.0
68F	5	4.8	5	5.0
69F	3	2.9	1	1.0
70F	22	21.2	17	16.8
71F	3	2.9	5	5.0
72F	28	26.9	34	33.7
73F	9	8.7	2	2.0
74F	9	8.7	4	4.0
75F	14	13.5	26	25.7
76F	3	2.9	2	2.0
77F	3	2.9	1	1.0
78F	3	2.9	0	0.0
79F	0	0.0	1	1.0
80F	1	1.0	0	0.0
90F	1	1.0	0	0.0

Table 4.19 shows that the clothing worn in the range of temperatures varied greatly, even between summer and winter respondents. However, it is not surprising that the majority of summer respondents, 62.5%, preferred wearing short-sleeved pajamas, while 60.4% of the winter survey participants preferred long-sleeved pajamas.

Table 4.19

Survey Respondents' Type of Clothes

Type of Clothes	Summer Survey		Winter Survey	
	n	%	n	%
No Clothes	2	1.9	1	1.0
Sleeveless short gown	14	13.5	4	4.0
Sleeveless long gown	5	4.8	1	1.0
Short-sleeve pajamas	65	62.5	21	20.8
Long-sleeve long gown	1	1.0	6	5.9
Long-sleeve short wrap robe	0	0.0	1	1.0
Long-sleeve pajamas	16	15.4	61	60.4
Short sleeve with pants pajamas	0	0.0	4	4.0
Pants only	0	0.0	1	1.0
Shorts only	0	0.0	1	1.0

Respondents were asked to report their activity level in living and sleeping areas. Table 4.20 shows that 61.5% of the summer survey respondents marked that they spend most of their time seated in the living area, compared with 68.3% of the winter survey respondents (see Table 4.20). Clearly, respondents tended to be sedentary, which is what one may expect from graduate students who spend a great deal of time studying.

Table 4.20

Survey Respondents' Activity Level in Living Area

Activity Level	Summer Survey		Winter Survey	
	n	%	n	%
Reclining	18	17.3	13	12.9
Seated	64	61.5	69	68.3
Standing relaxed	6	5.8	4	4.0
Light activity standing	6	5.8	9	8.9
Medium activity standing	8	7.7	3	3.0
High activity	2	1.9	3	3.0

Table 4.21 shows that the activity level in the sleeping area. Consistent with the previous findings, most of the respondents indicated that the prefer a sedentary position, in this case seated. Indeed, 77.9% of the summer respondents and 81.2% of the winter respondents reported a preference for reclining in the sleeping area.

Table 4.21

Survey Respondents' Activity Level in Sleeping Area

Activity Level	Summer Survey		Winter Survey	
	n	%	n	%
Reclining	81	77.9	82	81.2
Seated	17	16.3	11	10.9
Standing relaxed	3	2.9	3	3.0
Light activity standing	2	1.9	2	2.0
Medium activity standing	1	1.0	1	1.0
High activity	0	0.0	2	2.0

The time that the occupants spend cooking affects the indoor environmental quality, and thus it was investigated in this research. Table 4.22 shows that the time spent cooking varied greatly for both sets of respondents. However, about two-thirds (65.7%) of the summer respondents and almost three-quarters (73.2%) of the winter respondents spent between 20 – 80 minutes cooking.

Table 4.22

Survey Respondents' Time Spent Cooking

Time Spent Cooking	Summer Survey		Winter Survey	
	n	%	n	%
No Cooking	1	1.0	1	1.0
Less than 5 mins	7	6.9	3	3.0
5-10 mins	8	7.8	4	4.0
10 -20 mins	17	16.7	18	17.8
20-40 mins	30	29.4	38	37.6
40-80 mins	37	36.3	36	35.6
More than 80 mins	2	2.0	1	1.0

Respondents of the summer survey were asked to rank the four elements of indoor environmental quality (IEQ) according to their perceived importance in living and sleeping areas. Table 4.23 and Table 4.24 show that 46.1% prioritized thermal comfort, 32.4% prioritized Indoor Air Quality (IAQ), 10.8% prioritized visual comfort, and 10.8% prioritized acoustical comfort in living areas during the summer.

Table 4.23

Survey Respondents' Indoor Environmental Quality Ranking in the Living Area

IEQ Ranking	Summer Survey		Winter Survey	
	n	%	n	%
Indoor Air Quality				
No	69	67.6	57	56.4
Yes	33	32.4	44	43.6
Thermal Comfort				
No	55	53.9	64	63.4
Yes	47	46.1	37	36.6
Visual Comfort				
No	91	89.2	86	85.1
Yes	11	10.8	15	14.9
Acoustical Comfort				
No	91	89.2	96	95.0
Yes	11	10.8	5	5.0

Table 4.23 and Table 4.24 show that 44.2% prioritized thermal comfort, 27.9% prioritized Indoor Air Quality (IAQ), 17.3% prioritized visual comfort, and 10.6% prioritized acoustical comfort in sleeping areas in summer. Also, respondents of the winter survey were asked to rank the four elements of IEQ according to their perceived importance in living and sleeping areas. Table 4.23 and Table 4.24 show that 36.6% prioritized thermal comfort, 43.6% prioritized Indoor Air Quality (IAQ), 14.9% prioritized visual comfort, and 5.0% prioritized acoustical comfort in living areas in summer.

Table 4.23 and Table 4.24 show that 44.2% prioritized thermal comfort, 27.9% prioritized IAQ, 17.3% prioritized visual comfort, and 10.6% prioritized acoustical comfort in sleeping areas during the winter.

Table 4.24

Survey Respondents' Indoor Environmental Quality Ranking in the sleeping Area

IEQ Ranking	Summer Survey		Winter Survey	
	n	%	n	%
Indoor Air Quality				
No	75	72.1	67	66.3
Yes	29	27.9	34	33.7
Thermal Comfort				
No	58	55.8	55	54.5
Yes	46	44.2	46	45.5
Visual Comfort				
No	86	82.7	92	91.1
Yes	18	17.3	9	8.9
Acoustical Comfort				
No	93	89.4	89	88.1
Yes	11	10.6	12	11.9

4.2. Spatial Factors and Occupants' Beliefs

This study examined four levels of spatial factors that can contribute to the occupants' beliefs of operating windows and adjusting blinds: 1) site characteristics, 2) building features, 3) space type and 4) furniture location.

<u>H1: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with spatial factors.</u>

The researcher identified four beliefs associated with operating windows and four beliefs associated with adjusting blinds. Two multiple-choice questions were formed and included in the questionnaire that occupants were asked to respond to. Those questions are shown in Figure 4.1 and Figure 4.2. In addition, qualitative data were collected to investigate occupants' preferred spots in living and sleeping areas. The researcher provided the occupants with the floor plans of their apartments and used the heat map feature to record their responses. Also, occupants were asked to respond to an open-ended question to describe the reason why they selected their preferred spots, as shown in Figure 4.3.

Figure 4.1

Sample Item Investigating Occupants' Beliefs of Operating Windows

What do you think are the benefits of operating **windows** in the living area in summer? (Please select all that apply)

☐ Operating windows has no benefits
☐ It causes a desired change in temperature
☐ It causes a desired change in airflow
☐ It eliminates air pollution concerns
☐ It brings in outdoor pleasant sounds
☐ It saves energy, please explain why:
☐ If other, please specify:

Figure 4.2

Sample Item Investigating Occupant's Beliefs of Adjusting Blinds

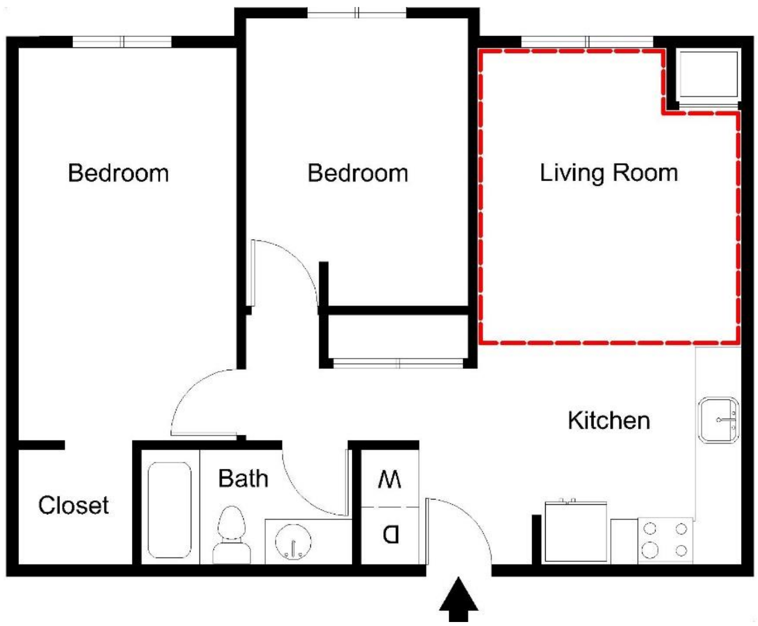
What do you think are the benefits of adjusting **blinds** in the living area in summer? (Please select all that apply)

☐ Adjusting blinds has no benefits
☐ It causes a desired change in temperature
☐ It causes a desired change in daylight
☐ It allows access to outdoor views
☐ It improves privacy concerns
☐ It saves energy, please explain why:
☐ If other, please specify:

Figure 4.3

Sample Item Investigating Occupant's Location Preference

The drawing below shows the floor plan of your apartment. Please click on the area on the drawing that indicates your preferred spot where you spend most of your time in the **living area** in summer.



Can you please explain if your preference of the spot that you selected in the previous question is related in any way to its location from the windows?

4.2.1. *Site Characteristics and Occupants' Beliefs*

The term site characteristics may be interpreted in different ways. This research focuses on the orientation of the building within site and the characteristics associated with this orientation, such as the outdoor view. The apartments under study have two orientations, north and south. The apartments with the north orientation are facing a parking lot, and the apartments with the south orientation are facing a green area.

The researcher selected to study four attributes related to operating windows: 1) indoor temperature, 2) airflow, 3) air pollution, and 4) acoustics. The researcher also selected four attributes related to adjusting blinds: 1) indoor temperature, 2) amount of daylighting, 3) outdoor views, and 4) privacy concerns. A Chi-Square test of associated was calculated, and there was no significant association found between occupants' beliefs of operating windows and adjusting blinds and the apartments' orientation in both summer and winter seasons (see Tables 4.25 – 4.32).

Table 4.25

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Living Area during the Summer and the Orientation (N=102)

Variable	Orientation
Operating windows in the living area cause the desired change in temperature	.889
Operating windows in the living area cause the desired change in airflow	.558
Operating windows in the living area eliminate air pollution concerns	.432
Operating windows in the living area bring in pleasant outdoor sounds	1.005

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

Table 4.26

Chi-square test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Sleeping Area during the Summer and the Orientation (N=103)

Variable	Orientation
Operating windows in the sleeping area cause the desired change in temperature	.762
Operating windows in the sleeping area cause the desired change in airflow	.105
Operating windows in the sleeping area eliminate air pollution concerns	.028
Operating windows in the sleeping area bring in pleasant outdoor sounds	2.035

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

Table 4.27

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Living Area during the Winter and the Orientation (N=101)

Variable	Orientation
Operating windows in the living area cause the desired change in temperature	.433
Operating windows in the living area cause the desired change in airflow	.533
Operating windows in the living area eliminate air pollution concerns	.029
Operating windows in the living area bring in pleasant outdoor sounds	.190

$^*p \leq .05$. $^{**}p \leq .01$. $^{***}p \leq .001$

Table 4.28

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Sleeping Area during the Winter and the Orientation (N=101)

Variable	Orientation
Operating windows in the sleeping area cause the desired change in temperature	1.393
Operating windows in the sleeping area cause the desired change in airflow	.876
Operating windows in the sleeping area eliminate air pollution concerns	.020
Operating windows in the sleeping area bring in pleasant outdoor sounds	.735

$^*p \leq .05$. $^{**}p \leq .01$. $^{***}p \leq .001$

Table 4.29

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Living Area during the Summer and the Orientation (N=103)

Variable	Orientation
Adjusting blinds in the living area causes the desired change in temperature	2.006
Adjusting blinds in the living area causes the desired change in daylighting	2.979
Adjusting blinds in the living area allows access to outdoor views	.374
Adjusting blinds in the living area improves privacy concerns	.761

$^*p \leq .05$. $^{**}p \leq .01$. $^{***}p \leq .001$

Table 4.30

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Sleeping Area during the Summer and the Orientation (N=103)

Variable	Orientation
Adjusting blinds in the sleeping area causes the desired change in temperature	.896
Adjusting blinds in the sleeping area causes the desired change in daylighting	.920
Adjusting blinds in the sleeping area allows access to outdoor views	.374
Adjusting blinds in the sleeping area improves privacy concerns	1.300

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

Table 4.31

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Living Area During the Winter and the Orientation (N=101)

Variable	Orientation
Adjusting blinds in the living area causes the desired change in temperature	2.870
Adjusting blinds in the living area causes the desired change in daylighting	1.194
Adjusting blinds in the living area allows access to outdoor views	1.566
Adjusting blinds in the living area improves privacy concerns	2.375

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

Table 4.32

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Sleeping Area during the Winter and the Orientation (N=101)

Variable	Orientation
Adjusting blinds in the sleeping area causes the desired change in temperature	.013
Adjusting blinds in the sleeping area causes the desired change in daylighting	.725
Adjusting blinds in the sleeping area allows access to outdoor views	.442
Adjusting blinds in the sleeping area improves privacy concerns	.048

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

H1a: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with site characteristics

Chi-Square test for association was used to investigate the relationship between occupants' beliefs of operating windows and adjusting blinds with the apartment orientation (see Tables 4.25 – 4.32). Since the p-value is greater than the significance level ($\alpha = 0.05$), it is concluded that there is not enough evidence to suggest an association between occupants' beliefs and one of the site characteristics which is orientation. This means that occupants' beliefs of the advantages and disadvantages of the operating windows and adjusting blinds is not affected by the apartment orientation. This result is consistent among living and sleeping areas, and in both seasons.

4.2.2. *Building Features and Occupants' Beliefs*

The relationship between the floor levels and the occupants' beliefs of operating windows and adjusting blinds was investigated in summer and winter. Chi-Square for association test was used to investigate this relationship. Results showed that there was no significant relationship between occupants' beliefs of operating windows and adjusting blinds and the apartments' floor level in both summer and winter seasons (see Tables 4.33 – 4.40).

Table 4.33

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Living Area during the Summer and Floor Level (N=102)

Variable	Floor Level
Operating windows in the living area cause the desired change in temperature	6.521
Operating windows in the living area cause the desired change in airflow	1.506
Operating windows in the living area eliminate air pollution concerns	.193
Operating windows in the living area bring in pleasant outdoor sounds	3.079

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

Table 4.34

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Sleeping Area during the Summer and Floor Level (N=103)

Variable	Floor Level
Operating windows in the sleeping area cause the desired change in temperature	4.057
Operating windows in the sleeping area cause the desired change in airflow	1.508
Operating windows in the sleeping area eliminate air pollution concerns	3.876
Operating windows in the sleeping area bring in pleasant outdoor sounds	6.783

*$p \le .05$. **$p \le .01$. ***$p \le .001$

Table 4.35

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Living Area during the Winter and Floor Level (N=101)

Variable	Floor Level
Operating windows in the living area cause the desired change in temperature	5.409
Operating windows in the living area cause the desired change in airflow	7.475
Operating windows in the living area eliminate air pollution concerns	1.985
Operating windows in the living area bring in pleasant outdoor sounds	2.855

*$p \le .05$. **$p \le .01$. ***$p \le .001$

Table 4.36

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Sleeping Area during the Winter and Floor Level (N=101)

Variable	Floor Level
Operating windows in the sleeping area cause the desired change in temperature	.448
Operating windows in the sleeping area cause the desired change in airflow	7.364
Operating windows in the sleeping area eliminate air pollution concerns	.817
Operating windows in the sleeping area bring in pleasant outdoor sounds	6.652

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

Table 4.37

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Living Area during the Summer and Floor Level (N=101)

Variable	Floor Level
Adjusting blinds in the living area causes the desired change in temperature	7.967
Adjusting blinds in the living area causes the desired change in daylighting	.361
Adjusting blinds in the living area allows access to outdoor views	1.378
Adjusting blinds in the living area improves privacy concerns	5.371

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

Table 4.38

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Sleeping Area during the Summer and Floor Level (N=103)

Variable	Floor Level
Adjusting blinds in the sleeping area causes the desired change in temperature	3.677
Adjusting blinds in the sleeping area causes the desired change in daylighting	2.193
Adjusting blinds in the sleeping area allows access to outdoor views	3.227
Adjusting blinds in the sleeping area improves privacy concerns	2.882

$*p \leq .05$. $**p \leq .01$. $***p \leq .001$

Table 4.39

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Living Area during the Winter and Floor Level (N=101)

Variable	Floor Level
Adjusting blinds in the living area causes the desired change in temperature	7.967
Adjusting blinds in the living area causes the desired change in daylighting	.361
Adjusting blinds in the living area allows access to outdoor views	1.378
Adjusting blinds in the living area improves privacy concerns	5.371

$*p \leq .05$. $**p \leq .01$. $***p \leq .001$

Table 4.40

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Sleeping Area during the Winter and Floor Level (N=101)

Variable	Floor Level
Adjusting Blinds in the sleeping area cause the desired change in temperature	8.341
Adjusting Blinds in the sleeping area cause the desired change in airflow	3.234
Adjusting Blinds in the sleeping area eliminate air pollution concerns	1.271
Adjusting Blinds in the sleeping area bring in pleasant outdoor sounds	.261

$^{*}p \leq .05$. $^{**}p \leq .01$. $^{***}p \leq .001$

<u>H1b: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with building features</u>

Chi-Square test for association was used to investigate the relationship between occupants' beliefs of operating windows and adjusting blinds with the apartment floor level (see Table 4.33 – Table 4.40). Since the p-value is greater than the significance level (α = 0.05), it is concluded that there is not enough evidence to suggest an association between occupants' beliefs and one of the building features, which is the floor level in this research. This means that occupants' beliefs of the advantages or disadvantages associated with the behavior of operating windows and adjusting blinds is not related to the floor level. This result applies to living and sleeping areas, and in summer and winter.

4.2.3. *Space Type and Occupants' Beliefs*

The apartments under study consist of one or two bedrooms, a bathroom, a kitchen and dining space open to the living area. The bathrooms do not have windows. Therefore, the researcher focused on studying occupants' beliefs of operating windows and adjusting blinds in the living area versus the sleeping area during the summer and the winter.

The results of the Chi-Square test for association shown in Table 4.41 – 4.44 indicated that most of the occupants' beliefs of operating windows in the living area were associated with their beliefs of operating windows in this area during the summer and the winter. However, there was no significant evidence of the association between occupants' beliefs of operating windows in the sleeping and living areas regarding the improvement of indoor temperature.

Table 4.41

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Living versus Sleeping Area during the Summer (N=102)

Variable	Operating windows in the sleeping area cause the desired change in temperature	Operating windows in the sleeping area cause the desired change in airflow	Operating windows in the sleeping area eliminate air pollution concerns	Operating windows in the sleeping area bring in pleasant outdoor sounds
Operating windows in the living area cause the desired change in temperature	2.262			
Operating windows in the living area cause the desired change in airflow		23.908***		
Operating windows in the living area eliminate air pollution concerns			25.880***	
Operating windows in the living area bring in pleasant outdoor sounds				31.715***

*$p \le .05$. **$p \le .01$. ***$p \le .001$

Table 4.42

Chi-square Test Results for the Relationship between Occupants' Beliefs of Operating Windows in the Living versus Sleeping Area during the Winter (N=101)

Variable	Operating windows in the sleeping area cause the desired change in temperature	Operating windows in the sleeping area cause the desired change in airflow	Operating windows in the sleeping area eliminate air pollution concerns	Operating windows in the sleeping area bring in pleasant outdoor sounds
Operating windows in the living area cause the desired change in temperature	29.100***			
Operating windows in the living area cause the desired change in airflow		19.455***		
Operating windows in the living area eliminate air pollution concerns			38.644***	
Operating windows in the living area bring in pleasant outdoor sounds				12.140***

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

Table 4.43

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Living versus Sleeping Area during the Summer (N=102)

Variable	Adjusting blinds in the sleeping area causes the desired change in temperature	Adjusting blinds in the sleeping area causes the desired change in daylighting	Adjusting blinds in the sleeping area allows access to outdoor views	Adjusting blinds in the sleeping area improves privacy concerns
Adjusting blinds in the living area causes the desired change in temperature	18.019***			
Adjusting blinds in the living area causes the desired change in daylighting		39.619***		
Adjusting blinds in the living area allows access to outdoor views			14.361***	
Adjusting blinds in the living area improves privacy concerns				26.688***

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

Table 4.44

Chi-square Test Results for the Relationship between Occupants' Beliefs of Adjusting Blinds in the Living versus Sleeping Area during the Winter (N=101)

Variable	Adjusting blinds in the sleeping area causes the desired change in temperature	Adjusting blinds in the sleeping area causes the desired change in daylighting	Adjusting blinds in the sleeping area allows access to outdoor views	Adjusting blinds in the sleeping area improves privacy concerns
Adjusting blinds in the living area causes the desired change in temperature	35.044***			
Adjusting blinds in the living area causes the desired change in daylighting		39.911***		
Adjusting blinds in the living area allows access to outdoor views			32.798***	
Adjusting blinds in the living area improves privacy concerns				26.921***

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

H1c: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with space type

Chi-Square test for association was used to investigate the relationship between occupants' beliefs of operating windows and adjusting blinds with the space type (see Tables 4.41 – 4.44). Since the p-value is lower than the significance level (α = 0.05), it is concluded that there is a significant association between occupants' beliefs of operating windows and adjusting blinds in the living area with the sleeping area. This association means that occupants are likely to perform the same behavior in both spaces. This result applies to occupants' behaviors in summer and winter.

4.2.4. *Furniture Location and Occupants' Beliefs*

Respondents were asked to select their preferred spot in the living and the sleeping areas. Since there are different apartment layouts, respondents were asked to answer some classification questions. For example, data were collected about the orientation, floor level, and the number of bedrooms. Based on the respondents' answers to the classification questions, they were given two different floor plans to choose from that represent their current apartment. Finally, respondents were asked to mark their preferred spot on the selected floor plan. Heat maps are a data visualization technique that represents the magnitude of a phenomenon using color (Qualtrics, 2020). Heat maps feature in Qualtrics survey software were used to collect and analyze the respondents' answers. The coordinates respondents selected are overlaid across the graphic as colored areas, with the color indicating the frequency of respondents' selections. The redder the area, the more respondents chose that coordinate. The numbers associated with the heat map plots in the following section represents the number of respondents. Also, respondents were asked to answer an open-ended question and describe the reason behind their preference for a specific spot.

4.2.4.1. Occupants' Location Preferences in the Living Area during the Summer

The figures below show the heat maps that represent the occupants' preferred spots in the living area during the summer season.

The responses of the respondents were analyzed qualitatively, and the results showed, in Figures 4.4 – 4.8, that about 27% indicated that their choice of preferred spot was related to the furniture layout, and about 8% selected their preferred spot based on the location of the television. About 24% of the respondents related to the selection of their preferred spot to the location of the window, while 11% mentioned that it was not related to the location of the window. About 19% said that they chose the spot because of the amount of natural daylight being close to the window. About 15% mentioned that they selected their preferred spot to be close to the window where they can have access to outdoor views. About 3% of the respondents preferred their selected spot as they can enjoy fresh air being close to the window. About 2% of the occupants selected their preferred spot depending on the location of the air conditioner vent.

Figure 4.4

Occupants' Preferred Spots in the Living Area in a Two-bedroom Apartment during the Summer

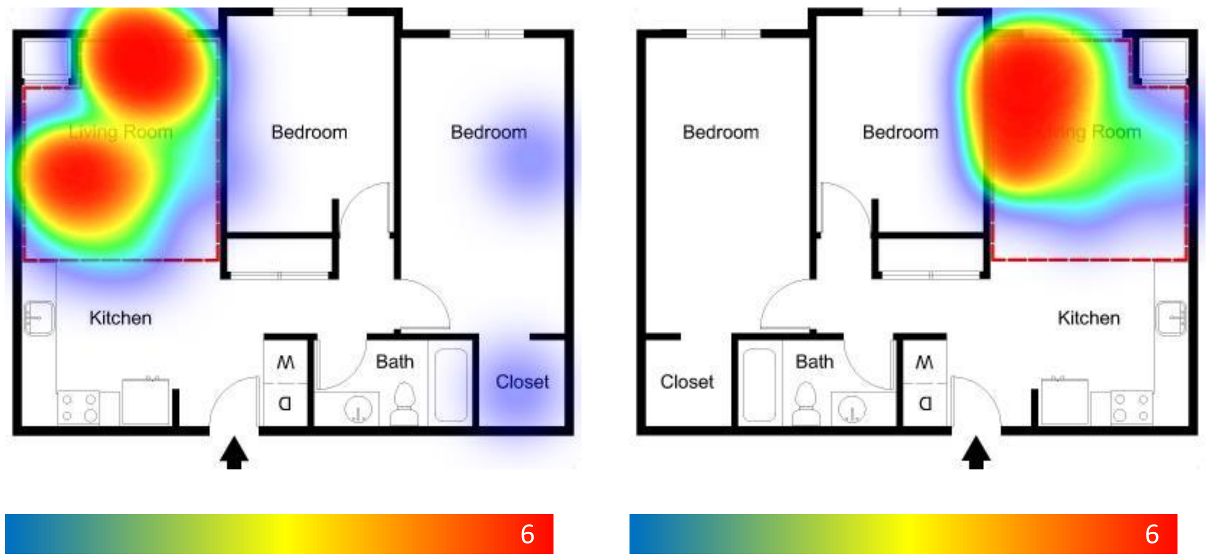


Figure 4.5

Occupants' Preferred Spots in the Living Area in a One-bedroom Apartment during the Summer

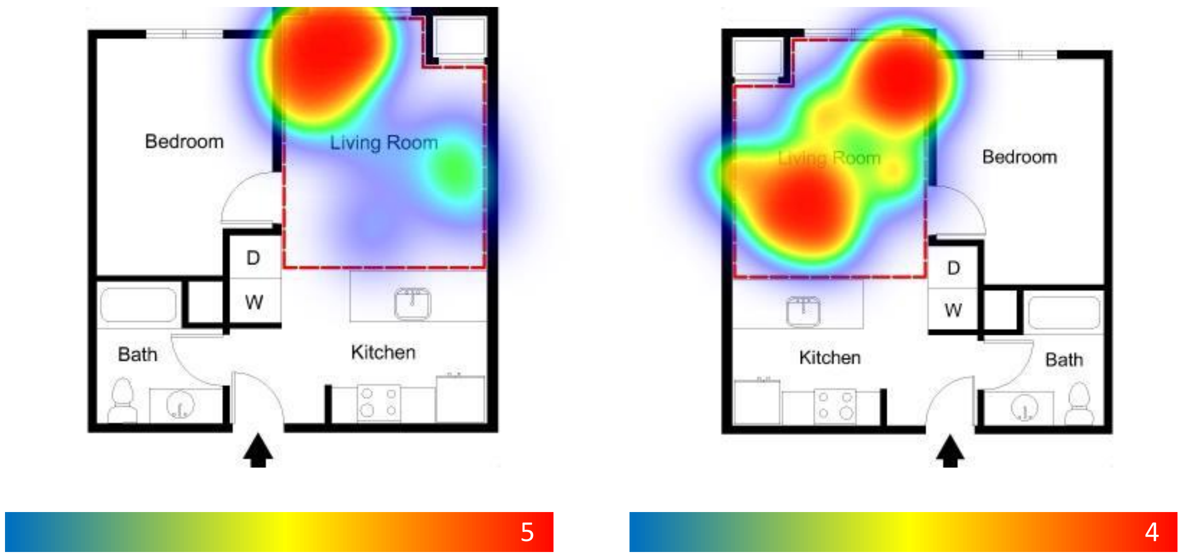


Figure 4.6

Occupants' Preferred Spots in the Living Area in a Corner Two-bedroom Apartment Located at the Corner of the Buildings during the Summer

Figure 4.7

Occupants' Preferred Spots in the Living Area in a Two-bedroom Apartment Located at the Corner of the Buildings during the Summer

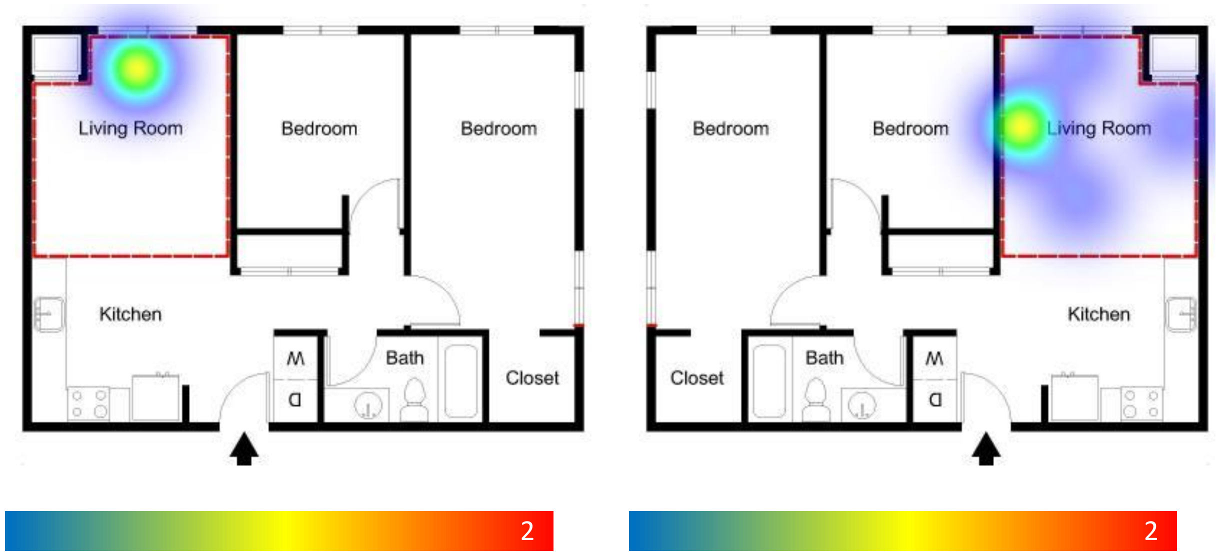


Figure 4.8

Occupants' Preferred Spots in the Living Area in a Two-bedroom Apartment Located at the Corner of the Buildings during the Summer

4.2.4.2. <u>Occupants' Location Preferences in the Sleeping Area during the Summer</u>

Figure 4.9, Figure 4.10, Figure 4.11, and Figure 4.12 show the heat maps that represent the occupants' preferred spots in the sleeping area during the summer season. Respondents were asked to answer an open-ended question and justify why they selected this spot and if their choice was related to the location of the window.

