The Role of Inhabitants’ Practices in Energy Use: The Kingdom of Saudi Arabia as Case Study

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Abstract

Saudi Arabia is considered to be one of the highest consumers of energy per capita because around 70% of its dwellings are uninsulated, which contributed to an increase in its energy demand. Some research has been undertaken about energy consumption in Saudi houses, which has focused on the technical and simulation aspects as a mean to reduce energy demand. This research was undertaken to understand the inhabitants' practices and how they may affect the energy demand in Saudi homes. It worked in identical regulated homes in Saudi Arabia to advance understanding of the role of inhabitants' practices in overall residential energy demand. The research was conducted by using a mixed methods approach and with the use of a practice theory. Longitudinal and cross-sectional time horizons were used to collect quantitative and qualitative data. The results of this research suggest that the technological and social aspects of energy use have at least an equality of importance, and both aspects affect the energy demand of Saudi dwellings. The improvement in the building envelope helped to achieve lower energy consumption compared to the actual average energy consumption for a conventional house. However, exploration of the causes of wide variations presented in energy demand between identical homes provides deep understanding on how inhabitants' practices influence the energy demand in Saudi homes through the investigation four elements of practices (e.g. technology, engagement, institutionalised knowledge and rules, know-how and embodied habits) and how they are brought together in the conduct of everyday life. Recommendations based on the thesis results are presented for the Saudi Royal Commission. Finally, some insights from social practices are provided for domestic policy to be considered for future housings.

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List of Abbreviations

RC	Royal Commission is a Saudi organization that was established as per a Royal Decree in 1975 its main objective is the development of Industrial Cities in the kingdom.
JIC	Jubail Industrial City is located in the Eastern province on the Arabian Gulf coast of Saudi Arabia.
HVAC	Heating, ventilation and air conditioning.
POE	Post occupancy evaluation.

Chapter 1: Introduction

Scientists around the world attribute much of climate change to the rapid growth in human made carbon emissions that has occurred over last century (Pachauri et al, 2014). Without rapid action to decrease these emissions, it is likely that temperatures, heat waves, flooding and storm damage will increase (Stevenson, 2019). Globally, greenhouse gases need to be cut significantly by about 50% by 2050 and at least by 80% by 2100 (Pelsmakers, 2017). The housing sector is the single largest emitter of all CO_2 emissions in the world (Jennings et al, 2011). The worldwide energy consumption of residential buildings accounts for 40% of global energy consumption (Bribian et al. 2009; Brebbia, and Pulselli, 2014; Al kanani et al., 2017). Climate change can impact the indoor environment of the buildings and occupants' health. For instance, the increase of temperature impacts the indoor environment, which in turn leads to an increase in the loads on the HVAC system and an increase in the energy consumption in term of its impact on health by decreasing productivity due to extreme temperatures and respiratory diseases (Spengler, 2012). A study by Berardi and Jafarpur (2020) conducted in Canada shows that higher temperature leads to a reduction of heating by 30% but it could increase the cooling by 15%-126% in the future (Berardi and Jafarpur, 2020). Other study suggest that the Kingdom of Saudi Arabia could expect an increase of the average temperature by 6°C in the summer months by 2081-2100 (Lelieveld et al., 2016). Constructing more energy-efficient houses may reduce carbon emissions by 60% or more in order to mitigate climate change and its impact on buildings (Tzikopoulos et al., 2005). Consequently, many of the developed countries are addressing energy conservation in the building sector in general and in residential buildings in particular. Some of these countries have established definitive standards for the energy consumption in domestic buildings in kWh/m² as low or very low to be met, based on the local climate conditions.

In the context of this research, Saudi Arabia is one of the highest consumers of energy per capita, the annual per capita electricity consumption was around 100MWh in 2014 (Asif, 2016). With the rapidly escalating population in Saudi Arabia, the domestic energy demand is increasing (Al kanani et al., 2017; Elgendy, 2011; Taleb and Sharples, 2011; Almatawa et al., 2012). With such high residential energy consumption, a strategy is urgently needed to reduce the consumption and so its impact on climate change. There have been many previous attempts to minimise the high energy demand in different cities of the Kingdom with technical solutions.

This chapter presents the research statement of the problem in Saudi Arabia in terms of energy consumption and an overview of the housings demand. The chapter presents the research-identified gap and the research contributions to the body of knowledge. The research questions, aims, and objectives are developed. The chapter then provides a thesis structure and brief explanations of each of the thesis chapters.

1.1 Problem of statement

The Kingdom of Saudi Arabia is one of the largest oil-producing and exporting supplier globally. Saudi Arabia generated more than 99% of its electricity in 2017 using fossil fuels (Krane, 2019). In 2011, 52% of the electricity was consumed by the domestic sector (Figure 1-1) (Electricity, 2011; SEEC, 2013; Dawood and Vukovic, 2017). The increase in the energy demand in Saudi Arabia has been driven by the rapid growth of population and economic growth (Soummane, S. and Ghersi, 2022). Saudi Arabia is also considered to be one of the highest consumers of energy per capita in the world (Asif, 2016; Felimban, 2019). It is reported that the total Saudi electricity demand reached 299.2TWh in 2018. It is found that this consumption is similar to more populated countries e.g. Mexico, whose population was 127.5 million, compared to 34.2 million for Saudi Arabia (Soummane and Ghersi, 2022). Energy consumed for air conditioning alone represents 70% of the total national electricity demand (SEEC, 2013).

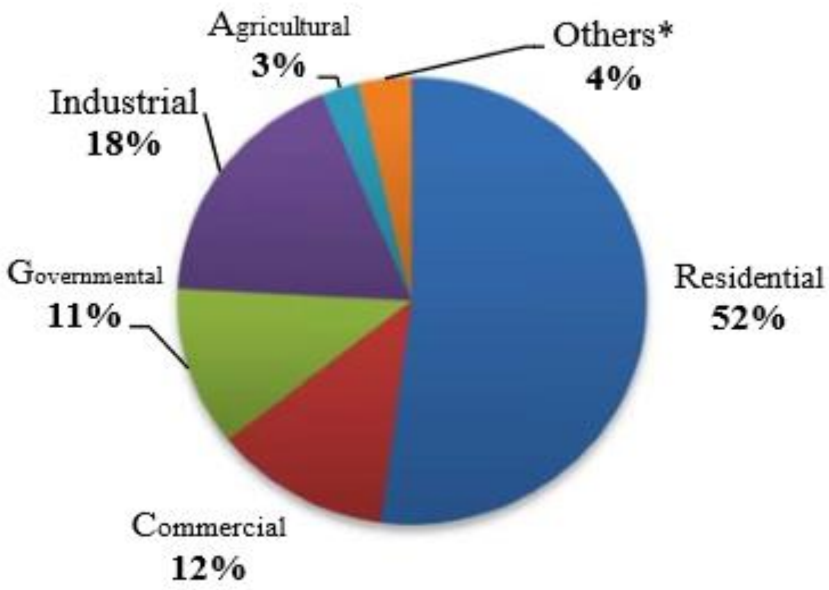


Figure 1-1 Energy consumption in Saudi Arabia by sectors (Electricity, 2010)

According to the International Energy Agency (IEA), total electricity generation in the kingdom of Saudi, increased by 1683% from 20,452 GWh to 344,209 GWh, between the period 1980 to 2020 (IEA, 2020). Figure 1-2 demonstrates the increase in energy generated and its direct relationship to the increase in carbon dioxide emissions during the past 40 years (Al-Tamimi, 2017: IEA, 2020).

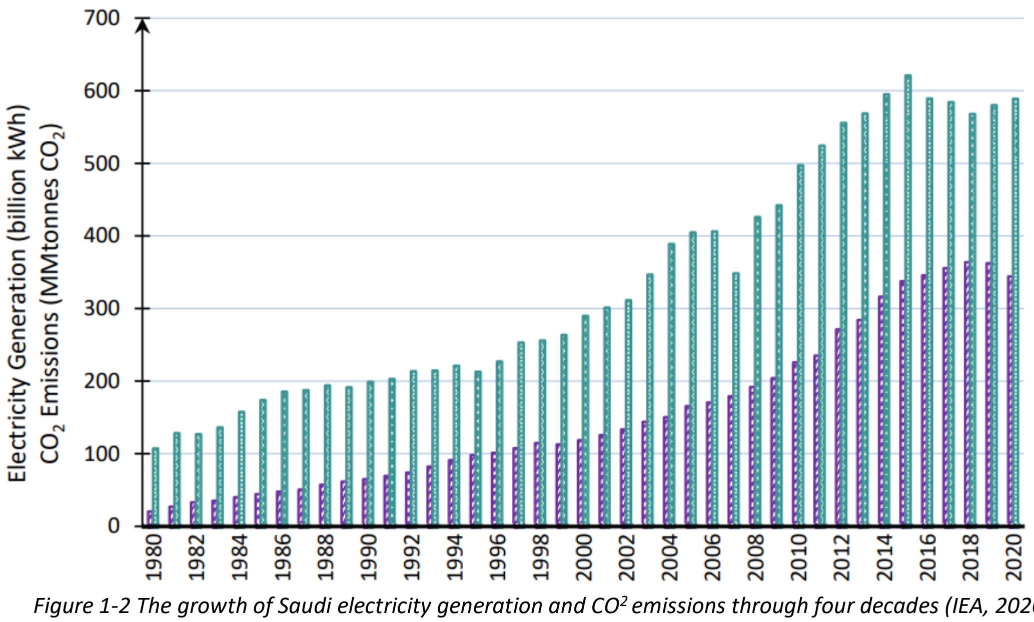


Figure 1-2 The growth of Saudi electricity generation and CO[2] emissions through four decades (IEA, 2020)

One of the main problems found in Saudi buildings that building envelopes were not designed to cope with the extreme weather (Al-Qahtani and Elgizawi, 2020). One key reason for this high-energy consumption is that around 70% of Saudi dwellings are not thermally insulated (Alshahrani and Boait, 2018; Alshenaif, 2015). It also has been found that the lack of mandatory energy conservation for the domestic sector policies contributed to high energy demand (Dawood and Vukovic, 2017). Although the building energy efficiency code was introduced in 2009 and later in 2010 was mandatory for the governmental buildings but was not enforced for all other buildings (Krarti et al, 2017).

All the factors mentioned above have pressurised government bodies in Saudi Arabia to design and construct homes that use less energy and therefore reduce greenhouse gas emissions. Studies conducted to develop sustainable residential designs in the Kingdom of Saudi paid more attention to the technology aspect (literature review).

1.2 Housing stock in the Kingdom of Saudi Arabia

The construction sector in Saudi Arabia is the largest and fastest-growing market in the Gulf countries (Ventures Middle East, 2014). This sector has great potential for growth as the demand for residential, commercial, and industrial buildings continues to rise (Alrashed, 2015). The residential sector is facing a strong growth as a result of the Saudi population increasing (Figure 1-3) (Deloitte, 2010). The population growth increases the demand for housing, and it need new housing that will be built has to be energy efficient to reduce the energy demand and climate change (Figure 1-4).

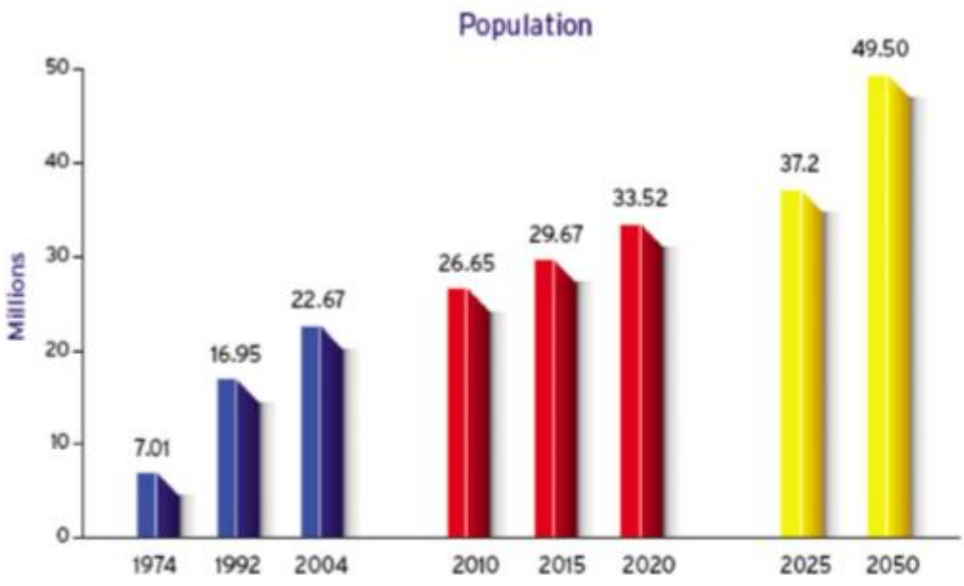


Figure 1-3 Saudi Arabia Population Growth (Assaf et al, 2010)

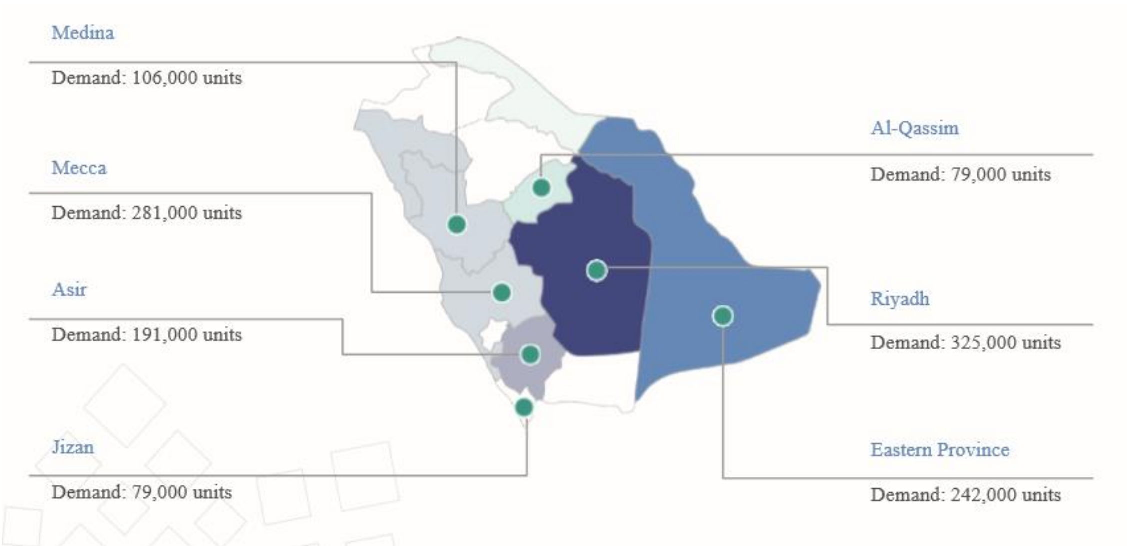


Figure 1-4 Housing Demand in Saudi Arabia (Ministry of Housing, 2020)

To meet the needs of the constantly growing population, the housings demand is very high in the central, eastern, and western provinces of the Kingdom (Ministry of Housing, 2020). It is reported that around 300,000 residential units will be built by the end of 2025 (Argaam, 2023).

1.3 Research questions

Main research question: What is the relationship between inhabitant's practices and households' energy consumption in dwellings of Saudi Arabia?

In order to answer the main research question, the following sub-questions were developed:

1. How much energy do regulated homes consume in Saudi Arabia? And why?
2. How do Saudi homes and technology perform in relation to thermal comfort?
3. How do inhabitant everyday practices contribute to energy consumption and why?
4. How do inhabitants' experience environmental control interfaces in everyday life?

1.4 Research aim and objectives

Aim: The aim of the study is to understand the role of inhabitants practices in the energy use of Saudi homes in order to provide recommendations for future home building projects.

Objectives:

1. Identify how much energy has been consumed in a selection of regulated homes.
2. Evaluate how a selection of regulated homes are performing in relation to thermal comfort.
3. Understand the usability of environmental control interfaces of selected regulated homes.
4. Explain the influence of inhabitant everyday practices on energy consumption and the indoor thermal environment.

1.5 Thesis structure

Chapter 1 *Introduction*: is the start point of the research. The chapter presents an overview of the significance and the problem statement of the research. The chapter presents an overview of the housing demand in Saudi Arabia and the developed research questions, the main aim, and objectives. Finally, the chapter shows the research contribution.

Chapter 2 *Literature review*: This chapter discusses clear justifications for choosing practice theory as a research theoretical framework and overview of its elements. Also, the chapter reviews of recent Saudi studies related to the subject of the research and the identified research gap. Finally, the chapter presents the post-occupancy evaluation approach in Saudi Arabia.

Chapter 3 *Research context*: the chapter presents an overview of the research context such as climatic characteristics of Saudi Arabia, the demonstration of the vernacular and the contemporary architecture of Saudi housing. Finally, the chapter highlights the sustainability initiatives and challenges that the kingdom could face.

Chapter 4 *Research methodology*: the chapter describes the research design and the sampling that was used to achieve the proposed aim and objectives. Also, mixed methods approaches are presented with a clear indication of the chosen methods. Descriptions of how data was analysed are also provided. The chapter has explained in details the design that selected for the research mixed methods approach. Finally, the chapter has covered and discussed the research philosophical standpoint.

Chapter 5 *Identify how much energy has been consumed in a selection of regulated homes and evaluate how these selected homes are performing in relation to thermal comfort*: the chapter starts with a description of the microclimatic data of the case study. It describes the quantitative results of the research through the use of e.g. environmental indoor monitoring (air temperature and relative humidity), building use study questionnaires and energy bills. It provides descriptive analysis of the seasonal indoor environment in the case studies by. Finally, the chapter discuss the energy consumption of the case studies.

Chapter 6 *Understand the usability of environmental control interfaces in Saudi homes.*

and explain the influences of inhabitant everyday practices on energy demand and the indoor thermal environment: the chapter describes the research data deductively by the use of the four elements of practice theory according to Gram Hanssen's elements (2010) (technology, engagement, institutionalised knowledge and rules, know-how and embodied habits). Also, each of the four elements has several sub-themes. Finally, the chapter presents a discussion of the inductive analytical themes.

Chapter 7 *Research discussion*: this chapter presents a discussion and triangulation of the research data, encompassing both quantitative and qualitative data and analysis. Also. It presents Interpretations of the seasonal indoor temperature, relative humidity, and energy consumption with the inhabitants' practices.

