

System's Energy Levels
 Low ————— High

Any energy level above the ground state is possible

..... Ground state



1 Introduction

1.1 Background and problem definition

Problem definition

People spend about 60% of their time in their homes: environments in which the person should feel comfortable and be healthy on account of the technical services and systems in their building (Jia, Srinivasan, & Raheem, 2017). The supply of a comfortable environment should be achieved in an energy efficient way, especially if we are to achieve the EU 2020 or 2030 targets of residential energy consumption. However, in spite of the technological advancements and energy efficient technologies that have already been developed to provide comfort, energy consumption is not decreasing at the rate it should (Tsemekidi Tzeiranaki et al., 2019). There are several complex factors affecting energy consumption of which occupant behaviours is one of them, and building systems, services, and products being some of the others. Moreover, the indoor environmental quality (IEQ) field seems to focus mainly on the thermal and other physiological aspects of comfort and energy expenditure. Yet, collaboration of the IEQ field with the fields of energy engineering and social sciences to combine knowledge to have a better grasp of both sides –building and occupant- of the issue of consumption, does not seem to occur (D'Oca, Hong, & Langevin, 2018; Sovacool, 2014). Therefore, the problem that energy savings have not been achieved with the currently available technological developments could be related to the behavioural factors influencing energy consumption.

Behavioural impact on energy use

Energy consumption in houses is partly the result of the way in which the occupants behave and interact with their comfort-providing technologies and their interfaces. This is because several of the behaviours exercised at home are done to achieve comfort, and many of them spend energy: either by using gas or electricity. It is estimated that occupant behaviours influence the final energy consumption of homes by factors of between 3 to 10 (D'Oca et al., 2018; Hong, Taylor-Lange, D'Oca, Yan, & Corgnati, 2016). Other behavioural factors that have an impact on the final energy use of the house are the characteristics of the occupants and of the household, lifestyles, schedules, socioeconomic status, or culture. Some of the unintended consequences of not studying behaviours when developing comfort-providing, energy-consuming technologies are phenomena such as the rebound effect, hacking of the technologies, rejection, or misuse, all tending to lead to higher-than-expected energy consumption (Scott, Bakker, & Quist, 2012). Other problems of neglecting the human factors in energy engineering result in performance gaps: the difference between actual and theoretical energy consumption; created by the occupant lifestyle and behaviours: variables that are not taken into account when calculating energy performance of a residence. Actual energy consumption is obtained from the final energy bills of a household, taking into account every behavioural pattern and appliance utilized by the householder. Theoretical consumption is the projected consumption of a household, by only taking into account lighting, heating, hot water, but excluding potential appliances that the occupants will use. Appliances represent an average of 32% of the final household energy consumption (Majcen, 2016; D Majcen, LCM Itard, & H Visscher, 2013; Milieucentraal, 2016).

Occupants carry out in their homes a wide variety of activities that result in energy expenditure. Many of which are performed to achieve comfort -beyond a thermal comfort or other physiological type of comfort. Several of these comfort-driven behaviours are also guided by the lifestyle of the occupant, their culture, their background, and their mental models and worldviews.

Behavioural Theories

Consequently, such behaviours need to be investigated and understood in depth, and to do so, it is necessary to study the factors lying behind and influencing behaviour both internally and externally. Internal factors are related to the psychology of the individual and external ones are environmental factors (positive or negative stressors or stimuli) to which the individual reacts and interacts with (Bluyssen, 2014b). To study behaviours, their motivations and influencing factors, behavioural theories are used.

Fields in the social sciences have different theories to study “energy behaviours”. It has to be noted that social sciences do not seek to predict behaviours: their purpose is to observe and describe tendencies. The reason for a focus on tendencies, rather than on predictions, is that humans, their behaviours, and contexts, are all factors that vary greatly for predictions to be made. Behavioural theories exist with four main lenses: economics, psychological, sociological, and educational.