Qualitative analysis of responses showed that 3% indicated that their choice of preferred spot is related to the furniture layout; specifically, the location of the bed and about 5% selected their preferred spot was based on the location of the desk. Approximately 14% of the respondents related to the selection of their preferred spot to the location of the window, while 18% mentioned that it was not related to the location of the window. About 4% said that they chose this spot because of the amount of natural daylight being close to the window, while 6% mentioned that they selected their preferred spot to be close to the window where they can have access to outdoor views. About 2% of the respondents preferred their selected spot as they can enjoy fresh air being close to the window. About 1% of the occupants selected their preferred spot depending on the location of the air conditioner vent.

Figure 4.9

Occupants' Preferred Spots in the Sleeping Area in a Two-bedroom Apartment during the Summer

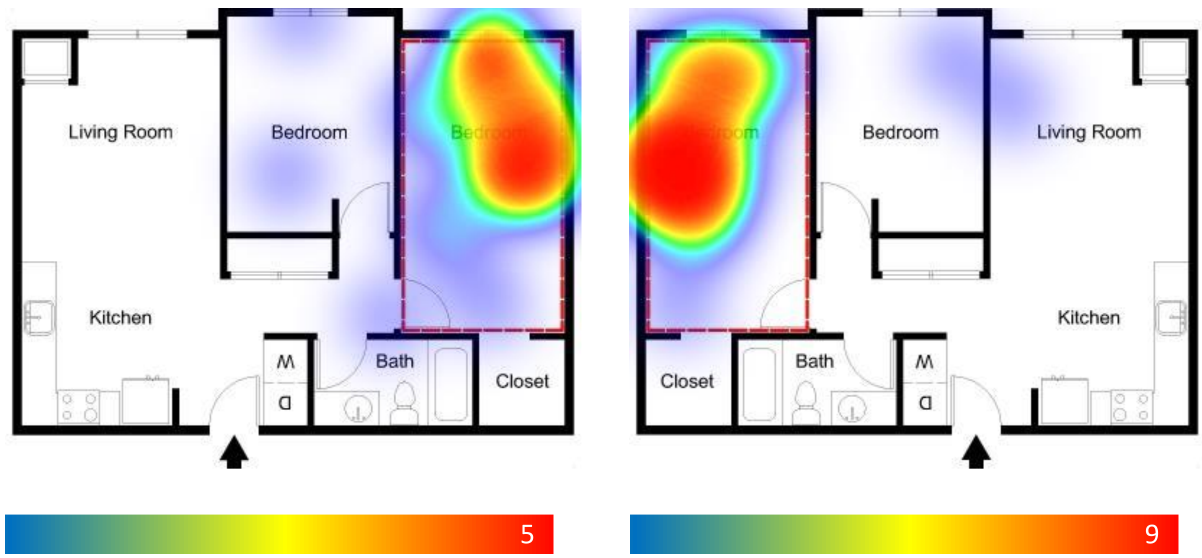


Figure 4.10

Occupants' Preferred Spots in the Sleeping Area in a One-bedroom Apartment during the Summer

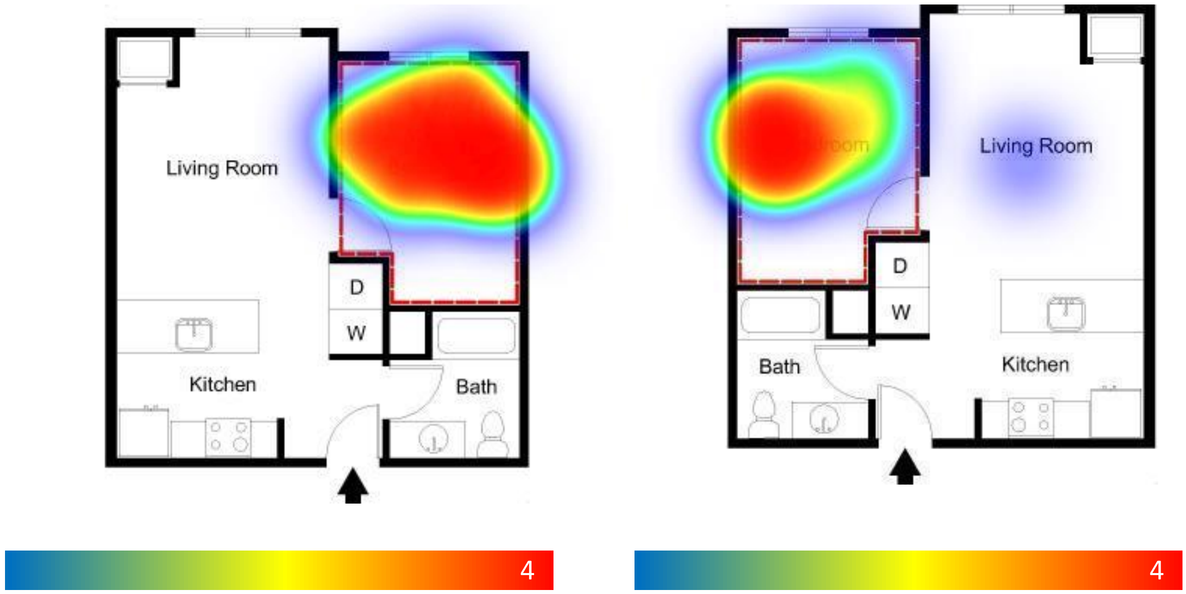


Figure 4.11

Occupants' Preferred Spots in the Sleeping Area in a Two-bedroom Apartment Located at the Corner of the Buildings during the Summer

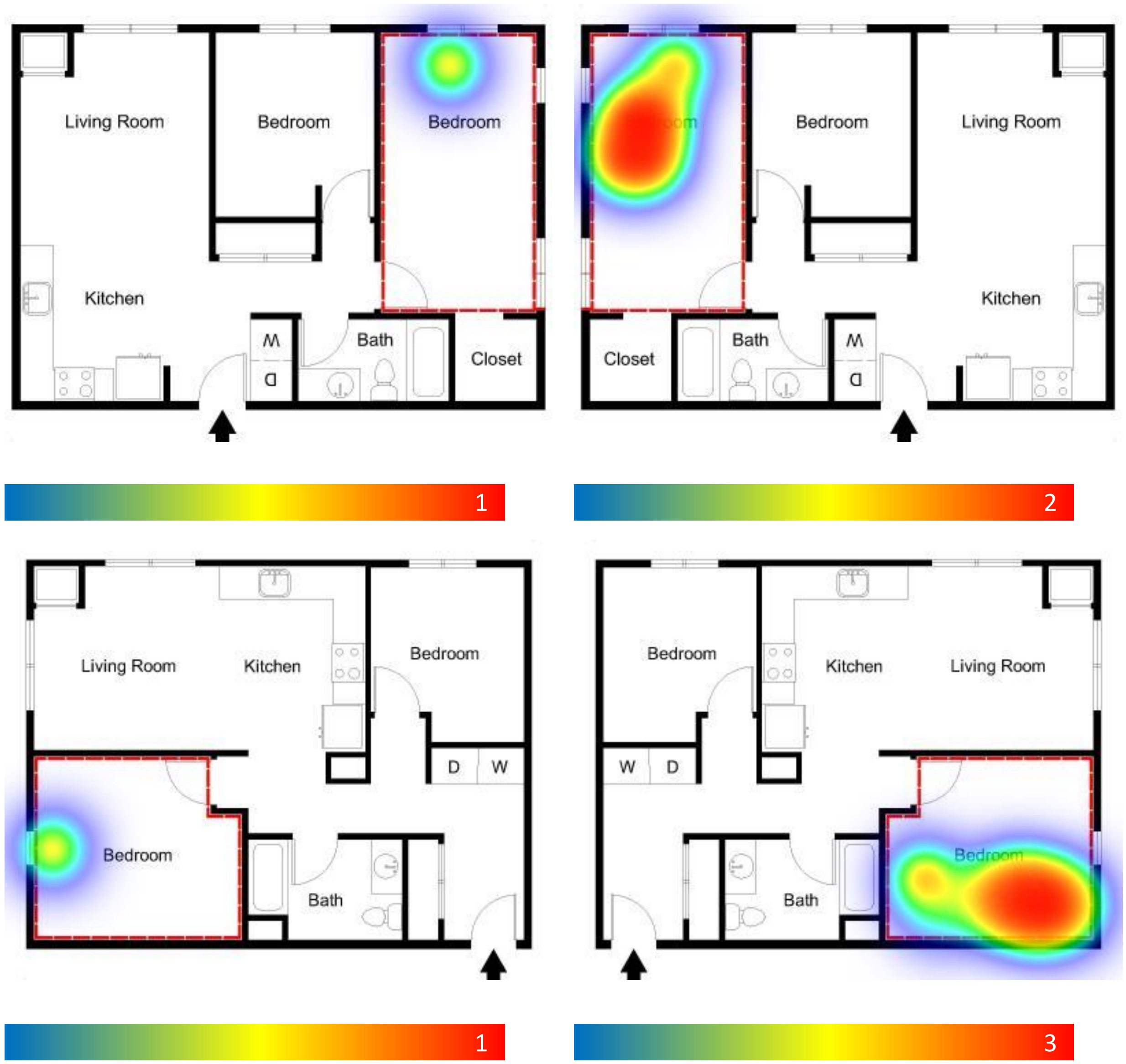
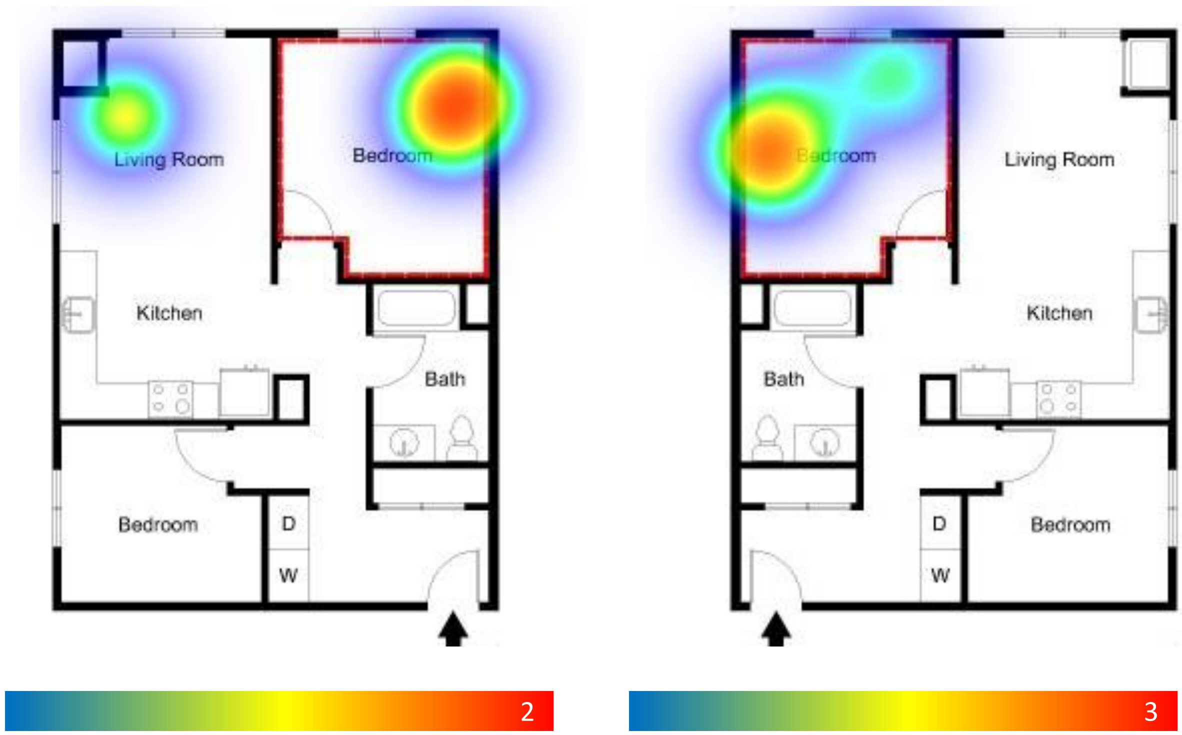


Figure 4.12

Occupants' Preferred Spots in the Sleeping Area in a Two-bedroom Apartment Located at the Corner of the Buildings during the Summer



4.2.4.3. <u>Occupants' Location Preferences in the Living Area during the Winter</u>

Figure 4.13, Figure 4.14, Figure 4.15, and Figure 4.16 show the heat maps that represent the occupants' preferred spots in the living area during the winter season. Respondents were asked to answer an open-ended question and justify why they selected this spot and if their choice was related to the location of the window.

Occupants' preferred locations in the living area in winter were analyzed qualitatively, and the results showed that about 26% indicated that their choice of preferred spot is related to the furniture layout, and nearly 11% selected their preferred spot was based on the location of the television. Approximately 20% of the respondents related to the selection of their preferred spot to the location of the window, while just 16% mentioned that it was not related to the location of the window. About 15%

said that they chose this spot because of the amount of natural daylight being close to the window. About 20% mentioned that they selected their preferred spot to be close to the window where they can have access to outdoor views. About 1% of the respondents preferred their selected spot as they can enjoy fresh air being close to the window. About 5% of the occupants selected their preferred spot because this is where they can fit their computer desk or use their laptops. Also, 2% mentioned that they prefer to sit away from the window as it gets colder near the window in winter.

Figure 4.13

Occupants' Preferred Spots in the Living Area in a Two-bedroom Apartment during the Winter

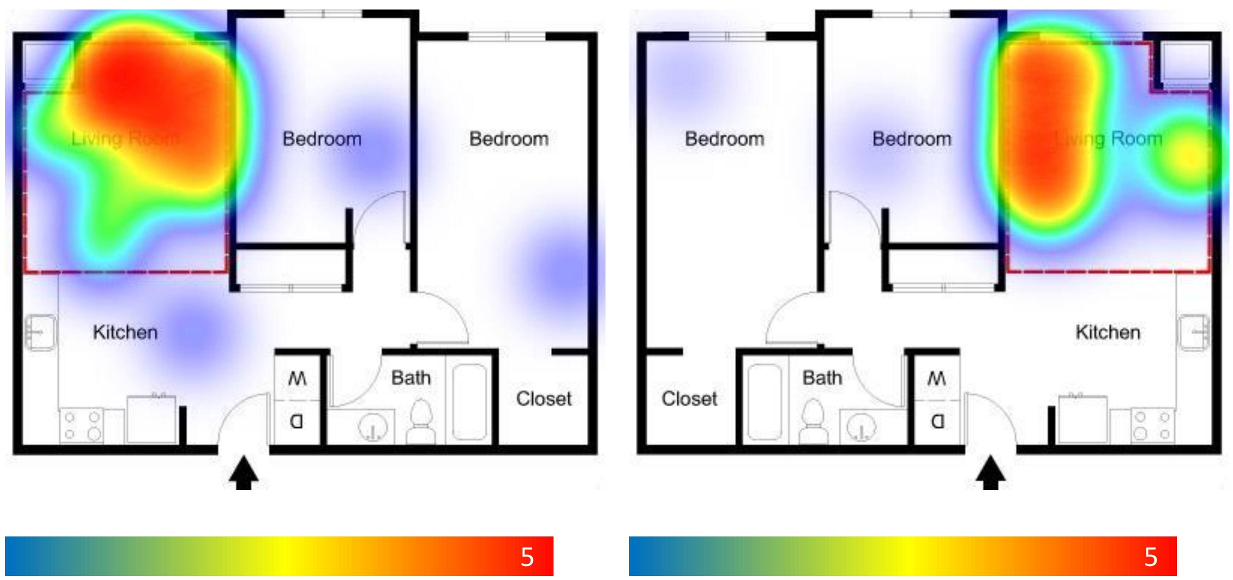


Figure 4.14

Occupants' Preferred Spots in the Living Area in a One-bedroom Apartment during the Winter

Figure 4.15

Occupants' Preferred Spots in the Living Area in a Two-bedroom Apartment Located at the Corner of the Buildings during the Winter

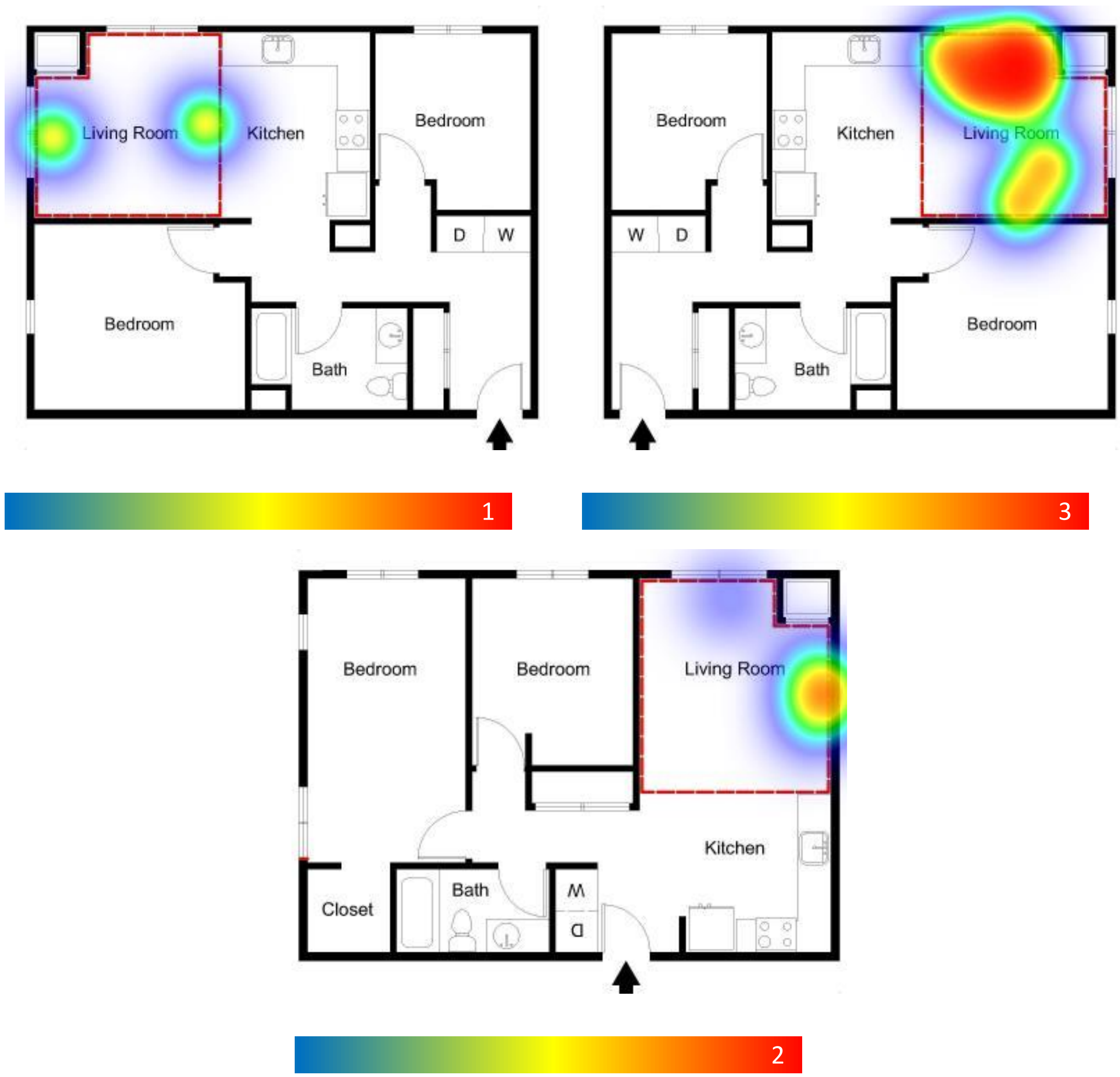
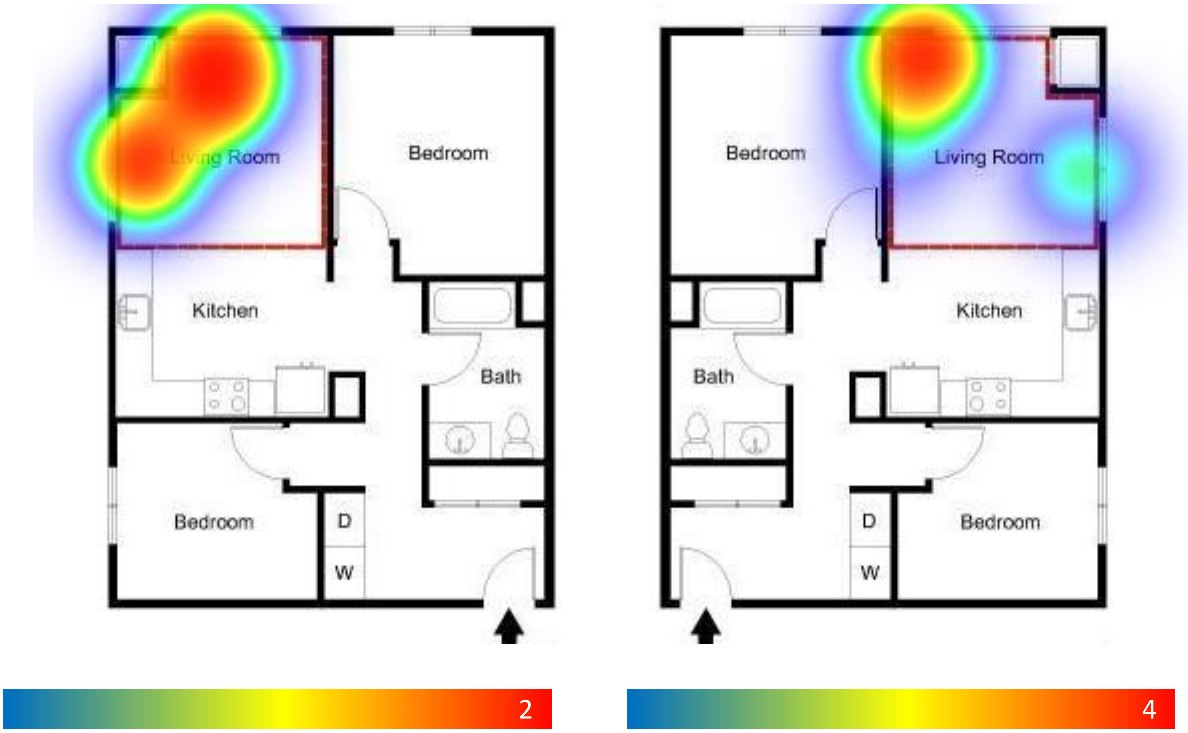


Figure 4.16

Occupants' Preferred Spots in the Living Area in a Two-bedroom Apartment Located at the Corner of the Buildings during the Winter



4.2.4.4. <u>Occupants' Location Preferences in the Sleeping Area during the Winter</u>

Figure 4.17, Figure 4.18, Figure 4.19, and Figure 4.20 show the heat maps that represent the occupants' preferred spots in the sleeping area during the winter season. Respondents were asked to answer an open-ended question and justify why they selected this spot and if their choice was related to the location of the window.

The results of the qualitative analysis of occupants' responses showed that about 41% of occupants referred the choice of their preferred spot to the furniture layout. About 36% of the occupants had a preferred spot that reflects the location of the bed and about 5% selected their preferred spot based on the location of the desk. A total of 11% of the respondents related to the selection of their preferred spot to the location of the window, while about 20% mentioned that it was not related to the location of the window. About 3% of the occupants chose this spot because of the amount of natural daylight being close to the window. About 4% mentioned that they selected their preferred spot to be close to the window where they can have access to outdoor views. About 1% of the respondents preferred their selected spot as they can enjoy fresh air being close to the window.

Figure 4.17

Occupants' Preferred Spots in the Sleeping Area in a Two-bedroom Apartment during the Winter

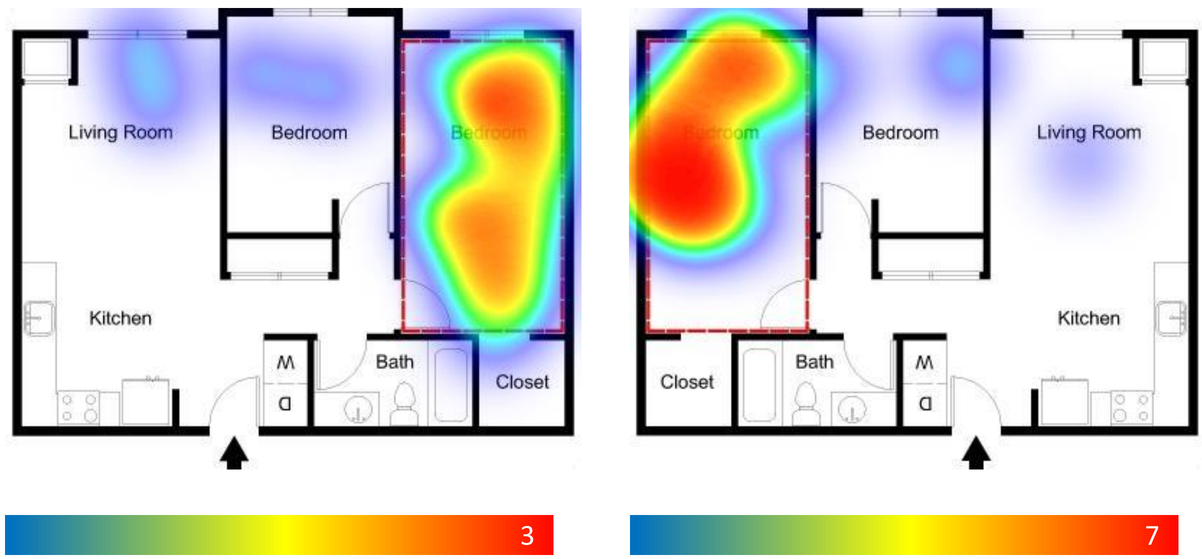


Figure 4.18

Occupants' Preferred Spots in the Sleeping Area in a One-bedroom Apartment during the Winter

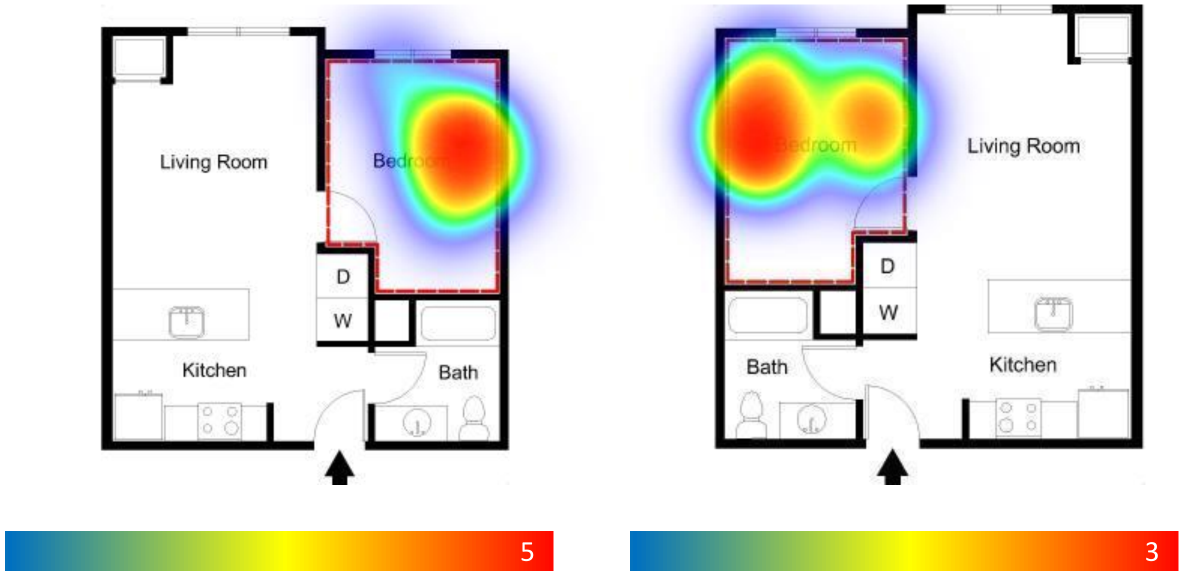


Figure 4.19

Occupants' Preferred Spots in the Sleeping Area in a Two-bedroom Apartment Located at the Corner of the Buildings during the Winter

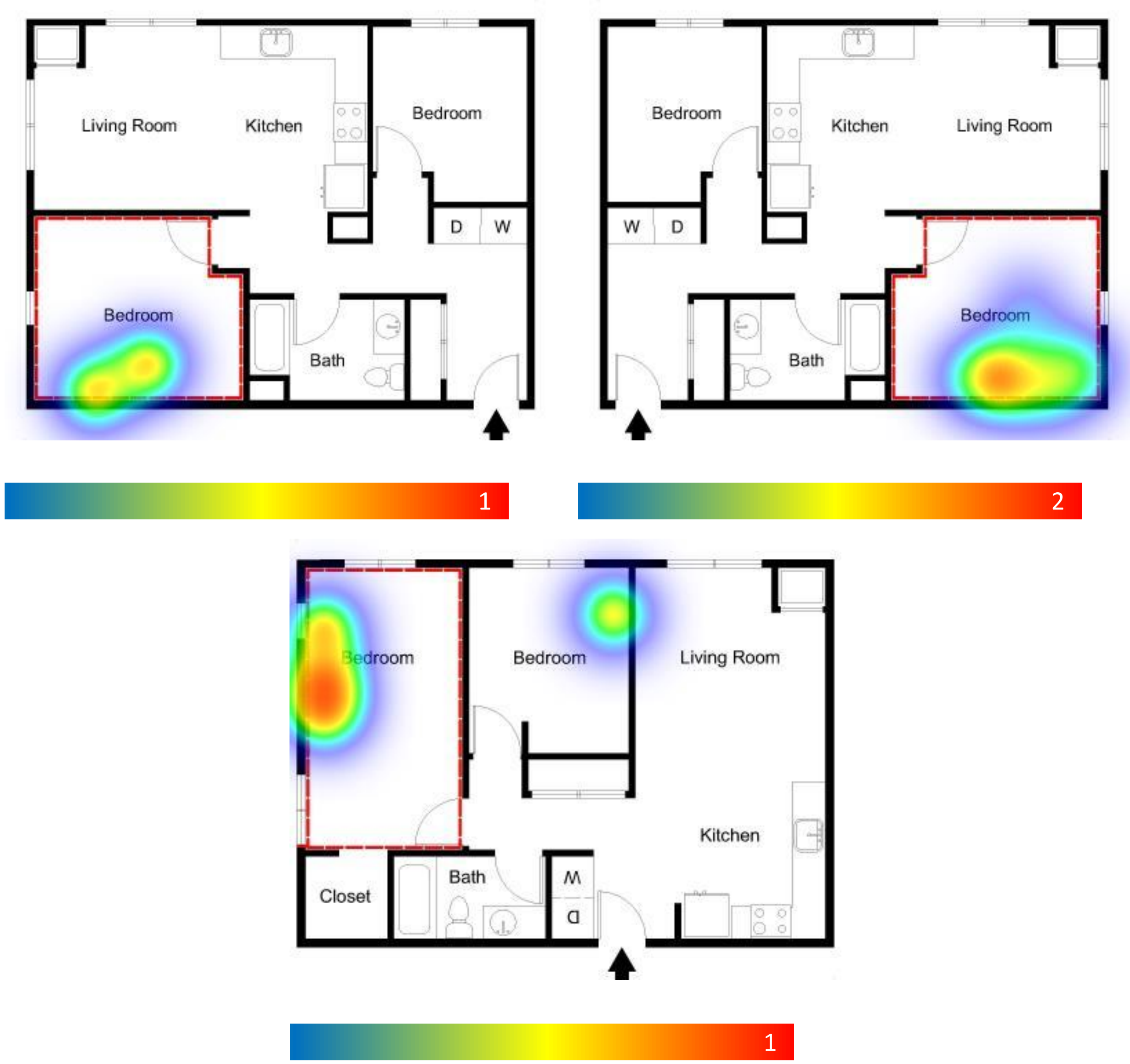
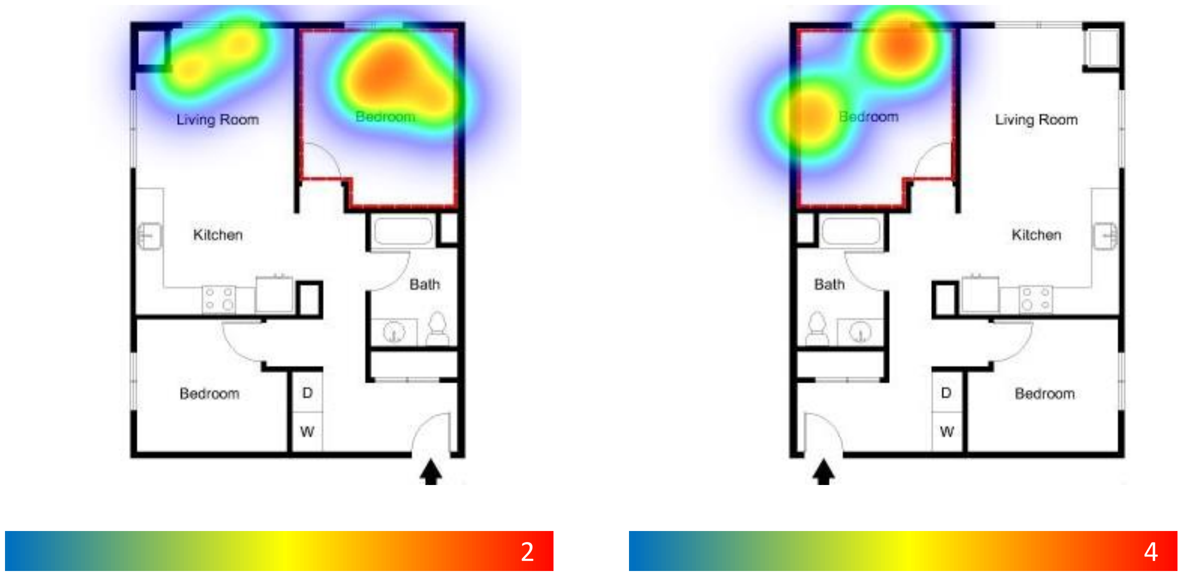


Figure 4.20

Occupants' Preferred Spots in the Sleeping Area in a One-bedroom Apartment during the Winter



RQ: How occupants' behavioral beliefs of operating windows and adjusting blinds are influenced by furniture location

Most of the occupants indicated that they selected their preferred spot in the living area and in the sleeping area according to the furniture layout in both seasons. Some of the occupants mentioned that their preferred location within the living area and sleeping area is related to the location of the window and the indoor environmental quality attributes it provides, such as daylighting, outdoor views, and airflow. A small number of the occupants mentioned that they select their spot based on the location of the air conditioner vent. Also, a small number of respondents indicated that they preferred to stay away from the window in winter to avoid cold air drafts.