Chapter 8 *Research conclusion*: the chapter summarizes the research findings and provides clear overview of key findings of each of the research objectives. Moreover, the chapter explains suggestions for future work that can be built on the findings of the present study. The chapter explains a brief description of the research limitations. Finally, the chapter offers some recommendations based on the research findings for the Royal Commission (RC), policy makers, and energy suppliers.

1.6 Chapter Summary

The chapter has highlighted the research questions, aim and objectives for the thesis, based on the problem definition, in order to explore and investigate inhabitants' practices in relation to energy demand and the actual performance of Saudi regulated homes in terms of indoor environment and energy use. This chapter has revealed that the residential sector is a major contributor to high energy consumption in Saudi Arabia, which is a significant problem. More than half of the electricity is consumed by the domestic sector. This electricity is currently generated by burning fossil fuels in the Kingdom. Another factor resulting in high energy consumption is the limited implementation of mandatory energy conservation policies. In addition, the growing population increased the demand for housing across the kingdom. Also, the literature review in this research rigorously demonstrates that previous energy studies in Saudi have focused more on the technical and simulation aspects as a means to reduce energy demand. There is a lack of knowledge on what underlies the causes of energy demand in Saudi residential sector that can account for wide variations in household energy use between houses that are the same and the actual energy use in reality rather than as simulated, revealing a critical research gap. Therefore, this research is being conducted to help to produce a fuller understanding of the causes for this demand, and to produce learning on how to minimise energy demand with implications for current and future developments in the Kingdom, and in similar climatic regions in the kingdom. A practice theory approach with post-occupancy methods helps to provide a rich analysis of hidden reasons behind the high energy demand in Saudi dwellings.

Chapter 2: Literature review

2.1 Introduction

The chapter discusses the rationales for choosing practice theory in this research are explained. In addition, the chapter explains the practice theory and its elements that are used in this research. Furthermore, the chapter provides overview of the post occupancy evaluation, definition and its benefits. Finally, the chapter has discussed various existing energy studies related to domestic buildings, clarifying the current gap in the literature to underpin the research aim and objectives.

2.2 Justification for using practice theory

After the research gap was identified, which was a lack of knowledge on what underlies the causes of the energy demand in the residential sector for example, what could underlie variations in household energy use between houses that are the same. The gap between technical predictions of house energy use and the realities of household energy use. Therefore, studying the technological aspect of the building e.g. improving the building envelope, it is found not sufficient. As a result, this research was conducted by studying the social aspect as well as the technical aspect to study the energy demand in Saudi dwellings. Previous studies have used different theoretical and empirical approaches to identify factors that contribute to energy demand in buildings.

However, due to the aim of this research, practice theory was more appropriate than other theories such as planned behaviour theory. The behavioural approach assumes that individual decision-making and behaviour is planned to achieve a goal based on values, attitudes, and norms (Stevenson, 2019). Social Practice Theory supports a holistic understanding of e.g. energy consumption. A growing number of scholars are arguing that the 'individualistic' perspective is fundamentally flawed (Warde, 2005, Shove, 2010, Hargreaves, 2011, Shove et al., 2012, Foulds et al., 2013). As stated by Stevenson (2019: p45) one of the key criticisms of behavioural theory is 'the separation of people from the influence of home technologies or energy policies'. For example, the study of (Faiers et al., 2007; Gill et al., 2010) that explored human behaviour within residential settings to explain the reasons why home inhabitants act the way they do. It focused on the individual, assuming a consistent behaviour pattern based on external determinants. However, in practice theory, the attention is redirected from the individual decision-making and centred on the practice itself (core unit), rather than the individuals who perform them or the social structures that surround them (Hargreaves, 2011; Shove & Warde, 2002). However, the role of individuals is not neglected in practice theory, the individuals become 'carriers' of social practices who carry out the various activities and tasks that the practice requires (Reckwitz, 2002; Hargreaves, 2011, p.83). In the context of the domestic buildings, practice theory focuses on the analysis on the mundane (e.g. cooking, showering, cleaning) and routinized practices of household' everyday life. Other studies of (e.g. Foulds et al., 2013; Galvin, 2013; Gram-Hanssen, 2011; Strengers & Maller, 2011) use social practice theory and its importance in terms of producing new insights into routinized everyday practices and their consequences for the indoor domestic environment. It has been used and tested by previous studies, demonstrating its capability to provide guidance in the investigation of empirical data. Social practice theory has been selected as an appropriate and useful theoretical framework in helping the researcher fulfil e.g. the third objective 'To understand and explain the influence of inhabitant everyday practices on energy consumption'. In which this theory focuses on the analysis of 'a routinized type of behaviour' (Reckwitz, 2002, p.249) of everyday life and emphasizes the context of social enquiry and the emergent dynamics of everyday life. However, if applying the theory of behaviour that focuses on causal factors and external drivers, attempting to explain the dynamic and complex practices of everyday life (e.g. cooling, heating, ventilation, cooking and laundry that may affect the energy demand in Saudi dwellings) it would be insufficient. Because it fails to recognise the routine complexities of decision-making in everyday domestic life (Shove & Guy, 2000). Behaviour theory ignores meanings and habits, but social practice theory addresses this deficit (Stevenson, 2019).

2.3 Practice theory and its elements

Practice approach became increasingly influential starting in the 1970s and have been applied to analyse a broad range of phenomena such as, policymaking, culture and consumption (Nicolini, 2012). There is a rapidly growing literature on social practice theory, highlighting the importance of adopting a practice approach to understanding and developing strategies to reduce domestic energy demand (Ellsworth-Krebs, 2017). Practice theory recognises the influence of its elements on the performance of the practices (Kermeci, 2018). Practice theory has developed through work of the sociologists Bourdieu, Giddens and then developed by Schatzki, Reckwitz and others (Table 2-1) (Reckwitz, 2002). Bourdieu views that habitus rooted unconsciously in human action and therefore shaping the social practices and structures. Moreover, Giddens (1984) defines the social practices as an interaction of agency (individuals) and social structure (Maller, 2012). Also, they argue that practices recognised as entities because of their regular reproduction. Their theories are social theories since the materials artefacts, infrastructures and products are hardly discussed (Shove and Pantzar, 2005). Adding to the assumption that habit and rules explain the human action, Schatzki has different view, and he added a third dimension to the notion of practice is the role of meaning and linked to purposes or aims 'teleoaffective'. Schatzki defined practice as nexuses of activity rooted in shared understanding, comprised three elements e.g. practical know how expressed as habit, explicit rules, and meanings (Schatzki et al, 2001).

The exclusion of non-human materials, technologies, objects and things are considered as key limitation of Bourdieu and Giddens accounts of social practices (Shove et al. 2012). Furthermore, the importance of including nonhumans in social research, should not be given an equal status to the agency of human actors (Schatzki 2002, 2010). Social practice theory elevates materials, objects and infrastructures to the status of active elements that constitute practices (Maller, 2015). The impact of non-human or materials objects on human activity was covered by Reckwitz, which is attributed largely to Bruno Latour. The materials objects are actors in human activity, non-human and human actors are accorded equal treatment. Reckwitz defined a practice as a routinised behaviour that involves interconnected elements of bodily and mental activities, objects or materials and shared knowledge, skills and competences (Warde, 2005). In Reckwitz's description, practice theory elements which include: body, mind, the agent, structure process, knowledge, discourse language, and things (Reckwitz, 2002). The body in his description means an instrument that the agent uses and the routinised actions with bodily performances (e.g. handling objects or intellectual activities such as talking, reading, and writing). Additionally, certain mental activities and knowledge are integral parts of practices (e.g. playing football with certain aims and know-how), and the agent (individual) is the carrier who carry out the practices. Structure/process is thus routine social practices (e.g. routines of moving the body, of understanding and wanting, of using things). Furthermore, knowledge is a way of understanding objects, humans, know-how, and also a way of wanting and feeling. Discourse/language represents different forms in which the world is meaningfully constructed in language or in other sign- systems, and contains bodily patterns, routinised mental activities, motivation and objects (e.g. in some cultures, a man shakes hands when he greets another man but refrains from doing so when greeting a woman). According to Reckwitz, actions are the relations between the subjects or between the subject and an object (e.g. the ball and playing football) (Reckwitz, 2002).

Reckwitz, Shove and Pantzar also emphasise that technologies are an important element in holding practices together. In addition, Warde (2004) focuses on 'things' e.g. items of consumption during the participation in practices. Schatzki explicitly argues that his theory is more about continuity than change, whereas others, such as Shove, deals more with the emergence of new practices or for example changes in distributions of competences within elements of practices (Gram-Hanssen, 2011). Furthermore, Shove (2003) highlights the importance of focusing more on the routinised and technologically structured parts of the consumer practices in order to understand households' energy consumption.

There is no agreement on naming the elements among the theorists, social practice theory is defined differently by different theorists (Schatzki 2002, Reckwitz 2002, Warde 2005, Shove and Pantzar 2005, Gram-Hanssen, 2010) as shown in Table 2-1. Schatzki states that practical understanding (also known as embodied routines or know-how) (the body knowing how to act or react to something) is classified as one element that holds a practice together. Whereas, the explicit rules and instructions of how to do things, what is allowed and what is not are a second element in holding a practice together (Gram-Hanssen, 2010).

Table 2-1 Practice Theory Development (Loscher et al., 2019)

Schatzki (2002)	**Reckwitz (2002)**	**Warde (2005)**	**Shove-Pantzar (2005)**	**Gram-Hanssen (2010)**
Practical understanding	Body Mind The agent	Understandings	Competences	Know-how and embodied habits
Rules	Structure/process	procedures	-	Institutional knowledge and rules
Teleoaffective structures	knowledge Discourse/language	Engagement	Meanings	Engagement
Technology/ things	Things	Items of consumption	Materials	Technologies /things/ products

Warde, Shove, and Pantzar added two further items – products/stuff (Shove) and items of consumption (Warde) as an element holding practices together, rather than a result of social practices as held by Schatzki. Gram-Hanssen builds on the proposals of these authors (practice theorists) in terms of the coherence of practices. In relation to energy consumption the focus of this research study, Gram-Hanssen particularly emphasised that ‘knowledge’ and ‘rules’ components are important, Gram-Hanssen (2010) builds on Schatzki’s notion of ‘explicit rules’ an element that is not included in Shove’s definition. While Schatzki excludes the tacit knowledge or implicit rules

Shove and Pantzar (2005) write about competences and do not differentiate between theoretical knowledge and implicit rules, which is not appropriate when dealing with housing energy consumption, according to Gram-Hanssen (2010). Gram-Hanssen (ibid) stated that differentiating between different types of knowledge, and their associated routines/bodily and mental activities which hold practices together, may lead to an incomplete picture of the issues surrounding energy consumption. The approach of

Gram-Hanssen (2010) to Practice Theory, will be followed in this research. She proposes that there are four elements holding practices together. know-how and embodied habits, institutional knowledge and rules, engagements, and technologies. Know-how and embodied habits meaning the routinized practices that people perform in their everyday lives. These practices can be performed subconsciously such as, waking up making coffee and getting dressed, and consciously e.g. when the inhabitants receive information on the importance of using their ventilation system as prescribed by the manufacturers, and this knowledge may influence their ventilation practices. Institutional knowledge means the way that things are supposed to be done culturally and individually determined, which includes rules of how to do things and technical knowledge (Palm and Darby, 2015). For instance, the information from the user manual and the knowledge obtained from cultural myths of the indoor environment. Engagement implies that the practices mean something to the people who perform them (Gram-Hanssen, 2014). An example of this element is (household desire to save money), can be found in the study of (Foulds et al, 2013). From the interviews, they found one household who desperately keen to minimize expenditure, cooking predominantly occurred in the microwave because that household believed it was the cheapest option. Another household was keen to reduce bills even further by turning off the MVHR most of the time during the day and ventilating the house naturally by opening the windows.

Last element in Gram-Hanssen's articulation of practice theory is the technological structure means the material components and things that people use such as the cooling system, heating system, ventilation system (Higginson and Thomson, 2014) and controls. In addition, technology element can be the house lay outs, which prefigure its use (Gram-Hanssen, 2010).

Researchers who applied practice theory in their research, base their analysis on different approaches of the theory according to their suitability in achieving the objectives of their studies. Therefore, the approach of Gram-Hanssen to practice theory, emphasising the socio-technical determinants of social practices, is followed and found particularly relevant to this socio-technical study. Energy use in buildings is not a technical but a socio-technical phenomenon that seeks to understanding the relationship between people and technology (Chiu et al, 2014). Energy consumption is not a practice in itself as Gram-Hanssen stated, but practices are all the different things that people do at home which consume energy, such as cooking, washing, etc (2014, p94). Gram-Hanssen's framework has been applied in domestic (Gram-Hanssen, 2010) and nondomestic environments such as the study of (Pothitou, 2020) to understand energy use practices.

2.4 Existing research on domestic energy use

The systematic literature review (SLR) approach was chosen for this research which investigated the literature to see if any studies covered inhabitant's practices in Saudi dwellings using Post Occupancy Evaluation (POE). Searching for relevant studies by using the search string steps that are developed to be used in electronic databases (Bettany-Saltikov, 2012; O'Brien and Guckin, 2016).

In the environmental studies of domestic buildings in Saudi Arabia in terms of practice, discovered through the SLR, there is a number that take into consideration the predicted energy consumption and the global phenomena of climate change. The majority of these studies focus heavily on the technological structures. However, there is no evidence of a study in Saudi Arabia that consider the social aspect e.g. residents' practices revealing a major research gap. Equally none of the studies discovered for Saudi have used comprehensive POE approach. For example, Aldossary (2015) discussed how to reduce energy consumption by improving the building envelop of eighteen homes with different climatic regions, in the hot and humid climate (city of Jeddah) and the hot and arid climate (city of Riyadh) with mountainous topography (City of Al-Baha). Taleb (2011) analysed the technological structures of six- existing apartments in the context of Jeddah City and established guidelines towards achieving sustainable architectural practices within the Saudi residential sector.

Ghabra (2018) focused on the 'technology' element to propose building envelope design solutions that aim to reduce high energy consumption and cooling loads while maintaining comfortable indoor environments for high rise residential buildings, in Saudi Arabia particularly in Jeddah City. Furthermore, Alrashed's (2015) study investigated the vernacular architecture techniques that could be applied to modern constructions in order to achieve low energy buildings. The study used Dhahran city, Guriat, Riyadh, Jeddah, and Khamis Mushait of Saudi Arabia as case studies in different locations and climates; eastern region, central region, western region, and southern west region, respectively. Some of these studies relied heavily on simulation only and others combined simulation with methods such as interviews and questionnaires. However, there was no evidence found for using usability questionnaire (Baborska and Stevenson, 2017) to reveal the system control and test the technology performance in relation to inhabitant's perceptions.

Aldossary (2015) used computer simulation (e.g. IES-VE Simulation) taking into account the building form, fabric, inhabitants' behaviour, and climatic conditions. The simulation examined the reduction of energy consumption by applying retrofitting solutions of solar Photovoltaic Systems and more efficient glazing. In addition, the study predicted that by utilizing shading devices, the potential annual energy consumption reduction would be in the range of 21% to 37% for each property in a hot and humid climate. Whereas, applying the same suggested solutions for the properties that located in the hot and arid climate, the predicted reduction was between 15% and 34%. The energy savings were around 20% to 34% for the properties that located in the mountainous topography which classified with cool and mild during the summer season.

Taleb (2011) investigated the energy and water consumptions using simulation software packages (e.g. Design Builder and Building Energy Simulation TEST) and suggested conservation measures. She predicted that improving the thermal insulation in the two case studies reduced the energy consumption by 7.5% for the apartment and 3.8% for the villa. The potential effect of improving glazing and importing shading devices predicted a reduced energy consumption for the apartment and villa of 17.7% and 13.7%, respectively. She predicted that the natural ventilation encouraged the inhabitants to shut down their AC units and open windows, especially during the nighttime. Consequently, it was estimated that it would be possible to achieve savings of 14.7% in Case 1 (apartment), and 11.3% in Case 2 (villa).

Abdulghani Hassan (2001) also used a simulation model in order to examine the reduction of energy consumption by applying thermal insulation to domestic buildings.

The model demonstrated a 19% and 31% reduction in cooling load as a result of applying insulation materials and shading devices. Ghabra (2018) used simulation to predict that adjusting the thermal properties of the wall type has the ability to reduce 10% of the cooling loads while applying external shading devices could contribute to a reduction of 30% in solar gains. The simulation also showed that effective consideration of building orientation had a significant effect on reducing the cooling loads by 25% and 60% for solar gains. Her theoretical study set generated guidelines to help designers determine the thermal performance and energy use of high-rise residential buildings in the early stages of the building design. She aimed to enhance the effectiveness of the local building codes and energy efficiency regulations in relation to this building type. Alrashed (2015) utilised simulations to show that adapting vernacular architecture techniques of Mashrabiyah, reduced the energy consumption by 3% to 4%, while applying adobe to a modern construction could decrease the energy consumption by 6% to 19%. The results also illustrate that implementation of the courtyard technique on modern constructions could theoretically reduce the lighting demand by 8% in all locations. On the other hand, it signified a predicted increase in the demand for the heating, ventilation, and air conditioning (HVAC) system between 9% in Jeddah and 11% in Khamis Mushait. The reason behind this predicted increase in energy is because the courtyard form is generally influenced by the climatic conditions of the region. In China for instance, the size of the courtyard is reduced from the cold climates (northern) to the warm climates in the southern regions. The northern region has a larger area to receive more solar radiation, whereas the southern region (warm climates) adopts smaller and deeper courtyards to prevent the solar heat gain (Zakaria and Kubota, 2014). Therefore, the study of Alrashed (2015) designed for just 16m^2 courtyard area in a house area of 200m^2 resulted in increasing the energy in cold climate of Khamis Mushait city.

Also, the study of Krarti et al. (2020) used various energy retrofit measures for three typologies e.g. villa, apartment and traditional house from different four regions across the kingdom. The technology aspect of the study includes improving the building envelop e.g. walls, roof, glazing, shading and provision of more efficient lighting system and cooling appliances. The predicted simulation results show that these measures reduce the annual energy consumption by 50%. Furthermore, a study of Arafah (2022) analysed the building envelope variables in an existing building in Riyadh capital city of Saudi Arabia. Measuring its effects on the energy consumption and the cooling loads, following ASHRAE 90.1-2019 and LEED guidelines. The researcher has used computer simulation such as REVIT software and the Hourly Analysis (HAP). The study concluded that by altering the wall thermal resistance, window thermal transmittance, solar heat gain coefficient, window-to-wall ratio, building orientation, and sun shading devices, the building envelope could save cumulatively 9.91% of energy consumption and 16.2% of energy load.