Each of the theories offers tools to observe the phenomenon of ‘energy consumption’, and each theory describes the phenomenon under different aspects of the behaviours. The four theories can be divided into two main schools of thought: those that have a focus on the ‘Individual’ as the energy user and those with a focus on the ‘Practices’ themselves. In the first case, the individual is someone who takes choices in a rational or irrational way, and his or her behaviours are the result of several factors, conscious or unconscious as well as some external variables. Psychology and economy theories are usually from the ‘Individual’ school of thought. The other school of thought puts the emphasis on the practices and context around which the individual and behaviours occur. This is the case with sociological and educational theories, in which variables such as communities, social norms, family, energy supply companies, etc. also take a role in the final behaviours (Chatterton, 2011).

Social practice approaches have been carried out for several years by researchers, such as Schatzki (1996), Shove (2014), and Strengers (2014). In such approach, practices that people perform are studied and understood across space and time, and the research in the field aims at studying patterns of group behaviours. In those studies, practices are defined as the results of shared social meanings (of brands, companies, suppliers, appliances) and social norms. Furthermore, ‘energy use’ is defined as the result of achieving such social practices. Ultimately, social practice theory aims at understanding trends and patterns of not only energy demand, but also provision, and supply, in order to explain how they change, develop and interact across space and time.

Theory of Interpersonal Behaviour

The core of the methodology of this thesis (see section 1.4) is a human-centered design approach. Additionally, in this project, comfort is assumed as a personal perception, and energy use is assumed as the result of exercising behaviours to achieve comfort. Because of the human-centered nature of this thesis, an individualist model of behaviour was selected to study energy behaviours and comfort, in addition to the fact that in this project the mental processes behind energy-consuming comfort-driven behaviours are the main study element.

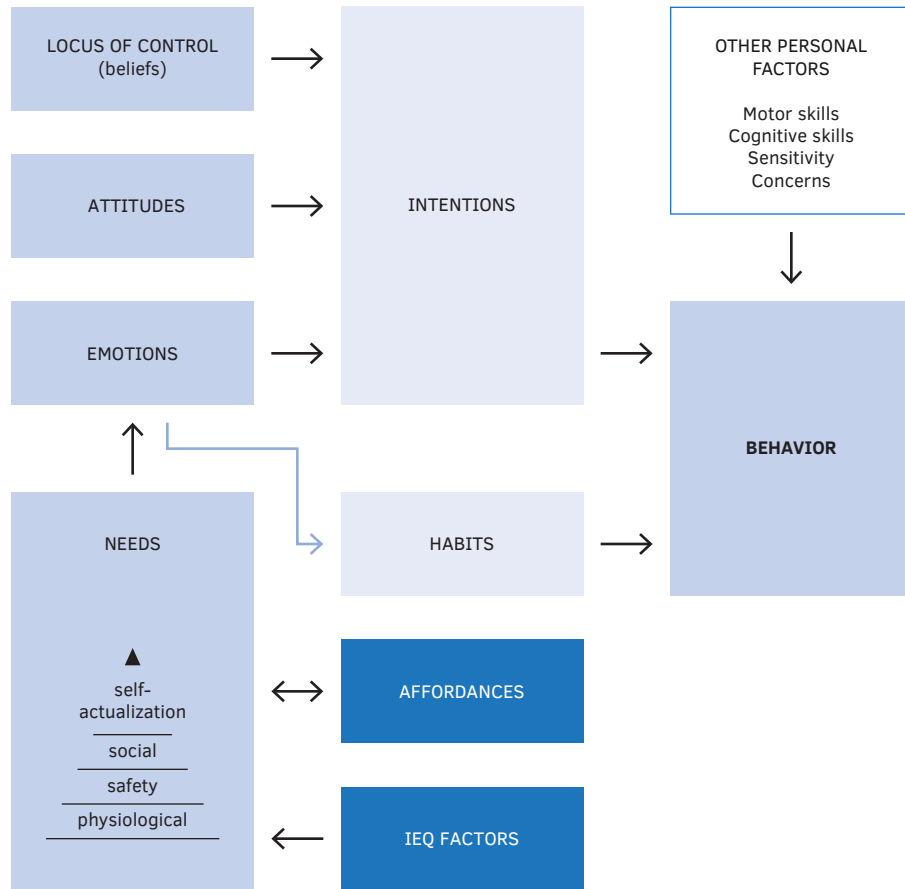


FIG. 1.1 Diagram of adapted version of theory of interpersonal behaviour (Triandis, 1977).