4.3. Occupants' Behavioral Beliefs and Attitudes

According to the Theory of Planned Behavior, the beliefs of individuals determine their attitudes (Ajzen, 1985). This research explored the relationship between the occupants' beliefs and attitudes towards operating windows and adjusting blinds in living and sleeping areas.

H2: Occupants' behavioral beliefs of operating windows and adjusting blinds are associated with their attitudes towards performing this behavior.

Respondents were asked to answer two multiple-choice questions regarding their beliefs of operating windows and adjusting blinds in the living area and the sleeping area as shown in Figure 4.21. The questions captured the occupants' beliefs of benefits and drawbacks of operating windows and adjusting blinds. The answers were coded as dummy variables in which zero is equal to "No," and one is equal to "Yes." On the other hand, the occupants' attitude towards operating windows and adjusting blinds was measured using a 7-point Likert scale as shown in Figure 4.22. The data collected was considered as categorical variable in this part of the analysis.

Figure 4.21

Example of Item Used to Collect Data about Occupants' Beliefs of Operating Windows and Adjusting Blinds

What do you think are the benefits of operating **windows** in the living area in summer? (Please select all that apply)

☐ Operating windows has no benefits
☐ It causes a desired change in temperature
☐ It causes a desired change in airflow
☐ It eliminates air pollution concerns
☐ It brings in outdoor pleasant sounds
☐ It saves energy, please explain why:
☐ If other, please specify:

Figure 4.22

Example of Item Used to Collect Data about Occupants' Attitude of Operating Windows

Operating **windows** in my living area in summer is:								
Extremely harmful	1	2	3	4	5	6	7	Extremely beneficial

The Chi-square test was used to detect the relationship between the two categorical variables since each variable has at least two categories. The null hypothesis of the Chi-square test for association states that there is no relationship between the variables in the total population. When the p-value of the test is lower than the significance level (0.05), the hypothesis is accepted, and a significant relationship is indicated between the variables.

In addition, The Cramer's V test was used to measure the strength of the relationship. When the p-value of the Cramer's V test is lower than 0.05, it is considered statistically significant. Also, the Cramer's V test takes values between zero and one, in which zero means no association, and one means perfect association (Sun et al. 2010). The association between the two variables is considered strong when the Cramer's V value is greater than 0.7, moderate when the Cramer's V value is between 0.3 and 0.7, and weak when the Cramer's V value is less than 0.3. Respondents were asked to answer several questions related to their beliefs of the advantages and disadvantages associated with operating windows and adjusting blinds in the living and sleeping areas.

4.3.1. *Occupants' Belief and Attitude towards Operating Windows in the Living Area during the Summer.*

Among summer survey respondents, 89.2% believed that operating windows in the living area has benefits, while 10.8% believed that it had no benefits. Table 4.45 shows that there is a significant association (p-value = 0.005) between the occupants' belief that operating windows in the living area has no benefits and their attitude towards operating windows in the living area during the summer.

Table 4.45

*Chi-Square Test for Association (Belief that operating windows in the living area has no benefits during the summer*Attitude towards operating windows in living area during the summer) (N=102)*

Variable	Attitude towards operating windows in the living area
The belief that operating windows in the living area has no benefits	18.455**
Cramer's V	.425**

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

H2a: Occupants' behavioral beliefs of operating windows are associated with their attitudes towards performing this behavior in the living area during the summer.

Results of the Chi-Square test for association indicate that there is a significant relationship between occupants' beliefs of operating windows in the living area during the summer and their attitudes towards performing this behavior in which X^2 (6, N = 102) = 18.455, p = .005. Therefore, this sub-hypothesis is accepted. Cramer's V test is significant (p = .005), and the association between the two variables is moderate because Cramer's V value is 0.425. The moderate effect size indicated a substantive relationship between occupants' beliefs and attitudes towards operating windows in the living area during the summer.

4.3.2. *Occupants' Belief and Attitude towards Operating Windows in the Living Area during the Winter.*

Among winter survey respondents, 88.1% believed that operating windows in the living area has benefits, while 11.9% believed that it had no benefits. Table 4.46 shows that there is a significant association (p-value = 0.003) between the occupants' belief that operating windows in the living area has no benefits and their attitude towards operating windows in the living area during the summer.

Table 4.46

*Chi-Square Test for Association (Belief that operating windows in the living area has no benefits during the winter*Attitude towards operating windows in the living area during the winter) (N=102)*

Variable	Attitude towards operating windows in the living area
The belief that operating windows in the living area has no benefits	20.091**
Cramer's V	.446**

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

H2b: Occupants' behavioral beliefs of operating windows are associated with their attitudes towards performing this behavior in the living area during winter.

Results of the Chi-Square test for association showed that there is a significant relationship between occupants' beliefs of operating windows in the living area during winter and their attitudes towards performing this behavior in which X^2 (6, N = 101) = 20.091, p = .003. Therefore, this sub-hypothesis is accepted. Cramer's V test is significant (p = .003), and the association between the two variables is moderate because Cramer's V value is 0.446. The moderate effect size indicated a substantive relationship between occupants' beliefs and attitudes towards operating windows in the living area during the winter.

4.3.3. *Occupants' Belief and Attitude towards Operating Windows in the Sleeping Area during the Summer*

Among summer survey respondents, 84.5% believed that operating windows in the sleeping area has benefits, while 15.5% believed that it had no benefits. Table 4.47 shows that there is a significant association (p-value = 0.000) between the occupants' belief that operating windows in the sleeping area has no benefits and their attitude towards operating windows in the sleeping area during the summer.

Table 4.47

*Chi-Square Test for Association (Belief that operating windows in the sleeping area has no benefits during the summer*Attitude towards operating windows in the sleeping area during the summer) (N=103)*

Variable	Attitude towards operating windows in the sleeping area
The belief that operating windows in the sleeping area has no benefits	25.905***
Cramer's V	.502***

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

<u>H2c: Occupants' behavioral beliefs of operating windows are associated with their attitudes towards performing this behavior in the sleeping area during summer.</u>

Results of the Chi-Square test for association showed that there is a significant relationship between occupants' beliefs of operating windows in the sleeping area during summer and their attitudes towards performing this behavior in which X^2 (6, N = 103) = 25.905, p = .000. Therefore, this sub-hypothesis is accepted. The Cramer's V test is significant (p = .000), and the association between the two variables is moderate because Cramer's V value is 0.502. The moderate effect size indicated a substantive relationship between occupants' beliefs and attitudes towards operating windows in the sleeping area during the summer.

4.3.4. *Occupants' Belief and attitude towards Operating Windows in the Sleeping Area during the Winter.*

Among winter survey respondents, 88.1% believed that operating windows in the living area has benefits, while 11.9% believed that it had no benefits. Table 4.48 shows that there is a significant association (p-value = 0.003) between the occupants' belief that operating windows in the living area has no benefits and their attitude towards operating windows in the living area during the summer.

Table 4.48

*Chi-Square Test for Association (Belief that operating windows in the sleeping area has no benefits during the winter*Attitude towards operating windows in the sleeping area during the winter) (N=101)*

Variable	Attitude towards operating windows in the sleeping area
The belief that operating windows in the sleeping area has no benefits	33.588***
Cramer's V	.577***

*p ≤ .05. **p ≤ .01. ***p ≤ .001

H2d: Occupants' behavioral beliefs of operating windows are associated with their attitudes towards performing this behavior in the sleeping area during winter.

Results of the Chi-Square test for association showed that there is a significant relationship between occupants' beliefs of operating windows in the sleeping area during winter and their attitudes towards performing this behavior in which X^2 (6, N = 101) = 33.588, p = .000. Therefore, this sub-hypothesis is accepted. The Cramer's V test is significant (p= .000), and the association between the two variables is moderate because Cramer's V value is 0.446. The moderate effect size indicated a substantive relationship between occupants' beliefs and attitudes towards operating windows in the sleeping area during the winter.

4.3.5. *Occupants' Belief and Attitude towards Adjusting Blinds in the Living Area during the Summer*

In terms of adjusting blinds in living areas among summer survey respondents, 95.1% believed that adjusting blinds in the living area has benefits, while 4.9% believed that it had no benefits. Table 4.49 shows that there is no significant association (p-value = 0.057) between the occupants' belief that adjusting blinds in the living area has no benefits and their attitude towards adjusting blinds in the living area during the summer.

Table 4.49

*Chi-Square Test for Association (Belief that adjusting blinds in the living area has no benefits during the summer*Attitude towards adjusting blinds in living area during the summer) (N=103)*

Variable	Attitude towards adjusting blinds in the living area
The belief that adjusting blinds in the living area has no benefits	10.745
Cramer's V	.323

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

<u>H2e: Occupants' behavioral beliefs of adjusting blinds are associated with their attitudes towards performing this behavior in the living area during the summer.</u>

Results of the Chi-Square test for association showed that there is no significant relationship between occupants' beliefs of adjusting blinds in the living area during the summer and their attitudes towards performing this behavior in which X^2 (5, N = 103) = 10.745, p = .057. Therefore, this sub-hypothesis is rejected. The Cramer's V test is not significant (p= .057), and the association between the two variables is weak because Cramer's V value is 0.323. There is not enough evidence to suggest an association between occupants' beliefs of adjusting blinds in the living area in summer and their attitudes towards performing this behavior.

4.3.6. *Occupants' Belief and Attitude towards Adjusting Blinds in the Living Area during the Winter*

Among winter survey respondents, 98.0% believed that adjusting blinds in the living area has benefits, while 2.0% believed that it had no benefits. Table 4.50 shows that there is no significant association (p-value = 0.197) between the occupants' belief that adjusting blinds in the living area has no benefits and their attitude towards adjusting blinds in the living area during the winter.

Table 4.50

*Chi-Square Test for Association (Belief that adjusting blinds in the living area has no benefits during the winter*Attitude towards adjusting blinds in the living area during the winter) (N=101)*

Variable	Attitude towards adjusting blinds in the living area
The belief that adjusting blinds in the living area has no benefits	7.327
Cramer's V	.269

*p ≦ .05. **p ≦ .01. ***p ≦ .001

H2f: Occupants' behavioral beliefs of adjusting blinds are associated with their attitudes towards performing this behavior in the living area during the winter.

Results of the Chi-Square test for association showed that there is no significant relationship between occupants' beliefs of adjusting blinds in the living area during the summer and their attitudes towards performing this behavior in which X^2 (5, N = 101) = 7.327, p = .197. Therefore, this sub-hypothesis is rejected. The Cramer's V test is not significant (p= .197), and the association between the two variables is weak because Cramer's V value is 0.269. There is not enough evidence to suggest an association between occupants' beliefs of adjusting blinds in the living area in winter and their attitudes towards performing this behavior.

4.3.7. *Occupants' Belief and Attitude towards Adjusting Blinds in the Sleeping Area during the Summer*

Occupants' belief and attitude towards adjusting blinds in the sleeping area in summer were examined. Among summer survey respondents, 94.2% believed that adjusting blinds in the sleeping area has benefits, while 5.8% believed that it had no benefits. Table 4.51 shows that there is a significant association (p-value = 0.037) between the occupants' belief that adjusting blinds in the sleeping area has no benefits and their attitude towards adjusting blinds in the sleeping area in summer.

Table 4.51

*Chi-Square Test for Association (Belief that adjusting blinds in the sleeping area has no benefits during the summer*Attitude towards adjusting blinds in the sleeping area during the summer) (N=103)*

Variable	Attitude towards adjusting blinds in the sleeping area
The belief that adjusting blinds in the sleeping area has no benefits	13.376*
Cramer's V	.360*

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

<u>H2g: Occupants' behavioral beliefs of adjusting blinds are associated with their attitudes towards performing this behavior in the sleeping area during the summer.</u>

Results of the Chi-Square test for association showed that there is a significant relationship between occupants' beliefs of adjusting blinds in the sleeping area during the summer and their attitudes towards performing this behavior in which X^2 (6, N = 103) = 13.376, p = .037. Therefore, this sub-hypothesis is accepted. The Cramer's V test is significant (p = .037), and the association between the two variables is moderate because Cramer's V value is 0.488. The moderate effect size indicated a substantive relationship between occupants' beliefs and attitudes towards operating windows in the sleeping area during the summer.

4.3.8. *Occupants' Belief and Attitude towards Adjusting Blinds in the Sleeping Area during the Winter*

Among winter survey respondents, 96.0% believed that adjusting blinds in the sleeping area has benefits, while 4.0% believed that it had no benefits. Table 4.52 shows that there is a significant association (p-value = 0.001) between the occupants' belief that adjusting blinds in the sleeping area has no benefits and their attitude towards adjusting blinds in the sleeping area during the winter season.

Table 4.52

*Chi-Square Test for Association (Belief that adjusting blinds in the sleeping area has no benefits during the winter*Attitude towards adjusting blinds in the sleeping area during the winter) (N=101)*

Variable	Attitude towards adjusting blinds in the sleeping area
The belief that adjusting blinds in the sleeping area has no benefits	24.004**
Cramer's V	.488*

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

H2h: Occupants' behavioral beliefs of adjusting blinds are associated with their attitudes towards performing this behavior in the sleeping area during the winter.

Results of the Chi-Square test for association showed that there is a significant relationship between occupants' beliefs of adjusting blinds in the sleeping area during the winter and their attitudes towards performing this behavior in which X^2 (6, N = 101) = 24.004, p = .001. Therefore, this sub-hypothesis is accepted. The Cramer's V test is significant (p = .001), and the association between the two variables is moderate because Cramer's V value is 0.488. The moderate effect size indicated a substantive relationship between occupants' beliefs and attitudes towards operating windows in the sleeping area during the winter.

4.4. Occupants' Attitudes, Subjective Norms, and Perceived Behavioral Control

According to the Theory of Planned Behavior, the aggregate of the attitudes, subjective norms, and perceived behavioral control lead to behavioral intentions (Fishbein & Ajzen, 2010).

H3: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows and adjusting blinds contribute to the explanation of their behavioral intention to perform this behavior.

The set of questions used to collect information about occupants' attitude, subjective norm, perceived behavioral control, and behavioral intention toward operating windows and adjusting blinds was developed based on Ajzen's (2006) recommendations to construct a questionnaire based on the Theory of Planned Behavior. An example of these items is shown in Figure 4.23.

Figure 4.23

Example of a Set of Items Used to Collect Data about Occupants' Attitude, Subjective Norm, Perceived Behavioral Control, and Behavioral Intention of Operating Windows

Operating **windows** in my living area in summer is:

Extremely harmful	1	2	3	4	5	6	7	Extremely beneficial

Most people whose opinions I value would appreciate me operating the **windows** in the living area in summer.

strongly disagree	1	2	3	4	5	6	7	Strongly agree

For me, operating **windows** in my living area in summer is:

Extremely difficult	1	2	3	4	5	6	7	Extremely easy

I intend to operate **windows** in my living area in the next week.

Extremely unlikely	1	2	3	4	5	6	7	Extremely likely

In this research, a multiple regression analysis (enter method) was performed to study the relationship between the occupants' behavioral intentions (dependent variable) and their attitudes, subjective norms, and perceived behavioral control (independent variables).

The multiple regression equation writes as follows:

$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + \ldots. b_kx_k + \varepsilon$

Where y is the dependent variable (behavioral intention), x_K is the independent variables also known as predictors (attitudes, subjective norms, and perceived behavioral control), b_K is the regression coefficient (respond variable), and b0 is the constant (intercept). The epsilon term (ε) is called the residual value or error. This value captures all the influences that are not explained by the independent variable (x).

Accordingly, the multiple regression equation for this research writes as follows:

Behavioral Intention = b_0 + b_1Attitude + b_2Subjective norm+ b_3Perceived Behavioral Control + ε

Eight multiple regression analysis procedures were run. The first and second predicted the intention of operating windows in the living area during the summer and the winter, the third and fourth predicted the intention of adjusting blinds in the living area in summer and winter, the fifth and sixth predicted the intention of operating windows in the sleeping area in summer and winter, and the seventh and eighth predicted the intention of adjusting blinds in the sleeping area in summer and winter. The independent variables in both models are based on the three constructs of the Theory of Planned Behavior, which are: 1- attitude 2-subjective norm, and 3-perceived behavioral control of operating windows and adjusting blinds in the living area. The confidence intervals (95% level) were calculated for the regression coefficients.

The linear multiple regression analysis is a parametric test, according to Field (2017), and fundamental assumptions must be checked before running the linear multiple regression analysis. First, the independent and dependent variables are continuous. In this research, seven-point Likert scale items were used to measure the independent and dependent variables. It was assumed that the intervals between the scale values would be approximately equal. Therefore, data collected can be treated as continuous variables (Sullivan & Artino, 2013).

Second, the relationship between the dependent variable and the independent variables are approximately linear, both for each independent variable and globally. A simple scatter plot representing the relationship between the dependent and independent variables was used to check the linearity assumption. Third, the dependent variable has the same variance for all the values of the independent variable (there is homoscedasticity). A simple scatter plot representing the relationship between the standardized predicted value and the standardized residual of the dependent variable was used to check the homoscedasticity assumption.

Fourth, there are no significant outliers in the data series. The casewise diagnostics were used to identify all the outliers outside three standard deviations. Also, checking the studentized deleted residuals shows if there are values that are greater than 3 in absolute value. Fifth, there is no relationship between the residual variable and the independent variables (the errors are independent). The Durbin-Watson test was issued to check the independence of errors. The Durbin Watson test value ranges between zero and four. Therefore, it is considered that the assumption of independence of errors is met because the value ranges between 1.50 and 2.50.

Sixth, the residual variable is approximately normally distributed. This assumption can be checked by running the Shapiro-Wilk test. If the p-value of the Shapiro-Wilk test is greater than 0.05, the hypothesis is rejected, and the standardized residual variable of the dependent variable is considered normally distributed. Also, normality can be assumed by checking the histogram and the P-P plot of the standardized residual variable of the dependent variable.

Finally, the independent variables are not strongly correlated with one another (no important multicollinearity). Variance Inflation Factor (VIF) and tolerance are the two indicators that were computed to measure the impact of collinearity on the analysis. VIF shows how variance of an estimated regression coefficient might increase because of collinearity. Tolerance is the reciprocal of VIF. If the VIF is lower than 10 or the tolerance is higher than 0.01 for all independent variables, multicollinearity is not a threat to the analysis.

4.4.1. *Predicting the Intention of Operating Windows in the Living Area during the Summer*

Table 4.53 shows the multiple regression model used to predict the occupants' intention of operating windows in the living area during the summer based on their attitudes, subjective norms, and perceived behavioral control. The value of the adjusted coefficient of determination (Adjusted R Square) is 0.411. This means that about 40% of the variance in the behavior of operating windows in the living area during the summer is explained by the independent variables (attitude, subjective norm, and perceived behavioral control of operating windows in the living area). The results of the analysis of variance are presented in Table 4.53. Since the p-value of the F-test is lower than 0.05, it is concluded that at least one regression coefficient is different from zero. So, the independent variables provide a satisfactory explanation for the response variable. The VIF is 1.51, 1.593, and 1.126 for the attitudes, subjective norms, and perceived behavioral control, respectively. Therefore, the correlation between predictor variables are within the acceptable range.

Table 4.53

Multiple Regression Analysis of Occupants' Attitude, Subjective Norm, Perceived Behavioral Control and Behavioral Intention of Operating Windows in the Living Area during the Summer (N=102)

Independent Variable	B	SE B	β	t	95% CI	
					LL	UL
Intercept	-.157	.688		-.227	-1.522	1.209
Attitude Towards Operating Windows in Living Area	.485	.132	.348***	3.678	.223	.746
Subjective norm Towards Operating Windows in Living Area	.438	.124	.343***	3.524	.191	.685
Perceived Behavioral Control Towards Operating Windows in Living Area	.089	.100	.073	.896	-.108	.287
R^2	.411					
Adjusted R^2	.394					
F	23.071***					

Note. Dependent variable: Intention of Operating Windows in Living Area

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

<u>H3a: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows contribute to the explanation of their behavioral intention to perform this behavior in the living area during the summer.</u>

Table 4.53 shows a significant regression equation in which: (F (3, 99) = 23.071, p ≤ .000, with R^2 of .411. Occupants' predicted behavioral intention (DV) is equal to -.157 + .485 (attitude) + .438 (subjective norm) + .089 (perceived behavioral control). About 40% of the variance in occupants' behavioral intention to operate windows in the living area during the summer could be explained by their attitude, subjective norm, and perceived behavioral control. Occupants with more positive attitudes (ß = .348, t = 3.678, p ≤ .000) and higher levels of subjective norm (ß = .343, t = 3.524, p ≤ .001)

appeared to have stronger behavioral intention towards operating windows in the living area during the summer. Perceived behavioral control did not contribute to the explanation of intentions (ß = .073, t = .896, p ≤ .372) when attitude and subjective norm were controlled for.

4.4.2. *Predicting the Intention of Operating Windows in the Living Area during the Winter*

Table 4.54 shows the multiple regression model used to predict the occupants' intention of operating windows in the living area during the winter based on their attitudes, subjective norms, and perceived behavioral control. The value of the adjusted coefficient of determination (Adjusted R Square) is 0.502. This means that about 50% of the variance in the behavior of operating windows in the living area during the winter is explained by the independent variables (attitude, subjective norm, and perceived behavioral control of operating windows in the living area). The results of the analysis of variance are presented in **Table *4.54***. Since the p-value of the F-test is less than 0.05, it is concluded that at least one regression coefficient is different from zero. So, the independent variables provide a satisfactory explanation for the response variable. The VIF is 1.316, 1.491, and 1.264 for the attitudes, subjective norms, and perceived behavioral control, respectively. Therefore, the correlation between predictor variables are within the acceptable range.

Table 4.54

Multiple Regression Analysis of Occupants' Attitude, Subjective Norm, Perceived Behavioral Control and Behavioral Intention of Operating Windows in the Living Area during the Winter (N=100)

Independent Variable	B	SE B	β	t	95% CI	
					LL	UL
Intercept	-.312	.452		-.691	-1.210	.585
Attitude Towards Operating Windows in Living Area	.549	.096	.461***	5.692	.357	.740
Subjective norm Towards Operating Windows in Living Area	.324	.091	.307***	3.568	.144	.504
Perceived Behavioral Control Towards Operating Windows in Living Area	.129	.091	.113	1.422	-.051	.309
R^2	.517					
Adjusted R^2	.502					
F	34.668***					

Note. Dependent variable: Intention of Operating Windows in Living Area

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

<u>H3b: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows contribute to the explanation of their behavior to perform this behavior in the living area during the winter.</u>

Table 4.54 shows a significant regression equation in which: (F (3, 97) = 34.668, p ≤ .000, with R^2 of .517. Occupants' predicted behavioral intention (DV) is equal to -.312 + .549 (attitude) + .324(subjective norm) + .129 (perceived behavioral control). About 50% of the variance in occupants' behavioral intention to operate windows in the living area during the winter could be explained by their attitude, subjective norm, and perceived behavioral control. Occupants with more positive attitudes (ß = .461, t = 5.692, p ≤ .000) and higher levels of subjective norm (ß = .307, t = 3.568, p ≤ .001) appeared to

have stronger behavioral intention towards operating windows in the living area during the winter. Perceived behavioral control did not contribute to the explanation of intentions (ß = .113, t = 1.422, $p \leq .158$) when attitude and subjective norm were controlled for.

4.4.3. *Predicting the Intention of Operating Windows in the Sleeping Area during the Summer*

Table 4.55 shows the multiple regression model used to predict the occupants' intention of operating windows in the sleeping area during the summer based on their attitudes, subjective norms, and perceived behavioral control. The value of the adjusted coefficient of determination (Adjusted R Square) is 0.514. This means that about 51% of the variance in the behavior of operating windows in the sleeping area in summer is explained by the independent variables (attitude, subjective norm, and perceived behavioral control of operating windows in the sleeping area). The results of the analysis of variance are presented in Table 4.55. Since the p-value of the F-test is less than 0.05, it is concluded that at least one regression coefficient is different from zero. So, the independent variables provide a satisfactory explanation for the response variable. The VIF is 1.462, 1.640, and 1.451 for the attitudes, subjective norms, and perceived behavioral control, respectively. Therefore, the correlation between predictor variables are within the acceptable range.

Table 4.55

Multiple Regression Analysis of Occupants' Attitude, Subjective Norm, Perceived Behavioral Control and Behavioral Intention of Operating Windows in the Sleeping Area during the Summer (N=102)

Independent Variable	B	SE B	β	t	95% CI	
					LL	UL
Intercept	-.855	.582		-1.468	-2.011	.300
Attitude Towards Operating windows in Sleeping Area	.250	.118	.180*	2.121	.016	.485
Subjective norm Towards Operating windows in Sleeping Area	.511	.113	.404***	4.503	.286	.736
Perceived Behavioral Control Towards Operating windows in Sleeping Area	.354	.106	.281**	3.326	.143	.565
R^2	.514					
Adjusted R^2	.500					
F	34.964***					

Note. Dependent variable: Intention of Operating Windows in Sleeping Area
**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

<u>H3c: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows contribute to the explanation of their behavioral intention to perform this behavior in the sleeping area during the summer.</u>

Table 4.55 shows a significant regression equation in which: (F (3, 99) = 34.964, p ≤ .000, with R^2 of .514. Occupants' predicted behavioral intention (DV) is equal to -.855 + .250 (attitude) + .511 (subjective norm) + .354 (perceived behavioral control). About 51% of the variance in occupants' behavioral intention to operate window in the sleeping area during the summer could be explained by their attitude, subjective norm, and perceived behavioral control. Occupants with more positive

attitudes (ß = .180, t = 2.121, p ≤ .036), higher levels of subjective norm (ß = .404, t = 4.503, p ≤ .000), and higher levels of Perceived behavioral (ß = .281, t = 3.326, p ≤ .001) appeared to have stronger behavioral intention towards operating windows in the sleeping area during the summer.

4.4.4. *Predicting the Intention of Operating Windows in the Sleeping Area during the Winter*

Table 4.56 shows the multiple regression model used to predict the occupants' intention of operating windows in the sleeping area during the winter based on their attitudes, subjective norms, and perceived behavioral control. The value of the adjusted coefficient of determination (Adjusted R Square) is 0.432. This means that about 43% of the variance in the behavior of operating windows in the sleeping area during the winter is explained by the independent variables (attitude, subjective norm, and perceived behavioral control of operating windows in the sleeping area). The results of the analysis of variance are presented in Table 4.56. Since the p-value of the F-test is less than 0.05, it is concluded that at least one regression coefficient is different from zero. So, the independent variables provide a satisfactory explanation for the response variable. The VIF is 1.622, 1.593, and 1.186 for the attitudes, subjective norms, and perceived behavioral control, respectively. Therefore, the correlation between predictor variables are within the acceptable range.