All above analysed Saudi studies relied solely on technological aspect of the building as well as the simulation predictions to propose the study findings. This dynamic modelling does not reflect the reality of housing performance, however; it is based on approximation from average default values rather than inhabitants' behaviour (Stevenson, 2019). A study by Ibrahim and Alfraidi (2018) was conducted for low-income of Hail region's Al-Ghazalah housing development that comprises 250 units in Saudi Arabia. The region is located in the northern part of the Kingdom. The study aim was to investigate the inhabitant's satisfaction with their current living in that development. The results from the questionnaire illustrated that inhabitants of the Al-Ghazalah development housing Complex of Hail were not satisfied enough with the home units provided and required an urgent maintenance. The constructed units in this complex had one prototype model that was applied to all the 250 units. As a result, the units had the same number of rooms without taking into consideration the family size. This study adopted a quantitative approach only to identify the resident's satisfaction on the building's functionality, e.g. housing lay out. Like the other studies mentioned above, it did not cover comprehensive Post Occupancy Evaluation (POE) methods such as Building Use Study (BUS) questionnaire and usability questionnaire revealing a significant research gap in the methodological approach to evaluating energy consumption in Saudi Arabia.

There is a number of international domestic energy studies such as the DEMAND research centre in the UK[1], argue that there is a gap in building energy performance between what predicted and what is in use (e.g. Gram-Hanssen and Georg, 2018; Palmer et al, 2016; Gram-Hanssen et el, 2017; Gram-Hanssen, 2010; Majcen et al, 2013; Shove and Walker. 2014). The body literature of these studies refer this gap to the misunderstanding of the inhabitants' practices and importance of its consideration in policy. Recent years have seen research increasingly addressing this gap, but overwhelmingly this research has focused on European, North American and Australian situations, leaving a significant research gap in understanding household energy use in situations like that of the Kingdom of Saudi Arabia. The next following section is describing the definition of the post occupancy evaluation approach, benefits and its role in this research.

2.5 Post occupancy evaluation (POE)

Post Occupancy Evaluation (POE) is a stage of building performance evaluation process, that evaluates the building after it is completed and inhabited. POE is defined as 'the process of understanding how well a building meets the needs of clients and building occupants. POE provides evidence for a wide range of environmental, social, and economic benefits. It can also address complex cultural issues such as identity, atmosphere, and belonging' (RIBA, 2016, p6). POE has been viewed as part of the BPE's process and 'tool' that evaluates 'buildings in a systematic and rigorous manner after they have been built and occupied for some time' (Preiser and Vischer, 2005.p8).

The purposes of POE can be defined in two further ways. It is a direct approach of evaluating the design by examining the design innovations, design features for certain group of occupants or the design process of a project. POE also evaluates the inhabitants' comfort, satisfaction, health and investigate the factors that affect their satisfaction, understanding their experiences of a space and their subsequent behaviour. On the other hand, the indirect approach of POE is to identify issues which

[1]www.demand.ac.uk

reveal functional failures or defects and the issues related to occupant control (Gill et al, 2011). Post occupancy evaluation is considered as the final step in a cyclical process of building life cycle. POE studies provide the knowledge feedback to improve a building's current conditions as well as to guide design in future projects (Zimmerman and Martin, 2001; Meir et al., 2009). Bordass et al. (2006: p11) described this type of building knowledge 'feedback' as a process of:

> '…*learning from what you are doing or from what you and others have done to understand where you are and to inform and improve what you are about to do'.*

Feedback refer to reported information about the level of success (or failure) of e.g. building technologies and other areas related to occupants e.g. their satisfaction. Also, due to the valuable feedbacks that can be offered as an outcome by a POE study, in which they can be beneficial for the RC developer in particular and for other developers in general, to be considered in future or/and retrofitting developments in the same or/and similar climatic region, as the housings demand is in increase across the kingdom.

Combining practice theory with Building Performance Evaluation (BPE) is useful to bridge the gap that BPE presents. Building performance evaluation ignores the meaning and habits that shaped by cultural beliefs and the societal forces that create and define housing needs (Stevenson,2019). Whereas, practice theory addresses this deficit.

2.6 Research gap

The literature reviewed highlights that there is a lack of knowledge on what underlies the causes of the energy demand in Saudi residential sector e.g. variations in household energy use between houses that are the same and the gap between technical predictions of energy use and the realities of household energy use. The review of literature illustrates a number of Saudi energy studies have concentrated on the technical elements of the building, such as the fabric performance, thermal insulation, and the integration of renewable energy sources. These studies relied heavily on predicted energy consumption without taking into account the social everyday practices. Also, the literature review revealed that there is a lack of post occupancy evaluation studies to study domestic energy consumption in Saudi Arabia. There is a growing number of building performance studies around the world that show how social practices play a significant role in the energy performance of buildings (Brown and Cole: 2008; Gram-Hanssen: 2010).

2.7 Chapter Summary

This chapter has revealed that the building sector is a major contributor to high energy consumption in Saudi Arabia which is significant problem. More than half of the electricity is consumed by the domestic sector. This electricity is currently generated by burning fossil fuels in the Kingdom. Another factor resulting in high energy consumption is the lack of mandatory energy conservation policies. Therefore, research is being conducted to help minimising the energy demand and develop associated residential design polices in the Kingdom. However, the literature review rigorously demonstrates that previous energy studies in Saudi have only focused on the technical and simulation aspects as a mean to reduce energy demand. The literature review also revealed the deficiency of studies around the inhabitants' practices in their homes and relation of that with the actual energy demand, rather than as simulated, revealing an important research gap. This study investigates the relation between the inhabitant's practices and the energy demand in Saudi dwellings. A practice theory approach helps to provide rich analysis of everyday practices in homes, which is fundamental in order to comprehend the various levels of energy consumption. There is a need to investigating and understanding the residents' routines, know-how, knowledge, and their engagement with energy technologies makes to the energy demand in Saudi homes.

Chapter 3: Research Context

3.1 Introduction

This chapter begins with an overview of the background of the research context, e.g. climatic data of Saudi Arabia and its architecture. It also discusses the sustainability initiatives that Saudi Arabia has implemented to a response to the high energy demand in domestic buildings and others. Although, the effort towards reducing energy demand has begun, future challenges that the kingdom of Saudi could face are explained.

3.2 Climatic characteristics of Saudi Arabia

The climate of Saudi Arabia varies from one region to another (Figure 3-1). Since the Kingdom of Saudi Arabia falls on a latitude of between 16 and 32 degrees north, the number of hours of sunshine that the country receives is very large in the summer; from twelve to thirteen hours and six to eight hours in the winter (Taleb, 2012). The summer starts in March and winter begins in October or November. Due to the various topographic features of Saudi Arabia the weather differs in different areas of the Kingdom. The climate is classified into three zones hot and arid, hot and humid, moderate (Alwetaishi, 2019). Three cities central (Riyadh), Coastal (Jeddah) and South Western (Abha) have used to demonstrate the climatic zones of each region (Table 3-1).

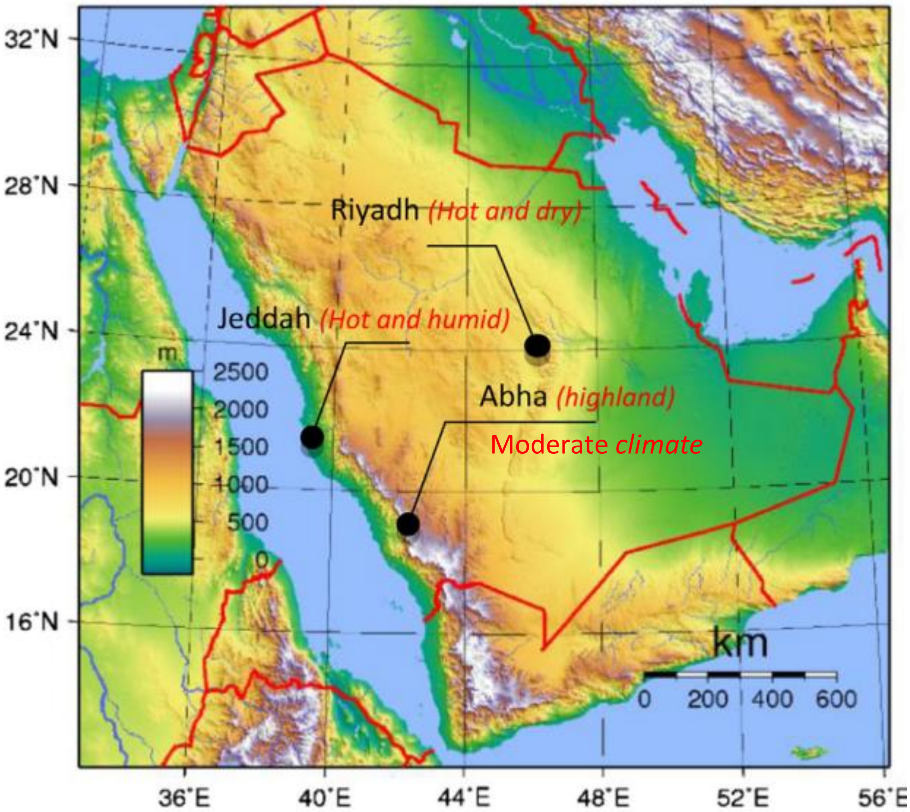


Figure 3-1Geographical topography of Saudi Arabia (Alwetaishi, 2019)

Table 3-1 Characteristics of the Climatic zones (Albogami and Boukhanouf, 2019)

Regions	Central	Coastal	South Western West highlands (>2000 m)
Climate zones	Dry and hot	Hot and humid	Moderate climate
city	Riyadh	Jeddah	Abha
Average annual temp ^{0}C	24	23	17
Average January Temp ^{0}C	13	12	11
Average July Temp ^{0}C	33	32	22
Average annual rainfall mm	95	91	539
Average January rainfall mm	13	17	97
Average July rainfall mm	0.4	0.1	27

Some parts of the country receive scant amounts of rain in winter and spring, with more in the South-Western Highlands, even during the summer. The coastal region which classifies as semitropical, and the humidity during the summer is very high (Maisel and Shoup, 2009). Table 3-2, Table 3-3 and Table 3-4 show three cities, representing each region: Riyadh is the capital city of Saudi Arabia in the central part of the Kingdom (central region), Jeddah is on the Western Coast (costal region), Abha is located in the South West highlands (South-western).

Table 3-2 Average Minimum and Maximum Temperatures in three Different Saudi Cities (National centre for meteorology, 2019)

	Riyadh		Jeddah		Abha	
Months	MIN	MAX	MIN	MAX	MIN	MAX
January	6.9^{0}C	20.1^{0}C	18.2^{0}C	28.9^{0}C	7.7^{0}C	19.5^{0}C
February	9.3^{0}C	23.3^{0}C	17.9^{0}C	29.4^{0}C	9.3^{0}C	20.9^{0}C
March	13.2^{0}C	27.7^{0}C	19.3^{0}C	31.6^{0}C	11.1^{0}C	22.8^{0}C
April	18.4^{0}C	33.3^{0}C	22^{0}C	34.8^{0}C	12.7^{0}C	25.1^{0}C
May	23.4^{0}C	39.4^{0}C	24^{0}C	37.1^{0}C	14.8^{0}C	28.4^{0}C
June	25.3^{0}C	42.6^{0}C	24.8^{0}C	38.2^{0}C	16.6^{0}C	30.8^{0}C
July	26.4^{0}C	43.7^{0}C	26.4^{0}C	39.4^{0}C	17.1^{0}C	30.5^{0}C
August	26.3^{0}C	43.7^{0}C	27.3^{0}C	38.7^{0}C	16.7^{0}C	30.4^{0}C
September	22.9^{0}C	40.6^{0}C	26.3^{0}C	37.6^{0}C	14.9^{0}C	29.4^{0}C
October	18.2^{0}C	35.5^{0}C	24^{0}C	36.6^{0}C	11.4^{0}C	25.9^{0}C
November	13.3^{0}C	28.1^{0}C	22.1^{0}C	33.3^{0}C	8.8^{0}C	22.8^{0}C
December	8.4^{0}C	23.3^{0}C	19.9^{0}C	30.6^{0}C	7.2^{0}C	20.7^{0}C

Table 3-3 Monthly Mean Total of Rainfall in three Different Saudi Cities (National centre for meteorology, 2019)

Months	Riyadh	Jeddah	Abha
January	16.6	11.1	16.8
February	9.2	3.2	21.5
March	21.8	2.5	45.5
April	26.3	2.4	48.3
May	6.0	0.2	24.8
June	0.0	0.0	8.0
July	0.0	0.2	15.5
August	0.0	0.5	25.5
September	0.0	0.1	5.6
October	1.2	1.0	4.0
November	13.0	23.0	4.8
December	9.2	11.4	4.7

Table 3-4 Monthly Mean humidity in three Different Saudi Cities (National centre for meteorology, 2019)

Months	Riyadh	Jeddah	Abha
January	41%	59%	64%
February	30%	60%	57%
March	24%	59%	52%
April	20%	57%	52%
May	14%	55%	51%
June	10%	55%	43%
July	11%	56%	50%
August	12%	62%	65%
September	14%	66%	56%
October	18%	65%	51%
November	35%	63%	62%
December	44%	61%	63%

In some parts of Saudi Arabia, extreme temperatures above 48°C are common during the summer. However, the temperatures are comparatively low in the southern region and this results in a pleasant summer. Humidity is high on the western coast, eastern and mountain regions all year round due to the geographical location. Moreover, the north winds bring sand storms from the northern deserts. This wind is strongest in February and March.

3.3 The architecture of Saudi Arabia

This section explains an overview of the two types of Saudi architecture; vernacular and contemporary. The vernacular architecture in Saudi Arabia is different from one region to another. However, during 1960s the adoption of modern technologies and urbanization, most Saudis have moved away from these sustainable vernacular traditions and lost functional relationships with them (Babsail and AlQawasmi, 2014).

3.3.1 Vernacular architecture

Saudi Arabia is divided into four regions depending on the climate and the responsive vernacular architecture style and materials. For example, the Central and northern region is called Najd region, hot and dry in the centre of the country. The Hijaz region is located in the western part, a hot humid coastal plain along the Red Sea. The eastern region, is a hot humid region along the Arabian Gulf. Finally, Asir represents the southern region, a high mountainous province to the southwest side (Ishteeaque and Al-Said 2008).

Najd (central) region (Figure 3-2), the Arabian Gulf region (Figure 3-3) and northern region, are characterised by a courtyard in the centre of the house, with two individual entrances at opposite sides of the house for gender separation. In addition, the courtyard is advantageous for ventilation and daylight. Openings within a courtyard in the centre of the house (Figure 3-2), do not omit the direct sunlight into the house, and allow the indirect natural light with natural air ventilation in the house. This also creates a safe play area for the family, especially for children under the supervision of their parents. All the rooms are arranged around the central courtyard and have small windows.

Figure 3-2 Vernacular Architecture Style of Najd Region (Lama Alhamawi, 2021)

Figure 3-3 Vernacular Architecture Style of Arabian Gulf region (Arab News, 2019)

The Hijaz region houses, in contrast, comprise two to five stories (Figure 3-4). One of the traditional Hijazi houses feature Roshan wooden balconies or windows that are decorated with ornamental carvings that sometimes extend over several stories (Taleb, 2012). These windows are allocated towards the north and west to obtain natural ventilation from the northern wind and western sea breezes without affecting the resident's privacy (Figure 3-5). AI-Murahhem (2008, p.16) defined 'Roshan' as ‘’an old term used for a wooden projected window found in the Islamic world’’, known as Mashrabiya in Egypt and North Africa.

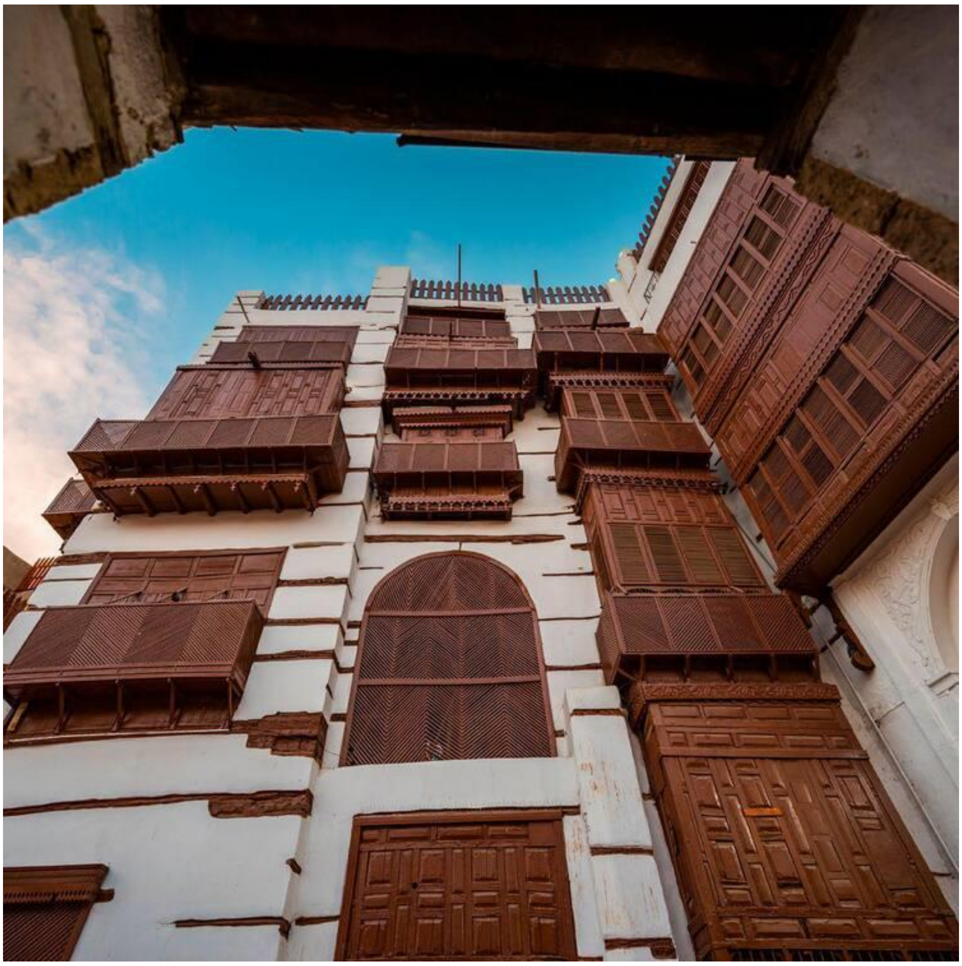


Figure 3-4 Vernacular Architecture Style of Hijaz Region (World Heritage Convention, n.d)

Figure 3-5 Roshan Window of Hijaz Region (Trilivas, 2021)

The Southern region (Figure 3-6) houses comprise more than 4 floors with small windows for privacy and relatively small area of about 100m^2 (Abu-Ghazzeh, 1995). Moreover, the traditional houses are painted internally, externally, and around the window' frame in bright colours with geometric designs and floral motifs.