The approach used in this thesis, is an adapted version of the Theory of Interpersonal Behaviour (TIB) by Triandis; it observes behaviours as exercised by a specific actor –in this case the home occupant– in a rational or semi-rational process (Triandis, 1977, 1980, 1989, 2018). This model has been successfully and widely applied amongst several fields especially related to sustainability and energy (i.e. health behaviours, technology adoption, dietary behaviours, sustainable product use), which is not the case with other individual models. Another reason for using it is that when compared to other individual behavioural models, TIB is more comprehensive and includes many of the factors used in other models to study energy behaviours (Jackson, 2005; Martiskainen, 2007; Sung, Cooper, & Kettley, 2019) Finally, the individualist model is more adequate to use in this project, as opposed to a social model, as the mental processes of energy-consuming comfort driven behaviours of the home occupants are the main focus.

The core of the model contends that there are several elements motivating and influencing behaviour. Figure 1.1 shows an adapted version of the TIB model. The TIB, in brown, shows the elements that guide behaviours: beliefs (in this case locus of controls), attitudes, emotions, and need. Habits are not part of intentions, and hence are special types of behaviours. The elements in purple are environmental elements. Affordances are environmental features that allow needs to be satisfied; while IEQ factors are stimuli only perceived physiologically but processed and interpreted by the brain.

Attitudes can be conscious (cognitive) and unconscious (affective). Affective attitudes refer to a person's feelings in response to an object, situation, or concept—in the domain of this thesis, to energy and energy use. Cognitive attitudes are the conscious beliefs about energy. Attitudes act as drivers that pull the person to act in certain ways. In the thesis, the questions for the attitude section of the questionnaire were developed from the guidelines as proposed by Ajzen (2006), for which six items related to energy and energy consumption were selected and paired with five-point scale semantic differentials. The use of these guidelines has been validated in a variety of fields to measure attitudes.

Locus of control is also referred to as “control beliefs”; they are the degree to which a person believes they can influence their environment. The locus of control scale by Levenson (1981) was used since it is the best established questionnaire for measuring an individual's locus of control, having been used in several fields. For this project, the scale was adapted for the domain of the home environment by using questions about concepts of the immediate residential environment. The formulation of these items was based on the “Internal Control” and “External Control” dimensions of the original instrument, with nine items per dimension.

In this work, the terms affordances and needs go hand in hand. A need is what an individual finds necessary to be satisfied, while an affordance is the object that allows that need to be satisfied. In other words, affordances are elements that the environment provides so that a person can perform an action to satisfy a need. In the questionnaire, questions were developed by selecting items from the housing literature, that relate to psychosocial and physiological comfort. These were rated on a 5-point scale in which a high rating indicated high importance of the item to be an affordance for comfort.

Emotions are constantly guiding an individual's behaviour. Emotions are affective reactions to an environmental stimulus. These reactions occur at psychological and physiological levels. Emotions are a driver of human behaviour, health, and comfort, since emotional, behavioural, and cognitive processes interact with the nervous and

immune systems (Ortony, Norman, & Revelle, 2012). Several tools exist to assess emotions. Here, an adapted version of PrEmo2 by Laurans and Desmet (2012) was used, as it is one of the few instruments using non-verbal scales.

Finally, the TIB and several other behavioural theories contend that habits are an important element of behaviour; however, they have to be treated differently to 'normal' behaviour. Habits are different to the rest of behaviours because they are semi-unconscious, repetitive, goal oriented, and are triggered by environmental stimuli (Wood & R nger, 2016). Because they bring a reward after execution, they play an important role to relieve stress. In this study's questionnaire, an adapted version of the Self-Report Habit Index by Mar chal (2010) was used; an instrument validated in previous questionnaires for people's habits in relation to energy use.