Table 4.56

Multiple Regression Analysis of Occupants' Attitude, Subjective Norm, Perceived Behavioral Control and Behavioral Intention of Operating Windows during the Winter (N=100)

Independent Variable	B	SE B	β	t	95% CI	
					LL	UL
Intercept	-.035	.477		-.072	-.982	.913
Attitude Towards Operating windows in Sleeping Area	.545	.105	.496***	5.173	.336	.754
Subjective norm Towards Operating windows in Sleeping Area	.175	.100	.166	1.744	-.024	.373
Perceived Behavioral Control Towards Operating windows in Sleeping Area	.145	.093	.128	1.566	-.039	.329
R^2	.449					
Adjusted R^2	.432					
F	26.379***					

Note. Dependent variable: Intention of Operating Windows in Sleeping Area

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

H3d: Occupants' attitude, subjective norm, and perceived behavioral control towards operating windows contribute to the explanation of their behavior to perform this behavior in the sleeping area during the winter.

Table 4.56 shows a significant regression equation in which: (F (3, 97) = 26.379, p ≤ .000, with R^2 of .449. Occupants' predicted behavioral intention (DV) is equal to -.035 + .545 (attitude) + .175(subjective norm) + .145 (perceived behavioral control). About 45% of the variance in occupants' behavioral intention to operate windows in the sleeping area during the winter could be explained by their attitude, subjective norm, and perceived behavioral control. Occupants with more positive attitudes (ß = .496, t = 5.173, p ≤ .000) appeared to have stronger behavioral intentions towards operating windows in the sleeping area during the winter. Subjective norm (ß = .160, t = 1.744, p ≤ .084) and perceived behavioral control did not contribute to the explanation of intentions (ß = .128, t = 1.566, p ≤ .121) when attitude was controlled for.

4.4.5. *Predicting the Intention of Adjusting Blinds in the Living Area during the Summer*

Table 4.57 shows the multiple regression model used to predict the occupants' intention of adjusting blinds in the living area during the summer based on their attitudes, subjective norms, and perceived behavioral control. The value of the adjusted coefficient of determination (Adjusted R Square) is 0.553. This means that about 55% of the variance in the behavior of operating windows in the living area is explained by the independent variables (attitude, subjective norm, and perceived behavioral control of adjusting blinds in the living area). The results of the analysis of variance are presented in Table 4.57. Since the p-value of the F-test is less than 0.05, it is concluded that at least one regression coefficient is different from zero. So, the independent variables provide a satisfactory explanation for the response variable. The VIF is 1.458, 1.590, and 1.300 for the attitudes, subjective norms, and perceived behavioral control, respectively. Therefore, the correlation between predictor variables are within the acceptable range.

Table 4.57

Multiple Regression Analysis of Occupants' Attitude, Subjective Norm, Perceived Behavioral Control and Behavioral Intention of Adjusting Blinds in the Living Area during the Summer (N=102)

Independent Variable	B	SE B	β	t	95% CI	
					LL	UL
Intercept	.140	.553		.252	-.957	1.237
Attitude Towards Adjusting Blinds in Living Area	.184	.096	.155	1.903	-.008	.375
Subjective norm Towards Adjusting Blinds in Living Area	.649	.100	.551***	6.501	.451	.847
Perceived Behavioral Control Towards Adjusting Blinds in Living Area	.196	.089	.168*	2.194	.019	.373
R^2	.553					
Adjusted R^2	.539					
F	40.747***					

Note. Dependent variable: Intention of Adjusting Blinds in Living Area

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

<u>H3e: Occupants' attitude, subjective norm, and perceived behavioral control towards adjusting blinds contribute to the explanation of their behavioral intention to perform this behavior in the living area during the summer.</u>

Table 4.57 shows a significant regression equation in which: (F (3, 99) = 40.747, p ≤ .000, with R^2 of .553. Occupants' predicted behavioral intention (DV) is equal to .140 + .184 (attitude) + .649(subjective norm) + .196 (perceived behavioral control). About 55% of the variance in occupants' behavioral intention to adjust blinds in the living area during the summer could be explained by their attitude, subjective norm, and perceived behavioral control. Occupants with higher levels of subjective norm (ß = .461, t = 5.692, p ≤ .000) and higher levels of perceived behavioral control (ß = .307, t = 3.568,

$p \leq .001$) appeared to have stronger behavioral intention towards adjusting blinds in the living area during the summer. Attitude did not contribute to the explanation of intentions (ß = .113, t = 1.422, $p \leq .158$) when subjective norm and perceived behavioral control were controlled for.

4.4.6. *Predicting the Intention of Adjusting Blinds in the Living Area during the Winter*

Table 4.58 shows the multiple regression model used to predict the occupants' intention of operating windows in the sleeping area during the summer based on their attitudes, subjective norms, and perceived behavioral control. The value of the adjusted coefficient of determination (Adjusted R Square) is 0.555. This means that about 55% of the variance in the behavior of operating windows in the sleeping area during the winter is explained by the independent variables (attitude, subjective norm, and perceived behavioral control of operating windows in the sleeping area). The results of the analysis of variance are presented in Table 4.58. Since the p-value of the F-test is less than 0.05, it is concluded that at least one regression coefficient is different from zero. So, the independent variables provide a satisfactory explanation for the response variable. The VIF is 1.582, 1.653, and 1.523 for the attitudes, subjective norms, and perceived behavioral control, respectively. Therefore, the correlation between predictor variables are within the acceptable range.

Table 4.58

Multiple Regression Analysis of Occupants' Attitude, Subjective Norm, Perceived Behavioral Control and Behavioral Intention of Adjusting Blinds in the Living Area during the Winter (N=100)

Independent Variable	B	SE B	β	t	95% CI	
					LL	UL
Intercept	-.326	.538		-.605	-1.395	.743
Attitude Towards Adjusting Blinds in Living Area	.474	.101	.394***	4.695	.274	.675
Subjective norm Towards Adjusting Blinds in Living Area	.252	.098	.220*	2.564	.057	.447
Perceived Behavioral Control Towards Adjusting Blinds in Living Area	.335	.094	.292**	3.546	.147	.522
R^2	.568					
Adjusted R^2	.555					
F	42.590***					

Note. Dependent variable: Intention of Adjusting Blinds in Living Area
**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

<u>H3f: Occupants' attitude, subjective norm, and perceived behavioral control towards adjusting blinds contribute to the explanation of their behavior to perform this behavior in the living area during the winter.</u>

Table 4.58 shows a significant regression equation in which: (F (3, 97) = 42.590, p ≤ .000, with R^2 of .568. Occupants' predicted behavioral intention (DV) is equal to -.326 + .474 (attitude) + .252 (subjective norm) + .335 (perceived behavioral control). About 57% of the variance in occupants' behavioral intention to adjust blinds in the living area during the winter could be explained by their attitude, subjective norm, and perceived behavioral control. Occupants with more positive attitudes (ß = .394, t = 4.695, p ≤ .000), higher levels of subjective norm (ß = .220, t = 2.564, p ≤ .012), and higher levels

of perceived behavioral control (ß = .292, t = 3.546, p ≤ .001) appeared to have stronger behavioral intention towards adjusting blinds in the living area during the winter.

4.4.7. *Predicting the Intention of Adjusting Blinds in the Sleeping Area during the Summer*

Table 4.59 shows the multiple regression model used to predict the occupants' intention of adjusting blinds in the sleeping area during the summer based on their attitudes, subjective norms, and perceived behavioral control. The value of the adjusted coefficient of determination (Adjusted R Square) is 0.445. This means that about 45% of the variance in the behavior of adjusting blinds in the sleeping area is explained by the independent variables (attitude, subjective norm, and perceived behavioral control of adjusting blinds in the sleeping area). The results of the analysis of variance are presented in Table 4.59. Since the p-value of the F-test is less than 0.05, it is concluded that at least one regression coefficient is different from zero. So, the independent variables provide a satisfactory explanation for the response variable. The VIF is 2.151, 2.247, and 1.405 for the attitudes, subjective norms, and perceived behavioral control, respectively. Therefore, the correlation between predictor variables are within the acceptable range.

Table 4.59

Multiple Regression Analysis of Occupants' Attitude, Subjective Norm, Perceived Behavioral Control and Behavioral Intention of Operating Windows during the Summer (N=102)

Independent Variable	B	SE B	β	t	95% CI	
					LL	UL
Intercept	.452	.617		.733	-.772	1.677
Attitude Towards Adjusting Blinds in Sleeping Area	.234	.139	.182	1.679	-.043	.510
Subjective norm Towards Adjusting Blinds in Sleeping Area	.452	.125	.399***	3.609	.203	.700
Perceived Behavioral Control Towards Adjusting Blinds in Sleeping Area	.256	.108	.207*	2.370	.042	.471
R^2	.461					
Adjusted R^2	.445					
F	28.208***					

Note. Dependent variable: Intention of Adjusting Blinds in Sleeping Area

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

H3g: Occupants' attitude, subjective norm, and perceived behavioral control towards adjusting blinds contribute to the explanation of their behavioral intention to perform this behavior in the sleeping area during the summer.

Table 4.59 shows a significant regression equation in which: (F (3, 99) = 28.208, p ≤ .000, with R^2 of .461. Occupants' predicted behavioral intention (DV) is equal to .452 + .234 (attitude) + .452 (subjective norm) + .256 (perceived behavioral control). About 45% of the variance in occupants' behavioral intention to adjust blinds in the sleeping area during the summer could be explained by their attitude, subjective norm, and perceived behavioral control. Occupants with higher levels of subjective norm (ß = .399, t = 3.609, p ≤ .000) and higher levels of perceived behavioral control (ß = .207, t = 2.370,

$p \leq .020$) appeared to have stronger behavioral intention towards adjusting blinds in the sleeping area during the summer. Attitude did not contribute to the explanation of intentions (ß = .182, t = 1.679, $p \leq .096$) when subjective norm and perceived behavioral control were controlled for.

4.4.8. *Predicting the Intention of Adjusting Blinds in the Sleeping Area during the Winter*

Table 4.60 shows the multiple regression model used to predict the occupants' intention of adjusting blinds in the sleeping area during the winter based on their attitudes, subjective norms, and perceived behavioral control. In Table 4.60, the value of the adjusted coefficient of determination (Adjusted R Square) is 0.485. This means that about 48% of the variance in the behavior of adjusting blinds in the sleeping area is explained by the independent variables (attitude, subjective norm, and perceived behavioral control of adjusting blinds in the sleeping area). The results of the analysis of variance are presented in Table 4.60. Since the p-value of the F-test is less than 0.05, it is concluded that at least one regression coefficient is different from zero. So, the independent variables provide a satisfactory explanation for the response variable. The VIF is 1.990, 2.332, and 2.177 for the attitudes, subjective norms, and perceived behavioral control, respectively. Therefore, the correlation between predictor variables are within the acceptable range.

Table 4.60

Multiple Regression Analysis of Occupants' Attitude, Subjective Norm, Perceived Behavioral Control and Behavioral Intention of Operating Windows during the Winter (N=99)

Independent Variable	B	SE B	β	t	95% CI	
					LL	UL
Intercept	.188	.558		.338	-.919	1.296
Attitude Towards Adjusting Blinds in Sleeping Area	.544	.125	.441***	4.337	.295	.792
Subjective norm Towards Adjusting Blinds in Sleeping Area	.094	.130	.079	.718	-.165	.352
Perceived Behavioral Control Towards Adjusting Blinds in Sleeping Area	.316	.124	.270*	2.540	.069	.563
R^2		.501				
Adjusted R^2		.485				
F		32.131***				

Note. Dependent variable: Intention of Adjusting Blinds in Sleeping Area
**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

H3h: Occupants' attitude, subjective norm, and perceived behavioral control towards adjusting blinds contribute to the explanation of their behavior to perform this behavior in the sleeping area during the winter.

Table 4.60 shows a significant regression equation in which: (F (3, 96) = 32.131, p ≤ .000, with R^2 of .501. Occupants' predicted behavioral intention (DV) is equal to .188 + .544 (attitude) + .094 (subjective norm) + .316 (perceived behavioral control). About 50% of the variance in occupants' behavioral intention to adjust blinds in the sleeping area during the winter could be explained by their attitude, subjective norm, and perceived behavioral control. Occupants with more positive attitudes (ß = .441, t = 4.337, p ≤ .000), higher levels of perceived behavioral control (ß = .220, t = 2.564, p ≤ .012) appeared to have stronger behavioral intention towards adjusting blinds in the living area during the winter. Subjective norm did not contribute to the explanation of intentions ($ß = .079$, $t = .718$, $p \leq .474$) when attitude and perceived behavioral control were controlled for.

4.5. Occupants' Intention and Behavior

According to the Theory of Planned Behavior, the intentions of individuals determine their performance of a behavior (Fishbein & Ajzen in 2010).

<u>H4: Occupants' behavioral intention of operating windows and adjusting blinds influences their actual behavior.</u>

The items used to collect information about occupants' behavioral intention and the actual behavior of operating windows and adjusting blinds were developed based on Ajzen's (2006) recommendations to construct a questionnaire based on the Theory of Planned Behavior. An example of these items is shown in Figure 4.24.

Figure 4.24

Example of Items Used to Collect Data about Occupants' Behavioral Intention and Actual Behavior of Operating Windows.

I intend to operate **<u>windows</u>** in my living area in the next week.

Extremely unlikely	1	2	3	4	5	6	7	Extremely likely

In the past week, I have operated **<u>windows</u>** in my living area.

Extremely false	1	2	3	4	5	6	7	Extremely true

In this research, the simple linear regression was used to study the relationship between two continuous variables, thus predict the values of the occupants' behavior (dependent variable) based on the values of the occupants' intention (independent variable).

The simple linear regression equation writes as follows:

$y = b_0 + b_1x + \varepsilon$

Where y is the dependent variable (behavior), x is the independent variable (intention), b_1 is the regression coefficient, and b_0 is the constant (intercept). The epsilon term (ε) is the residual value or error. This value captures all the influences that are not explained by the independent variable (intention). The simple regression analysis is used to determine whether the variations of the independent variable can explain the variations in the dependent variable, and to what extent. Accordingly, the simple regression equation for this research writes as follows:

$\text{Behavior} = b_0 + b_1\text{Intention} + \varepsilon$

The regression analysis has two types of goals. First, it can measure the effect of the independent variable on the dependent variable, so it is used in this research to verify the relationship between the variables of the Theory of Planned Behavior. Also, the regression analysis will be used later in this research for predicting the values of the dependent variable for different values of the independent variable in the agent-based model.

The simple linear regression analysis is a parametric test, and according to Field (2017), fundamental assumptions must be checked before running the linear multiple regression analysis. First, the independent and dependent variables are continuous. In this research, seven-point Likert scale items are used to measure the independent and dependent variables. The researcher assumes that the intervals between the scale values are approximately equal. Therefore, data collected can be treated as continuous variables (Sullivan & Artino, 2013).

Second, the relationship between the variables is approximately linear. A simple scatter plot was used to represent the relationship between the dependent and independent variables to check the linearity assumption. Third, the dependent variable has the same variance for all the values of the independent variable (there is homoscedasticity). Scatter plot diagrams were built to check for homoscedasticity. They represent the relationship between the standardized residuals and the standardized predicted values of the dependent variable.

Fourth, there are no significant outliers in the data series. The casewise diagnostics were used to identify all the outliers outside three standard deviations. Also, outliers can be identified by checking the studentized deleted residuals that are greater than 3 in absolute value. Fifth, The Durbin-Watson test is issued to check the independence of errors. The Durbin Watson test value ranges between zero and four. Therefore, it is considered that the assumption of independence of errors is met because the value ranges between 1.50 and 2.50.

Finally, the residual variable is approximately normally distributed. Both visual and numerical methods were used to check for normality. The visual method consists of inspecting the histogram charts. The numerical methods use the standardized residual values of the dependent variable to run a Shapiro-Wilk normality test. If the p-value of the Shapiro-Wilk is larger than 0.05, it is confirmed that the residual values are normally distributed (Shapiro & Wilk, 1972).

Four simple linear regression analysis procedures were run to predict the occupants' behavior based on their intention. The confidence intervals (95% level) were calculated for the regression coefficients.

Table 4.61

Variables of the Four Simple Linear Regression Models

Independent Variable	Dependent Variable
Intention of operating windows in the living area	Behavior of operating windows in the living area
Intention of adjusting blinds in the living area	Behavior of adjusting blinds in the living area
Intention of operating windows in the sleeping area	Behavior of operating windows in the sleeping area
Intention of adjusting blinds in the sleeping area	Behavior of adjusting blinds in the sleeping area

4.5.1. *Predicting the Occupants' Behavior of Operating Windows based on their Intention from the Summer Survey*

The coefficient of determination - adjusted R Square - ranges between zero and one. If the R Square ranges between 0.30 and 0.70, then the influence is medium. The simple regression models, in Table 4.62 studies the relationship between the occupants' intentions (independent variable) and their behavior towards operating windows in living and sleeping areas during the summer. The adjusted R Square for the two models is 0.710 and 0.796 respectively, which means that 71.0% and 80% of the variance in the test scores were explained by the independent variables. Since the R Square for the four models is higher than 0.70, the influence of the occupants' intention on their behavior is strong. The t-test for coefficient tells whether that coefficient is significantly different from zero. In these models, the coefficient of the independent variable is statistically significant from zero because their p-values of the t-tests are lower than 0.05.

Table 4.62

Simple Regression Analysis of Occupants' Behavioral Intention and Actual Behavior of Operating Windows During the Summer (N=103)

Model #	Independent Variable	B	SE B	β	t	95% CI LL	95% CI UL
Model 1	Constant	.630	.305		2.064	.025	1.236
	Intention Towards Operating Windows in Living Area	.889	.056	.844***	15.914	.778	1.000
	R^2		.713				
	Adjusted R^2		.710				
	F		253.247***				
Model 2	Constant	.377	.231		1.633	-.081	.834
	Intention Towards Operating Windows in Sleeping Area	.886	.044	.892***	19.926	.798	.975
	R^2		.796				
	Adjusted R^2		.794				
	F		397.030***				

Note. Dependent variable: Intention of Operating Windows

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

H4a: Occupants' behavioral intention of operating windows influences their actual behavior in the living area during the summer.

A simple linear regression was calculated to predict occupants' behavior of operating windows in the living area during the summer based on their behavioral intention to perform this behavior. Table 4.62 shows that a significant regression equation was found in which: (F (1, 102) = 253.247, p≤ 0.000), with R^2 of 0.713. Occupants' predicted behavior (DV) is equal to .630 + .899 (behavioral intention). About 71% of the variance in occupants' behavior to operate windows in the living area during the summer could be explained by their behavioral intention. Occupants with more positive behavioral intention (ß = .844, t = 15.914, p ≤ .000) are more likely to operate windows in the living area during the summer.

H4b: Occupants' behavioral intention of operating windows influences their actual behavior in the sleeping area during the summer.

A simple linear regression was calculated to predict occupants' behavior of operating windows in the sleeping area during the summer based on their behavioral intention to perform this behavior. Table 4.62 shows that a significant regression equation was found in which: (F (1, 102) = 397.030, p≤ 0.000), with R^2 of 0.796. Occupants' predicted behavior (DV) is equal to .377 + .886 (behavioral intention). About 80% of the variance in occupants' behavior to operate windows in the sleeping area during the summer could be explained by their behavioral intention. Occupants with more positive behavioral intention (ß = .892, t = 19.926, p ≤ .000) are more likely to operate windows in the sleeping area during the summer.

4.5.2. *Predicting the Occupants' Behavior of Operating Windows based on their Intention from the Winter Survey*

The coefficient of determination - adjusted R Square - ranges between zero and one. If the R Square ranges between 0.30 and 0.70, then the influence is medium. The simple regression models in Table 4.63 studies the relationship between the occupants' intentions (independent variable) and their behavior towards operating windows in living and sleeping areas during the summer. The adjusted R Square for the two models is 0.547 and 0.694 respectively, which means that 55.0% and 70% of the variance in the test scores were explained by the independent variables. Since the R Square for the two models is between 0.30 and 0.70, the influence of the occupants' intention on their behavior is medium. The t-test for coefficient tells whether that coefficient is significantly different from zero. In these models, the coefficient of the independent variable is statistically significant from zero because their p-values of the t-tests are lower than 0.05.

Table 4.63

Simple Regression Analysis of Occupants' Behavioral Intention and Actual Behavior of Operating Windows during the Winter (N=101)

Model #	Independent Variable	B	SE B	β	t	95% CI LL	95% CI UL
Model 3	Constant	.713	.713		2.300	.098	1.328
	Intention Towards Operating Windows in Living Area	.776	.776	.743***	11.037	.637	.916
	R^2		.552				
	Adjusted R^2		.547				
	F		121.816***				
Model 4	Constant	.384	.237		1.623	-.086	.854
	Intention Towards Operating Windows in Sleeping Area	.862	.057	.835***	15.100	.749	.975
	R^2		.697				
	Adjusted R^2		.694				
	F		228.015***				

Note. Dependent variable: Intention of Operating Windows

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

H4c: Occupants' behavioral intention of operating windows influences their actual behavior in living area during the winter.

A simple linear regression was calculated to predict occupants' behavior of operating windows in the living area during the winter based on their behavioral intention to perform this behavior. Table 4.63 shows that a significant regression equation was found in which: ($F (1, 99) = 121.816$, $p \leq 0.000$), with R^2 of 0.552. Occupants' predicted behavior (DV) is equal to .713 + .776 (behavioral intention). About 55% of the variance in occupants' behavior to operate windows in the living area during the winter could be explained by their behavioral intention. Occupants with more positive behavioral intention (ß = .743, t = 11.037, p ≤ .000) are more likely to operate windows in the living area during the winter.

H4d: Occupants' behavioral intention of operating windows influences their actual behavior in the sleeping area during the winter.

A simple linear regression was calculated to predict occupants' behavior of operating windows in the sleeping area during the winter based on their behavioral intention to perform this behavior. Table 4.63 shows that a significant regression equation was found in which: (F (1, 99) = 228.015, p≤ 0.000), with R^2 of 0.697. Occupants' predicted behavior (DV) is equal to .384 + .862 (behavioral intention). About 70% of the variance in occupants' behavior to operate windows in the sleeping area during the winter could be explained by their behavioral intention. Occupants with more positive behavioral intention (ß = .835, t = 15.100, p ≤ .000) are more likely to operate windows in the sleeping area during the winter.

4.5.3. *Predicting the Occupants' Behavior of Adjusting Blinds based on their Intention from the Summer Survey*

The coefficient of determination - adjusted R Square - ranges between zero and one. If the R Square ranges between 0.30 and 0.70, then the influence is medium. The simple regression models in Table 4.64 studies the relationship between the occupants' intentions (independent variable) and their behavior towards adjusting blinds in living and sleeping areas during the summer. The adjusted R Square for the two models is 0.769 and 0.795 respectively, which means that 77.0% and 80% of the variance in the test scores were explained by the independent variables. Since the R Square for the four models is higher than 0.70, the influence of the occupants' intention on their behavior is strong. The t-test for coefficient tells whether that coefficient is significantly different from zero. In these models, the coefficient of the independent variable is statistically significant from zero because their p-values of the t-tests are lower than 0.05.

Table 4.64

Simple Regression Analysis of Occupants' Behavioral Intention and Actual Behavior of Operating Windows and Adjusting Blinds during the Summer (N=103)

Model #	Independent Variable	B	SE B	β	t	95% CI	
						LL	UL
Model 5	Constant	.377	.298		1.264	-.214	.968
	Intention Towards Adjusting Blinds in Living Area	.925	.050	.878***	18.534	.826	1.024
	R^2		.771				
	Adjusted R^2		.769				
	F		343.506***				
Model 6	Constant	.430	.266		1.614	-.098	.958
	Intention Towards Adjusting Blinds in Sleeping Area	.908	.045	.893***	20.032	.818	.998
	R^2		.797				
	Adjusted R^2		.795				
	F		401.284***				

Note. Dependent variable: Intention of Adjusting Blinds

*$p \leq .05$. **$p \leq .01$. ***$p \leq .001$

H4e: Occupants' behavioral intention of adjusting blinds influences their actual behavior in the living area during the summer.

A simple linear regression was calculated to predict occupants' behavior of adjusting blinds in the living area during the summer based on their behavioral intention to perform this behavior. Table 4.64 shows that a significant regression equation was found in which: (F (1, 102) = 343.506, $p \leq 0.000$), with R^2 of 0.771. Occupants' predicted behavior (DV) is equal to .377 + .925 (behavioral intention). About 77% of the variance in occupants' behavior to adjust blinds in the living area during the summer could be explained by their behavioral intention. Occupants with more positive behavioral intention (ß = .878, t = 18.534, p ≤ .000) are more likely to adjust blinds in the living area during the summer.

H4f: Occupants' behavioral intention of adjusting blinds influences their actual behavior in the sleeping area during the summer.

A simple linear regression was calculated to predict occupants' behavior of adjusting blinds in the sleeping area during the summer based on their behavioral intention to perform this behavior. Table 4.64 shows that a significant regression equation was found in which: (F (1, 102) = 401.284, p≤ 0.000), with R^2 of 0.797. Occupants' predicted behavior (DV) is equal to .430 + .908 (behavioral intention). About 80% of the variance in occupants' behavior to adjust blinds in the living area during the summer could be explained by their behavioral intention. Occupants with more positive behavioral intention (ß = .893, t = 20.032, p ≤ .000) are more likely to adjust blinds in the sleeping area during the summer.

4.5.4. *Predicting the Occupants' Behavior of Adjusting Blinds based on their Intention from the Winter Survey*

The coefficient of determination - adjusted R Square - ranges between zero and one. If the R Square ranges between 0.30 and 0.70, then the influence is medium. The simple regression models in Table 4.65 studies the relationship between the occupants' intentions (independent variable) and their behavior towards adjusting blinds in living and sleeping areas during the summer. The adjusted R Square for the two models is 0.572 and 0.782 respectively, which means that 57.0% and 78% of the variance in the test scores were explained by the independent variables. Since the R Square for the two models is between 0.30 and 0.70, the influence of the occupants' intention on their behavior is medium. The t-test for coefficient tells whether that coefficient is significantly different from zero. In these models, the coefficient of the independent variable is statistically significant from zero because their p-values of the t-tests are lower than 0.05.

Table 4.65

Simple Regression Analysis of Occupants' Behavioral Intention and Actual Behavior of Operating Windows during the Winter (N=101)

Model #	Independent Variable	B	SE B	β	t	95% CI	
						LL	UL
Model 7	Constant	1.032	.414		2.492	.210	1.854
	Intention Towards Adjusting Blinds in Living Area	.816	.070	.759***	11.614	.676	.955
	R^2		.577				
	Adjusted R^2		.572				
	F		134.879***				
Model 8	Constant	.302	.287		1.054	-.267	.871
	Intention Towards Adjusting Blinds in Sleeping Area	.923	.049	.884***	18.730	.825	1.020
	R^2		.782				
	Adjusted R^2		.779				
	F		350.795***				

Note. Dependent variable: Intention of Adjusting Blinds

**p* ≤ .05. ***p* ≤ .01. ***p ≤ .001

H4g: Occupants' behavioral intention of adjusting blinds influences their actual behavior in living area during the winter.

A simple linear regression was calculated to predict occupants' behavior of adjusting blinds in the living area during the winter based on their behavioral intention to perform this behavior. Table 4.65 shows a significant regression equation was found in which: (F (1, 99) = 134.879, p≤ 0.000), with R^2 of 0.577. Occupants' predicted behavior (DV) is equal to 1.032 + .816 (behavioral intention). About 58% of the variance in occupants' behavior to adjust blinds in the living area during the winter could be explained by their behavioral intention. Occupants with more positive behavioral intention (ß = .759, t = 11.614, $p \leq .000$) are more likely to adjust blinds in the living area during the winter.

H4h: Occupants' behavioral intention of adjusting blinds influences their actual behavior in the sleeping area during the winter.

A simple linear regression was calculated to predict occupants' behavior of adjusting blinds in the sleeping area during the winter based on their behavioral intention to perform this behavior. Table 4.65 shows that a significant regression equation was found in which: ($F (1, 98) = 350.795$, $p \leq 0.000$), with R^2 of 0.782. Occupants' predicted behavior (DV) is equal to .302 + .923 (behavioral intention). About 78% of the variance in occupants' behavior to adjust blinds in the living area during the winter could be explained by their behavioral intention. Occupants with more positive behavioral intention (ß = .884, t = 18.730, $p \leq .000$) are more likely to adjust blinds in the sleeping area during the winter.

4.6. Summary of the Occupants' Survey Results

This chapter shows the results and hypotheses testing related to the two occupants surveys that were conducted in this study. The results of the Chi-square test that was conducted to test for association between spatial factors and occupants' behavioral beliefs showed that there is not enough evidence to suggest an association between occupants' behavioral beliefs and the site characteristics such as orientation, and building features such as floor levels. However, results showed that there is a significant association between occupants' behavioral beliefs of operating windows and adjusting blinds in both space type including living and sleeping areas. For example, if occupants believed that operating window caused a desired change in the airflow in the living area, they will also maintain the same belief regarding the sleeping area. The qualitative analysis of the heat map plots showed that most of the occupants indicated that they selected their preferred spot in the living area and in the sleeping area according to the furniture layout in summer and winter. For example, occupants indicated that they select the spot that they use most of the time according to the location of the bed. Some of the occupants mentioned that their preferred location within the living area and sleeping area is related to the location of the window and the indoor environmental qualities it provides, such as daylighting, outdoor views, and airflow. Moreover, those who would like to have a visual escape to outdoor views are more likely to select a spot facing the window. Also, a small number of respondents indicated that they prefer to stay away from the window during the winter to avoid cold air drafts.

The results of the Chi-square test that was conducted to test for association between occupants' behavioral beliefs and attitudes showed that there is a significant relationship between occupants' behavioral beliefs of operating windows and adjusting blinds in the living and sleeping areas and their attitudes towards performing those behaviors during the summer and winter. Also, the results of the multiple regression analysis that was computed to predict occupants' behavioral intentions based on their attitudes, subjective norms, and perceived behavioral control showed that significant regression equations were found ($p \leq .001$). About 50% of the variance in occupants' behavioral intention to operate windows and adjust blinds in the living area and sleeping area during summer and winter could be explained by their attitude, subjective norm, and perceived behavioral control towards performing these behaviors. These results confirm that the constructs of the Theory of Planned Behavior can be used to predict occupants' behavioral intention towards the behaviors under study. Finally, the results of the multiple regression analysis that was computed to predict occupants' behaviors based on their behavioral intentions showed that significant regression equations were found ($p \leq .001$). About 70% of the variance in occupants' behavior to operate windows and adjust blinds in the living area and sleeping area during the summer and winter could be explained by their behavioral intention towards performing these behaviors. These results confirm that the constructs of the Theory of Planned Behavior can be used to predict occupants' actual behaviors under study.