Figure 3-6 Vernacular Architecture Style of Southern Region (Arab News, 2022)

The construction materials vary from one region to another due to the climate conditions. For instance, the vernacular architecture in Hijaz region structure with massive coral stone, locally called ‘Hajar al manqaby’ (Figure 3-7). Due to the softness and porosity of coral stone, walls have been reinforced horizontally by wooden beams (Figure 3.8) (Al-lyaly, 1990). The floors and roofs were structured with timber boarding laid on wooden joists. The type of wood used for the structure was called ‘Al qandal’. The main construction materials of the eastern vernacular architecture are coral stone, mud, and wood (Babsail and Al-Qawasmi, 2014). Roofs were constructed with palm trunk and tamarisk branches used to make the roofing poles (Attia, 2014). Tamarisk has the ability to expand and shrink with changes in weather and resists cracking (ibid). The traditional construction materials in the central region (Najd) was mud bricks by mixing mud, water, and straw (Figure 3-9). Also, mud was used as a plastering material for internal and external walls (Facey, 1997). External walls were thick, about 50–80 cm to perform as highly effective insulation from excessive heat in the summer e.g. the u-value of 60cm mud wall is 0.6 W/m^2K. In the southern region (Asir) the traditional housing materials were stone, mud, and wood (Figure 3-10). *Arundo donax* trees were used as frequent roofing materials (Samir et al., 2018). The use of thick mud walls keeps the temperature of the house warm during winter and cool during summer, this act is also achieved in some modern buildings through insulation (Susilawati and Al Surf, 2011).

Figure 3-7 Hijasz Region building materials Coral (hajar al manqaby) (Nyazi, 2018)

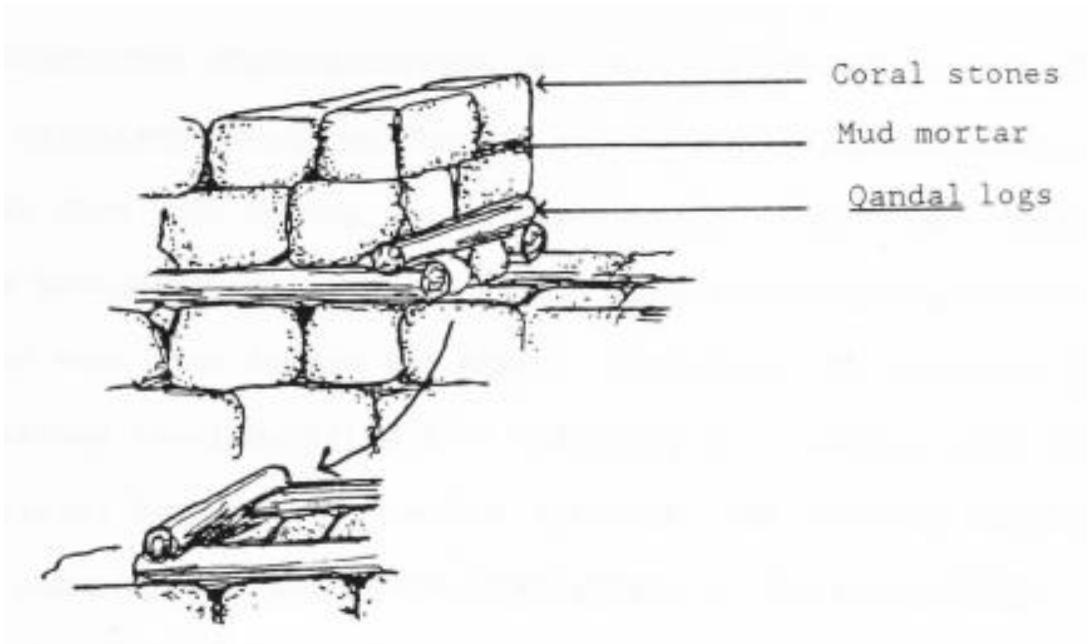


Figure 3-8 Hijasz Region building materials wall structure (Al-Lyaly, 1990)

Figure 3-9 Najd Region Building Materials (Mortada, H., 2016)

Figure 3-10 Asir Region Building Materials Stone and Mud Wall (Altaledi, n.d)

3.3.2 Features of contemporary architecture

Modern residential buildings in Saudi Arabia can be divided into three main types: apartment complexes, villas, and high-rise residential buildings (Figure 3-11, Figure 3-12, and Figure 3-13). The apartment complex in Saudi Arabia is called 'Emarah' in Arabic; it typically contains two to five floors. This type of building is preferable for a specific Saudi class in society; those who cannot afford to build their own houses. Usually, the ground floor of the apartment complex is used for retail purposes. Secondly, the villa type of residence is preferred by the high class in Saudi society and comprises a maximum of two storeys. Villas became a symbol of high status in Saudi society when the Arabian American Oil Company (ARAMCO) and Saudi government constructed villas to accommodate their employees 1950s, in the eastern province of Saudi Arabia. Their employees were considered to be from the high class of society (Al-hathloul, 1981; Akbar, 1998; Alharkan, 2017). The villa has a courtyard with a fence around the villa to ensure privacy for the resident. The high rise type of residential buildings usually can be found in areas that are experiencing high density of population, including large cities such as Riyadh and Jeddah.

Figure 3-11 Typical apartments in Saudi Arabia (Arab News, 2020)

Figure 3-12 Typical villa in Saudi Arabia (Susie of Arabia, 2020)

Figure 3-13 Typical high residential building in Saudi Arabia (Susie of Arabia, 2017)

The largest construction sector in the Middle East can be found in the Kingdom of Saudi Arabia (Al-Nagadi, 2010). Due to the availability of construction materials and their cost effectiveness, the main Saudi residential buildings materials are reinforced concrete for the floors and internal and external walls (Figure 3-14) (Lasker, 2016). Some buildings use metal to support the structure. For the façade facing bricks, plaster, stones, glass or marble is used. Wood is used sometimes for windows and internal doors but not utilised structurally in the building frameworks. The most popular material for window frames and external doors is aluminium. Furthermore, gypsum boards are sometimes used for the interior partition walls (Taleb, 2012).

Figure 3-14 Building construction in Saudi Arabia (Taleb, 2012)

3.4 Sustainability initiatives in the kingdom of Saudi Arabia

Due to the rapid economic growth and population increase, there was a sharp expansion in Saudi electricity consumption from both the building and industrial sectors. The lack of energy efficiency standards and regulations for residential buildings has made the rise in Saudi energy consumption (Krarti et al, 2017).

Recently, controlling energy consumption have been a goal for the government of Saudi Arabia (vision 2030, 2016). The desert climate of Saudi Arabia is distinguished by its high temperature most of the year (May to October), from this climatic circumstance, the importance of building codes has emerged to assess building performance and sustain the country's natural resources (Arafah, 2022).

Recently, the Saudi government has taken strong measures towards improving energy efficiency. It has introduced several strategies to increase energy efficiency and to control the CO_2 emissions (AlFaraidy and Azzam 2019). It started by increasing the price of local fuel for industrial firms in order to use energy efficient technologies (Matar

2016; Alardhi et al, 2020). Moreover, The Saudi Building Code (SBC) was formulated based on the International Energy Efficiency Code and the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). It involved technical guidance and specifications that define the minimum construction standards for buildings. Other Saudi governmental initiative is the Saudi Energy Efficiency Centre (SEEC), which was created to rationalize the production and consumption of energy in order to increase the energy efficiency in the Kingdom, to preserve Saudi's natural resources and enhance the economy. A National Energy Efficiency Program (NEEP) was founded to discuss the energy demand issues by developing various energy efficiency and conservation measures that target the residential, commercial, and industry sectors (Alyousef & Varnham, 2019).

Furthermore, the Energy Efficiency Registration (EER) established the energy efficiency label for electrical appliances to educate the consumer. The label is attached on the electrical appliances such as air conditioners, refrigerators and other, it includes clarification of the appliances' performance as shown in Figure 3-15. It was intended to ensure that the energy efficiency of each product is documented. The label helps Saudi consumers choosing the most efficient device from (A) degree to the least (G) (Saudi standards, 2019). In addition, it will contribute to rationalize the electricity consumption on the country and the consumer, which leads to reducing the burden of monthly expenses. A study by Ouda et al (2017) conducted survey to assess the public awareness on energy conservation and residents' willingness to use energy efficient appliances in their houses. The respondents were asked if they would check the appliances energy efficiency label before purchasing, it was found that 48% of participants are not looking at the labels before purchasing a product. Whereas, 52% of the participants said they do pay attention to the label before purchasing. The study reported that these findings highlight the need for additional work to increase the average Saudi consumer awareness for energy conservation.

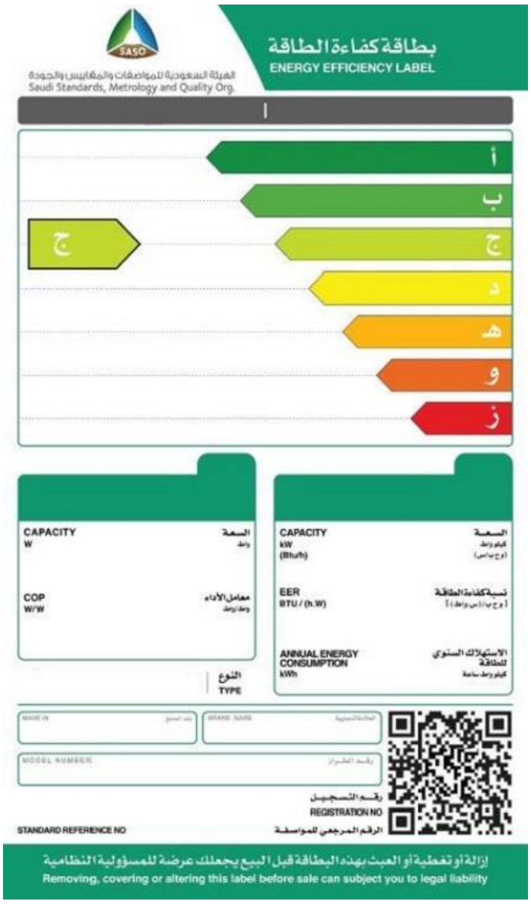


Figure 3-15 Saudi energy efficiency label (Saudi standards, 2019)

3.5 Sustainability challenges in Saudi Arabia

There are some challenges of sustainability in Saudi Arabia such as the public awareness necessary for energy preservation practices in the kingdom. A survey undertaken by Alshahrani et al (2018), showed that 66% of the respondents never shut down their ACs when they leave home, while 22% of occupants usually close off their ACs and the remaining 12% fall between these two extremes. It is stated that 63% of participants set their AC thermostats to between 18°C and 20°C.

Due to the hot extreme climate of Saudi Arabia, the external temperature can reach 50°C; therefore, a significant amount of energy is used to keep buildings cool and comfortable. It is reported in the housing energy survey by the Saudi General Authority for Statistics, window air conditioners constitute the highest proportion (71.3%) of cooling/heating systems used in Saudi housings (General Authority for Statistics, 2019). This result indicates that majority of Saudi homes still relying on the use of AC window units and are still available on market due to its effective cost (Krarti and Howarth, 2020). The Saudi energy efficiency centre (SEEC) (2013) reported that central AC and split ACs are more energy-efficient than ACs installed in window units and could reduce energy consumption levels by 48%. Furthermore, the study of Ouda et al (2017) reported that the appliances used in the participants' houses are not energy efficient according to energy efficiency label, such as refrigerator 53%, oven 72.7%, washing machine 68.2%, dryer 76.3% and dishwasher 81.8%. In term of the type of lighting system, the respondents were asked about their knowledge and the type of lighting used in their dwellings. The study illustrates that the participants respond no answer to different types of lighting e.g. 72% fluorescent tubes, 79% CFL, 61% LED and 95% motion sensors, which represent the low awareness of the respondents towards efficient appliances (Ouda et al, 2017). The study highlights the energy efficiency programs must be accelerated and promoted by government. For example, by focusing on educating the consumer through SEEC and media, schools, universities and even mosques. It will be valuable to educate the children about the energy efficiency and add it to the school curriculum (ibid).

3.6 Chapter Summary

This chapter has explained an overview background of the research context, e.g. climatic zones for each region in Saudi Arabia. The climate is classified into three zones hot and arid, hot and humid and moderate. Selecting three cities to represent each region in the kingdom. Also, an overview of the architectures in Saudi Arabia such as the vernacular and the contemporary in terms of the design and the building materials. It also discusses how Saudi Arabia responses to the high energy demand in domestic buildings and others by creating variety of the sustainability initiatives. Although, the effort towards reducing energy demand, future challenges that the kingdom of Saudi could face and need to be addressed such as public awareness and availability of AC window units on the market and its cost.

Chapter 4: Research methodology

4.1 Introduction

This chapter of the thesis starts with explanation of the research design and the rationale for using it. The type of research methodology was employed in order to achieve the research's aim and objectives is discussed in details. Also, the chapter discusses the sampling, the mixed methods used for data generation, and the approaches employed for analysis. The chapter discusses the pilot study that conducted for calibrating the sensors that used in the environmental monitoring method. Finally, the chapter presents the ethical considerations of the carried out research.

4.2 Research design

A case study is adopted as the research design because the nature of this research is exploratory. As Gray (2004: p.124) stated 'Case studies are particularly well suited to exploratory research when 'a 'how' or 'why' question is being asked about a contemporary set of events over which the researcher has no control'. A case study provides an excellent means for interrogating problems in depth (Yin, 2009). In addition, a widely used definition is that a case study is "an empirical inquiry that investigates a contemporary phenomenon (the case) in depth and within its real-world context" (Yin, 2014, p.16). Also, a case study is defined by Robson (2002, p179) as 'a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence'. In this study, the phenomenon under enquiry is the energy demand associated with the undertaking of everyday inhabitants' practices and the real-world context is the Saudi domestic setting.

According to Thomas (2011: p513), 'case studies are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods'. Case study research aims to gain a rich and detailed understanding of what is being studied and analysed, whether one case or multiple cases (Thomas, 2013). This approach is appropriate for the research since the data analysis will be combined together (Yin, 2009).

Jubail Industrial City (JIC) was used as a single case study that is an 'Exemplar' (Flyvbjerg, 2006). Jubail Industrial City (JIC) is an unusual case study because the residential buildings in the city were built to Royal Commission (RC) standards and internationally adopted regulations, unlike all other cities in the kingdom with the exception of Yanbu Industrial City (YIC) that also run by the RC. Case studies may not be suited for broader statistical generalizations; Stevenson (2019) argues that even a single case study of one home can validate a building's performance if it provides insight into key issues for the housing sector. The scope of the research focused on Saudi domestic buildings. The investigation and exploration of this empirical study in JIC examining the building performance related to energy and indoor environment of existing Saudi homes may help the RC developer to improve its approach (section 7.5.1). The design of the case study was cases (12 homes) within a case (JIC), and the cases were selected through the snowballing technique. The findings from the 'exemplar case' could potentially be considered in relation to any other similar housing developments in the same climatic region or similar climatic regions in the Kingdom of Saudi Arabia. In addition, the RC is planning to construct domestic buildings in 'Ras Al-Khair' and 'Jazan' industrial cities in the future, for which this study will be useful. It is worth mentioning that the study had recognition and support from the RC.

Although there are benefits of case studies that have been discussed above, which is also evidenced in the large amount of research studies using the case study approach, this research design has been criticised by some for its bias towards verification, for its weakness in allowing generalisations and its lack of scientific value (Campbell & Stanley, 1966). In contrast, proponents of case study research, such as Flyvbjerg (2006), argue that the perceived weaknesses of such methods are misunderstandings or oversimplifications about the nature of the research. Flyvbjerg presents in his paper of the 'five common misunderstandings of case study research' and refutes each of these misunderstandings in turn. He argues that a case study is a valid and important method for social enquiry as it takes into account context-dependent knowledge, which is an integral part of human affairs'. He also reiterates that case studies contain a substantial element of good narrative which best captures the complexities and contradictions of real life.

4.3 Case Study contextual data

Jubail industrial city (JIC) is located in the Eastern province on the Arabian Gulf coast of Saudi Arabia (Figure 4-1), and it was chosen as a case study (Research design). Jubail industrial city was developed by the Royal Commission (RC). It is a Saudi organization that was established as per a Royal Decree in 1975. This organization acts as the governor and the policy maker in the city. Furthermore, Jubail industrial city has eight residential areas in which three areas are existed and the rest are future residential areas (Figure4-2). Moreover, 'Al Jalmudah' area was chosen because it has newly built homes (Figure4-3). Jubail Industrial City (JIC) is an unusual case study because the residential buildings in the city were built to Royal Commission (RC) standards and internationally adopted regulations, unlike all other cities in the kingdom with the exception of Yanbu Industrial City (YIC) that also run by the RC.

In terms of the weather, generally with the exception of the province of Asir on the southern region, Saudi Arabia has a desert climate characterized by extreme heat during the day and average temperature reach up to 39.6 °C and the average temperature drops at night reaching 31.5°C (Peerbocus at el, 2020). Jubail Industrial City (JIC) has a hot and humid climate. The average annual rainfall is 88 mm, typically with heavy rains occurring between November and January. There is considerable variation in temperature and humidity. The heat becomes intense shortly after sunrise and lasts until sunset. In the winter, the temperature rarely drops below 0° C, and the high winds-chill factor make a quite cold atmosphere (Table 4-1) (Royal Commission, 2019).