1.2 Aim of the study

The aim of this thesis is to better understand energy use of home occupants from a comfort-driven perspective by proposing an innovative way to research it. This is done by taking a human-centered design approach to the challenge of energy consumption and comfort.

1.3 Research questions

Following from the aim of this study the main research question emerges.

Main Question

How can energy behaviours be studied from a comfort-driven perspective in order to facilitate the development of environmental features that support more efficient occupant behaviours and that provide the comfort needs of the person?

The main question is deconstructed into each of the following key questions, which are answered in different chapters of this dissertation.

Key Questions

Part 1: Literature Review and development of Questionnaire (Chapter 2)

- 1 What lies behind behaviour?
- 2 What characterizes habits?
- 3 What is comfort?
- 4 How do home occupants achieve comfort?
- 5 How are comfort behaviours and energy use related in homes?

This chapter deals with the background of this dissertation. It presents a review performed to understand the steps, concepts, and variables needed to identify home energy use and its relation to comfort behaviours. Comfort is presented from different fields, from a biological perspective to emotional, behavioural, and physiological ones. The relationships between comfort, health, and wellbeing are also presented. Further on, focus is given to the energy use in buildings, and it is proposed how the energy use is related to behaviours and ultimately comfort. It is concluded that comfort is a psycho-behavioural reaction to environmental stimuli. The results of this literature review served as the stepping-stone for the development of the questionnaire (Ortiz, Kurvers and Bluysen, 2017).

Part 2: Validation of Questionnaire, Analysis, and Development of Clusters (Chapter 3)

- 6 Can home occupants be grouped based on their behavioural motivations?

This chapter describes the administration of the newly developed questionnaire designed to study comfort behaviour and the selection of a good method to cluster respondents. A pilot study was performed on a sample of students from the faculty of Architecture and the Built Environment of the TU Delft. With the use of the TwoStep cluster analysis, clusters were created based on the variables of the questionnaire. With this sample, six preliminary archetypes were found. It was concluded that the developed questionnaire and the analysis method –the TwoStep cluster analysis– were an adequate method and tool to identify clusters of comfort-driven, energy-consuming patterns. However, to validate and fine tune the clusters, qualitative data from the occupants (interviews about habits, actions, needs, motivations) needed to be collected and incorporated to the clusters as well (Ortiz and Bluysen 2018). The results of this proof-of-concept gave the green light to administer the questionnaire to the full sample, from which five final clusters were produced and were the subject of study in the subsequent parts.

Part 3: Enhancement of clusters with Interview data and building features data (Chapter 4)

- 7 How does the indoor environment of occupant archetypes differ?
- 8 How do the characteristics of their buildings differ?
- 9 How do the different archetypes differ in their daily use of energy?
- 10 How do the different archetypes express comfort habits, energy, and affordances in their homes?

This chapter shows the development of the final archetypes, by administering the questionnaire to 761 respondents, and by substantiating the TwoStep cluster analysis results with those of a field study, in which interviews, IEQ monitoring, energy readings, and building checklist data were taken. Five clusters were found with the statistical analysis. The field study was performed with 15 participants, who volunteered to be interviewed and to have their dwellings monitored. The results identified that home characteristics and the indoor environment did not seem to determine the archetypes. However, energy consumption varied greatly among archetype, albeit, the sample was too small to conclude statistically significant differences. Furthermore, the analysis of the interviews suggested that each of the archetypes expresses different sentiments about their opinions on comfort habits, energy use, and environmental affordances (Ortiz and Bluysen 2019).

Part 4: Development of the Final Archetypes (Chapter 5)

- 11 How do the archetypes differ in their “home comfort experience”?
- 12 How do the archetypes perceive their own “experience of using energy in their homes”?

In this chapter, the enhanced archetypes are further complemented with the data from focus groups. In the focus groups, representatives of each of the archetypes were invited to produce, with generative techniques, artefacts that express their mental models in terms of the meaning of using energy in their homes, and what they regard as being an ideal home experience. It was concluded that indeed, each type of occupant processes their past experiences of energy consumption differently from each other, with some being more concerned in personal, financial, or environmental factors. Likewise, each of the archetypes has different desires, wishes, needs, and expectations as to what an ideal home experience should be (Ortiz, Kim, Bluysen 2019).