CHAPTER FIVE:

AGENT-BASED MODEL EXPERIMENTS

5.1. Experiments: Examining the Effect of Occupants' Beliefs on Energy Consumption

This chapter provides a proof of concept for the proposed agent-based model. The experiments examined how the different beliefs of occupants towards operating windows and adjusting blinds affected the buildings' energy consumption.

5.1.1. *Experiments Overview*

The experiments consisted of 10 occupants. Each occupant occupied an apartment in a multifamily residential building. Each occupant had different beliefs towards the advantages and disadvantages of operating windows and adjusting blinds. These beliefs affected the occupant's behavior of operating windows and adjusting blinds and are thus expected to affect the buildings' energy consumption.

- Window beliefs: operating windows affect indoor environmental conditions. They can affect the indoor temperature, air quality, and the quality of acoustics. The window beliefs parameters are shown in Figure 5.1.

Figure 5.1

Window Beliefs

beliefTowardsOperatingWindow_Temperature
beliefTowardsOperatingWindow_AirQuality
beliefTowardsOperatingWindow_Acoustics

- Blind beliefs: adjusting blinds affect indoor environmental conditions. They can affect the indoor temperature, amount of daylighting, and access to outdoor views. The blind beliefs parameters are shown in Figure 5.2.

Figure 5.2

Blind Beliefs

beliefTowardsAdjustingBlind_Temperature

beliefTowardsAdjustingBlind_Lighting

beliefTowardsAdjustingBlind_View

5.1.2. *Model Assumptions*

The assumptions mentioned below were set up to utilize the proposed framework in examining the effect that the occupants' beliefs had on energy consumption.

- Occupants' beliefs towards operating windows and adjusting blinds may vary according to the season. Therefore, the experiments assumed that "season" as a fixed parameter.
- Occupants' beliefs towards operating windows and adjusting blinds may vary according to the orientation of the apartment. Therefore, the experiments assumed that "apartment orientation" as a fixed parameter.

Based on the Theory of Planned Behavior and the results of the survey conducted in the survey presented in chapter four, the occupants' beliefs influenced their attitude towards operating windows and adjusting blinds. Therefore, in the experiments, the attitude is calculated based on the beliefs shown in Table 5.1 and Table 5.2.

Table 5.1

Calculating Occupants' Attitude Based on Their Beliefs of Operating Windows

Occupants' Beliefs of Operating Windows

Case Number	1	2	3	4	5	6	7	8
Temperature	⁄	⁄	X	⁄	⁄	X	X	X
Air Quality	⁄	⁄	⁄	X	X	⁄	X	X
Acoustics	⁄	X	⁄	⁄	X	X	⁄	X
Points Assigned	7	5	5	5	3	3	3	1

⁄ = Improve

X = Worsen

Table 5.2

Calculating Occupants' Attitude Based on Their Beliefs of Adjusting Blinds

Occupants' Beliefs of Adjusting Blinds								
Case Number	1	2	3	4	5	6	7	8
Temperature	⁄	⁄	X	⁄	⁄	X	X	X
Lighting	⁄	⁄	⁄	X	X	⁄	X	X
Views	⁄	X	⁄	⁄	X	X	⁄	X
Points Assigned	7	5	5	5	3	3	3	1

⁄ = Improve

X = Worsen

- Based on the Theory of Planned Behavior, the occupants' subjective norm and perceived behavioral control towards operating windows and adjusting blinds may influence their behavioral intention and thus influence their behavior. Therefore, the experiments considered "subjective norm" and 'perceive behavioral control' as fixed parameters.
- The occupants' behavioral intention of operating windows and adjusting blinds was calculated based on the Theory of Planned Behavior constructs, as shown in Figure 5.3.

Figure 5.3

Functions Used to Calculate Occupants' Behavioral Intention windowIntention = windowAttitude + windowSubjectivedNorm + windowPerceivedBehaviouralControl

blindIntention = blindAttitude + blindSubjectivedNorm + blindPerceivedBehaviouralControl

- The experiments assumed that occupants would be sleeping and not interacting with the building systems form 10:00 p.m. to 6:00 a.m. every day. However, the HVAC works automatically during the nighttime.
- The experiments assumed that if the occupants are dissatisfied with any of the IEQ conditions, they will first start interacting with the passive building systems (windows and blinds). If the occupants remain dissatisfied, then they will interact with the active building systems (HVAC and artificial light).
- The experiments assumed that every second of the HVAC system being on consumes 0.05 kWh. It also assumes that every second of artificial lights being on consumes 0.01 kWh.

5.1.3. ***Model Development***

The model development was divided into three parts: input, process, and output. Every experiment had different inputs while maintaining the same process to compare the outputs.

5.1.3.1. <u>Input</u>

The experiments include constant inputs such as the occupants' beliefs of operating windows and adjusting blinds. Figure 5.1 shows that the researcher identifies three beliefs related to operating windows, and Figure 5.2 shows three beliefs related to adjusting blinds. The are many possibilities that can occur based on the six factors. However, the experiments will focus on studying the two ends of the spectrum. The first set of input will assume that occupants have positive beliefs towards operating windows and adjusting blinds, which are cases number 1 in Table 5.1. The second set of input will assume that occupants have negative beliefs towards operating windows and adjusting blinds, which are cases number 8 Table 5.2.

In addition, each occupant is expected to rank indoor environmental quality (IEQ) conditions: thermal comfort, visual comfort, acoustical comfort, and air quality according to their personal preferences. Also, each one of the IEQ factors has a different influence on the occupants' decision-making process. Therefore, the IEQ priorities were included as a constant input in each experiment.

The experiments also include environmental variable inputs such as the temperature, lighting, views, acoustics, and air quality that are updated on hourly basis from excel files associated with the model. To include occupants' diverse preferences, some of the survey outputs were used as variable inputs in the proposed agent-based model as shown in Table 5.3.

Table 5.3

Survey outputs as ABM Inputs

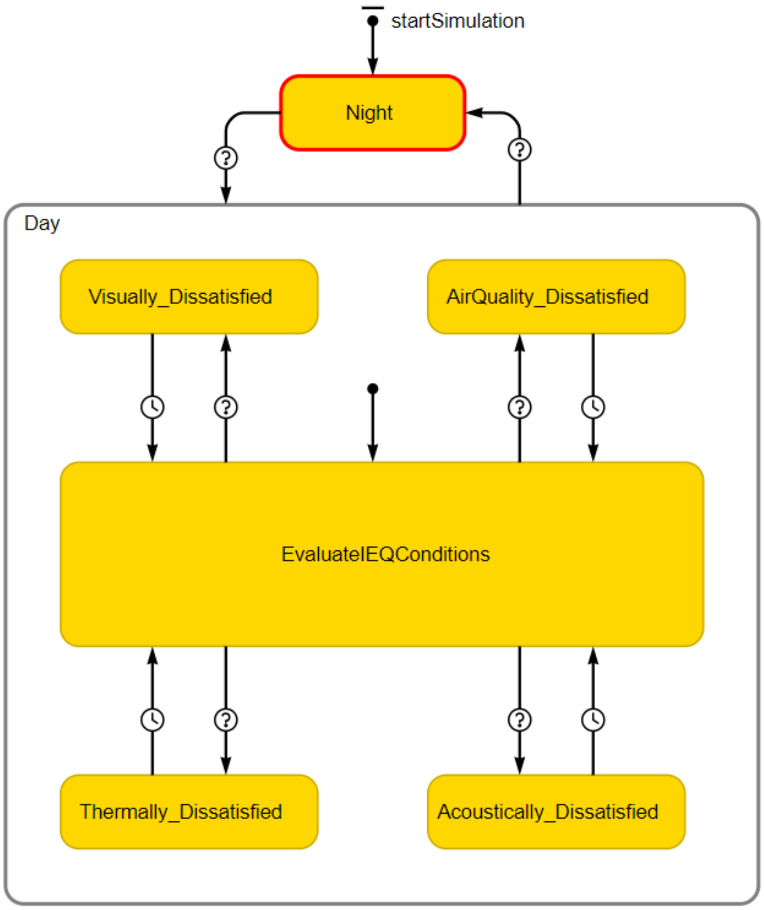
Survey Output	ABM Input	Use in ABM
Occupants' Behavioral Beliefs	Constant	Option List
Occupants' Subjective Norm	Constant	Integer
Occupants' Perceived Behavioral Control	Constant	Integer
Average Cooking Time	Variable	Custom Distribution
Occupants' Preferred Temperature	Variable	Custom Distribution
Occupants' Indoor Environmental Quality Ranking	Constant	Option List

5.1.3.2. Process

The process of the proposed model can be described using the state chart as shown in Figure 5.4. The experiments assumed that occupants do not interact with building systems from 10:00 p.m. to 6:00 a.m. Therefore, the researcher identified two main states: day and night. All the occupants' interaction with the building systems happens during the daytime. However, an event was created to turn on the air conditioning/ heating system automatically when needed during the nighttime.

Figure 5.4

Agent-Based Model State Chart



Once the agent occupant enters the day state, they check the indoor environmental conditions, which includes the temperature, amount of daylighting, access to outdoor views, air quality, and acoustics. Each instance of the agent occupant has a specific preferred temperature and a preferred amount of lighting. The preferred air quality and acoustics were described in the form of an interval to simplify the model. However, a custom distribution was used to describe the amount of cooking that takes place in each apartment as it influences the indoor air quality.

Each instance of the agent occupant then compares their preferred conditions against the existing indoor environmental conditions. Also, each instance of the agent occupant has their own priority of IEQ criteria. For example, if the occupant prioritized thermal comfort and was identified as thermally dissatisfied, then the state will change to the thermally dissatisfied state. In this state, the occupant checks the status of the window and blind and make an action to improve the IEQ conditions through operating windows or adjusting blinds. Then the occupant re-evaluates the IEQ conditions after performing this behavior. If the occupants' IEQ priority was satisfied (in this example: thermal comfort), the occupant will not turn on the air conditioning/heating system. If the occupant remains thermally dissatisfied after interacting with the window and/or blind, then the occupant will turn on the air conditioning/heating system, and this is when the energy consumption counter starts counting.

5.1.3.3. Output

The output of this model is an estimated energy consumption measured in kWh. If the occupants interacted with the building's passive systems, such as windows and blinds, to control their indoor environmental conditions, then there is no energy consumption in this case. The energy consumption is associated with the occupants' interaction with the active building systems such as the HVAC and artificial light.

5.1.4. *Simulations Results*

The results of the four experiments are described in this section. In addition, the results of experiment one and two and experiment three and four were compared.

5.1.4.1. Experiment One

The first experiment assumed that the simulation takes place in July. The results shown below are based on 732 iterations. The occupants have exclusively positive beliefs of operating windows and adjusting blinds, which are cases number 1 in Table 5.1. It aimed to study the effect that each IEQ has on energy consumption. Therefore, four different runs were performed. The first, second, third, and fourth runs assumed that occupants prioritize thermal comfort, visual comfort, air quality, and acoustical comfort, respectively.

Figure 5.5

Predicted Energy Consumption for Different IEQ Priorities during the Summer when Occupants have Exclusively Positive Beliefs of Operating Windows and Adjusting Blinds

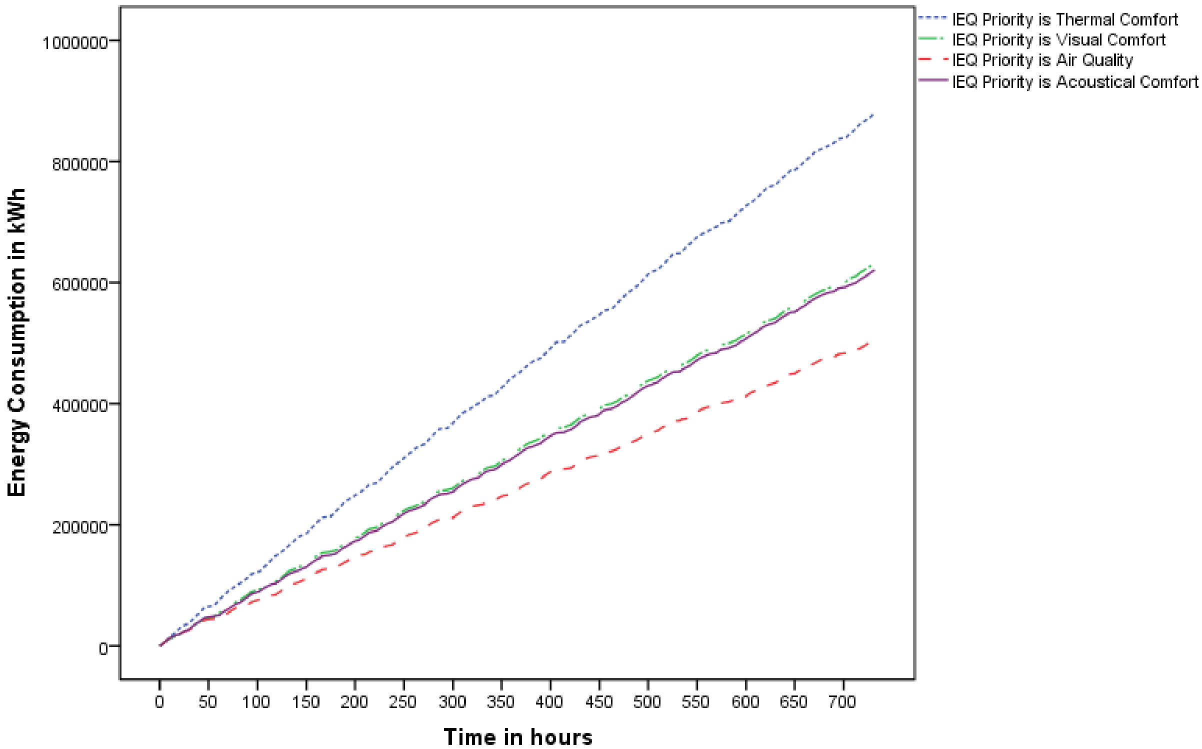


Figure 5.5 shows that energy consumption is expected to be highest (880735.78 kWh) when occupants prioritize thermal comfort. It also shows that prioritizing visual comfort and acoustical comfort results in energy consumption of 632583.1 kWh and 620785.7 kWh, respectively. Finally, it shows that energy consumption is expected to be lowest (506096.28 kWh) when occupants prioritize Air Quality over the other IEQ criteria.

5.1.4.2. <u>Experiment Two</u>

In this experiment, it was assumed that occupants had exclusively negative beliefs of operating windows and adjusting blinds, which are cases number 8 in Table 5.2. All other assumptions are like experiment three.

Figure 5.6

Predicted Energy Consumption for Different IEQ Priorities during the Summer when Occupants have Exclusively Negative Beliefs of Operating Windows and Adjusting Blinds

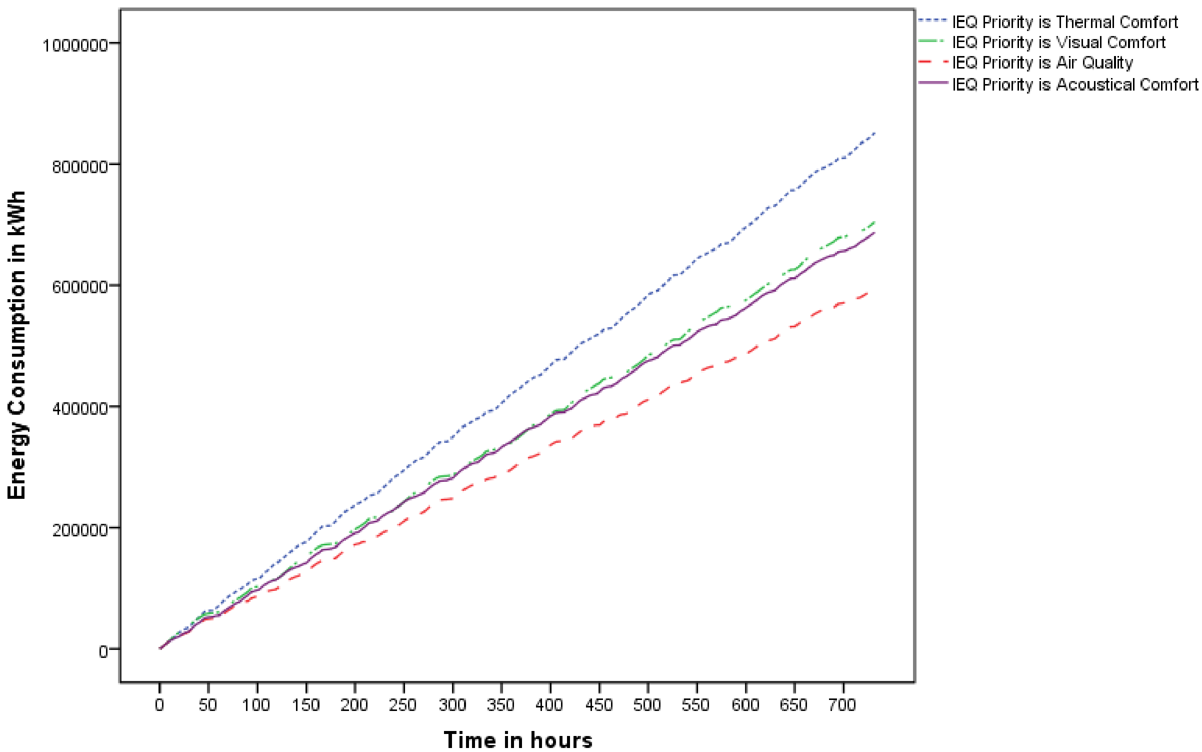


Figure 5.6 shows that energy consumption is expected to be highest (851886.6 kWh) when occupants prioritize thermal comfort. It also shows that prioritizing visual comfort and acoustical comfort results in energy consumption of 704399.1 kWh and 687090.75 kWh, respectively. Finally, it shows that energy consumption is expected to be lowest (595978.77 kWh) when occupants prioritize Air Quality over the other IEQ criteria.

5.1.4.3. <u>Comparing Results of Experiment One and Experiment Two</u>

In this section, a detailed comparison between the first and second experiment was conducted. The results are displayed in Figures 5.7 – 5.10.

Figure 5.7

Comparing Predicted Energy Consumption Values in Summer when Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative and IEQ Priority is Thermal Comfort

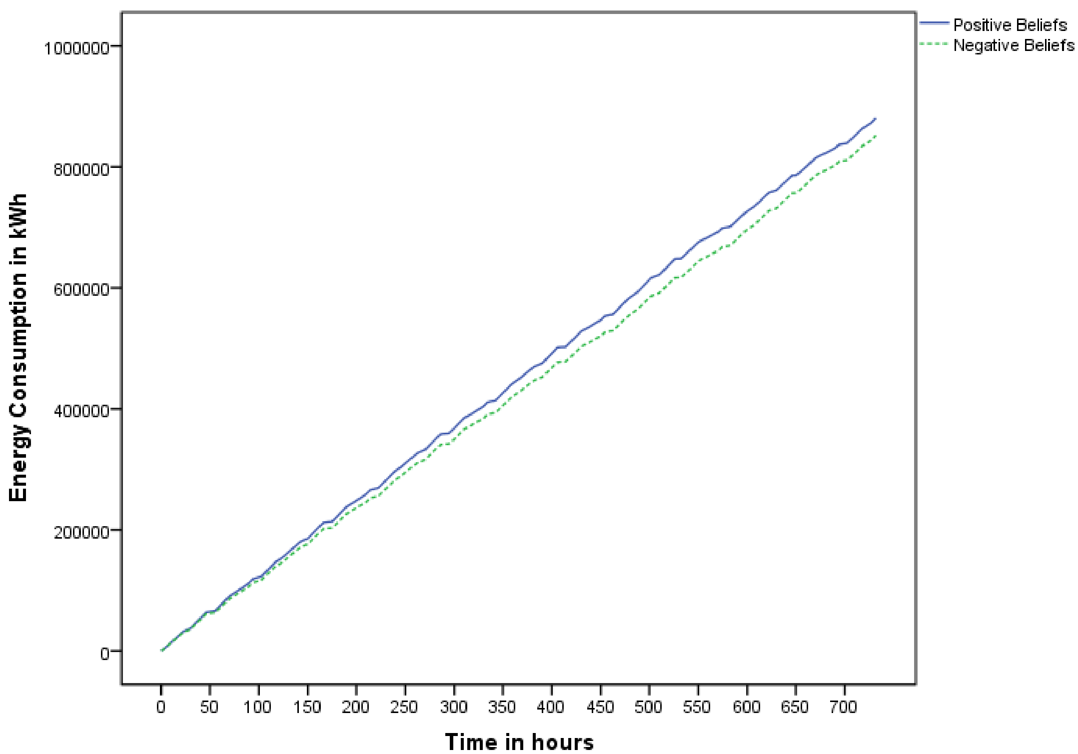


Figure 5.7 shows that the predicted energy consumption when occupants have exclusively negative beliefs of operating windows and adjusting blinds when IEQ priority-thermal comfort is 851886.6 kWh, compared to 880735.78 kWh when occupants have exclusively positive beliefs of operating windows and adjusting blinds.

Figure 5.8

Comparing Predicted Energy Consumption Values in Summer when Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative and IEQ priority is Visual Comfort

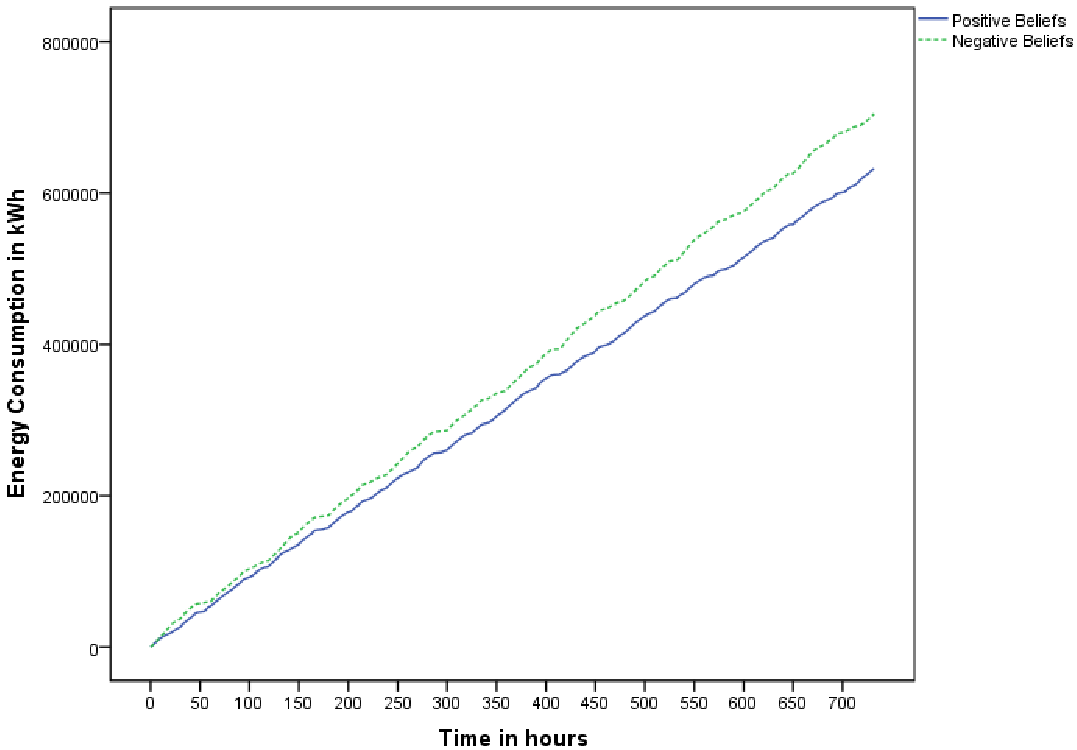


Figure 5.8 shows that the predicted energy consumption when occupants have exclusively negative beliefs of operating windows and adjusting blinds, and IEQ priority is visual comfort is 704399.1 kWh, while it is 632583.1 kWh when occupants have exclusively positive beliefs of operating windows and adjusting blinds.

Figure 5.9

Comparing Predicted Energy Consumption Values in Summer when in Winter Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative and IEQ Priority is Air Quality

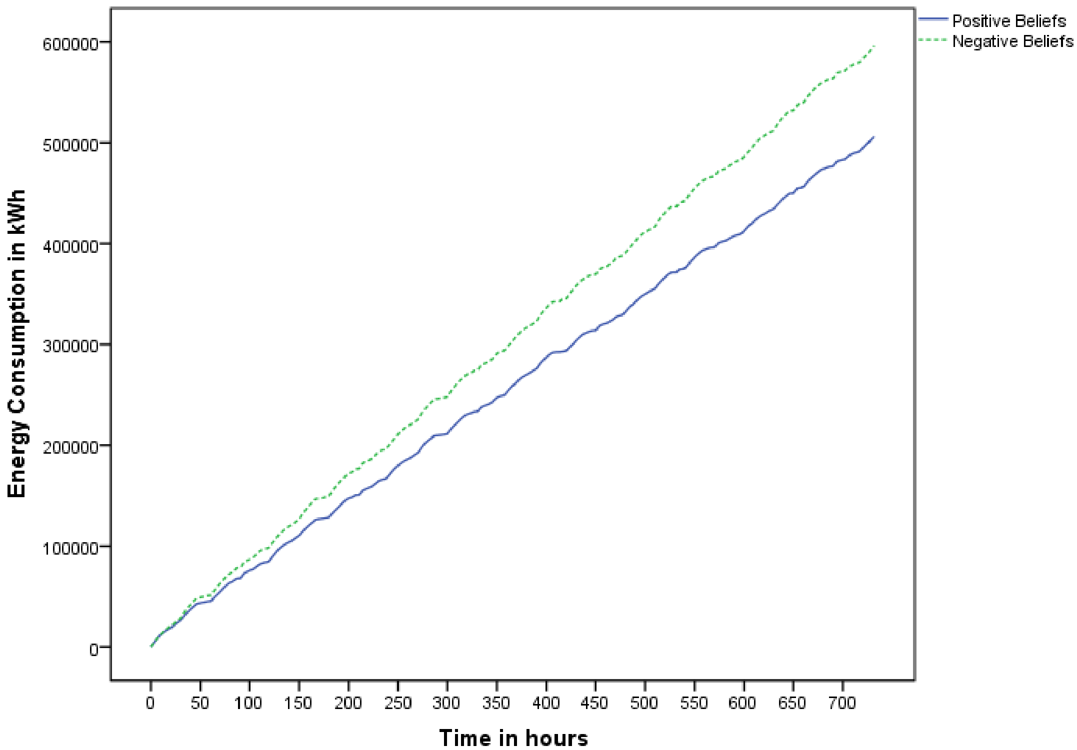


Figure 5.9 shows that the predicted energy consumption when occupants have exclusively negative beliefs of operating windows and adjusting blinds when IEQ priority-air quality is 595978.77 kWh, compared to 506096.28 kWh when occupants have exclusively positive beliefs of operating windows and adjusting blinds.

Figure 5.10

Comparing Predicted Energy Consumption Values in Summer when Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative and IEQ priority is Acoustical Comfort

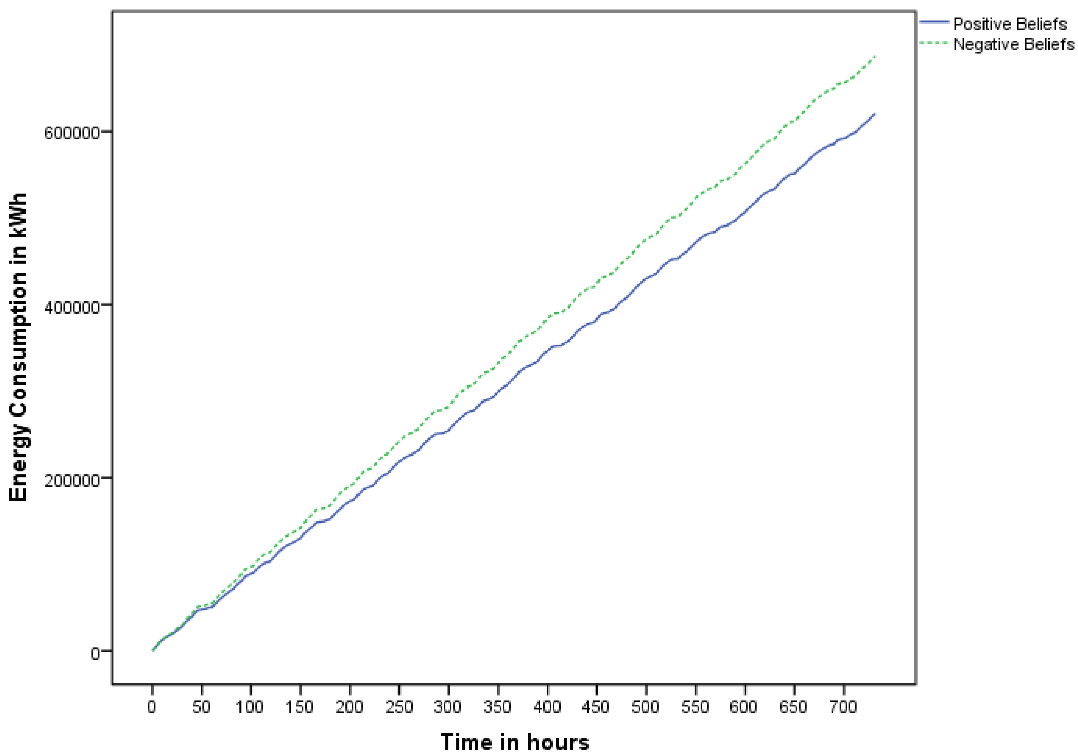


Figure 5.10 shows that the predicted energy consumption when occupants have exclusively negative beliefs of operating windows and adjusting blinds, when IEQ priority- acoustical comfort is 687090.75 kWh, compared to 620785.7 kWh when occupants have exclusively positive beliefs of operating windows and adjusting blinds.

5.1.4.1. <u>Experiment Three</u>

The third experiment assumed that the simulation takes place in January. The results shown below are based on 732 iterations. The occupants have exclusively positive beliefs of operating windows and adjusting blinds, which are cases number 1 in Table 5.1. It aimed to study the effect that each IEQ has on energy consumption. Therefore, four different runs were performed. The first, second, third, and fourth runs assumed that occupants prioritize thermal comfort, visual comfort, air quality, and acoustical comfort, respectively.