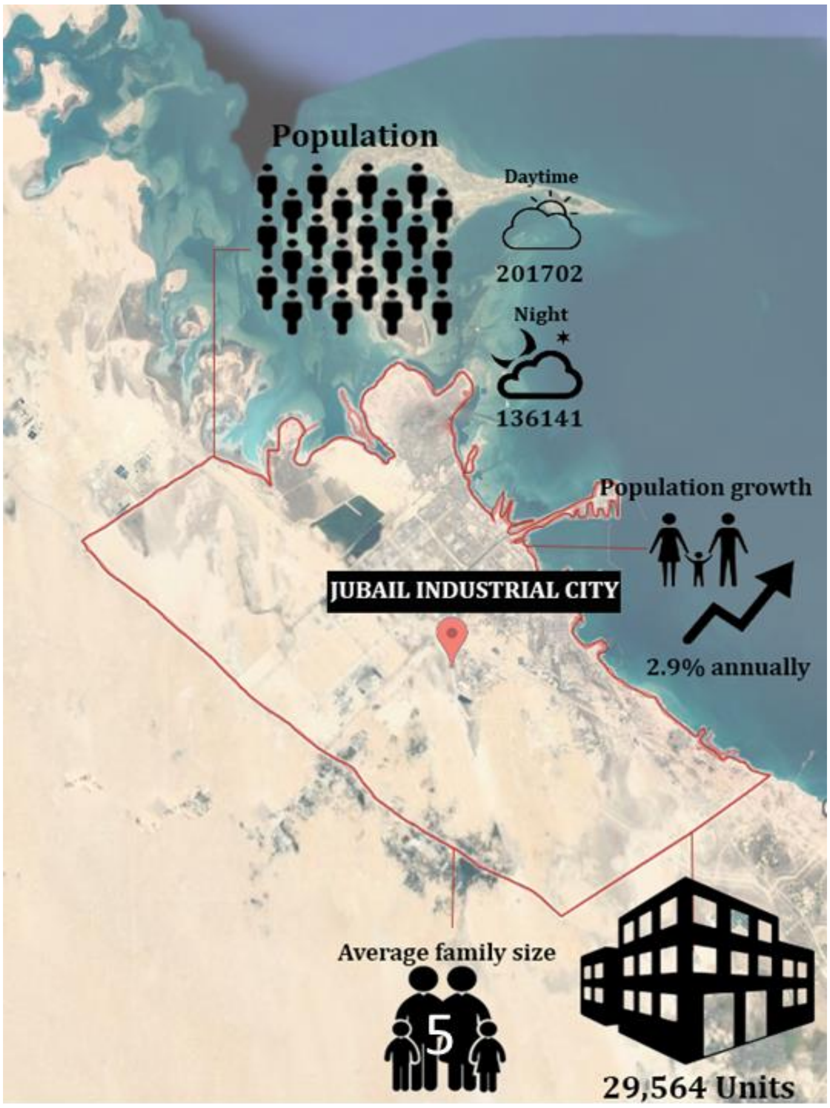


Figure 4-1 Case study location (Author, 2020)

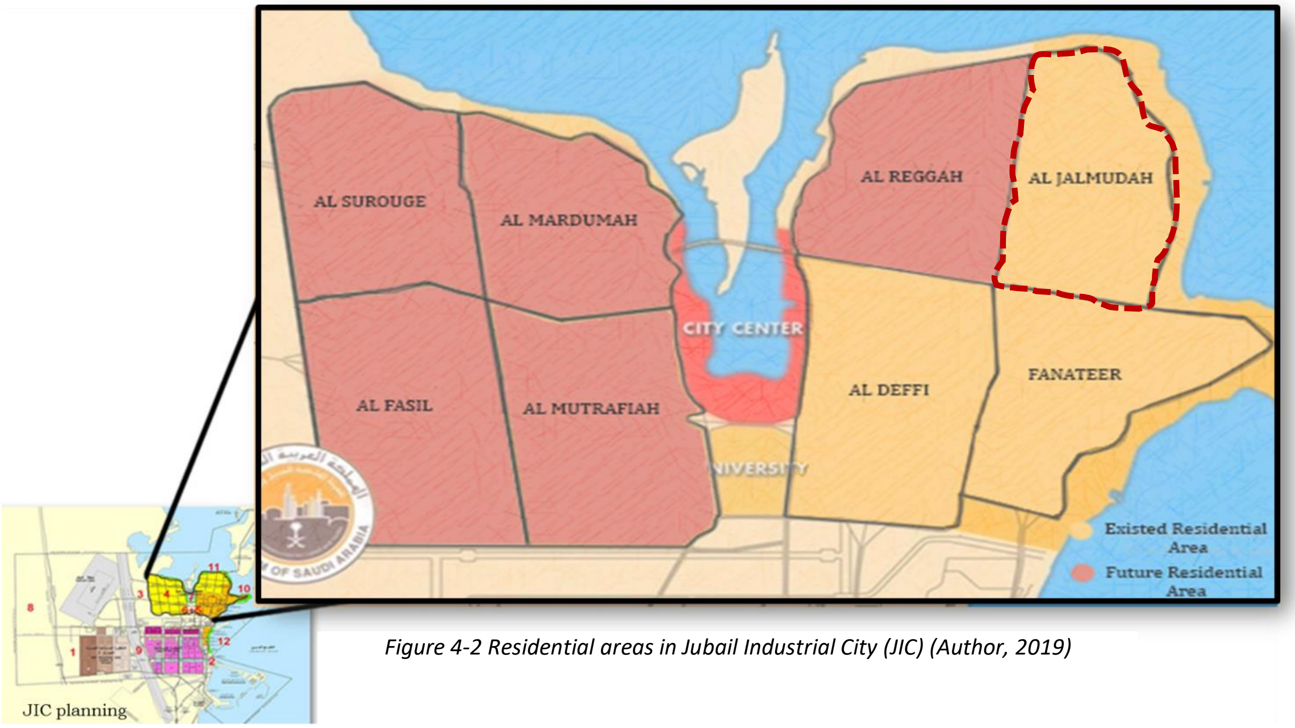


Figure 4-2 Residential areas in Jubail Industrial City (JIC) (Author, 2019)

Figure 4-3 Al Jalmudah district homes (Author, 2024)

Table 4-1 Case study weather (Weather station data, 2021)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average temperature (°c)	16.1	17.5	22	28	34	35.4	37	39	34	27	21	19.3
Average humidity	66.7%	64.6%	52.9%	43.3%	37.3%	43.5%	44.3%	45.9%	52.8%	56.5%	64.7%	66.6%
Max Temperature (°c)	27.5	29.6	34	37.4	43.9	46	47	49	45	39	31.7	29.5
Max humidity	89.5%	89.4%	90.5%	85.7%	71.9%	76.6%	82.2%	83%	86.1%	90.2%	92.9%	99.2%
Min Temperature (°c)	8.9	10.8	11	22	23.8	27.5	28.5	30.8	25.3	22	17.5	9.8
Min humidity	10.6%	25.3%	7.2%	7.8%	7.2%	7.5%	6.7%	11.7%	11.5%	11.7%	32.3%	15.6%
Solar daylight hours	11. 39	11.37	12.20	12.45	13.48	13.47	13.39	12.41	12.22	11.45	10.37	10.30

4.4 Sampling

Sampling is a selection of individuals from within a population or a group in order to form an understanding of the research problem and phenomena at study (Robson, 2002: Creswell, 2007: Barbour, 2007). The aim of this study was to obtain insights into the phenomenon (Ishak and Bakar, 2014) of energy consumption in Saudi housing, not to generalize to a population. The aim in this study to select homogeneous sampling of the case studies to help focusing on understanding and explaining the inhabitants' practices. The selected homogeneous samples were identical in terms of the house size, typology, building construction, number of bedrooms, floors and energy system (Figure 4-4); in which made the study more meaningful to focus on different social practices. The sample identified some diversities in terms of e.g. household sizes, and house orientations (Table 4-2). The sample size for any particular research should involve the consideration issues e.g. the nature of the research questions and the resource availability (Sarantakos, 2013; Saunders et al, 2009; Opoku et al, 2016). The sample of this research may considered as a small number (12 Saudi dwellings), but the sampling size of this research allowed searching for a deeper understanding of the phenomena rather than breadth, particularly when the research was undertaken under a non-positivist paradigm (Boddy, 2016; Vasileiou at el, 2018).

The sample were selected through the use of snowballing. This technique is extensively used in qualitative research when the population is hard-to-reach or hidden (Simkus,2023). Participants can identify a new potential participants or subjects. It was sent an electronic guide to the potential participants explaining the study and the purpose of it and the methods that will be used (Appendix 1). When the participants were agreed to participate in the study consent forms were sought (Appendix 2).

Table 4-2 Sampling characteristics

Participant code	P01	P17	P04	P05	P08	P10	P11	P12	P13	P14	P15	P16
House size	400m^2											
House type	A1											
Number of floors	3 floors											
Number of bedrooms	5 bedrooms											
Energy system	HVAC											
Family size	5	4	6	7	3	5	6	7	4	6	4	1
House orientation	South	North	North	North	East	North	North	North	West	West	West	west

Figure 4-4 Case study floors plans

4.5 Data collection methods

Post Occupancy Evaluation (POE) approach that involves mixed methods was used to conduct this research. POE can inform future projects, by providing recommendations for future retrofitting projects or for new developments based on the feedback (Gill et al, 2011; Li at el, 2018). Mixed methods research is when the researcher collect data through using quantitative and qualitative approaches (Tashakkori & Creswell, 2007). Also, it is more than simply collecting and analysing both types of data, it provides strength to the research and it is greater than either qualitative or quantitative research (Creswell, 2007). It has been used as a useful frame for interdisciplinary research, offering researchers the best chance of fulfilling their research objectives (Johnson & Onwuegbuzie, 2004), and this was the rationale of using mixed methods. The robust mixed- method approach provided complementary data in this research. The thesis attempts to answer a set of research questions, which are interdisciplinary and they involve the use of both quantitative and qualitative enquiries. The mixed methods were used to achieve the research objectives such as indoor environmental monitoring, home walkthrough, document review, building use study questionnaire, usability questionnaire, and interview (Table 4-3). The following section is explaining each of the research methods in details with the rational of its use.

Table 4-3 Methods used to achieve research objectives (Author, 2020)

Research objectives	**Research methods**					
	Document Review	**Home walkthrough**	**Environmental monitoring**	**BUS Questionnaire**	**Usability Questionnaire**	**Interview**
• Identify how much energy has been consumed in a selection of regulated homes.						✓
• Evaluate how a selection of regulated homes are performing in relation to thermal comfort.	✓		✓	✓		✓
• Understand the usability of environmental control interfaces of selected regulated homes.	✓	✓			✓	
• Explain the influence of inhabitant everyday practices on energy consumption and the indoor thermal environment.	✓	✓	✓		✓	✓

4.5.1 Indoor environmental monitoring

The monitoring of buildings can enhance the understanding of everyday life. It usually provides context e.g. differences in performing practices and help to diagnose problems (Foulds et al, 2013). This empirical study was collaboratively conducted with inhabitants by placing the measurement tools internally to measure their indoor environment by using specific tools. The reason for involving participants of e.g. downloading the app for the smart sensors and placing them in the places that needed to be measured, was due to the Covid-19 pandemic, when methods had to be conducted digitally. The tools were sent to the participants with restricted Covid-19 instructions that need to follow (Appendix 3). Also, participants were provided with instructions in written document and video on how to download the app, how to use the tools and how they work and why these tools are being used and how to send the data monthly.

The smart sensor (Figure 4-5) is a tool that measures the indoor dwelling's environment. It includes indoor air temperature, indoor relative humidity levels. Twelve homes in the study placed 4 of smart sensors each to capture all orientations: one in the living room, one in the guest room, one in the main bedroom and the last one was in bedroom2 (a bedroom located in the second last floor). The participants placed the sensors away from any heat/cold sources and direct sunlight. Within a height of 1.1 m and 1.7 m and 100–500 mm away from the wall to not be affected by the wall surface temperatures, in accordance with ASHRAE (2017), ISO 7726 (2001) and others e.g. (Dartevelle et al, 2021) and (Stevenson, 2019). The measurement data will be combined with the other research methods in order to identify the thermal comfort, understand and explain the inhabitant's practices. According to Gram-(Hanssen, 2014) in energy consumption studies, it is preferable to combine social-science approaches with actual measurements.

Figure 4-5 Physical Environmental Measurements Tool. (Author, 2020)

4.5.2 Document review

Wolfgang Preiser expressed that gathering data analysis for POE is comparable with a 'doctor's need to carry out a series of increasingly detailed and focused tests to diagnose a complex illness' (2013, p170). The design guide and design drawings and construction detail specifications were gained but were not allowed to be presented in this thesis due to its confidentiality. While the home user guide was obtained from the participants when the home walk thorough was conducted. The home user guide helped in understanding, explaining the influence of inhabitants' practices on energy consumption and their experiences related to the usability of the environmental control interfaces in their homes. Furthermore, understanding the relevant used standards in the RC homes e.g. ASHRAE helped to evaluate indoor thermal comfort of each homes and compared it with this standard.

4.5.3 Questionnaires

Two questionnaires were used in this research: The Building Use Study (BUS) questionnaire and; the usability questionnaire. BUS is a method that is used in this research and originally developed by Adrian Leaman (2005). The BUS questionnaire provides feedback on the levels of occupant satisfaction within buildings which can be used to create solutions to improve the occupant experience and optimise building performance (Bordass and Leaman, 2005). This questionnaire evaluates several areas e.g. indoor air quality (IAQ), thermal comfort, acoustics, lighting, design, health and energy consumption (Cohen et al, 2010: Lollini et al., 2020) (Appendix 5). It reveals the inhabitant's needs, satisfaction and identifying any key issues. The questionnaire was translated in Arabic; it is a first time was used in Arabic culture. This questionnaire helped to achieve the research objective 'the performance of regulated Saudi homes in relation to thermal comfort'.

The second quantitative method is the usability questionnaire, it is an inhabitant centred diagnostic tool, used to understand the user control of the system and testing the technology performance in relation to inhabitants' perception. 'A designer or controls supplier may know what a device is supposed to do, controllers provided for those devices do not always make the device functions clear to the end user' (Bordass et al, 2007.p14) (Appendix 4). One study examining the reduction of domestic energy consumption through an inclusive interface design project (Combe, 2012) used usability study of heating controls to focus on the issues experienced by older people. The findings show a significant number of people over 50 years of age were excluded from using heating control interface due to its complexity. The study developed an inclusive control interface prototype for heating. As a result, of the newly modelled prototype, the energy modelling indicated that saving energy annually by 14.5%-15.6% can be achievable. The usability questionnaire covers different sections of domestic controls such as HVAC system controls, renewables controls, boiler controls, windows and doors, electricity & and lighting controls, and emergency controls (Baborska-Narożny et al, 2019). The conducted usability helped achieve the research objective of 'understanding and explaining participants' experiences of the environmental controls interfaces' in their homes.

The BUS questionnaires were sent digitally to the inhabitants to complete via a link, while the usability was handed to the participants to be filled. None of the questionnaires were aiming for representativeness, the study targeted to collect at least 200 questionnaires in order to be statistically meaningful. Since the nature of the research is exploratory, there was no formal sample size calculation (Polit and Beck, 2004). Twelve usability questionnaires are gathered from participants who are already involved in the study to understand the environmental monitoring data in the context of usability. The study obtained a 100% return rate for both questionnaires. The answers in both questionnaires are based on a 1-7 scale (1: is unsatisfactory and 7: is satisfactory for the BUS) and for the usability (1: is very poor and 7: is very good).

4.5.4 Home walkthrough

Home walkthrough is one of the research methods, and was conducted by using the home tour guide and the researcher took notes e.g. about issues with controls (Appendix 6). The home walkthroughs were conducted after the interviews with participants accompanied by photography e.g. system original, retrofitted controls, general observations e.g. how participants used the space, and informal short conversations. After, the home tour finished the researcher collected the energy bills from the participants. The home walkthrough tours helped support the other data. For instance, when analysing the indoor environment, it is found that one of the reasons that may have contributed to increasing the indoor temperature in one home was the use of freezer in the measured bedroom2 in one of the studied homes, this was not mentioned in the interview but was observed during the home walkthrough. The following section explains the methods used for analysing the data.

4.5.5 Interview

Interviewing is a method used to collect in depth qualitative data and there are several types of interviews which are widely used in social science research (Jamshed, 2014). It is currently the most frequently used qualitative research method for understanding the role of inhabitants in domestic energy demand (Osz, 2016). To answer the research questions, semi-structured interview was used to gain more in depth information about the inhabitants' practices. Semi structured interview 'allow the interviewer to pose particular question with flexibility to digress and investigate based on interactions during the interview' (Klandermans and Staggenborg, 2002. P 92), while, open-ended interviews follow the inhabitants more. Conducting qualitative approach interviews can provide data on the understanding of know-how (habits), engagements, attitudes, and feelings (Arksey and Knight, 2011) (Appendix 7). The interviews took an hour to an hour and a half with inhabitants and were carried out in the inhabitants' homes each interview was recorded and later transcribed. The researcher undertook the transcription in person, and it was multiple listening to the audio recordings was carried out until the written texts were faithfully recorded of the words spoken. The focus of the transcripts was on the words spoken rather than the way they are spoken or the non-vocal behaviour (Braun and Clarke 2006). The reason for listening multiple times to the audio recordings was to eliminate as far as possible the 'deletions, additions and substitutions' (Kowal and O'Connell, 2014.p70). After this process was done, the transcriptions were shared with the participants to confirm that this was what they meant to say (Mero-Jaffe, 2011). After, confirmation with the participant about the transcription, the interview transcript was checked by the supervisor for accuracy, bias, and advising on technique.

The aim of this research was to conduct interviews with many members of the household (children excluded). The study obtained 13 in-depth interviews and helped achieve more in-depth data for the research objective 'to understand and explain the influence of inhabitant everyday practices related to energy consumption'.