1.4 Methodology

The methodology of this research is a mixed-methods procedure and is divided into four parts, as shown below. The core of the methodology is grounded on a human-centered design approach aiming at studying phenomena by keeping people's lives and desires at the core, allowing achieving innovative solutions. In other words, human-centered design is a creative problem-solving process with a starting point from the people one designs for and with an end point of new solutions that are custom-made to satisfy their needs (IDEO.org, 2015).

The choice of methods is intended to delve into different types of occupant knowledge, which ranges from procedural knowledge (conscious) to interpretive knowledge (unconscious) (Bogner et al., 2009). Thus, as depicted in Figure 1.2 below, different methods exist to collect data from different levels of consciousness. The advantage of such techniques is that deep-lying needs and values are elicited, rather than only what people think they need (Visser et al., 2005).

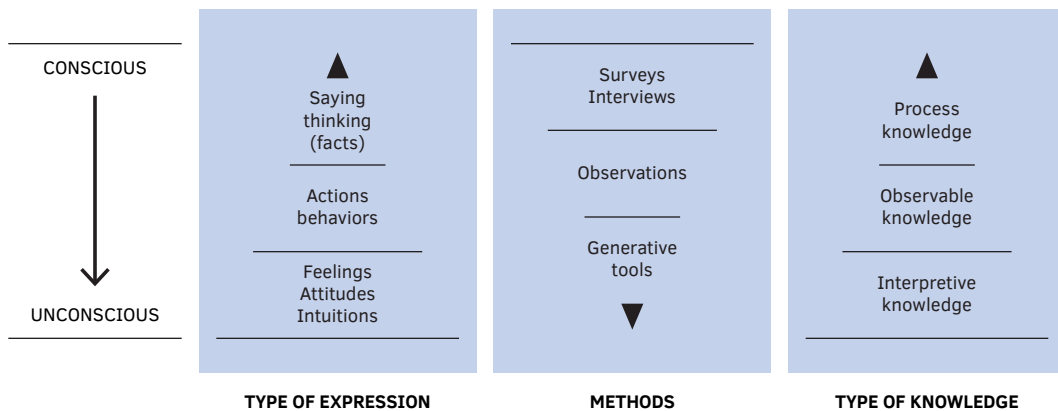


FIG. 1.2 Knowledge levels and respective eliciting methods (adapted from (Bogner et al., 2009; Visser et al., 2005)).

Part 1

The first part of the research involves carrying out a state-of-the-art review, with the most current research on the topics of comfort, from a multidisciplinary perspective, as well as behavioural theories, and energy consumption and behaviours at home. From its outcomes, the questionnaire was developed (see Appendix A) as key factors were identified to assess to understand comfort and energy behaviours.

Publications:

- Ortiz Sanchez, M., Kurvers, S., & Bluysen, P. M. (2016). Energy consumption and comfort in homes. In P. K. Heiselberg (Ed.), CLIMA 2016: proceedings of the 12th REHVA World Congress (Vol. 6, pp. 1-11). [765] Aalborg: Aalborg University.
- Ortiz Sanchez, M., Kurvers, S. R., & Bluysen, P. M. (2017). A review of comfort, health, and energy use: Understanding daily energy use and wellbeing for the development of a new approach to study comfort. *Energy and Buildings*, 152, 323-335. <https://doi.org/10.1016/j.enbuild.2017.07.060>

Part 2

The second phase is the development of the questionnaire, pilot testing it, and administering it. Additionally, several possible analysis approaches were researched, and the TwoStep cluster analysis was selected as the most adequate one, based on the type of variables. This was published as a proof-of-concept. Following the proof-of-concept step, the questionnaire was administered to the rest of the population and analysed in its entirety. The final Cluster model was produced, in which the outcome was five clusters.