Figure 5.11

Predicted Energy Consumption for Different IEQ Priorities during the Winter when Occupants have Exclusively Positive Beliefs of Operating Windows and Adjusting Blinds

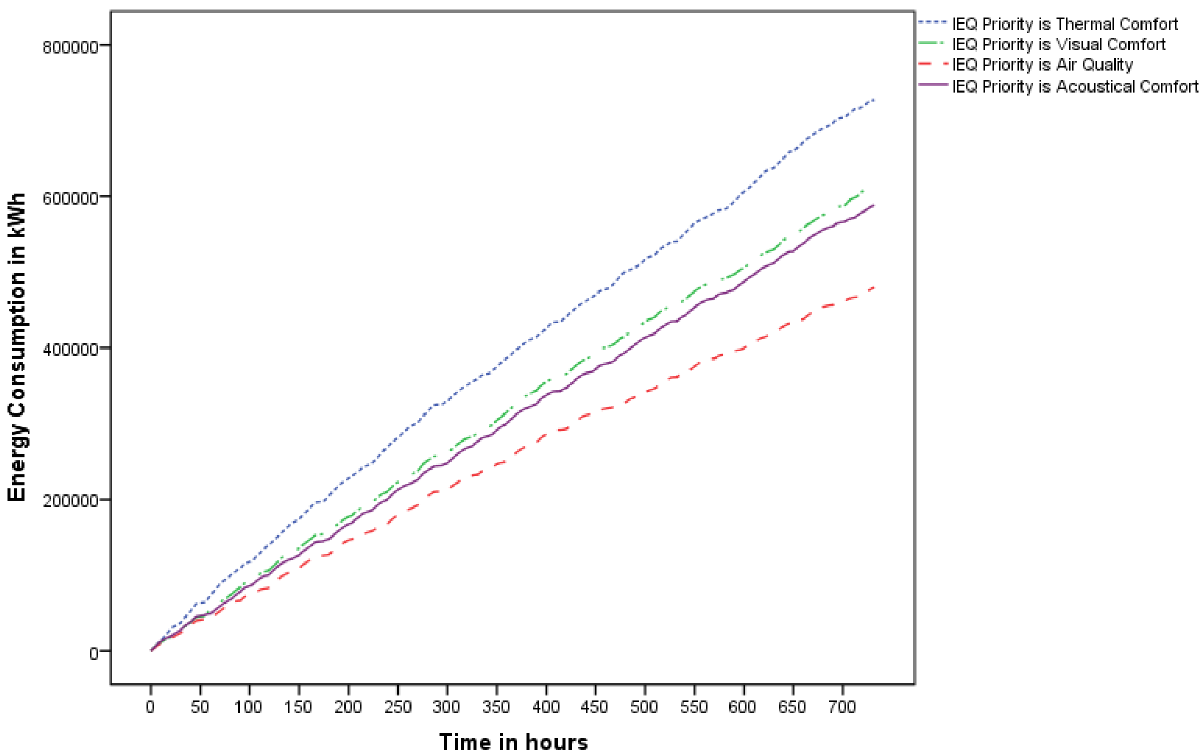


Figure 5.11 shows that energy consumption is expected to be highest (727821.13 kWh) when occupants prioritize thermal comfort. It also shows that prioritizing visual comfort and acoustical comfort results in energy consumption of 618952.79 kWh and 588614.75 kWh, respectively. Finally, it shows that energy consumption is expected to be lowest (480139.33 kWh) when occupants prioritize Air Quality over the other IEQ criteria.

5.1.4.2. Experiment Four

In this experiment, it was assumed that occupants had exclusively negative beliefs of operating windows and adjusting blinds, which are cases number 8 in Table 5.2. All other assumptions are like experiment one.

Figure 5.12

Predicted Energy Consumption for Different IEQ Priorities during the Winter when Occupants have Exclusively Negative Beliefs of Operating Windows and Adjusting Blinds

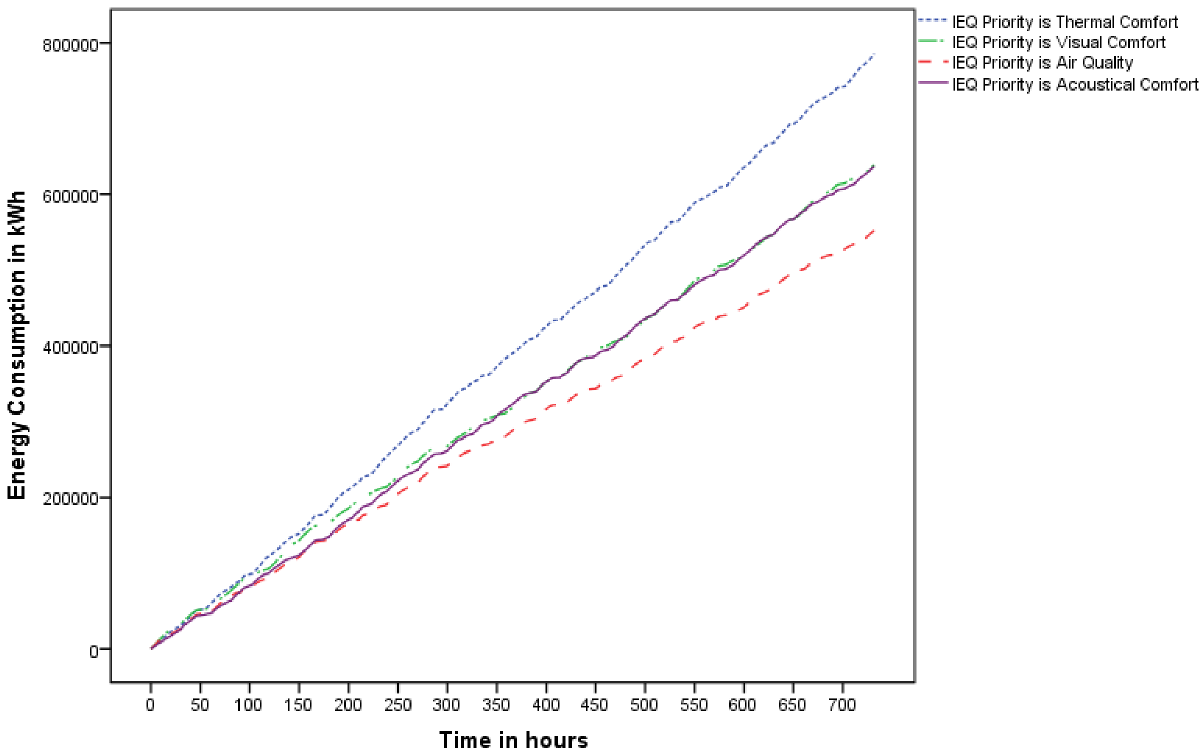


Figure 5.12 shows that energy consumption is expected to be highest (785942.94 kWh) when occupants prioritize thermal comfort. It also shows that prioritizing visual comfort and acoustical comfort results in energy consumption of 638923.2 kWh and 636933.25 kWh, respectively. Finally, it shows that energy consumption is expected to be lowest (552496.73 kWh) when occupants prioritize Air Quality over the other IEQ criteria.

5.1.4.3. <u>Comparing Results of Experiment Three and Experiment Four</u>

In this section, a detailed comparison between the first and second experiment was conducted. The results are displayed in Figures 5.13 – 5.16.

Figure 5.13

Comparing Predicted Energy Consumption Values in Winter when Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative and IEQ Priority is Thermal Comfort

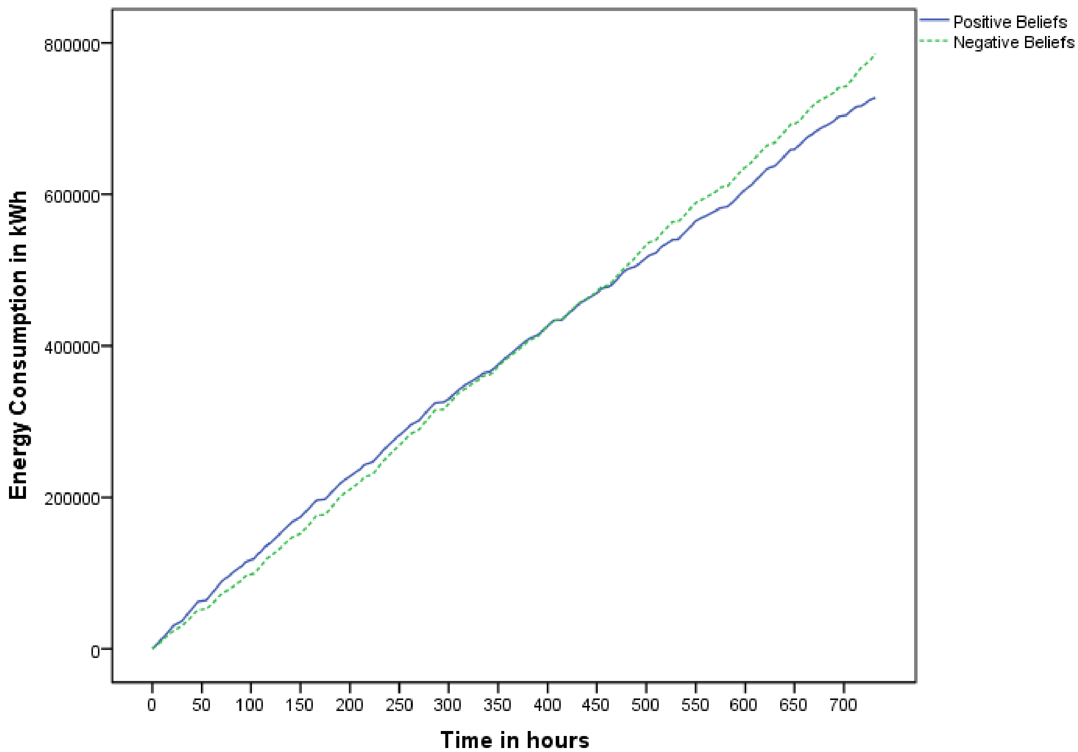


Figure 5.13 shows that the predicted energy consumption when occupants have exclusively negative beliefs of operating windows and adjusting blinds, and IEQ priority is thermal comfort is 785942.94 kWh, while it is 727821.13 kWh when occupants have exclusively positive beliefs of operating windows and adjusting blinds.

Figure 5.14

Comparing Predicted Energy Consumption Values in Winter when Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative and IEQ priority is Visual Comfort

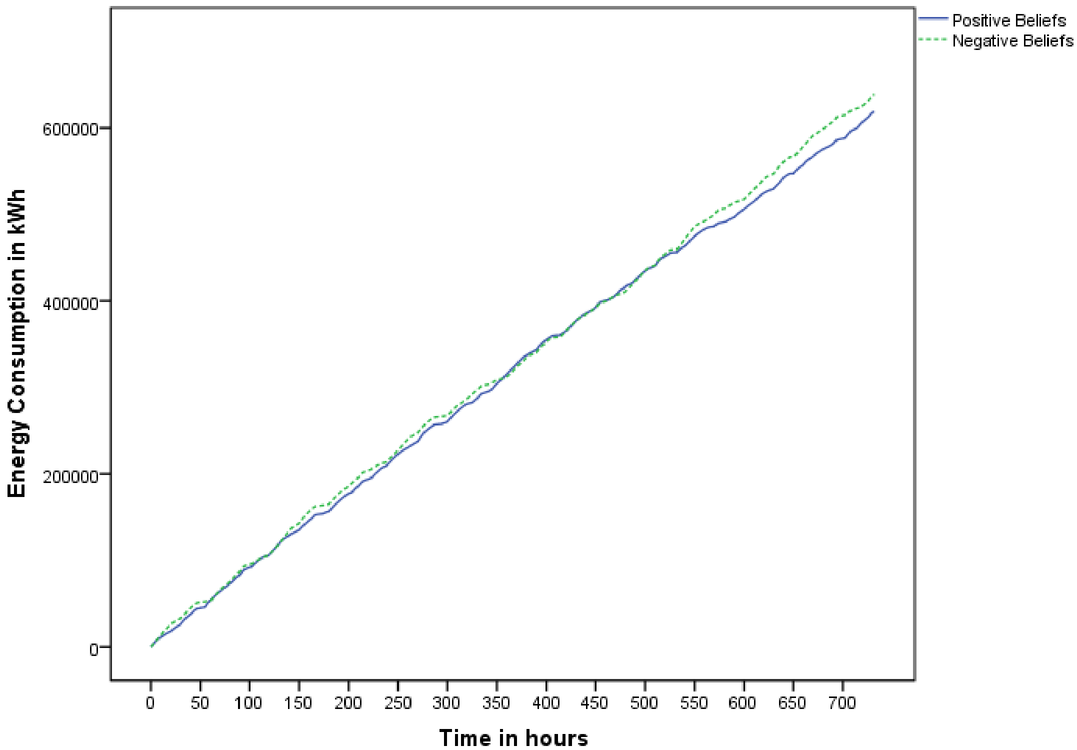


Figure 5.14 shows that the predicted energy consumption when occupants have exclusively negative beliefs of operating windows and adjusting blinds, and IEQ priority is visual comfort is 638923.2 kWh, while it is 618952.79 kWh when occupants have exclusively positive beliefs of operating windows and adjusting blinds.

Figure 5.15

Comparing Predicted Energy Consumption Values when in Winter Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative and IEQ priority is Air Quality

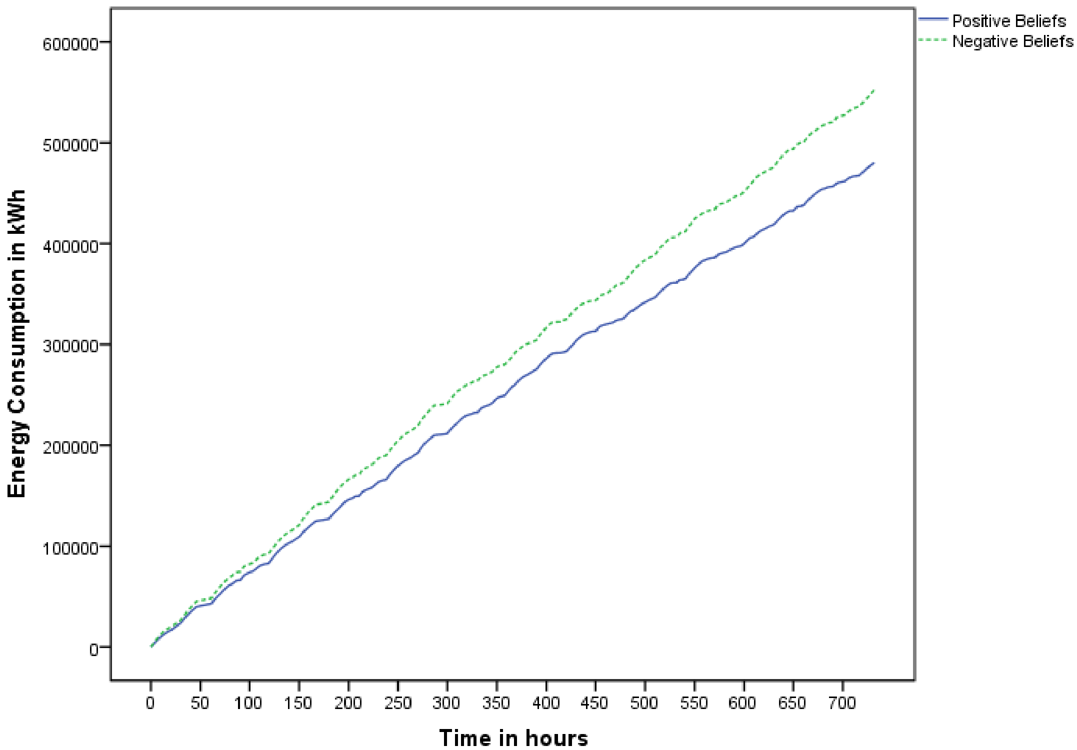


Figure 5.15 shows that the predicted energy consumption when occupants have exclusively negative beliefs of operating windows and adjusting blinds, and IEQ priority is air quality is 552496.73 kWh, while it is 480139.33 kWh when occupants have exclusively positive beliefs of operating windows and adjusting blinds.

Figure 5.16

Comparing Predicted Energy Consumption Values in Winter when Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative and IEQ Priority is Acoustical Comfort

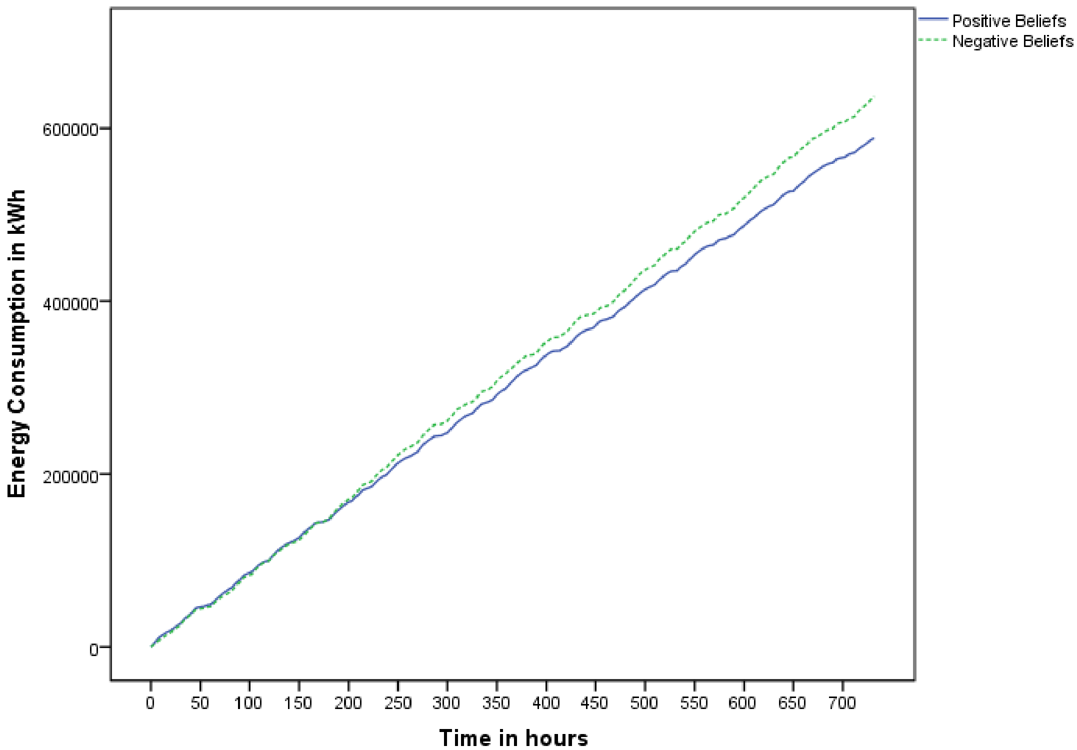


Figure 5.16 shows that the predicted energy consumption when occupants have exclusively negative beliefs of operating windows and adjusting blinds, and IEQ priority is acoustical comfort is 636933.25 kWh, while it is 588614.75 kWh when occupants have exclusively positive beliefs of operating windows and adjusting blinds.

<u>H5: Occupants' behavioral beliefs of operating windows and adjusting blinds influence the building's energy consumption.</u>

The proposed agent-based model was used to simulate occupants' behavior based on their beliefs and calculate the energy consumption associated with the occupants' behavior.

H5a: Occupants with positive beliefs of operating windows and adjusting blinds consumes less energy than those who have negative beliefs of those behaviors during the summer.

Two experiments were run to test sub-hypothesis H5a. The first experiment assumed that all instances of the agent (occupants) had positive beliefs of operating windows and adjusting blinds. This means that occupants believed that operating windows enhance the thermal, acoustical, and air quality conditions of the interior space that they are occupying. In addition, occupants believed that adjusting blinds enhance the thermal comfort, amount of daylighting, and will provide them access to quality outdoor view. The second experiment assumed that all instances of the agent (occupants) had negative beliefs about operating windows and adjusting blinds. The results of the experiments summed, up in Figure 5.17, showed that occupants with positive beliefs of operating windows and adjusting blinds tend to consume less energy than those who have negative beliefs of the same behavior. Therefore, sub-hypothesis H5a is confirmed. Results also showed that occupants who prioritize thermal comfort tend to consume more energy than those who prioritized air quality. Occupants who prioritized visual or acoustical comfort tend to consume a similar amount of energy.

H5b: Occupants with positive beliefs of operating windows and adjusting blinds consumes less energy than those who have negative beliefs of those behaviors during the winter.

Two similar experiments were run to test sub-hypothesis H5b. The results of experiment three and four were consistent with the results of experiments one and two. However, comparing the results of experiment three and four in Figure 5.17 showed that occupants with positive beliefs of operating windows and adjusting blinds tend to consume less energy than those who have negative beliefs of the same behavior, except for occupants who prioritized thermal comfort. Occupants who prioritized thermal comfort tend to use a similar amount of energy if they had positive or negative beliefs of operating windows and adjusting blinds.

Figure 5.17

Comparing Predicted Energy Consumption Values in Summer when Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative

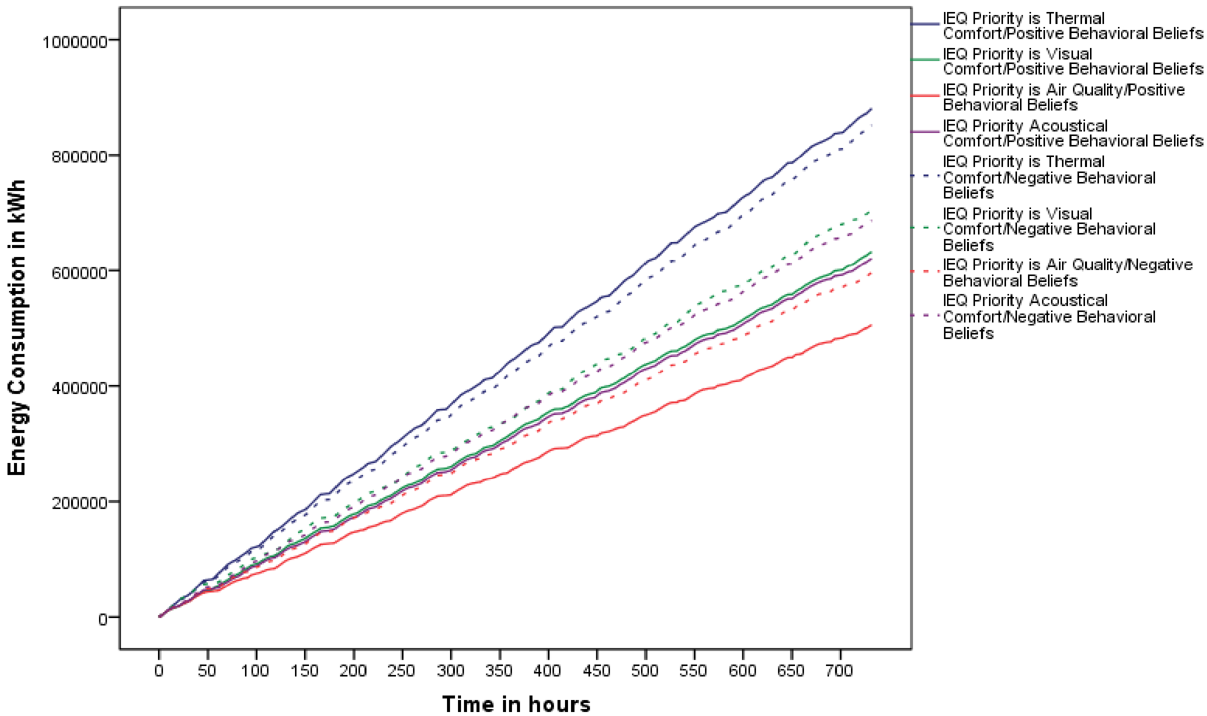
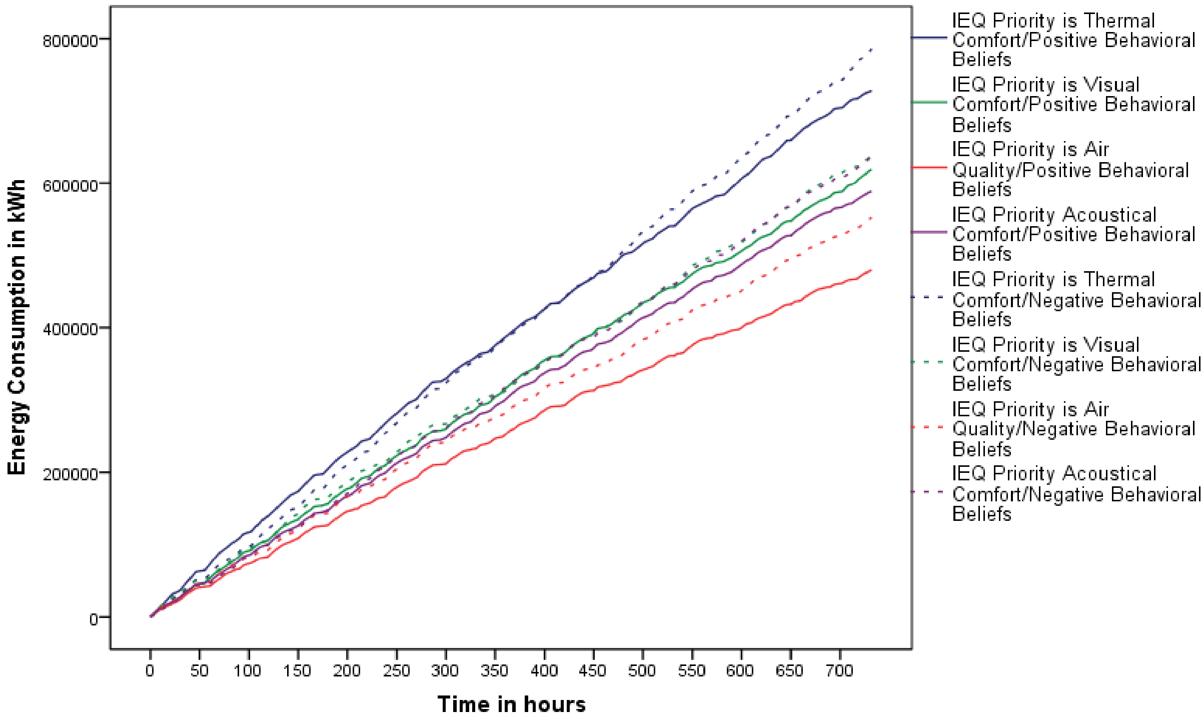


Figure 5.18

Comparing Predicted Energy Consumption Values in Winter when Occupants Beliefs of Operating Windows and Adjusting Blinds are Exclusively Positive versus Exclusively Negative



5.2. Summary of the Agent-Based Model Results

This chapter provides a proof of concept for the proposed agent-based model. The agent-based model proposed in this chapter suggest that occupants' behavioral beliefs influences the buildings' energy consumption. Four experiments were run to experiment this concept. Two of those experiments utilized data form the summer survey as inputs to the ABM, while the other two experiments utilized data from the winter survey as inputs to the ABM.

The first observation that can be inferred from Figure 5.17 and Figure 5.18 is that the total energy consumption is more in summer compared to winter. Multiple reasons can contribute to these results, and one of them is the survey respondents' preferred temperature. The second observation is that occupants' who have positive beliefs towards operating windows and adjusting blinds tend to use less energy than those who have negative beliefs. Occupants who have positive beliefs towards these behaviors are more likely to interact with passive building systems to control the indoor environmental condition. This behavior results in less energy consumption. This observation applies to both seasons with an exception of occupants who rank temperature as their IEQ priority. During the summer, those occupants tend to consume more energy compared to the occupants who have negative beliefs towards operating windows and adjusting blinds. One of the explanations for this observation is that occupants can be more encouraged to interact with windows and blinds during the summer.

The third observation is that occupants who indicated that thermal comfort or air quality as their IEQ priority tend to result in the highest energy consumption. Meanwhile, occupants who indicated that visual or acoustical comfort is their IEQ priority tend to result in moderate energy consumption. These observations are consistent in summer and winter and can be further explored by conducting sensitivity analysis in future studies.

The experiments have some limitations that need to be addressed in future research. First, the environmental factors, such as temperature and lighting, are updated hourly based on excel sheets that were prepared by the researcher. This information was obtained from Local Climatological Data (LCD) from the National Centers for Environmental Information (NCEI) for Lansing Capital City Airport Station. Also, the air quality and acoustics are updated hourly based on simplified data stored in excel files. Those environmental factors would be best if obtained from building energy simulation software that predicts the exact values of those factors depending on the simulated buildings' conditions in real time.

The experiments shown in this study used the extreme cases for the occupants' behavioral beliefs. As a result, one experiment assumed that occupants have positive beliefs towards operating windows and adjusting blinds, while the other experiment assumed that occupants have negative beliefs. However, there are other possibilities that need to be explored. For example, an instance of an agent occupant might believe that operating windows improves the temperature but worsen the air quality or acoustics within the space that they are using. The differences among occupants' behavioral beliefs of spatial factors might influence the buildings' energy performance and should be studied in more detail in future research.

The experiments described in this chapter assumed that the occupants' behavioral beliefs are associated with their attitudes towards performing the behavior of operating windows and adjusting blinds. This assumption is based on the results obtained from the Chi-square tests for association that were computed for the occupants' Reponses to the survey. However, the researcher suggested a simplified way to calculate occupants' attitudes in the proposed agent-based model which are presented in Table 5.1 and Table 5.2. These calculations lack the realistic weights that are expected to be associated with each behavioral belief outcome evaluation.

In addition, the experiments assumed that the occupants' subjective norms and perceived behavioral control are constants to focus on the impact that their behavioral beliefs of spatial factors have on the energy consumption. Those values implicitly represent occupants' interaction with each other and with their surrounding environment. Therefore, it is suggested that future research incorporates those values as parameters to add more complexity and thus realism and accuracy to the simulations.

For simplification, the experiments had the occupants' preferred temperature as a custom distribution that is based on the occupants' responses to the survey. Other factors can be added to have more realistic representation of occupants' preferred temperature, such as the type of cloths that the occupants wear and the amount of activity that they perform in different spaces.

Also, occupants' behaviors were simulated in the experiments presented in this chapter regardless the type of space that they are occupying. To add more complexity, occupants can be simulated in different spaces of their apartments according to a stochastic schedule. For, example, occupants can be present in the living area and performing tasks for a certain amount of time, then move to the sleeping area where they perform another type of behaviors. Including movement of occupants between different interior spaces is expected to yield informative results for building designers.

The decision-making process is simplified in the experiments discussed in this chapter. Simple if-then rules were used to guide occupants' behavior. Also, the decision-making process did not include learning or memory. Therefore, the simulations lacked the path dependence as the occupants' behavior traits are fixed. It is suggested to add a more advanced decision-making process in future studies to obtain more realistic simulated outputs. Finally, since this experiment is based on a stochastic model, it is recommended to run the model multiple times to get a range of values per time step.

CHAPTER SIX:

DISCUSSION AND CONCLUSION

This research was designed to study energy-related building occupant interaction. Previous research focused on studying either operating windows or adjusting blinds. Also, most of these studies were conducted for office buildings (Barakat & Khoury, 2016; D'Oca et al., 2017; Musau & Steemers, 2008; O'Brien & Gunay, 2014). In this study, two surveys were conducted to understand how occupants operate windows and adjust blinds in residential apartments. In addition, the information gathered from the surveys was used to build an agent-based model.