4.6 Data analysis approaches and methods

As mentioned above that the thesis applied a mixed methods research approach, that involved multiple sources of data. Therefore, it required a robust analytical strategy (Yin, 2014). There are two ways to relate the data collection to analysis e.g. a linear-sequential approach and an iterative approach (Kennedy and Thornberg, 2018). With a linear-sequential approach, the researcher collected all the data and then started to analyse. In this research the quantitative data were collected such as environmental monitoring first for about 8 months then were analysed. Whereas, the iterative approach, the researcher moves back and forth between the data collection and the analysis. For example, after the environmental monitoring were analysed, some of the interview questions (related to indoor environment) were developed. Timeline for each research methods was demonstrated in (Figure 4-6).

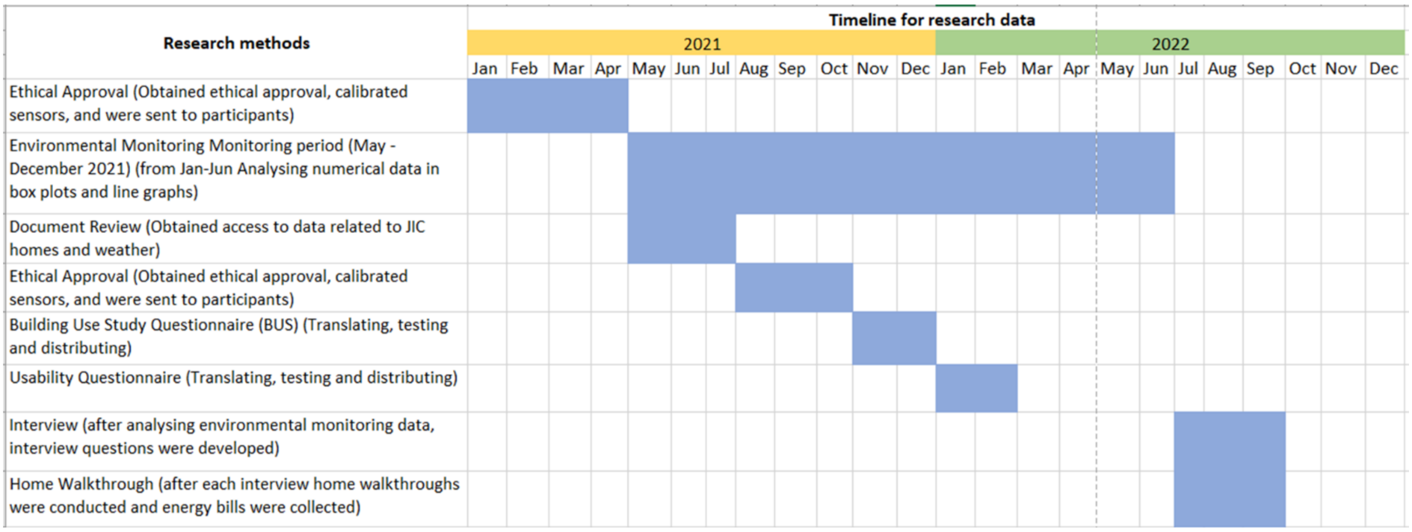


Figure 4-6 Research methods timeline (Author,2024)

In terms of the relationship between the theory and the data, the researcher used theoretical knowledge to interpret and analyse the data. Therefore, social practice theory was used as a vital analytical tool or lens in this thesis, this approach is called a deduction. The deduction begins with a specific existing theory and the collected data are analysed according to an existing theoretical framework (Reichertz, 2007). Also, at the same time the researcher was open to discovering new patterns, themes, concepts, or theories from data, this approach is known as induction. The inductive reasoning approach consists of inferring conclusions that emerged from the data through the researchers' interactions with the data without pre-supposing such outcomes a priori (Thornberg and Charmaz, 2014). After describing the approaches that were used for data analysis, the following section explains the methods used for analysing the qualitative and quantitative data.

4.6.1 Qualitative Data Analysis Methods

The qualitative data in this thesis were analysed by using the two cycles of coding, drawing on Saldaña (2009). Coding is one of the significant steps taken during analysis to organize and make sense of data (Basit, 2003). Utilizing coding in the research helps to allocate units of meaning to inferential information collected during a study (Gibbs, 2007). Codes are usually attached to varying-sized set of words, phrases, sentences or a whole paragraph. Looking for similarities, patterns and relationships in order to explain the research phenomenon (Saldaña, 2021). The two cycles of coding were carried out manually due to the language that was used when gathering the data.

The first cycle when the text was read, reread line by line and coded until all text was coded, adding new codes to what has already created. Each chunk of the coded text was long enough 'to provide sufficient context without clouding the integrity of the coded passage by the inclusion of text with a different meaning' (Jackson et al, 2019.p70). Using too small section of the text would result in superficial coding, and using too large an amount of the text would result in unreliable results, in both cases affecting its validity (Krippendorff, 2013). The systematic and exhaustive coding was crucial to the validity and the reliability of the research, 'no unit may be excluded because of a lack of descriptive terms' (ibid). To fully capture the speaker's meaning, multiple coding was used 'sparingly' as a large number of codes attached to a single chunk of data may 'suggest that there is no clear or focused research purpose and thus a clear lens and filter for analysing the data' (Saldana 2016.p81).

Coding the data was done by using a descriptive coding method (ibid). This method is described as 'meaning coding' by using one or keywords for 'identification' of the text (Brinkmann and Kvale, 2018.p122). The second cycle of coding allows the researcher to refine codes and categories that were created in the first cycle and then it was used a 'Pattern Coding' (Saldana 2016.p209) in order to develop the sub-themes (Figure 4-7). Grouping similarities, differences and repetition of codes in order to create smaller number of sets (Ryan & Bernard, 2003). In this study themes were aligned with practice theory and some were not and considered as inductive themes (chapter 6).

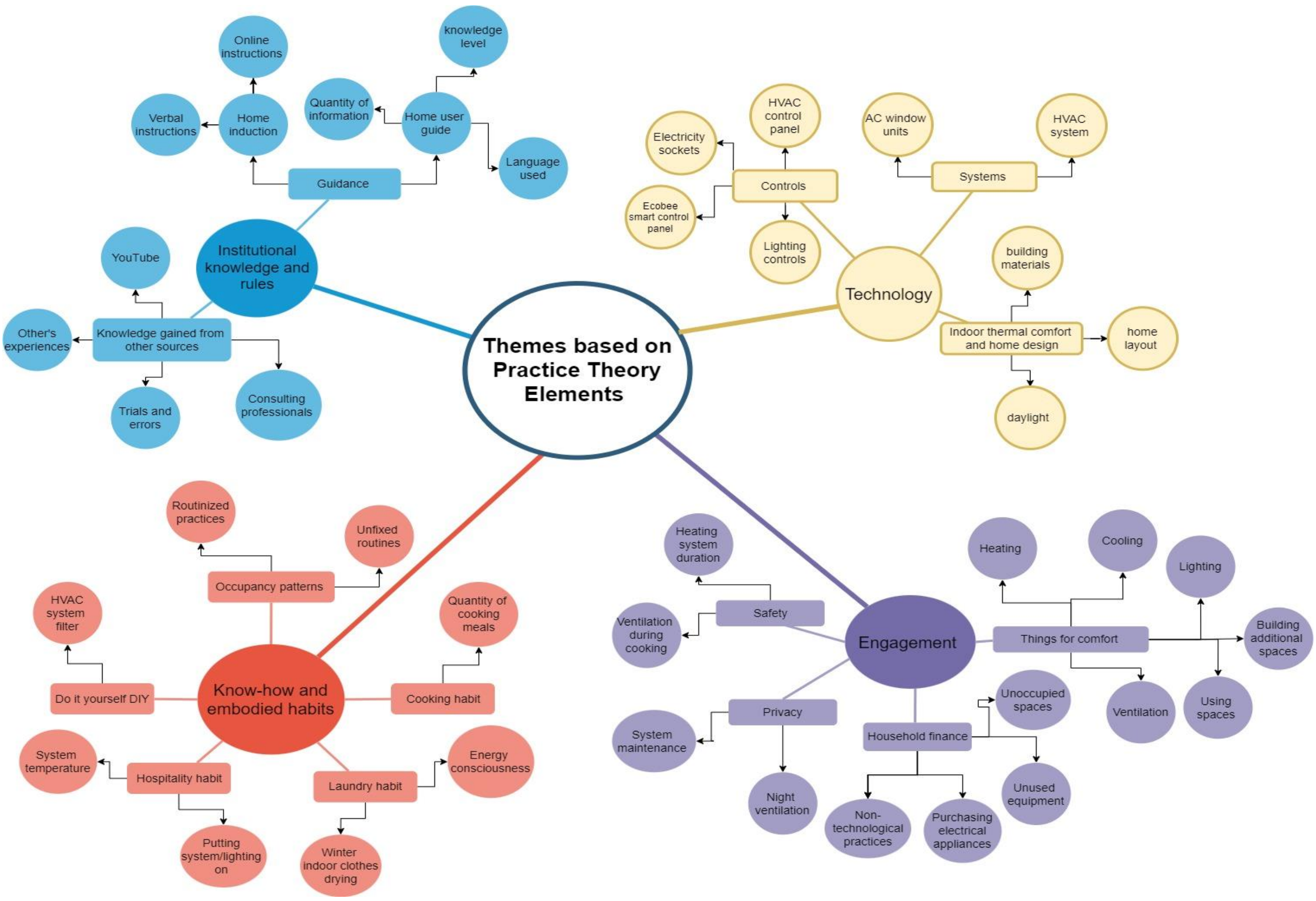


Figure 4-7 Example of Themes based on practice theory elements (Gram-Hanssen 2010), sub-themes and second cycle of coding (Author,2024)

4.6.2 Quantitative Data Analysis Methods

For the quantitative data, descriptive statistics analysis was used in this thesis to organise and summarise large amounts of monitoring data (measurement lasted for 8 months in 4 measured rooms in 12 homes), allowing better analysis and interpretation of those data (Triola, 2015). As explained by Thomas (2013, p.250), ''descriptive statistics are the simplification, organisation, summary and graphical plotting of numerical data''. Some methods are used to analyse the environmental monitoring data e.g. maximum, minimum, average, median and standard deviations. All these numerical data were analysed using Excel software and presented in boxplot graphs, line graphs, and tables. The BUS and usability questionnaires are benchmarked and used widely in research (section 3.5.4). The descriptive statistical analysis was conducted also to analyse the questionnaires. The questionnaire data were plotted and analysed by using Excel software and generated graphs to show the percentages of responses of each questions were analysed (Figure 4-8). The descriptive statistics analysis helped the researcher to organise and summarise the data were then more easily visualised, interpreted, and answered the research objectives. The next section explains the triangulation in this study.

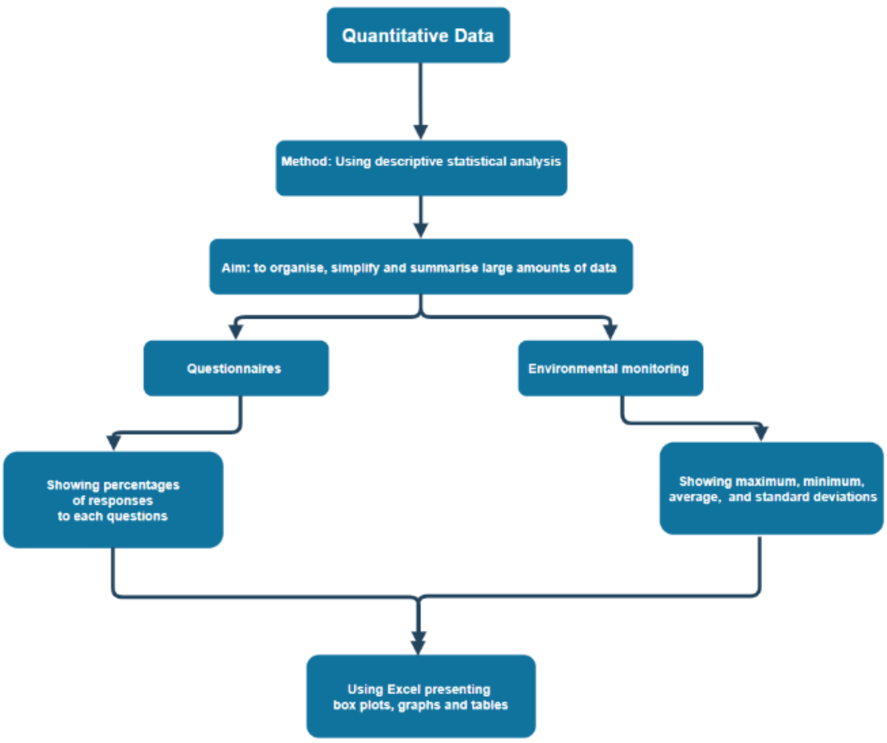


Figure 4-8 Quantitative analysis method

4.6.3 Mixed Methods Design

The mixed method design applied in this study is sequential triangulation (Figure 4-9), consists of two distinct phases: quantitative followed by qualitative. It is most common and well-known approach to mixing methods (Creswell and Plano Clark, 2006). The purpose of this design is “to obtain different but complementary data on the same topic” (Morse, 1991, p. 122) to best understand the research phenomenon. The term triangulation refers that evidence can be collected from multiple sources (Rowley, 2002). For example, using more than one research methods or sources to validate the research findings (Kane & O'Reilly-de Brún, 2001). Using many different sources of evidence is a major strength of case studies (Yin, 2014). The benefit of triangulation is that it strengthens the validity of the research findings (Abowitz & Toole, 2010; Jick, 2008; Yin, 2014).

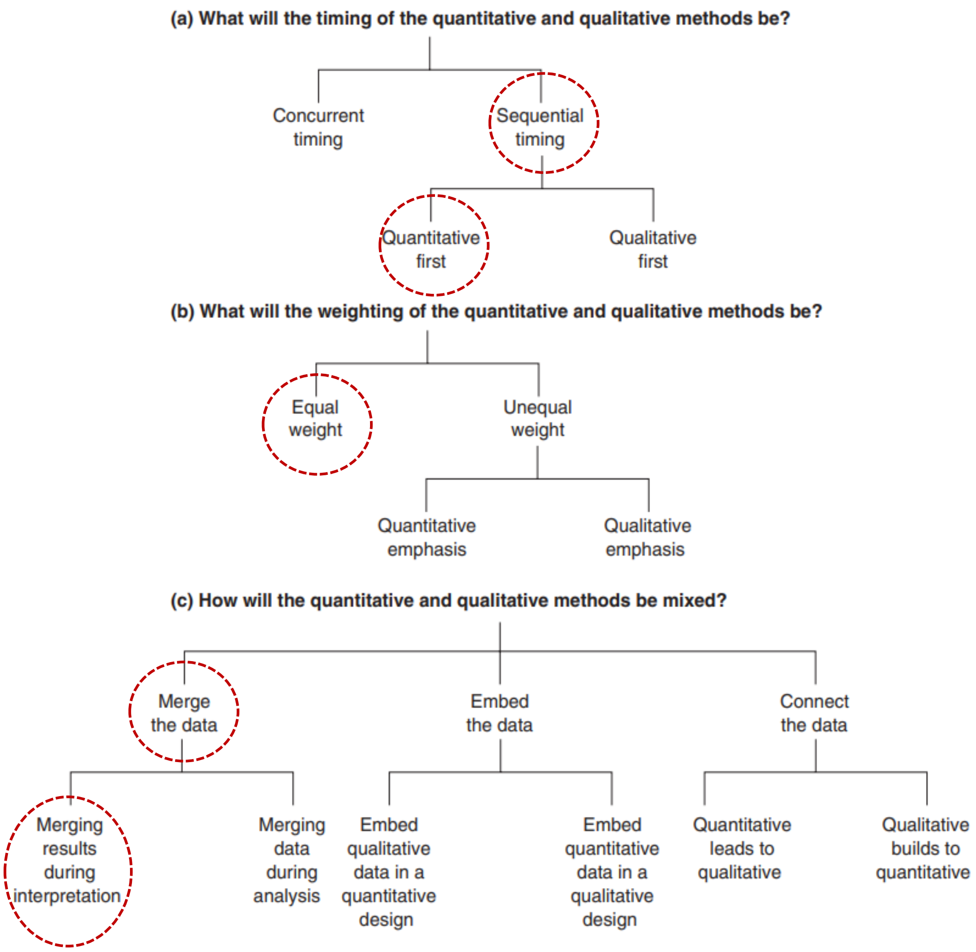


Figure 4-9 Study decision tree for mixed methods design (adopted from Creswell et al., 2003)

The purpose of triangulation that it can be used as a technique to reduce researcher bias and improve validity (John turner,2016). Triangulation applied in this research due to the use of more than one methods to collect data about the same phenomenon (Gerrish and Lacey, 2010). In this research data were collected using mixed methods to achieve the study objectives. For instance, the objective of the first part of the research is to evaluate the indoor environment of Saudi homes and their energy consumption. This required the use of the physical monitoring of indoor environment parameters (indoor air temperature and indoor relative humidity), Building Use Study (BUS) questionnaire, participant interviews (e.g. their thermal comfort experiences), document review (e.g. building construction details and drawings) and collection of energy consumption data from the participants (kwh/m^2). The second part of the research was to explain how inhabitants' everyday practices contribute to energy consumption and understand their experiences of environmental control interfaces. This type of enquiry requires the use of qualitative and quantitative research methods, such as participant interview, home walkthrough and usability questionnaire.

In this design (triangulation), the researcher first collected quantitative data and analysed the numeric data. Then the qualitative data were collected and analysed. The quantitative data was conducted first (e.g. environmental data) then the qualitative was due to develop some of the interview questions to explain and elaborate on the analysis observed in the numerical data. The rationale for using this approach is that the quantitative data and their subsequent analysis describes 'what' and the qualitative data and their analysis explain 'why' refine those numerical results by exploring participants' views in more depth (Creswell, 2003). Then the researcher merged the two data sets, typically by bringing the separate results together in the interpretation or analysis (Figure 4-10) (Creswell and Plano Clark, 2006).