Publications

- Ortiz Sanchez, M., Kurvers, S., & Bluysen, P. M. (2017). Introduction to a questionnaire for occupant energy and wellbeing behaviours in homes. In Proceedings of the international scientific conference Healthy Buildings 2017-Europe [0021]
- Ortiz Sanchez, M., & Bluysen, P. M. (2018). Proof-of-concept of a questionnaire to understand occupants' comfort and energy behaviours: First results on home occupant archetypes. *Building and Environment*, 134, 47-58. <https://doi.org/10.1016/j.buildenv.2018.02.030>

Part 3

Phase 3 involved a trial workshop to assess habits and a mixed-methods field study. For the workshop, with a special methodology, students were asked to think of comfort-driven energy-consuming habits. For the field study, representatives from each of the clusters from the previous phase were asked to be interviewed and to have their IEQ at home monitored. Fifteen interviews were conducted, IEQ measurements were taken, and their actual energy readings were recorded for one month in the summer. Interviews were analysed with sentiment analysis and the descriptive statistics were done for the quantitative data. These were used to complete and substantiate the clusters and produce the behavioural profiles.

Publications

- Ortiz Sanchez, M., & Bluysen, P. M. (2018). Qualitative classification of energy consuming habits of young home occupants. Abstract from Behave 2018: 5th European Conference on Behaviour and Energy Efficiency, Zurich, Switzerland.
- Ortiz Sanchez, M., & Bluysen P. M. (2019). “Developing home occupant archetypes: first results of mixed- methods study to understand occupant comfort behaviours and energy use in homes”. *Building and Environment*, 163, 106331. <https://doi.org/10.1016/j.buildenv.2019.106331>.

Part 4

Seventeen participants representing each of the five Archetypes were invited to take part in focus group sessions. The focus groups were conducted to gain deeper understanding on the tacit knowledge of each of the profiles about energy use at home and their comfort ideals. This data was analysed qualitatively with affinity diagrams and used to have a complete picture of the Archetypes.

Publications

- Ortiz Sanchez, M., & Bluysen P. M. (2019). “Substantiation of Home Occupant Archetypes with Generative Techniques: Analysis and Results of Focus Groups”. *Building Research & Information*, submitted.

1.5 Outline of thesis

As shown in Figure 1.3, in addition to the introduction and the conclusion, this dissertation has four parts to it:

Part 1, Literature Review and development of Questionnaire, has its basis on the literature review which culminates in a proposition to a new perspective of comfort and energy behaviours (Chapter 2). This literature review results in the development of the questionnaire.

Part 2, Administration and validation of Questionnaire, development of Clusters, validates the questionnaire as an appropriate instrument for the topic, and demonstrates that the clustering method is suitable for the analysis (Chapter 3).

In Part 3, Enhancement of clusters with Interview data and building features data, the full dataset with 761 respondents was analysed with the TwoStep cluster analysis, resulting in the five final clusters. Then, a field study was carried out with representatives of each cluster in which they were interviewed and their homes were monitored. The results of the field study served as the enhancement of the clusters to develop the archetypes (Chapter 4).

Part 4, Complementing the archetypes with qualitative data from focus groups, shows the results of the presentation of the final archetypes, with them being complemented with the data generated in the focus groups (Chapter 5).

Finally, Chapter 6 shows the conclusions and recommendations of the entire work, by answering the key questions and the main questions, and providing a final detailed description of the archetypes as well as the environmental features that they need to improve their comfort while reducing their energy consumption.

INTRODUCTION

Chapter 1
- Background
- Aim of the research
- Research questions
- Methodology

PART 1: STATE-OF-THE-ART

Chapter 2
A review of comfort, health, and energy use: Understanding daily energy use for the development of a new approach to study comfort.

Development of questionnaire

PART 2: QUANTITATIVE OCCUPANT DATA

Questionnaire full sample

6-Cluster model

Chapter 3
Proof-of-Concept of a questionnaire to understand occupants' comfort and energy behaviors: First results of home occupant archetypes.

PART 3: MIXED METHODS FIELD STUDY

Field Study:
Interviews
IEQ monitoring
Energy Readings
Building checklist

Chapter 4
Developing home occupant archetypes: Understanding occupant comfort behaviors and energy use at home.