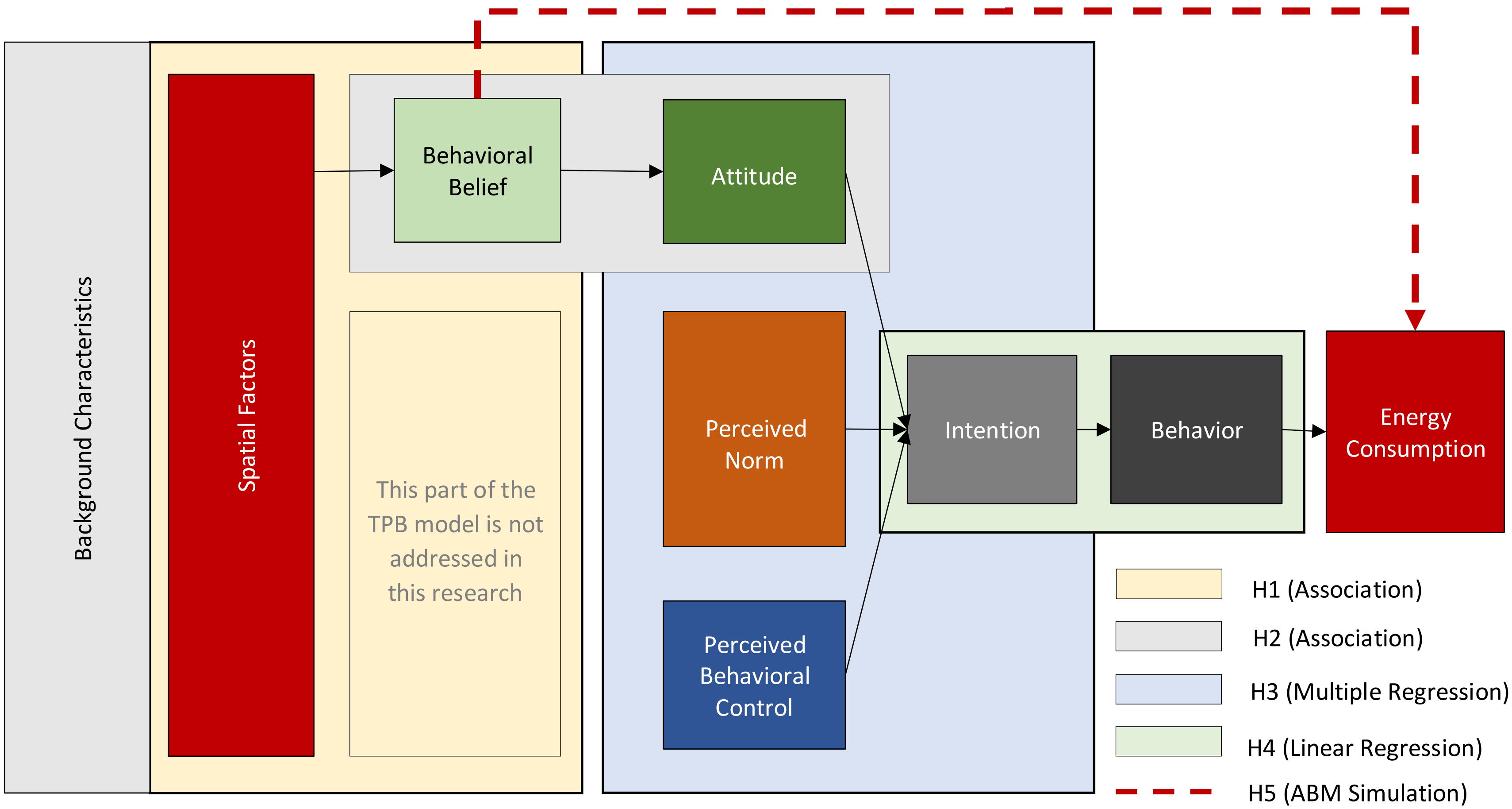
Figure 6.1 shows how the research variables were organized. It also shows how the hypothesis was tested using different analysis methods. The survey started by collecting information about the general characteristics of the occupants and the apartments that they are occupying during the time of the study. This information allowed the researcher to draw connections between the spatial factors such as the orientation, floor level, space type, and furniture location and the occupants' behavioral beliefs of operating windows and adjusting blinds.

The core questions in the survey were based on the constructs of the Theory of Planned Behavior. This allowed the researcher to account for psychological factors that influence the occupants' behavior of operating windows and adjusting blinds. The Theory of Planned Behavior Constructs can be arranged into three layers. The first layer focused on the influence of occupants' behavioral beliefs of their attitude. Chi-Square test for association and Cramer's V tests were used to test the magnitude and direction of this relationship.

Different constructs of the Theory of Planned Behavior were used to validate the output of the agent-based model. The proposed agent-based model was used to predict the energy consumption based on the occupants' behavioral beliefs towards operating windows and adjusting blinds.

Figure 6.1

Diagram Representing the Research Variables, Hypothesis, and Analysis Methods



6.1. Discussion

The researcher investigated occupants' background characteristics to have a better understanding of the population for this study. The total number of valid responses collected from the summer survey is 104, and the total number of valid responses collected from the winter survey is 101. The ratio of male to female responses in both surveys is almost similar, with about 50% of male respondents and about 50% of female respondents. More than 50% of the respondents were in the age range between 25 to 34 years old, and about 20% were in the age range between 35 to 44 years old. About 50% of respondents of both surveys were Asian or Asian American, while about 25% were white Caucasian or European American. Other races and ethnicity were included but with smaller percentages such as Black or African American, Arab, or Middle Eastern, and Latin American or Hispanic. Responses of both surveys showed about 90% of the occupants lived with their spouses or partners in the multifamily residential building under study. Also, more than 50% of the respondents indicated that they do not have children, while others had one, two, or three children.

More than 60% of the respondents to the summer and winter surveys were undergraduate or graduate students of Michigan State University (MSU), while more than 20% were spouses or partners of MSU students. Responses showed that more than 40% of respondents of both surveys held a master's degree, and more than 10% held doctoral degrees. More than 60% of the respondents reported that their average household income was between $12,000 to $36,000.

The researcher collected information about the housing characteristics in summer and winter surveys to explore the relationship between spatial factors and occupants' beliefs towards operating windows and adjusting blinds. Both surveys had an almost equal number of responses from occupants of apartments facing the parking lot versus those who are living in apartments facing the green area. It can be concluded from the design of the building and its location on google maps that all apartments that are facing the parking lot have a north orientation while all the apartments facing the green area have a south orientation. Also, results showed that there were enough responses from the occupants of each floor level.

Energy-related characteristics were collected and used by the researcher as input for the agent-based model. Some of those characteristics include the occupants' preferred temperature. Occupants' responses varied from 65 Fahrenheit to 80 Fahrenheit. It also shows that more than 60% of occupants preferred temperature between 70 Fahrenheit and 75 Fahrenheit during the summer and the winter seasons. Results of the summer survey showed that about 60% of occupants wore short-sleeve pajamas while the results of the winter survey showed that more about 65% of occupants wore long-sleeve pajamas.

Respondents were asked to indicate the level of activity that they usually have in living and sleeping areas. More than 60% of respondents indicated that they spend most of their seating time in the living area, while more than 80% of respondents indicated that they spend most of their time reclining in the sleeping area. These results were consistent during the summer and winter seasons. Respondents also reported the average amount of time that they spend for cooking each day as this information influences the indoor air quality. More than 80% of respondents spent between 10 minutes to 40 minutes for cooking each day.

In addition, occupants ranked the Indoor Environmental Quality according to their preference in the living and the sleeping areas during the summer and the winter. Results showed that almost 50% of the occupants ranked thermal comfort as their priority, followed by air quality. These results are aligned with the results in previous research that Stazi et al. conducted in 2017. Their study focused on driving factors that influence energy-related building occupants' interaction. They indicated that indoor and outdoor temperatures are the major drivers for occupants to interact with windows. They also referred to the Co2 concentration as a variable that influences occupant behavior mostly in residential buildings.

Results from the hypothesis one testing are consistent with previous research. Fabi et al. (2012) and O'Brien and Gunay (2014) noted that the window and blind use are affected by spatial factors such as dwelling type, room type, room orientation, and furniture layout. In addition, Stazi et al. (2017) indicated that the trigger factors for adjusting blinds are not decisive, yet two factors occurred more frequently in previous studies, which are external illuminance and solar radiation.

Hypotheses two, three, and four testing showed that the variables of the Theory of Planned Behavior could be used to predict occupants' behavior. This result is consistent with the results of previous studies. For example, Kaiser and Gutscher (2003) demonstrated that the three components of the Theory of Planned Behavior (attitude, subjective norm, and perceived behavioral control) explained 81% of the intention's variance. Accordingly, the constructs of the Theory of Planned Behavior were used to define the agent's decision-making process in the proposed agent-based model.

The agent-based model proposed in this study that aims to focus on occupants' behavioral beliefs of spatial factors. Different concepts were adopted from the frameworks that represent occupant-building interaction (Cha & Kim, 2015; Cha et al., 2017; Hong et al., 2017). Also, the results from the occupants' surveys during the summer and the winter seasons were used to experiment with the ABM. Results of the ABM simulations show that occupants' behavioral beliefs have an impact on the buildings' energy performance in both seasons. However, the proposed ABM needs to be developed by adding more complexity and conducting in depth evaluation.

6.2. Conclusion

This study examines the influence that spatial factors (such as site characteristics, building features, space type, and furniture layout) have on occupants' energy-related behaviors. The literature review revealed that occupants interact in many ways with the buildings causing energy consumption. This research focuses on the occupants' interaction with the building systems to control their indoor environmental conditions. Therefore, this research investigated occupants' behaviors of operating windows and adjusting blinds as previous research proved that they influence energy consumption.

Previous research has extensively studied occupants' behavior of operating windows and adjusting blinds. Some research focused on quantifying the impact that occupants' behaviors have on the building's energy performance. Other research studied the motivations that drive occupants' interaction with building systems such as windows, blinds, thermostats, and lighting. Researchers suggested that occupants' behavior of operating windows and adjusting blinds are influenced by environmental, physiological, psychological, contextual factors (Hong et al., 2015; O'Brien & Gunay, 2014).

Some researchers suggested that occupants' behavior is influenced by contextual factors such as the dwelling type, room type, and room orientation (Fabi et al., 2012). Other researchers indicated that interior design is one of the contextual factors that have a significant impact on occupants' comfort and thus influences their behavior (O'Brien & Gunay, 2014). However, those researchers pointed out that the influence that contextual factors have on occupant's behavior has been underestimated (Yan et al., 2015). Therefore, this research focused on the spatial factors that influence occupants' behavior of operating windows and adjusting blinds.

This study identified four levels of spatial factors that were assumed to influence the occupants' behavior of operating windows and adjusting blinds. The first spatial factor that was studied was the site characteristics, and it included orientation and outdoor views. The apartments that the occupants reside at were classified into two groups. The first group of apartments had a north orientation and were facing a parking lot. The second group of apartments had south orientation and were facing a green area. Statistical analysis of occupants' responses did not find a significant association between the orientation and the occupant's behavior of operating windows and adjusting blinds, and between the outdoor views and the occupant's behavior of operating windows and adjusting blinds.

The second spatial factor that was examined was the floor level, which was identified as one of the building's characteristics. Statistical analysis of occupants' responses did not find a significant association between the floor level and the occupant's behavior of operating windows and adjusting blinds. Space type was the third spatial factor. Results showed that there is a significant correlation between occupants' beliefs of operating windows and adjusting blinds in living and sleeping areas. Finally, occupants indicated in their responses that furniture layout and location of the window influence the choice of their preferred spot in the living and sleeping areas.

This research utilized the Theory of Planned Behavior as its theoretical framework to understand the relationship among occupants' beliefs, attitudes, subjective norms, perceived behavioral control, behavioral intention, and their actual behavior of operating windows and adjusting blinds. Statistical results showed that there is a significant relationship between the occupant's beliefs of operating windows and adjusting blinds in living and sleeping areas and during the summer and winter seasons and their attitude towards performing this behavior.

The variables from the Theory of Planned Behavior (attitude, subjective norm, perceived behavioral control) were able to explain the variance in occupants' behavioral intention towards operating windows and adjusting blinds in the sleeping area during the summer and the winter. The multiple regression equation can be used to predict, with some approximation, the occupants' behavioral intention towards operating windows and adjusting blinds in the living and sleeping area during the summer and the winter.

Finally, the results of the simple regression model showed that behavioral intention is a determinant of the occupants' actual behavior of operating windows and adjusting blinds during the summer and the winter. Therefore, the researcher decided to incorporate the constructs of the Theory of Planned Behavior in the decision-making process of the proposed agent-based model.

The proposed agent-based model was designed based on the drivers, needs, actions, and systems framework created by Hong et al. (2015). The environmental factors were identified as the drivers of the occupants to control the indoor environmental conditions. It was also inspired by the users, activities, and spaces framework developed by Kim and Fischer (2014). Therefore, the individual and spatial factors were recognized as triggers for occupants' needs to control indoor environmental conditions. In addition, the researcher acknowledged the psychological and social factors, as suggested by D'Oca et al. (2017) who formed an interdisciplinary framework for context and occupant behavior formed in 2017. The theory of Planned Behavior constructs (attitude, subjective norm, perceived behavioral control) was used to predict the occupants' behavioral intention towards operating windows and adjusting blinds.

The proposed agent-based model was also led by the models created by Barakat (2015) and developed by Barakat and Khoury (2016), and advanced by Hajj-Hassan and Khoury (2018). These researchers aimed to reproduce the occupants' multi-comfort level in office buildings. Similarly, this research recognized that occupants' control multiple indoor environmental conditions, including thermal, visual, acoustical, and air quality conditions. This study assumed that occupants' have preferences for those indoor environmental criteria. Therefore, occupants were asked to rank the IEQ criteria in living and sleeping areas during the summer and the winter seasons. Results were consistent with previous studies in which thermal comfort ranked on top of the IEQ criteria, followed by air quality.

The occupants' ranking of IEQ criteria was incorporated into the decision-making process of the proposed agent-based model. The instances of the agent (occupants) checking the indoor environmental conditions on an hourly basis, which is determined by the building systems statuses (i.e., windows, blinds, thermostats, and lights) and the spatial factors (i.e., orientation, floor level, space type, and furniture location). If the instances of the agent (i.e., occupants) were not satisfied by the indoor environmental conditions, they would interact with the building's system.

The occupants' behavior is based on their beliefs of the advantages and disadvantages of operating windows and adjusting blinds and is calculated using the multiple regression equation using the constructs of the Theory of Planned Behavior such as attitude, subjective norm, and perceived behavioral control. Results from the proposed agent-based model experiment showed that occupants' who have positive beliefs of operating windows and adjusting blinds tended to consume less energy compared to occupants who had negative beliefs towards the same behaviors.

This study contributes to the energy-related occupant-building interaction research. It is a synthesis of multiple frameworks (Cha & Kim, 2015; Cha et al., 2017; Hong et al., 2017) that aims to propose a proof of concept of an agent-based model. The proposed agent-based model is designed to simulate occupants' interaction with passive and active building systems to control the four elements indoor environmental quality (IEQ) simultaneously. It accounts for the dynamic environmental drivers of occupants' behaviors. In addition, it includes stochastic physical and psychological needs of occupants with a focus on spatial factors.

This research is an initial attempt to explore energy-related occupant-building interaction from a design perspective integrated with technical and psychological aspects. It aims to provide designers with a foundation of a computational tool that allows them to experiment and explain occupants' energy-related behaviors with a focus on spatial factors. This tool is expected to assist designer in making informed design decisions that accounts for occupants' comfort and buildings' energy performance.

6.2.1. *Implications of the Study*

This research claims that the spatial factors influence occupants' beliefs of the advantages and disadvantages associated with the behavior of operating windows and adjusting blinds. Therefore, it is suggested that residential design requires an integrated project team that consists of designers, planners, engineers, managers, and any other team members. The integrated project team needs to consider the site characteristics, building features, space planning, and furniture layout at an early stage of the design process. It is also recommended that the integrated project team learn about the potential occupants' beliefs of operating windows and adjusting blinds concerning the spatial factors. This information can be collected using surveys, interviews, or in an experimental setting using virtual environments.

This research confirms that the Theory of Planned Behavior may provide the integrated project team with helpful information about the energy-related occupants' behavior. The results of this study confirm that the occupants' beliefs of operating windows and adjusting blinds influence their attitude towards these behaviors. This research also acknowledges the role that the social factors influence the occupants' behaviors of operating windows and adjusting blinds. It also recognizes the importance of the technical factors of operating windows and adjusting blinds. Since the results of this study show that the occupants' attitude, subjective norm, and perceived behavioral control influence the occupants' intention of operating windows and adjusting blinds, it is suggested that the integrated project team study these factors early in the early stages of the design process.

In addition, this research proposes an agent-based model that aims to provide a framework to predict occupants' behavior of operating windows and adjusting blinds based on their beliefs that are influenced by the spatial factors. The proposed agent-based model can provide an integrated project team with energy-use and space-use information. It can also be developed and incorporated with building performance simulation software. It is expected that incorporating the proposed agent-based model with building energy simulation software would increase the accuracy of the predicted buildings' energy performance. It is also expected to be a useful design support tool for professional designers. It can also be integrated into the interior design education curriculum to teach design students about the energy implications of occupant-building interaction.

6.2.2. *Limitations and Suggestions for Future Research*

Some limitations and suggestions for future research need to be considered. First, the data collected from occupants in this study are limited to the buildings under study, which are in Michigan in the United States. Although respondents had diverse ethnic and racial backgrounds and were of different age groups and with different average household incomes, yet they were all students at Michigan State University. Therefore, including more diverse building locations and groups of occupants is recommended for future study. In addition, the buildings under study are in a college town that is known to be quiet and safe. More studies are needed to address buildings at different locations to search for more clear occupants' behavior patterns.

The data for this study were collected using a survey, which is a self-reporting subjective method. Occupant behavior monitoring studies have more rigorous results when surveys are conducted along with objective data collection using monitoring equipment such as sensors or cameras. In addition, the survey conducted consisted of 13 pages, with a total of 65 questions. Therefore, the measurements used single-item questions instead of multiple items which resulted in a mono-operation bias that compromised the reliability and construct validity of the responses. For the same reason, some data were collected using multiple choice questions instead of using Likert-scale such as for the behavioral belief. The data collected in the form of dichotomous variables limited the opportunity to conduct more inferential statistics. In addition, reducing the levels of measurement of the Theory of Planned Behavior constructs threatens the construct validity of the questionnaire. It is recommended that future research considers collecting data on an interval or ratio variables to allow for more elaborative and advanced statistical analysis. It is also recommended to use Likert scale with a minimum of three items to measure each construct of the TPB to increase the construct validity of the questionnaire (Marsh, Hau, Balla, & Grayson, 1998).

There are also some limitations related to the proposed agent-based model. The agent-based model proposed in this research is a prototype that needs to be developed through more rigorous verification, validation, calibration, and sensitivity analysis. The proposed agent-based model utilizes the “if-then” rules for the occupants’ decision-making process. It is suggested that future research consider including advanced architecture that accounts for agents’ memory and learning. In addition, it is recommended that future research incorporates the proposed agent-based model with building energy simulation software so that both programs can exchange data in real-time and produce more accurate and realistic output. Lastly, it is important to note that the buildings targeted for this research study did not have submeters in individual apartment units. Therefore, comparing the real energy consumption to the simulated energy consumption was not possible for the current study, but this comparison is recommended for future research.

APPENDICES

APPENDIX A:

SAMPLE SIZE CALCULATION

Finding a Base Sample Size with +/- 5% Margin of Error

	Variability				
Population	50%	40%	30%	20%	10% [d]
100 [e]	81	79	63	50	37
125	96	93	72	56	40
150	110	107	80	60	42
175	122	119	87	64	44
200	134	130	93	67	45
225	144	140	98	70	46
250	154	149	102	72	47
275	163	158	106	74	48
300	172	165	109	76	49
325	180	173	113	77	50
350	187	180	115	79	50
375	194	186	118	80	51
400	201	192	120	81	51
425	207	197	122	82	51
450	212	203	124	83	52
500	222	212	128	84	52
600	240	228	134	87	53
700	255	242	138	88	54
800	267	252	142	90	54
900	277	262	144	91	55
1,000	286	269	147	92	55
2,000	333	311	158	96	57
3,000	353	328	163	98	57
4,000	364	338	165	99	58
5,000	370	343	166	99	58
6,000	375	347	167	100	58
7,000	378	350	168	100	58
8,000	381	353	168	100	58
9,000	383	354	169	100	58
10,000	385	356	169	100	58
15,000	390	360	170	101	58
20,000	392	362	171	101	58
25,000	394	363	171	101	58
50,000	397	366	172	101	58
100,000	398	367	172	101	58

Note. Source: Pennsylvania State University (PSU) (2014) An equation for determining the final sample size from program evaluation tipsheet #60— how to determine sample size. URL: https://ucanr.edu/sites/CEprogramevaluation/files/143304.pdf

Qualifications:

a) This table **assumes a 95% confidence level,** identifying risk of 1 in 20 that actual error is larger than the margin of error (greater than 5%).

b) The base sample size should be **increased** to take into consideration potential non-response.

c) A **five percent margin of error** indicates a willingness to accept an estimate within +/- 5 of the given value.

d) When the estimated population with the smaller attribute or concept is less than 10 percent, the sample may need to be increased.

e) The assumption of a normal population is poor for 5% precision levels when the population is 100 or less. The entire population should be sampled, or a lesser precision accepted.

APPENDIX B:

QUESTIONNAIRE

August 14th, 2019

Dear 1855 Place Resident,

I am Hebatalla Nazmy a Ph.D. candidate in the School of Planning, Design, and Construction at Michigan State University. I am requesting your input as a resident of Michigan State Family Housing. I am researching the occupants' behaviors of operating windows and adjusting blinds within residential spaces as part of my Ph.D. research that I am conducting under the supervision of Dr. Suk-Kyung Kim, Associate Professor of Interior Design.

The United States Environmental Protection Agency (EPA) reports that people spend about 90 percent of their time indoors. Also, research shows that indoor environmental conditions impact the occupants' well-being, health, comfort, and satisfaction. Therefore, the occupants' feedback on how and why they control the indoor environmental conditions is very informative to design high quality and environmentally friendly buildings.

You are being asked to participate in a research study that aims to examine the relationship between occupants' energy-related behavior and spatial contextual factors. This questionnaire is designed to verify the occupants' behaviors in controlling indoor environment conditions, specifically through operating windows and adjusting blinds. It also contains questions about your demographics and socioeconomic characteristics and educational background for classification purposes. You must be at least **18 years old** to participate in this research.

Your participation in this study is completely voluntary. You may choose to participate, to skip any questions that you do not want to answer, and you can end your participation at any time. Your information and responses will be confidential, and all results will be reported in a summary form. There are no foreseeable risks associated with this project. The survey should take about 15-20 minutes of your time to complete. It may take timing depending on your answers and the level of detail you wish to provide. **You will receive a $5 gift card for your participation in this study before August 31, 2019**. In addition, the results of this study may provide information to develop the interior designer's involvement in sustainability.

<u>You can complete this questionnaire and return it using the prepaid envelope enclosed</u>
<u>Or type the URL below into your internet browser to take the online version:</u>
https://msu.co1.qualtrics.com/jfe/form/SV_9EVlohtViMBQgwB

All 1855 Place residents are encouraged to participate - Please feel free to share the link to this sur y members who are living with you in the same apartment and they will get an **additional $5 Amazon gift card** as a thank you for completing the survey.

If you have questions at any time about the survey or the procedures, please contact:

Hebatalla Nazmy
Ph.D. Candidate, Environmental Design
School of Planning, Design, and Construction
Michigan State University
Phone: 517- 763- 5663
E-mail: nazmyheb@msu.edu

Suk-Kyung Kim, Ph.D.
Associate Professor of Interior Design
School of Planning, Design, and Construction
Michigan State University
Phone: 517- 353- 9367
Email: kimsk@msu.edu

I indicate my voluntary consent to participate in this study by completing and submitting my responses.

1. Since when have you been living in 1855 Place family housing? (Please select one answer)

☐ Fall 2016	☐ Fall 2017	☐ Fall 2018	☐ Fall 2019
☐ Spring 2017	☐ Spring 2018	☐ Spring 2019	☐ Spring 2020
☐ Summer 2017	☐ Summer 2018	☐ Summer 2019	

2. Did you change your apartment since July 2019? (Please select one answer)
   - ☐ Yes
   - ☐ No

3. Which floor is your current apartment in? (Please select one answer)
   - ☐ First floor
   - ☐ Second floor
   - ☐ Third floor
   - ☐ Fourth floor

4. How many bedrooms do you have in your apartment? (Please select one answer)
   - ☐ One-bedroom
   - ☐ Two-bedrooms

5. What is the best description of the apartment that you are currently living in? (Please select one answer)
   - ☐ Apartment overlooking the green area
   - ☐ Apartment overlooking the parking lot
   - ☐ Corner apartment overlooking the green area
   - ☐ Corner apartment overlooking the parking lot

6. Including yourself, please indicate the total number of people currently living in your apartment? (Please select all that apply)

☐ 1 adult	☐ 0 children
☐ 2 adults	☐ 1 child
☐ 3 adults	☐ 2 children
☐ 4 adults	☐ 3 children
☐ 5 adults	☐ 4 children

7. What type of clothes do you prefer to wear at home in the **summer**? (Please select one answer)

☐ Sleeveless short gown

☐ Sleeveless long gown

☐ Short-sleeve pajamas

☐ Long-sleeve long gown

☐ Long-sleeve short wrap robe

☐ Long-sleeve pajamas

☐ Other Please specify:

8. How much time do you approximately spend in the living area during the summer daytime on weekdays? (Please select all that apply)
   - ☐ 6 a.m. – 7 a.m.
   - ☐ 7 a.m. – 8 a.m.
   - ☐ 8 a.m. – 9 a.m.
   - ☐ 9 a.m. – 10 a.m.
   - ☐ 10 a.m. – 11 a.m.
   - ☐ 11 a.m. – 12 p.m.
   - ☐ 12 p.m. – 1 p.m.
   - ☐ 1 p.m. – 2 p.m.
   - ☐ 2 p.m. – 3 p.m.
   - ☐ 3 p.m. – 4 p.m.
   - ☐ 4 p.m. – 5 p.m.
   - ☐ 5 p.m. – 6 p.m.
   - ☐ Other Please specify: ____________

9. How much time do you approximately spend in the living area during the summer daytime on **weekends**? (Please select all that apply)
   - ☐ 6 a.m. – 7 a.m.
   - ☐ 7 a.m. – 8 a.m.
   - ☐ 8 a.m. – 9 a.m.
   - ☐ 9 a.m. – 10 a.m.
   - ☐ 10 a.m. – 11 a.m.
   - ☐ 11 a.m. – 12 p.m.
   - ☐ 12 p.m. – 1 p.m.
   - ☐ 1 p.m. – 2 p.m.
   - ☐ 2 p.m. – 3 p.m.
   - ☐ 3 p.m. – 4 p.m.
   - ☐ 4 p.m. – 5 p.m.
   - ☐ 5 p.m. – 6 p.m.
   - ☐ Other Please specify: ____________

10. How much time do you spend using the **oven and/or stove** per day in summer? (Please select one answer)
    - ☐ Less than 5 mins
    - ☐ 5-10 mins
    - ☐ 10 -20 mins
    - ☐ 20-40 mins
    - ☐ 40-80 mins
    - ☐ Other Please specify: ____________

11. What degree do you normally set your **thermostat** at in summer? (Please select one answer)
    - ☐ 68 °F
    - ☐ 69 °F
    - ☐ 70 °F
    - ☐ 71 °F
    - ☐ 72 °F
    - ☐ Other Please specify: ____________

The following questions will ask you about operating windows and adjusting blinds <u>in the living area</u> in summer during the daytime.

12. Please rank the indoor environmental qualities in the **<u>living area</u>** in order of importance to you in summer, 1 being your most important quality and 4 being your least important quality.

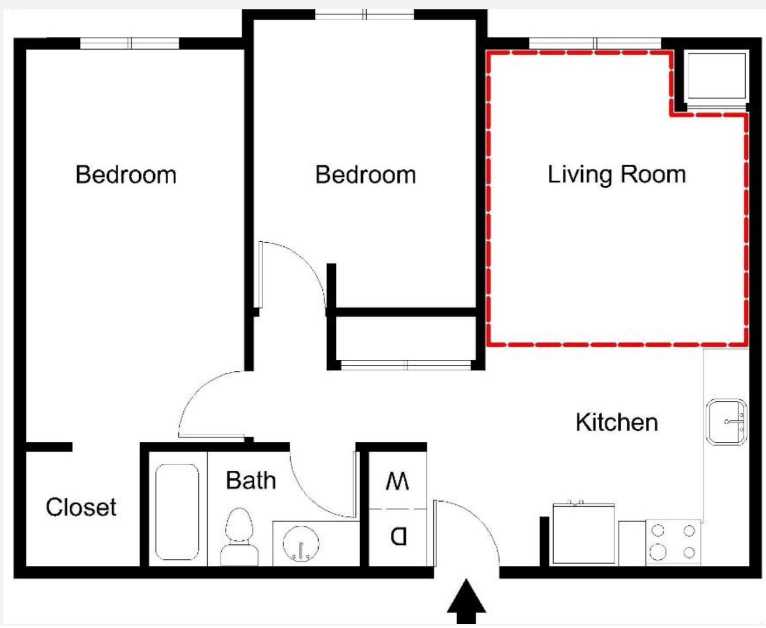
☐ Indoor air quality (the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants).

☐ Thermal comfort (the condition of mind that expresses satisfaction with the thermal environment and is assessed by a subjective evaluation).

☐ Visual comfort (enough lighting and views provided by a certain visual environment to make it comfortable and pleasing for occupants).

☐ Acoustical comfort (the feeling of a building or the acoustic environment such as noise-producing transport, equipment, activity, neighborhood).

13. The drawing below shows the floor plan of your apartment. Please click on the area on the drawing that indicates your preferred spot where you spend most of your time in the **<u>living area</u>** in summer.



14. Can you please explain if your preference of the spot that you selected in the previous question is related in any way to its location from the windows?