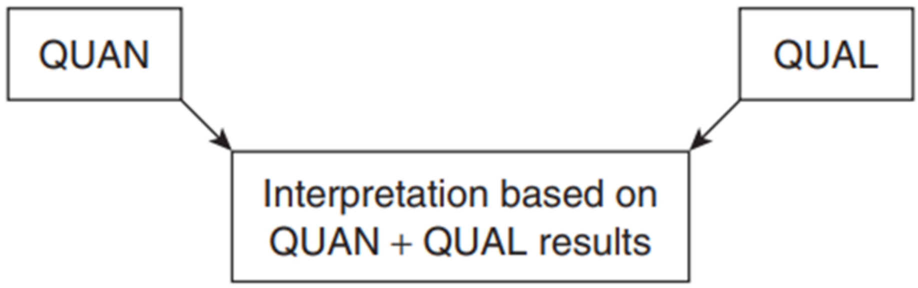


Figure 4-10 Triangulation design (adopted from Creswell and Plano Clark, 2006)

4.7 Ontological Standpoint

Although the mixed methods approach has been used widely in researches in different areas (Sale et al., 2002), there are some arguments against it. One of the arguments is based on the idea that researchers who used mixed methods approach should locate their research in a selected paradigm (Bryman, 2012). There are three elements of the research paradigm, ontology (the nature of reality), epistemology (how we know what we know) and methodology (the process of research) inference how the researcher views the world and they interpret it (Doyle et al., 2009). In this thesis, the ontology of pragmatism has been adopted as the most appropriate paradigmatic stance to be used when conducting mixed-methods research study (Figure 4-11). The logic of enquiry of pragmatists includes the use of both induction and deduction (Johnson and Onwuegbuzie,2004), which in this research are adopted. The time horizons of conducting the data in this research were cross-sectional for (questionnaires, interview and home walkthrough) and longitudinal for (the environmental monitoring) Pragmatism originates from the work of Peirce, James, Mead, and Dewey (Cherryholmes, 1992). Pragmatists have believed in an external world independent of the mind as well as that lodged in the mind (Creswell, 2014). Pragmatics recognise that there are many different ways of interpreting the world and undertaking research, that no single point of view can ever give the entire picture, and that there may be multiple realities' (Saunders et al, 2012). Therefore, mixed methods pragmatic researchers adapt both quantitative and qualitative enquiries because these researchers work to provide the best understanding of a research problem (Creswell, 2014).

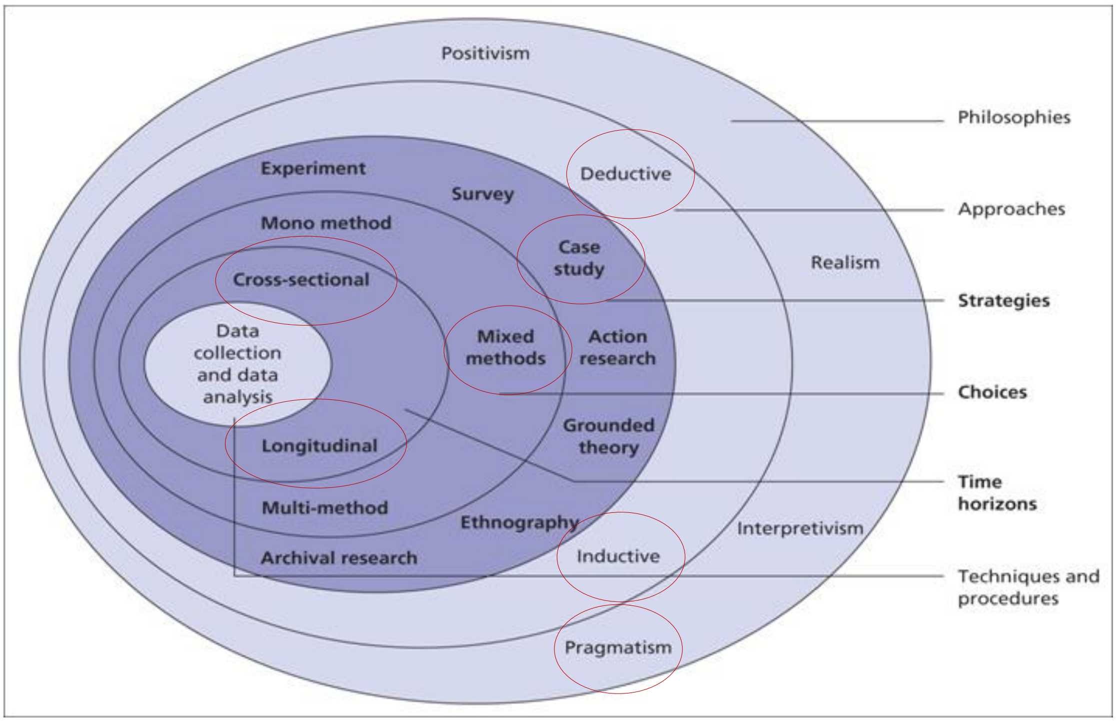


Figure 4-11 Research Onion (Source: Saunders et al., 2012, p.160)

According to pragmatism research philosophy, the research question is the most important determinant of the research philosophy. Pragmatics can combine both, positivist and interpretivist positions within the scope of a single research according to the nature of the research questions. Pragmatism could be related to a world with different layers, where some are objective, some are subjective, and some are a mixture of both (Dewey, 1925). As Feilzer (2010, p.8) explained, pragmatism 'sidesteps the contentious issues of truth and reality, accepts, philosophically, that there are single and multiple realities that are open to empirical inquiry and orient itself toward solving practical problems in the real world'. As Johnson & Onwuegbuzie (2004, p.17-18) explained for pragmatists 'what is most fundamental is the research questions – research methods should follow research questions in a way that offers the best chance to obtain useful answers'. Since pragmatism focuses on addressing the research problem and the necessity to answer the research questions, this research paradigm was used for this study. Having set the theoretical standpoint and the philosophical standpoint, the next section describes the ethical considerations to conduct this research.

4.8 Ethical consideration

As explained by Vanderstoep & Johnston (2009, p.12), research ethics deals with how we treat those who participate in our studies and how we handle the data after we collect them'. The ethical considerations for this thesis were made according to the University of Sheffield research ethics policy. It provides protection for participants, and also helps to protect the researcher. All the ethical considerations were considered that include the ethical approval process before collecting the research data, informed consent, data protection, anonymity and confidentiality (Appendix 8).

4.9 Chapter Summary

This chapter has highlighted the research design and the mixed methods that are used for data collection in order to explore and investigate inhabitant's practices and households' energy in Saudi dwellings, using a combination of qualitative methods and quantitative methods. It also discussed the analysis approaches and methods used to achieve the research aim and objectives. The results from using these methods were used to understand the context and problems arising, as well as proposed recommendations for the developer to improve current and future developments. These methods were particularly beneficial for revealing problems that may contributed to high-energy demand in domestic buildings of Saudi Arabia. The chapter also provides a conducted pilot study to calibrate the sensors to ensure that the data gathered are accurate and credible. Finally, the chapter described the ethical considerations of this research.

Chapter 5: Research findings on indoor environment and energy consumption

5.1 Introduction

This chapter presents the indoor environmental data such as the interior temperatures and relative humidity levels of twelve homes for eight months, in order to achieve the research objectives 'evaluate how Saudi regulated homes are performing in relation to thermal comfort and how much energy has been consumed'. This objective was achieved by conducting environmental monitoring methods, energy consumption bills, and building use study questionnaires (BUS). The chapter evaluates the seasonal variations of indoor temperatures and relative humidity levels are illustrated in box plots and line graphs.

5.2 Indoor environment

Indoor temperature and humidity were monitored and collected from four rooms in each house including the living room and guest room (located in the ground floor), main bedroom (located in the first floor) and bedroom 2 (located in the second floor) of the twelve Saudi homes. The indoor design conditions in each of the studied four rooms in the twelve homes are designed with ASHRAE international standard requirements for indoor environment. In all studied rooms, the indoor design temperatures requirement is recommended to be from 23°C to 26°C in summer and from 20°C to 23°C in winter, and the indoor design relative humidity should be from 40% to 60%.

The typology of the twelve studied dwellings in this research are identical in terms of the number of bedrooms, the layout floor plan, number of floors and the home size. The difference between the twelve homes is orientation of the monitored rooms and the family size (average, below the average and above the average) (Table 5-1).

Table 5-1 Case study characteristics (Author, 2021)

Participant code	P01	P17	P04	P05	P08	P10	P11	P12	P13	P14	P15	P16
House size	400m^2											
House type	A1											
Number of floors	3 floors											
Number of bedrooms	5 bedrooms											
Energy system	HVAC											
Family size	5	4	6	7	3	5	6	7	4	6	4	1
House orientation	South	North	North	North	East	North	North	North	West	West	West	west

5.2.1 Seasonal indoor temperature

The boxplot graphs below show the seasonal variation in temperatures in four rooms; living room (Figure 5-1), guest room (Figure 5-2), main bedroom (Figure 5-3), and bedroom2 (Figure 5-4), respectively. The central line is the median for the whole month, with the box showing the 25th and 75th centiles. The outer whiskers demonstrate the full range of the results. Due to issues with data downloads, a full set of data is not available for all months, so not all buildings are shown every month. The living room and guest room are located on the ground floor, the main bedroom located on the first floor, and the bedroom2 located on the second floor of each home. The data presented in the boxplot graphs were classified into three groups low variation (green), medium variation (yellow), and high variation (red) based on the standard deviations. The standard deviation of temperature that is less than and an equal 2 is classified as low variation, the standard deviation of greater than or an equal to 4 is classified as high, and the standard deviation falling in between classified as medium variation. From the Jubail weather station data, it is found that there were variations in the outdoor temperatures in March, April and May. Therefore, it was used May month (monitoring started from May) to represent the weather transition period, when the temperatures started to rise from maximum temperatures 34°C in March and 37.4°C in April to reach 43.9°C as maximum temperature in May (**Error! Reference source not found.**).

In the transition and the summer periods, the indoor recorded temperatures were above 21°C for 75% of the time. The highest observed interior temperature of the living room was found in P10 in the transition period at 36°C with a lower temperature at 24°C (Figure 5-1). This high recorded temperature found in this household's living room may be due to the room orientations facing south and west. The indoor temperature of this household can be also justified by their practices, such as room occupancy (chapter 7). The maximum indoor temperature of the living room in P04 during the same period was not exceeding 27°C with the lowest indoor temperature at 20°C. Although the orientations of the living room in this household face south and west, heat gain and this also can be explained by their practices in this room (chapter 7). The standard deviation of the mean indoor temperature (29°C) was found in P15 at ±5.08 in the summer season. This can be explained by their occupancy of this room, their practices of using the HVAC system level, the colour that is used for their living room’s curtains, and their cleaning practices (chapter 7). Their living room's high indoor recorded temperatures can be justified by the living room orientations facing south and east. Households 14 and 16 have the same orientations to P15 of their living rooms, but it can be seen there is a variation in their indoor temperatures not exceeding 35°C (Figure 5-1), which can be explained by their everyday practices.

In winter, the indoor recorded temperatures exceeded 23°C which is the maximum recommended winter indoor temperature found in most of the participants living rooms (Figure 5-1). This can be explaining by the effect of the living rooms orientations in P11, P05, P13, P04, P17 facing e.g. (west & south), p14 and p16 (south& east) and P01 (north & east). Also, this could be due to the homes construction material such as concrete (high thermal mass material) has contributed in creating warm indoor environment in the living rooms, absorbing the radiations due to the windows are open during daytime and release it at night. However, the lowest winter indoor temperature was noticed in household 14 at approximately 17°C (Figure 5-1). Although the living room in this participant home was facing more heat gain orientations e.g. south& east, this can be explained by their practice of opening windows (chapter 7). The lowest mean temperatures of the living rooms were found among the studied homes ranged from 22°C to24°C compared with the transition and the summer season (Table 5-2).

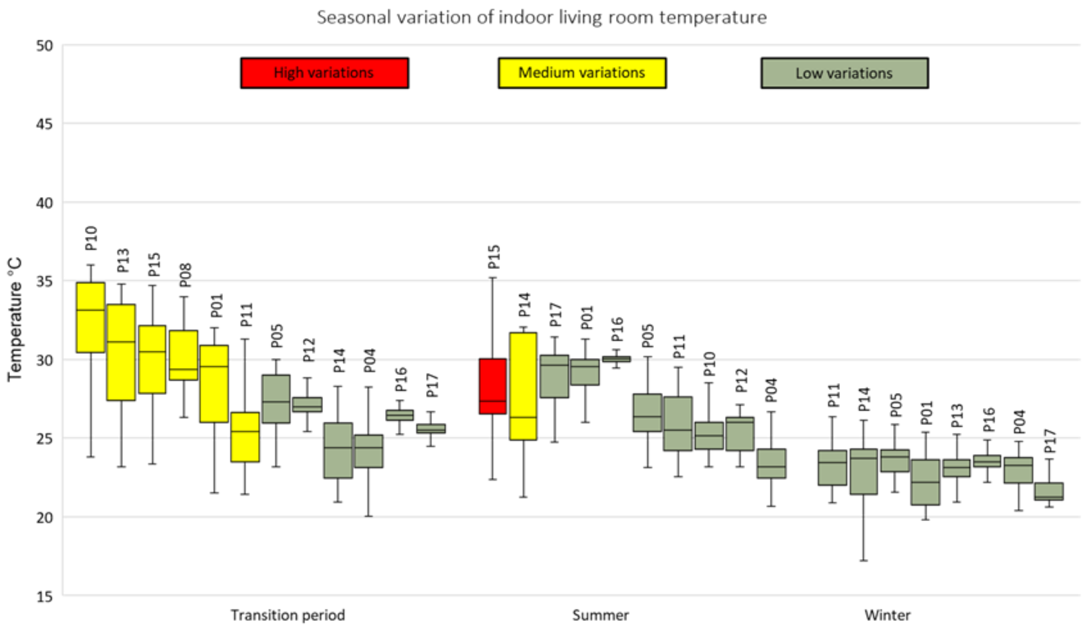


Figure 5-1 Boxplots showing the seasonal variations in temperature of the living rooms. Each box represents monthly data for each home

Table 5-2 Temperature standard deviation of living room in summer and winter

Participant code	P01	P08	P04	P05	P11	P13	P17	P10	P12	P16	P14	P15
Room Orientation	North & East	North & West	South & West	South & West	South & West	South & West	South & West	South & West	South & West	South & East	South & East	South & East
Transition period mean temperature and standard deviation	26°C ± 3.28	29.8 2.30	24.1°C ± 1.68	27.4°C ±1.74	25°C ±2.00	30°C ±3.84	26°C ±0.94	32°C ±3.95	27°C ±0.92	26°C ±0.42	24°C ±1.89	29.2°C ±2.84
Summer mean temperature and standard deviation	29°C ± 1.22	-	23.5°C ± 1.32	26°C ±1.58	25°C ±1.82	-	28°C ±1.87	25°C ±1.02	25°C ±1.15	29°C ±1.97	27°C ±3.62	29°C ±5.08
Winter mean temperature and standard deviation	22°C ± 2.32	-	23°C ± 1.00	24°C ± 0.82	23°C ± 3.01	23°C ± 0.90	23°C ±1.32	-	-	24°C ± 0.60	24°C ± 1.39	-

The internal recorded temperature of all the guest rooms have low to medium variations (Figure 5-2) comparing to other measured rooms (e.g. living room, main bedroom and bedroom 2). The participants' everyday practices of using this room and its system e.g. use it when they are having guests (chapter 6 and 7). The highest standard variations of the mean indoor temperature (30°C) was found in P08 at ±3.33 among the three seasons. This can be justified by the effect of the room orientation facing east and north as well as their everyday practices e.g. using this room. The lowest indoor main variation of P12 and P14 in transition period and the summer season, at ±0.41 and ±0.40, respectively (Table 5-3). This is low variations may due to their room orientations facing north and west (P12) and south and west (P14), but also can be explained by their everyday routine of e.g. using the room and the system there (chapter 6). Even in winter the guest rooms had minimal variations recorded in their indoor temperatures. Furthermore, warm indoor temperatures were recorded in households' 16 and 14 guest rooms at 25°C and 26°C, respectively (Figure 5-2). The positioning of their rooms, facing towards the west and south, can be interpret in creating warm indoor environment. Also, this can be explained by their practices e.g. not using curtains on their guest rooms windows (chapter 7). Below 20°C of winter indoor temperature was captured in P17 for approximately 75% of the time, this recorded indoor temperature may due to the room orientation that is facing north and west. Also, this can be due to their everyday practices e.g. opening windows (chapter 6 and 7). Maximum indoor temperature during winter season was found in P14 at 27°C, this may due to the room orientations facing south and west (Figure 5-2). The lowest standard variation of indoor mean temperature (24°C) was found in P16 at ±0.42. this may due to the room orientation facing south and west as well as the participant everyday practices e.g. using the room, heating practices (chapter 6 and 7).