Five Preliminary Archetypes

PART 4: QUALITATIVE OCCUPANT DATA

Chapter 5
Substantiation of occupant archetypes with the use of generative techniques: analysis and results of focus groups.

Focus Groups sessions

CONCLUSIONS

Chapter 6:
- Answer to research questions
- Strengths and limitations
- Future recommendations
- Implications

Full archetypes + Archetypal design parameters

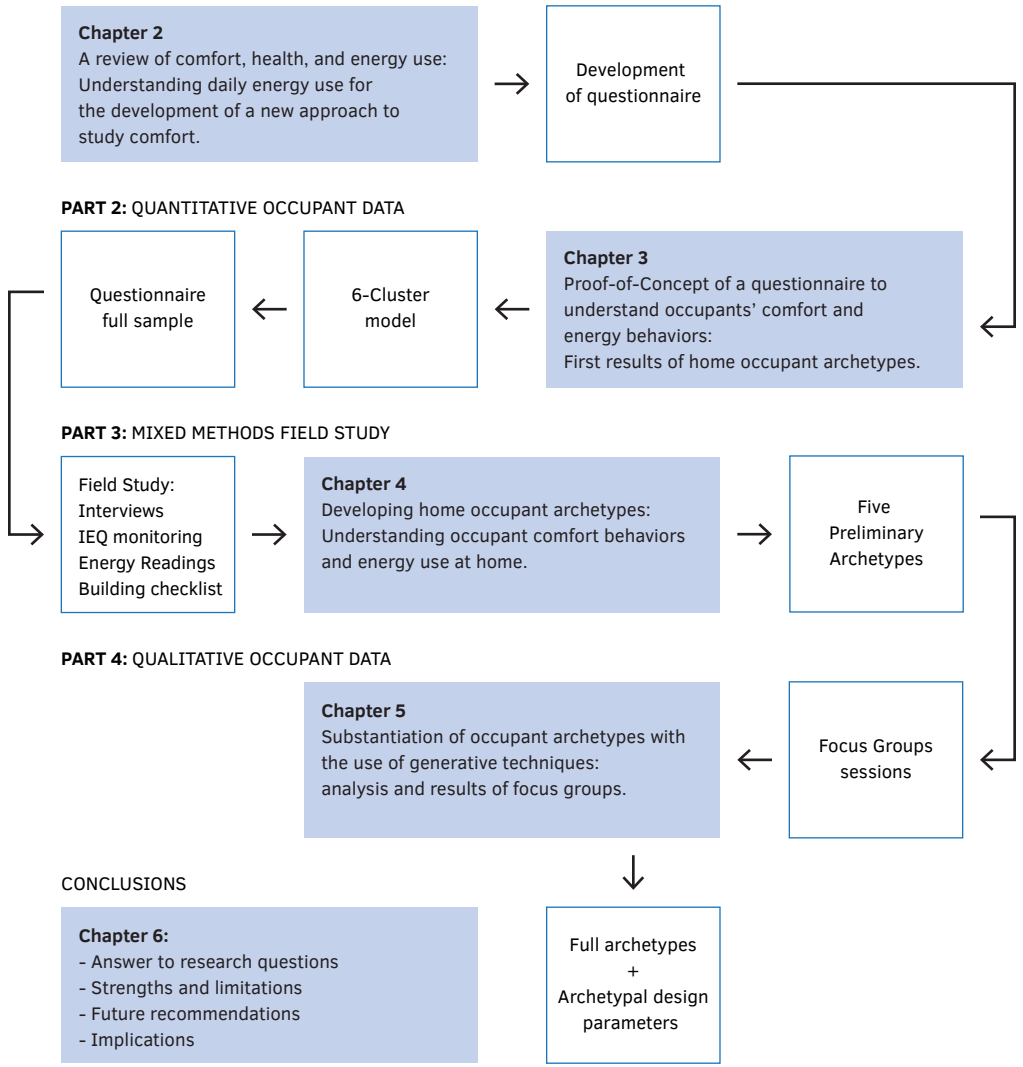


FIG. 1.3 Outline of thesis

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