15. What is your most common activity level in the **living area** in the summer? (Please select one answer)
    - ☐ Reclining
    - ☐ Seated
    - ☐ Standing relaxed
    - ☐ Light activity standing
    - ☐ Medium activity standing
    - ☐ High activity

16. How often would you say that you have been operating **windows** in your living area over the last week?

Never 1 2 3 4 5 6 7 Very frequently

17. How often would you say that you have been adjusting **blinds** in the living area over the last week?

Never 1 2 3 4 5 6 7 Very frequently

18. How much would you say that you have been operating **windows** in your living area over the last week?

Fully closed 1 2 3 4 5 6 7 Fully opened

19. How much would you say that you have been adjusting **blinds** in the living area over the last week?

Fully closed 1 2 3 4 5 6 7 Fully opened

20. Operating **windows** in my living area in summer is:

Extremely harmful 1 2 3 4 5 6 7 Extremely beneficial

21. What do you think are drawbacks of operating **windows** in the living area in summer? (Please select all that apply)
   - ☐ Operating windows has no drawbacks
   - ☐ It causes an undesired change in temperature
   - ☐ It causes an undesired change in airflow
   - ☐ It raises air pollution concerns
   - ☐ It raises noise concerns
   - ☐ It wastes energy, please explain why:
   - ☐ If other, please specify:

22. What do you think are the benefits of operating **windows** in the living area in summer? (Please select all that apply)
   - ☐ Operating windows has no benefits
   - ☐ It causes a desired change in temperature
   - ☐ It causes a desired change in airflow
   - ☐ It eliminates air pollution concerns
   - ☐ It brings in outdoor pleasant sounds
   - ☐ It saves energy, please explain why:
   - ☐ If other, please specify:

23. Adjusting **blinds** in my living area in summer is:

Extremely harmful 1 2 3 4 5 6 7 Extremely beneficial

24. What do you think are drawbacks of adjusting **blinds** in the living area in summer? (Please select all that apply)
   - ☐ Adjusting blinds have no drawbacks
   - ☐ It causes an undesired change in temperature
   - ☐ It causes an undesired change in the amount of daylighting
   - ☐ It hinders access to outdoor views
   - ☐ It raises privacy concerns
   - ☐ It wastes energy, please explain why:
   - ☐ If other, please specify:

25. What do you think are benefits of adjusting **blinds** in the living area in summer? (Please select all that apply)
    - ☐ Adjusting blinds has no benefits
    - ☐ It causes desired change in temperature
    - ☐ It causes desired change in the amount of daylighting
    - ☐ It allows access to outdoor views
    - ☐ It improves privacy concerns
    - ☐ It saves energy, please explain why:
    - ☐ If other, please specify:

26. Most people whose opinions I value would appreciate me operating the **windows** in the living area in summer.

strongly disagree 1 2 3 4 5 6 7 Strongly agree

27. Most people whose opinions I value would appreciate me adjusting **blinds** in my living area in summer.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

28. For me, operating **windows** in my living area in summer is:

Extremely difficult 1 2 3 4 5 6 7 Extremely easy

29. For me, adjusting **blinds** in my living area in summer is:

Extremely difficult 1 2 3 4 5 6 7 Extremely easy

30. I intend to operate **windows** in my living area in the next week.

Extremely unlikely 1 2 3 4 5 6 7 Extremely likely

31. I intend to adjust **blinds** in my living area in the next week.

Extremely unlikely 1 2 3 4 5 6 7 Extremely likely

32. In the past week, I have operated **windows** in my living area.

Extremely false 1 2 3 4 5 6 7 Extremely true

33. In the past week, I have adjusted **blinds** in my living area.

Extremely false 1 2 3 4 5 6 7 Extremely true

The following questions will ask you about operating windows and adjusting blinds <u>in the sleeping area</u> in summer during the daytime.

34. Please rank the indoor environmental qualities in the **<u>sleeping area</u>** in order of importance to you in summer, 1 being your most important quality and 4 being your least important quality.

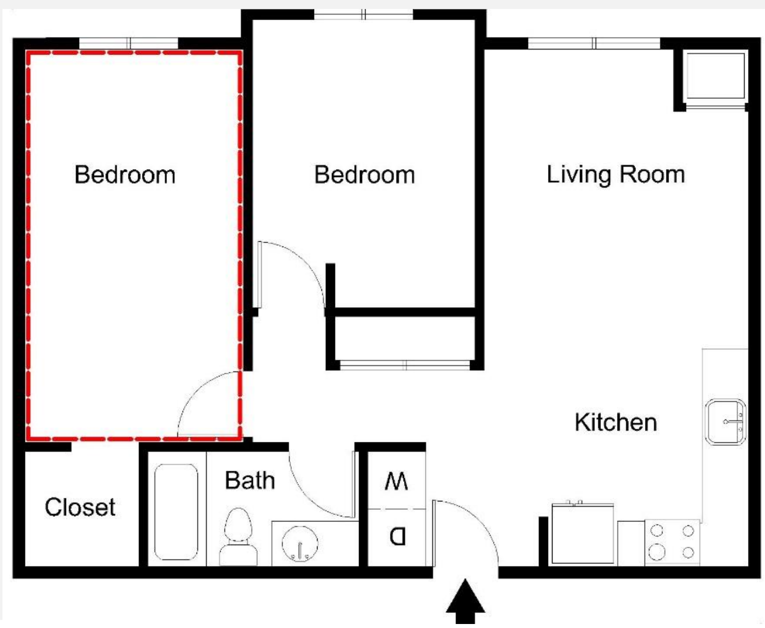
☐ Indoor air quality (the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants).

☐ Thermal comfort (the condition of mind that expresses satisfaction with the thermal environment and is assessed by a subjective evaluation).

☐ Visual comfort (enough lighting and views provided by a certain visual environment to make it comfortable and pleasing for occupants).

☐ Acoustical comfort (the feeling of a building or the acoustic environment such as noise-producing transport, equipment, activity, neighborhood).

35. The drawing below shows the floor plan of your apartment. Please click on the area on the drawing that indicates your preferred spot where you spend most of your time in the **<u>sleeping area</u>** in summer.



36. Can you please explain if your preference of the spot that you selected in the previous question is related in any way to its location from the windows?

☐

37. What is your most common activity level in the **sleeping area** in summer?
   ☐ Reclining
   ☐ Seated
   ☐ Standing relaxed
   ☐ Light activity standing
   ☐ Medium activity standing
   ☐ Hight activity

38. How often would you say that you have been operating **windows** in your sleeping area over the last week?

   Never 1 2 3 4 5 6 7 Very frequently

39. How often would you say that you have been adjusting **blinds** in the sleeping area over the last week?

   Never 1 2 3 4 5 6 7 Very frequently

40. How much would you say that you have been operating **windows** in your sleeping area over the last week?
   Fully closed 1 2 3 4 5 6 7 Fully opened


41. How much would you say that you have been adjusting **blinds** in the sleeping area over the last week?

   Fully closed 1 2 3 4 5 6 7 Fully opened


42. Operating **windows** in my sleeping area in summer is:

   Extremely harmful 1 2 3 4 5 6 7 Extremely beneficial

43. What do you think are drawbacks of operating **windows** in the sleeping area in summer? (Please select all that apply)
   - ☐ Operating windows has no drawbacks
   - ☐ It causes an undesired change in temperature
   - ☐ It causes an undesired change in airflow
   - ☐ It raises air pollution concerns
   - ☐ It raises noise concerns
   - ☐ It wastes energy, please explain why:
   - ☐ If other, please specify:

44. What do you think are benefits of operating **windows** in the sleeping area in summer? (Please select all that apply)
   - ☐ Operating windows has no benefits
   - ☐ It causes a desired change in temperature
   - ☐ It causes a desired change in airflow
   - ☐ It eliminates air pollution concerns
   - ☐ It brings in outdoor pleasant sounds
   - ☐ It saves energy, please explain why:
   - ☐ If other, please specify:

45. Adjusting **blinds** in my sleeping area in summer is:

Extremely harmful 1 2 3 4 5 6 7 Extremely beneficial

46. What do you think are drawbacks of adjusting **blinds** in the sleeping area in summer? (Please select all that apply)
   - ☐ Adjusting blinds have no drawbacks
   - ☐ It causes an undesired change in temperature
   - ☐ It causes an undesired change in the amount of daylighting
   - ☐ It hinders access to outdoor views
   - ☐ It raises privacy concerns
   - ☐ It wastes energy, please explain why:
   - ☐ If other, please specify:

47. What do you think are benefits of adjusting **blinds** in the sleeping area in summer? (Please select all that apply)
- ☐ Adjusting blinds has no benefits
- ☐ It causes desired change in temperature
- ☐ It causes desired change in the amount of daylighting
- ☐ It allows access to outdoor views
- ☐ It improves privacy concerns
- ☐ It saves energy, please explain why:
- ☐ If other, please specify:

48. Most people whose opinions I value would appreciate me operating the **windows** in the sleeping area.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

49. Most people whose opinions I value would appreciate me adjusting **blinds** in my sleeping area.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

50. For me, operating **windows** in my sleeping area are:

Extremely difficult 1 2 3 4 5 6 7 Extremely easy

51. For me, adjusting **blinds** in my sleeping area is:

Extremely difficult 1 2 3 4 5 6 7 Extremely easy

52. I intend to operate **windows** in my sleeping area in the next week.

Extremely unlikely 1 2 3 4 5 6 7 Extremely likely

53. I intend to adjust **blinds** in my sleeping area in the next week.

Extremely unlikely 1 2 3 4 5 6 7 Extremely likely

54. In the past week, I have operated **windows** in my sleeping area.

Extremely false 1 2 3 4 5 6 7 Extremely true

55. In the past week, I have adjusted **blinds** in my sleeping area.

Extremely false 1 2 3 4 5 6 7 Extremely true

To make sure that this research represents everyone in your community, the next questions are about you and your household.

56. What is your approximate age? (Please select one answer)
    - ☐ 18-24 years old
    - ☐ 25-34 years old
    - ☐ 35-44 years old
    - ☐ 45-54 years old
    - ☐ 55-64 years old
    - ☐ 65 years or older
    - ☐ Prefer not to answer

57. What is your gender? (Please select one answer)
    - ☐ Male
    - ☐ Female
    - ☐ Other Please Specify: ________
    - ☐ Prefer not to answer

58. How would you describe yourself? (Please select all that apply)
    - ☐ American Indian or Alaska Native or Indigenous or First Nations
    - ☐ Asian or Asian American
    - ☐ Black or African American
    - ☐ Native Hawaiian or Pacific Islander
    - ☐ White or Caucasian or European American
    - ☐ Arab or Middle Eastern
    - ☐ Other Please Specify: ________
    - ☐ Prefer not to answer

59. What is the highest degree or level of school you have completed? (If you are currently enrolled in school, please indicate the highest degree you have *received.*)
    - ☐ Less than a high school diploma
    - ☐ High school degree or equivalent (e.g. GED)
    - ☐ Some college, no degree
    - ☐ Associate degree (e.g. AA, AS)
    - ☐ Bachelor’s degree (e.g. BA, BS)
    - ☐ Master’s degree (e.g. MA, MS, MEd)
    - ☐ Professional degree (e.g. MD, DDS, DVM)
    - ☐ Doctorate (e.g. PhD, EdD)
    - ☐ Other Please specify: ________
    - ☐ Prefer not to answer

60. Please select the answer that best describes your affiliation with MSU. (Please select one answer)
- ☐ MSU student yourself
- ☐ Spouse or domestic partner of MSU student
- ☐ Child of MSU student
- ☐ Relative of MSU student
- ☐ Other
- ☐ Prefer not to answer

Please specify: ☐

What is your marital status? (Please select one answer)
- ☐ Single
- ☐ Married or domestic partnership
- ☐ Widowed
- ☐ Divorced
- ☐ Separated
- ☐ Other Please specify: ☐
- ☐ Prefer not to answer

61. What is your current employment status? (Please select all that apply)
- ☐ Employed full-time (40 or more hours per week)
- ☐ Employed part-time (up to 39 hours per week)
- ☐ Unemployed and currently looking for work
- ☐ Unemployed and not currently looking for work
- ☐ Undergraduate student
- ☐ Graduate student
- ☐ Retired
- ☐ Homemaker
- ☐ Self-employed
- ☐ Unable to work
- ☐ Other Please specify: ☐
- ☐ Prefer not to answer

62. What is your yearly average household income? (Please select one answer)
- ☐ $ 0
- ☐ $ 1- $ 12,000
- ☐ $ 12,001- $ 24,000
- ☐ $ 24,001- $ 36,000
- ☐ $ 36,001- $ 48,000
- ☐ $ 48,001- $ 60,000
- ☐ $ 60,001- $ 72,000
- ☐ $ 72,001- $ 84,000
- ☐ $ 84,001- $ 96,000
- ☐ $ 96,000 or more
- ☐ Other Please specify: ☐
- ☐ Prefer not to answer

Please provide all the information below, and we will send you the $5 gift card.

- ☐ Building Number:
- ☐ Apartment Number:
- ☐ Email address:

Please feel free to share the link to this survey with family members who are living with you in the same apartment and they will get an additional $ 5 gift card as a thank you for completing the survey.

Thank you so much for taking the time to respond to this questionnaire!

APPENDIX C:

FIRST SURVEY REMINDER

Date: November 13th, 2019

Subject Line: 1855 Place Resident, Share Your Feedback Once More. Get Another $5 Amazon Gift Card.

Message Body:

Dear 1855 Place Resident,

This is Hebatalla Nazmy, a Ph.D. student in the School of Planning, Design, and Construction at Michigan State University. I am requesting your input in as a resident of Michigan State University Family Housing. I am researching the occupants' behaviors in controlling indoor environment conditions, specifically through operating windows and adjusting blinds. **This is the second and last round of this survey in which the questions focus on occupant-building interaction during the winter months.**

The United States Environmental Protection Agency (EPA) reports that people spend about 90 percent of their time indoors. Also, research shows that indoor environmental conditions impact the occupants' wellbeing, health, comfort, and satisfaction. Therefore, the occupants' feedback on how and why they control the indoor environmental conditions is very informative to design high quality and environmentally friendly buildings.

You are invited to participate in a 15-20-minute online survey. Your information and responses will be confidential.

Please help a fellow spartan and get a $5 Amazon gift card!

Click here to take the survey

Or copy and paste the URL below into your internet browser:
https://msu.co1.qualtrics.com/jfe/form/SV_20hVm7OvjKcL6AZ

All 1855 Place residents are encouraged to participate - Please feel free to share the link to this survey with family members who are living with you in the same apartment and they will get an **additional $5 Amazon gift card** as a thank you for completing the survey.

For more information, please contact Hebatalla Nazmy at nazmyheb@msu.edu

Many Thanks,

Hebatalla Nazmy
Ph.D. Candidate, LEED AP
Environmental Design
School of Planning, Design, and Construction
Michigan State University

APPENDIX D:

SECOND SURVEY REMINDER

Date: November 20th, 2019

Subject Line: 1855 Place Resident, Share Your Feedback Once More. Get Another $5 Amazon Gift Card.

Message Body:

Dear 1855 Place Resident,

Last week, an email was sent to you asking for your help with a study about occupants' behaviors in controlling indoor environment conditions, specifically through operating windows and adjusting blinds. **This is the second and last round of this survey in which the questions focus on occupant-building interaction during the winter months.**

If you or someone in your household has already completed the questionnaire, please accept our sincere thanks. If not, please consider participating in a 15-20-minute online survey. Your information and responses will be confidential.

Please help a fellow spartan and get a $5 Amazon gift card!

Click here to take the survey

Or copy and paste the URL below into your internet browser:
https://msu.co1.qualtrics.com/jfe/form/SV_20hVm7OvjKcL6AZ

All 1855 Place residents are encouraged to participate - Please feel free to share the link to this survey with family members who are living with you in the same apartment and they will get an **additional $5 Amazon gift card** as a thank you for completing the survey.

For more information, please contact Hebatalla Nazmy at nazmyheb@msu.edu

Many Thanks,

Hebatalla Nazmy
Ph.D. Candidate, LEED AP
Environmental Design
School of Planning, Design, and Construction
Michigan State University

APPENDIX E:

THIRD SURVEY REMINDER

Date: December 4th, 2019

Subject Line: 1855 Place Resident, Share Your Feedback Once More. Get Another $5 Amazon Gift Card.

Message Body:

Dear 1855 Place Resident,

About three weeks ago, an email was sent to you asking for your help with a study about occupants' behaviors in controlling indoor environment conditions, specifically through operating windows and adjusting blinds. **This is the second and last round of this survey in which the questions focus on occupant-building interaction during the winter months.**

The occupants' feedback on how and why they control the indoor environmental conditions is very informative to design high quality and environmentally friendly buildings. You are receiving this email again because of the importance that your responses have for helping to get accurate results.

If you or someone in your household has already completed the questionnaire, please accept our sincere thanks. If not, please consider participating in a 15-20-minute online survey. Your information and responses will be confidential.

Please help a fellow spartan and get a $5 Amazon gift card!

Click here to take the survey

Or copy and paste the URL below into your internet browser:
https://msu.co1.qualtrics.com/jfe/form/SV_20hVm7OvjKcL6AZ

All 1855 Place residents are encouraged to participate - Please feel free to share the link to this survey with family members who are living with you in the same apartment and they will get an **additional $5 Amazon gift card** as a thank you for completing the survey.

For more information, please contact Hebatalla Nazmy at nazmyheb@msu.edu

Many Thanks,

Hebatalla Nazmy
Ph.D. Candidate, LEED AP
Environmental Design
School of Planning, Design, and Construction
Michigan State University

APPENDIX F:

FOURTH SURVEY REMINDER

Dear 1855 Place Resident,

In recent weeks, a letter was sent to you asking for your input in a study about occupants' behaviors of operating windows and adjusting blinds. You are receiving this postcard because of the importance that your responses have for helping to get accurate results.

If you or someone in your household has already completed the questionnaire, please accept our sincere thanks. If not, please consider participating in a 15-20 minutes online survey by 1/31/2020 and get a **$5 Amazon gift card!**

All 1855 Place residents are encouraged to participate and get an **additional $5 Amazon gift card**.

Please copy and paste the URL below into your internet browser:
https://msu.co1.qualtrics.com/jfe/form/SV_20hVm7OvjKcL6AZ

Or scan this QR code using your smartphone

For more information, please contact Hebatalla Nazmy at nazmyheb@msu.edu

Many Thanks,
Hebatalla Nazmy, PhD Candidate, SPDC, MSU

APPENDIX G:

IRB APPROVAL LETTER

MICHIGAN STATE
UNIVERSITY

EXEMPT DETERMINATION
Revised Common Rule

July 2, 2019

To: Suk Kyung Kim

Re: **MSU Study ID:** STUDY00002932
Principal Investigator: Suk Kyung Kim
Category: Exempt 2i
Exempt Determination Date: 7/2/2019
Limited IRB Review: Not Required.

Title: Examining the Relationship Between Occupants' Energy-Related Behaviors and Spatial Contextual Factors Using an Agent-Based Modelling Approach

This study has been determined to be exempt under 45 CFR 46.104(d) 2i.

Principal Investigator (PI) Responsibilities: The PI assumes the responsibilities for the protection of human subjects in this study as outlined in Human Research Protection Program (HRPP) Manual Section 8-1, Exemptions.

Continuing Review: Exempt studies do not need to be renewed.

Modifications: In general, investigators are not required to submit changes to the Michigan State University (MSU) Institutional Review Board (IRB) once a research study is designated as exempt as long as those changes do not affect the exempt category or criteria for exempt determination (changing from exempt status to expedited or full review, changing exempt category) or that may substantially change the focus of the research study such as a change in hypothesis or study design. See HRPP Manual Section 8-1, Exemptions, for examples. If the study is modified to add additional sites for the research, please note that you may not begin the research at those sites until you receive the appropriate approvals/permissions from the sites.

Please contact the HRPP office if you have any questions about whether a change must be submitted for IRB review and approval.

New Funding: If new external funding is obtained for an active study that had been determined exempt, a new initial IRB submission will be required, with limited exceptions. If you are unsure if a new initial IRB submission is required, contact the HRPP office. IRB review of the new submission must be completed before new funds can be spent on human research activities, as the new funding source may have additional or different requirements.

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Human Research Protection Program

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APPENDIX H:

CURRICULUM VITAE

Hebatalla Nazmy

Ph.D., LEED® AP BD+C

E-mail: hebanazmi@gmail.com

EDUCATION

Ph.D. in Planning, Design, & Construction, concentration on Environmental Design. August 2020. Michigan State University, USA. Dissertation Title: "Examining the Relationship Between Occupants' Energy-Related Behaviors and Spatial Contextual Factors Using an Agent-Based Modeling Approach".

Master's in Interior Architecture. July 2013. Helwan University, Egypt. Thesis Title: "Virtual Environment as a Design Tool for Residential Spaces". It was chosen to be sent to Catania University in Italy.

Computer Graphic for Media Production Diploma. September 2008. Information Technology Institute, Egypt. Relevant coursework includes computer-aided drafting programs such as Maya and computer editing programs such as Illustrator Premier, Audition and Combustion and virtual reality platforms such as Second Life and Cult 3D.

Bachelor of Fine Arts. May 2007. Helwan University, Egypt. Concentrations in Interior Architecture. I was awarded annual scholarships and achieved the first rank five years on a row.

PROFESSIONAL CERTIFICATION

LEED® AP BD+C, U.S. Green Building Council. (August 2017)

LEED® Green Associate, U.S. Green Building Council. (January 2017)

Certified Green Professional (CGP), National Association of Home Builders (NAHB). (In-progress).

Certification in College Teaching, Michigan State University. (In-progress)

HONORS AND AWARDS

The abstract entitled 'Promoting Active Learning in an Interior Design Lecture-Based Course' scored in the top ten of all accepted Poster abstracts at the Interior Design Educators Council (IDEC 2019) annual conference.

The abstract entitled 'Experiential Learning Through Virtual Field Trips in History of Interior Design Education' scored in the top five of all accepted Poster abstracts at the Interior Design Educators Council (IDEC 2020) annual conference.

Fellowships

Dissertation Completion Fellowship from the College of Agriculture and Natural Resource, Office of Academic and Student Affairs, Summer 2019. **$7,000**

Scholarship of Undergraduate Teaching and Learning (SUTL). Fall 2019. Michigan State University. **$5,000**

Summer Critical Needs fellowship funds from the College of Agriculture and Natural Resource, Office of Academic and Student Affairs, Summer 2019. **$7,000**

Environmental Science and Policy Program (ESPP) fellowship. Summer 2017. Michigan State University. **$7,000**

Egyptian Ministry of Higher Education Fully Funded Ph.D. fellowship covering tuition, stipend, medical insurance, and other allowances. **$180,000**

Scholarships

Mary Louise Gephart Donnell Scholarship, Spring 2020. $3,000

Council of Graduate Student Childcare Award, Spring 2020. $300

School of Planning, Design, and Construction, and Interior Design Program Travel Fund, Spring 2020. $500

Research Enhancement Award, Fall 2019. $1,275

Margaret Mika Endowed Scholarship in Human Environment and Design, Fall 2019 and Spring 2020. $1,100

Data Visualization Summer Institute, Summer 2019. $500

College of Agriculture and Natural Resources, School of Planning, Design, and Construction, and Interior Design Program Travel Fund, Spring 2019. $250

Fellowship from Graduate School and College of Agriculture and Natural Recourses, Spring 2019. $300

School of Planning, Design, and Construction, and Interior Design Program Travel Fund, Spring 2019. $350

Margaret Mika Endowed Scholarship in Human Environment and Design, Spring 2019. $350

Mary Louise Gephart Donnell Scholarship, Fall 2018 and Spring 2019. $900

Margaret Mika Endowed Scholarship in Human Environment and Design, Fall 2018. $800

Student Parents on A Mission Scholarship, Fall 2018. $500

IAPS Young Research Workshop Grant, Summer 2018. $330

Graduate School and International Studies and Programs Travel Fund, Summer 2018. $600

Council of Graduate Student Childcare Award, Spring 2018. $500

Mary Louise Gephart Donnell Scholarship, Fall 2017 and Spring 2018. $2,887

Margaret Mika Endowed Scholarship in Human Environment and Design, Fall 2017. $613

Council of Graduate Student Childcare Award, Fall 2017. $500

Fellowship from Graduate School and College of Agriculture and Natural Recourses, Spring 2017. $1,713

Special fellowship from the College of Agriculture and Natural Recourses, Fall 2016 and Spring 2017. $500

Mary Louise Gephart Donnell Scholarship, Fall 2016 and Spring 2017. $3,150

RESEARCH ACTIVITY

Research Assistant for Associate Professor Suk-Kyung Kim, a project of national park renovations funded by the Michigan Department of Natural Resources.

Peer-Reviewed Journal Articles

Published

Nubani, L.N., Kim, S.K., Nazmy, H. (2018). Using design charrettes in interior design education to improve learning outcomes and collaboration with professionals. *Journal of Architectural and Planning Research 35*(3), 218-234.

Nazmy, H., & Kim, S.K. (2018). New urbanism and its reflection on residential interior design in Egypt. In Catalani et al. (Eds.), *Cities' Identity Through Architecture and Arts*. Paper presented at The International Conference on Cities' Identity Through Architecture and Arts, Fairmont Nile City Hotel, Cairo, Egypt, 11-13 May 2017 (pp. 59-72). London: Taylor & Francis Group.

Nazmy, H. (2015). *Virtual environment as a design tool for sustainable residential spaces in light of the theory of planned behavior.* Proceedings from Asia Pacific International Conference on Environment-Behavior Studies. Barcelona, Spain.

In preparation

Nazmy, H., & Kim, S.K. Architectural Determinants on Occupants' Blind Using Behaviors in Multifamily Residential Buildings. *Journal of Green Building*. In preparation.

Nazmy, H., & Kim, S.K. Assessment of interior designers' involvement in sustainable buildings design based on the Theory of Planned Behavior. *Journal of Interior Design*. In preparation.

Nazmy, H., & Kim, S.K. Promoting active learning in an interior design lecture-based course. *Journal of Interior Design*. In preparation.

Conference Presentations

Nazmy, H., & Kim, S.K. "Experiential Learning Through Virtual Field Trips in History of Interior Design Education" Interior Design Educators Council Conference, 5 March 2020, Hyatt Regency Tulsa Downtown, Tulsa, OK.

Nazmy, H., & Kim, S.K. "Assessment of interior designers' involvement in sustainable residential buildings design based on the Theory of Planned Behavior." Environmental Design Research Association Conference, 25 May 2019, Tandon School of Engineering, Brooklyn, NY.

Nazmy, H., & Kim, S.K. "Promoting active learning in an interior design lecture-based course." Interior Design Educators Council Conference, 7 March 2019, Sheraton/Le Meridian Charlotte Hotel, Charlotte, NC.

Nazmy, H., & Kim, S.K. "Interior designer's participation in the energy-efficient building design." International Association People-Environment Studies. 9 July 2018, Roma Tre University, Rome, Italy.

Nazmy, H., Kim, & S.K. "The relation between building, site, and occupant behavior in sustainable residential design." International Association People-Environment Studies. 10 July 2018, Roma Tre University, Rome, Italy.

Symposium Presentations

Nazmy, H., & Kim, S.K. "*Residential interior design and its reflection on the urban environment.*" Environmental Science and Policy Program Symposium. 27 October 2017, Kellogg Hotel and Convention Center, East Lansing, MI.

TEACHING EXPERIENCE

Teaching Assistant for IDES 452 (Interior Design synthesis lll). Spring 2020. Interior Design Program, School of Planning, Design, and Construction, Michigan State University. Assisting Dr. Linda Nubani in teaching the studio and grading students' projects.

Instructor for IDES 152 (Interior Environments). Fall of 2019. Interior Design Program, School of Planning, Design, and Construction, Michigan State University. Fully responsible for teaching the class of 46freshmen and sophomore students in addition to grading students' assignments and exams.

Teaching Assistant for IDES 452 (Interior Design synthesis lll). Spring 2019. Interior Design Program, School of Planning, Design, and Construction, Michigan State University. Assisting Dr. Linda Nubani in teaching the studio and grading students' projects.

Instructor for IDES 152 (Interior Environments). Fall of 2018. Interior Design Program, School of Planning, Design, and Construction, Michigan State University. Fully responsible for teaching the class of 44 freshmen and sophomore students in addition to grading students' assignments and exams.

Teaching Assistant for IDES 452 (Interior Design synthesis lll). Spring 2018. Interior Design Program, School of Planning, Design, and Construction, Michigan State University. Assisting Dr. Linda Nubani in teaching the studio and grading students' projects.

Instructor for IDES 152 (Interior Environments). Fall of 2017. Interior Design Program, School of Planning, Design, and Construction, Michigan State University. Co-teaching the class of 47 freshmen and sophomore students in addition to grading students' assignments and exams.

Assistant Instructor. Fall 2014 through Spring 2016. Faculty of Fine arts, Helwan University, Cairo, Egypt. Assisting instructor in teaching for Geometric Perspective, Design Principles, Design Studio, and Graduation Project Studio.

Teaching Assistant. Fall 2010 through Spring 2011. Arab Academy for Science, Technology and Maritime Transport, Cairo, Egypt. Assisting lecturer in Design Principles and Interior Architecture Courses.

Teaching Assistant. Fall 2008 through Spring 2013. Faculty of Fine arts, Helwan University, Cairo, Egypt. Assisting instructor in teaching for Geometric Perspective, Design Principles, Design Studio, and Graduation Project Studio.

PROFESSIONAL PRACTICE

Designer. June 2008-July 2008. ITS, Cairo, Egypt. Training in an E-Learning Company in which I worked on designing ITS campus on Second Life.

Interior Architect. May 2007-September 2007. Architectural Firm, Cairo, Egypt. Training in an architectural firm in which I worked on designing residential and hospitality projects.

Interior Architect. May 2006-September 2006. Architectural Firm, Cairo, Egypt. Training in an architectural firm in which I worked on designing healthcare and commercial projects.

SERVICE

Reviewer for Environmental Design Research Association (EDRA) 2019.

Member of Interior Design Educators Council.

INDEPENDENT STUDY AND WORKSHOPS

An Introduction to Evidence-Based Undergraduate STEM Teaching. Fall of 2019. Self-paced 8 weeks online course on edX, offered by the Center for the integration of Research, Teaching, and Learning (CIRTL).

Data Visualization Summer Institute. Summer of 2019. This summer institute allows selected faculty and graduate students to explore the pedagogic possibilities of three exciting large-scale digital learning technology platforms available at Michigan State University, East Lansing, Michigan.

Certification in College Teaching Institute. Summer 2018. Through a combination of interactive group sessions and focused breakouts, students gain skills in core competency areas of the Certification, plan a mentored teaching project, and develop the template for a final portfolio.

Leadership Academy Institute. Spring 2018. An intensive, cohort style, the developmental experience offered by Leadership Institute, Michigan State University, East Lansing, Michigan.

Quantitative Methods. Fall of 2017. Self-paced 8 weeks online course on Coursera, offered by the University of Amsterdam.

Questionnaire Design for Social surveys. Fall of 2017. Self-paced 8 weeks online course on Coursera, offered by the University of Michigan.

Introduction to Missing Data Analysis. Spring 2017. One day workshop offered by the Center for Statistical Training and Consulting, Michigan State University, East Lansing, Michigan.

Introduction to Sampling. Spring 2017. One day workshop offered by the Center for Statistical Training and Consulting, Michigan State University, East Lansing, Michigan.

EXHIBITION

Crafting Light. 2010. An exhibition of the outputs of a lighting units' design workshop organized by Rimal and Al Khatoun at Sabil El Selehdar, Cairo, Egypt.

REFERENCES

REFERENCES

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