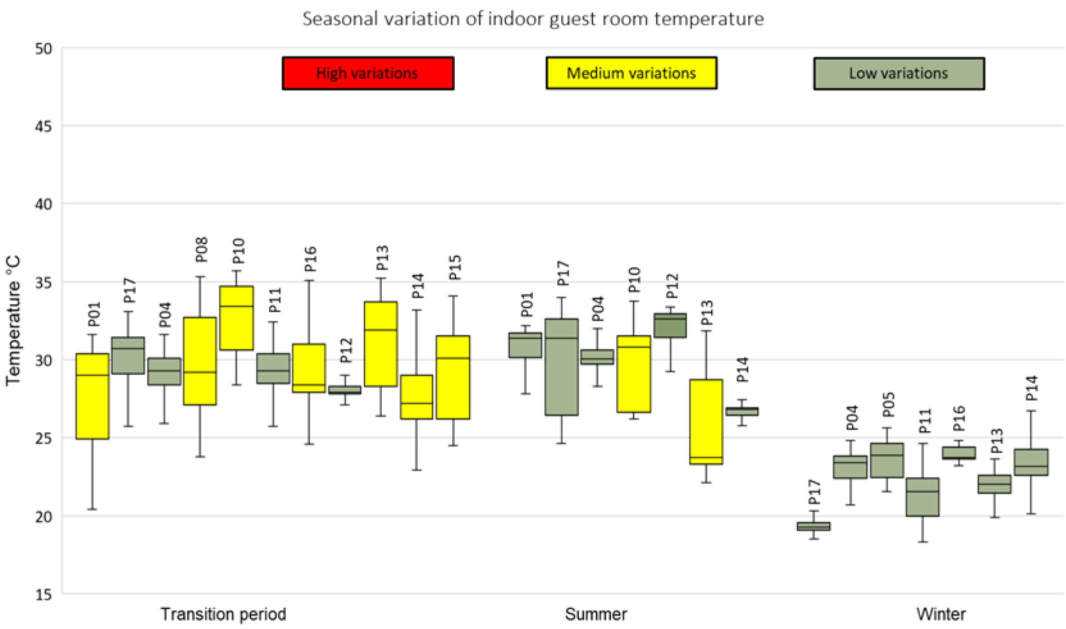


Figure 5-2 Boxplots showing the seasonal variations in temperature of the guest rooms. Each box represents monthly data for each home

Table 5-3 Temperature standard deviation of guest room in summer and winter

Measured months	P01	P17	P04	P05	P08	P10	P11	P16	P12	P13	P14	P15
Room Orientation	South & East	North & West	North & West	North & West	North & East	North & West	North & West	South & West	North & West	North & West	South & West	South & West
Transition period mean temperature and standard deviation	27°C ±3.22	30°C ±1.54	29°C ±1.19	-	30°C ±3.33	33°C ±2.23	29°C ±1.29	29°C ±2.33	28°C ±0.41	31°C ±2.87	28°C ±2.15	29°C ±2.85
Summer mean temperature and standard deviation	31°C ±1.10	30°C ±3.10	30°C ±1.44	-	-	30°C ±2.31	-	-	32°C ±1.37	26°C ±2.89	27°C ±0.40	-
Winter mean temperature and standard deviation	-	20°C ±0.84	23°C ±0.95	24°C ±1.00	-	-	22°C ±1.74	24°C ±0.42	-	22°C ±0.85	24°C ±1.97	-

For the main bedroom, the highest recorded indoor temperature was found in household 15 at approximately 40°C in summer. The west facing main bedroom window may have contributed to the high recorded interior temperature. Also, other practices may increase this e.g. their routine of using the HVAC system and the use of dark colour curtains (chapter 7). However, the highest standard variation of the main indoor temperature was found in P15 in summer season at ±5.57. Although participant 14 has the same facing orientation as P15, but it is found lower recorded indoor temperature than P15 and the maximum temperature reached 27°C (Figure 5-3). This can be explained by their everyday routine of using the system as well as the use of light colour curtains (chapter 6 and 7). Another, high indoor temperature was found in household 1 main bedroom and the maximum temperature reached 31°C (Figure 5-3), this high observed indoor temperature may have affected by the south orientation of this room. And their routine of using their HVAC system in the first floor rooms may have contributed to increase the main bedroom temperature. Households 12, 10, 17, 4, 14 and 13 have same bedrooms' orientations north as a result their recorded indoor temperatures are found lower than the other households at 27°C (Figure 5-3), also their routine of using their HVAC system e.g. setting their systems at certain temperature (chapter 6 and 7). However, although household 11 main bedroom is facing north similar to (Households 12, 10, 17, 4, 14 and 13) but it is observed that had high recorded indoor temperature at approximately 35°C (Figure 5-3). This can be explained by their everyday routine e.g. of turning their system off when the space is unoccupied (chapter 6 and 7).

During the winter season, variations in indoor temperatures of the main bedrooms were noticed in all homes (Figure 5-3). Low indoor recorded temperature in P01, P04 and P11 were at 19°C and 18.5°C, respectively. This can be explained by the room orientations facing north, meaning less heat gain. However, household 14 their main bedroom is facing west and it can be seen that their indoor recorded temperature was approximately at 24°C (Figure 5-3). Although, in the main bedroom of the household 13 faces north orientation, warm indoor temperature was found between 20°C to 23°C (Figure 5-3), This might be explained by their heating practices (chapter 6). Low indoor mean temperatures variations were found in the main bedrooms across all homes during winter season with standard deviations ranged between ±0.68 (e.g. P17) to ±1.67 (e.g. P01) (

Table 5-4).

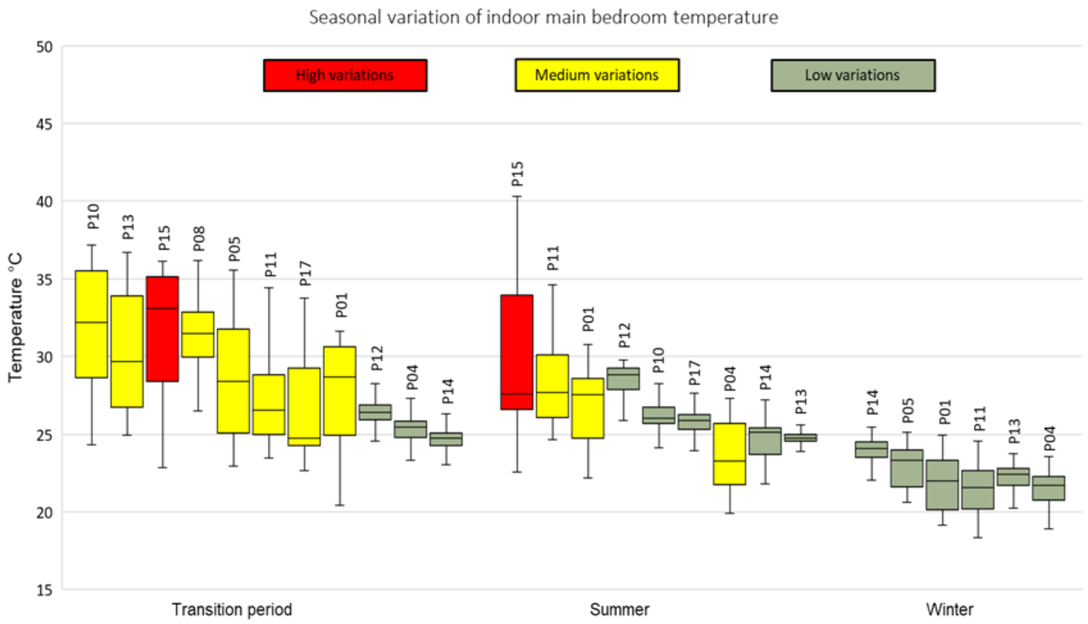


Figure 5-3 Boxplots showing the seasonal variations in temperature of the main bedrooms. Each box represents monthly data for each home

Table 5-4 Temperature standard deviation of main bedroom in summer and winter

Measured months	P01	P08	P17	P04	P05	P10	P11	P12	P13	P16	P14	P15
Room Orientation	South	East	North	North	North	North	North	North	North	West	West	West
Transition period mean temperature and standard deviation	28°C ±3.24	30°C ±3.74	27°C ±3.38	25°C ±1.00	29°C ±3.68	33°C ±3.04	27°C ±2.43	26°C ±0.83	31°C ±4.18	-	25°C ±0.69	32°C ±2.16
Summer mean temperature and standard deviation	27°C ±2.18	-	26°C ±1.00	24°C ±2.10	-	26°C ±0.69	28°C ±2.42	29°C ±1.05	25°C ±0.44	-	25°C ±1.03	30°C ±5.57
Winter mean temperature and standard deviation	22°C ±1.00	-	19°C ±0.68	21°C ±1.00	23°C ±0.36	-	21°C ±0.64	-	22°C ±0.79	23°C ±0.75	24°C ±0.79	-

According to the weather station data, the maximum extreme summer outdoor temperature reached 49 °C. The standard deviation of temperature variation in bedroom2 was ranged from 0.49 which can be seen in the participant 13 home, to highest temperature variation with standard deviation of 6.12 in the house of participant 15 respectively, (Table 5-5).

Differences in the indoor temperatures among the studied homes were noticed. The highest indoor temperatures recorded were found in bedroom2 across all rooms in each home and among the households. In addition, the bedrooms 2 orientations in the studied homes are facing heat gain orientations. For example, P01 (east), P13, P11 and P17 (west) and P16, P15, P16, P12 and P14 (south). This can be interpreted the high indoor temperatures found in those homes in transition period and summer season (Figure 5-4). Also, another factor that may contributed to this high temperature in P01, P13, P11, P17, P16, P15, P16, P12 and P14 is the low albedo affect. The external surface (slab tiles) of the future room (is an optional room that can be built by inhabitants depending on their needs) is originally in dark grey colour which means more solar gain in these participants' bedrooms2. The gained heat during the day time and later more ambient temperature released. The household 8 has the highest indoor temperature recorded in the transition period reported at 44°C, although this room is facing north, meaning less heat gain. This indicate that this household carries out different practices that may lead to this observed high indoor temperature, this is disused more in details in the discussion chapter (7) where both set of data were triangulated. Indoor temperature variation of bedroom 2 is found in household 10, the minimum temperature reached approximately 19.5 °C especially in the summer season, although the room orientation is facing south. This may due to their practices of using this room which is discussed in chapter (7). However, the south orientation of this room can explain the maximum indoor temperature in the transition period and the summer season at approximately 38°C. it is found similarities in bderoom2 indoor temperatures between households 4 and 5 at maximum temperature of approximately 35°C. Both bedrooms2 are facing west orientation which may explain the high observed indoor temperatures in both homes. Because Saudi Arabia is located near to the equator and more heat gain from the east and the west orientations. In winter the recorded external temperature was at 10°C, low indoor temperatures variations are found in all four measured rooms in winter season compared to the transition period and the extreme summer season. the monitored four rooms' interior temperatures had not exceeded approximately 27°C across all homes.

Temperatures that lower than 20°C were recorded and observed in all four measured rooms. This room found facing south, west and east orientations in the studied homes.

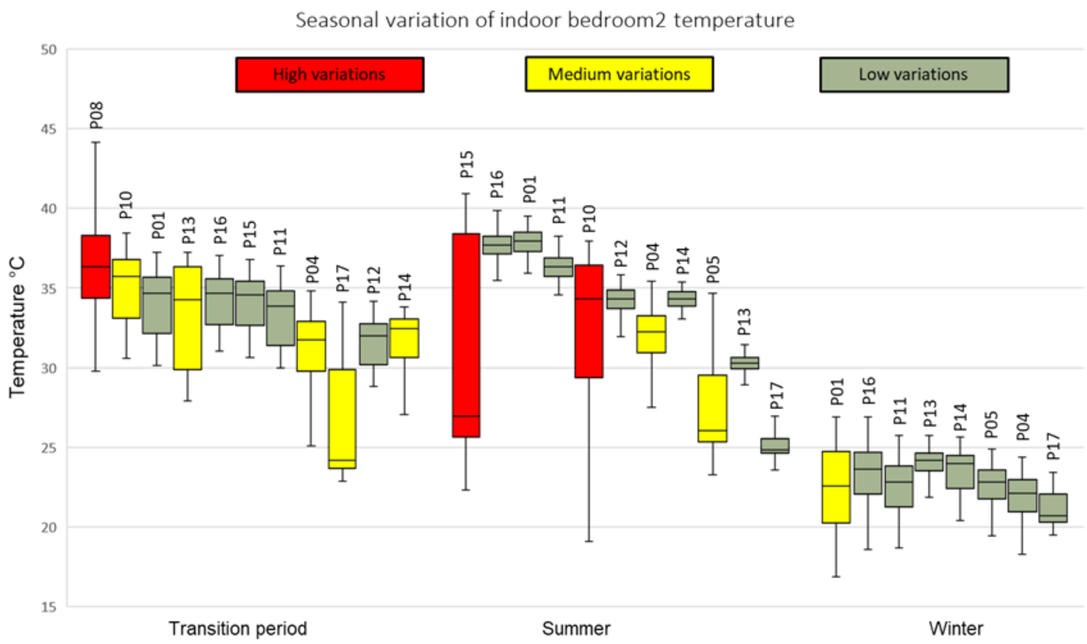


Figure 5-4 Boxplots showing the seasonal variations in temperature of the bedrooms 2. Each box represents monthly data for each home

Although the orientation of this room means more solar gain, there found low recorded indoor temperature at 17°C (e.g. P01) and 19°C (e.g. P04, P11 and P16) (Figure 5-4). These minimum indoor temperatures may explain their practices e.g. natural ventilation this discussed more in chapter (7). The standard deviations of the bedrorms2 mean indoor temperatures among the studied homes compared with transition and summer standard deviations. The highest standard variation of indoor mean temperature of bedroom2 across all studied homes was found in P15 at ±6.12 in the summer period (Table 5-5). The lowest standard deviation of mean indoor bedroom2 was found in P13 at ±0.49 in the summer season.

Table *5-5 Temperature standard deviation of bedroom 2 in summer and winter*

Participant code	P01	P17	P04	P05	P11	P13	P08	P10	P16	P12	P14	P15
Room Orientation	East	West	West	West	West	West	North	South	South	South	South	South
Transition period mean temperature and standard deviation	34°C ± 1.95	26 °C ± 3.75	31°C ± 2.29	-	33°C ±1.81	33°C ±3.15	36°C ±4.51	35°C ±2.51	34°C ±1.57	32°C ±1.41	32°C ±2.25	34°C ±1.63
Summer mean temperature and standard deviation	38°C ± 0.79	25 °C ±1.11	32°C ±2.39	27°C ±2.96	36°C ±0.79	30°C ±0.49	-	32°C ±5.35	38°C ±0.86	34°C ±0.73	34°C ±0.53	30°C ±6.12
Winter mean temperature and standard deviation	23°C ± 2.32	21°C ± 1.04	22°C ± 1.52	23°C ± 1.05	23°C ± 1.76	24°C ± 0.84	-	-	23°C ± 1.92	-	24°C ± 0.97	-

It is worth mentioning that the noticeable variations in the indoor temperatures in most of the participants' measured rooms (e.g. living room, guest room, main bedroom and bedroom 2) during the transition period, were because participants have left their home for approximately two weeks for holiday. As a result, some participant turned off their system off (e.g. P15, P10, P13, P08, P05, P12 and P11) and some set it at higher certain temperature (e.g. P14, P16, P01, P04 and P17).

5.2.2 Seasonal indoor relative humidity

The boxplot graphs below show the seasonal variation in relative humidity in four rooms; living room (Figure 5-5), guest room (Figure 5-6), main bedroom (Figure 5-7) and bedroom2 (Figure 5-8), respectively. The central line is the median for the whole month, with the box showing the 25th and 75th centile. The outer whiskers demonstrate the full range of the results. Due to issues with data downloads a full set of data is not available for all months and so not all buildings are shown in every month. The living room and guest room are located in the ground floor, main bedroom located in the first floor and the bedroom2 located in the second floor of each homes. The data presented in the boxplot graphs were classified into three groups low variation (green), medium variation (yellow) and high variation (red) based on the standard deviations. The standard deviation of relative humidity that is less 1 classified as low variation, the standard deviation of four and greater than 4 classified as high and the standard deviation falling in between classified as medium variation.

According to the data collected, it was discovered that during the summer, the indoor humidity levels were low in all the rooms that were monitored in the homes. Conversely, during the winter season, high levels of humidity were observed in all the monitored rooms in the homes. In the summer, the low relative humidity levels could be the result of the increase of the indoor temperature (is inversely related to temperature) that was seen above. low indoor RH could be the result of a low amount of water vapour in the air. When the temperature increases, air has the ability to hold a greater amount of water vapour than air at lower temperatures. The relative humidity will decrease when temperature increases, since warmer air is capable of holding more water [Rafidi, 2017]. However, this relationship is only true if no more water vapour is introduced to the air.

It is observed that there are differences in seasonal relative humidity levels in the monitored four rooms. Some of monitored houses presented RH levels between 40% and 60% for 75% of the time during the summer season, in the monitored living room and guest room. However, the relative humidity levels in studied main bedroom and the bedroom2 were below 40% for approximately for 75% of the time in the summer season. In the winter, it can be seen that most of the houses the indoor relative humidity was between 40%-60% for approximately 75% in all monitored four rooms. In the transition period, it is noticed that the indoor relative humidity in all studied rooms were ranged from 25% to 60% across all homes, with exception of P12 and P05. It can be seen that the indoor humidity levels were obtained from all rooms ranged from 18% as the lowest in P12 bedroom2 in the summer season, to 88% as the highest in P05 living room in the winter season (Figure 5-5) and (Figure 5-8).

Indoor relative humidity variations are noticed in the living rooms of all participants in all seasons. In the summer and transition period, most of participants' living rooms indoor humidity levels were approximately not higher than 60% but lower than 40% (Figure 5-5). Comparing to winter indoor relative humidity were above 60% in most of the living rooms. The variations observed of RH% levels in the monitored living rooms can be explained by the inverse relationship of the recorded indoor temperature. However, it could be also the participants' everyday practices e.g. P15 relative indoor humidity level has exceeded 60% due to their opening windows during the cleaning time (chapter 6 and 7). Since the case study (Jubail industrial city) is located on the Arabian Gulf coast of Saudi Arabia and it is classified with hot and humid climate. External weather may have contributed in affecting the indoor relative humidity since the external humidity reached at 99.2% as maximum and 15.6% as minimum in winter. The weather station reported that the maximum humidity reached 38% and minimum 11.7%. Exchanging the inner air with outer air may result in variations of the indoor relative humidity. In addition, participant 12 RH level exceeded 60% during summer season (Figure 5-5), this can be explained by the low recorded indoor temperature of their living room. Also, other practices may have contributed to this high RH% level e.g. using humidifier machine (chapter 6). Also, the design layout of the ground floor that kitchen is an open plan area to the living room have consider as one of the reasons led to the variations of the indoor RH% levels that were observed. For example, practices of ventilation, cooking, washing and drying clothes, using dishwasher and cleaning (chapter 6 and 7).

Table 5-6 Relative humidity standard deviation of living room in summer and winter

	P01	P17	P04	P05	P08	P10	P11	P16	P12	P13	P14	P15

Room Orientation	North & East	South & west	South & west	South & west	North & West	South & west	South & west	South & East	South & west	South & west	South & East	South & East
Transition period mean RH% and standard deviation	32% ±3.88	40.6% ±2.63	38.2% ±3.98	40.5% ±4.52	43.3% ±7.27	46.6% ±2.99	35.9% ±5.72	42.2% ±3.38	43.2% ±4.51	49.3% ±2.49	43.5% ±6.17	39.1% ±4.24
Summer mean RH% and standard deviation	34.6% ±5.23	36.8% ±3.44	45% ±4.40	42% ±4.66	-	49% ±3.89	38% ±5.90	41% ±6.89	47% ±5.66	-	44% ±5.61	47% ±11.90
Winter mean RH% and standard deviation	55.1% ±5.64	61.7% ±8.10	48.7% ±5.49	56.6% ±5.24	-	-	49.8% ±2.57	-	-	53.8% ±5.56	55.8% ±5.67	-

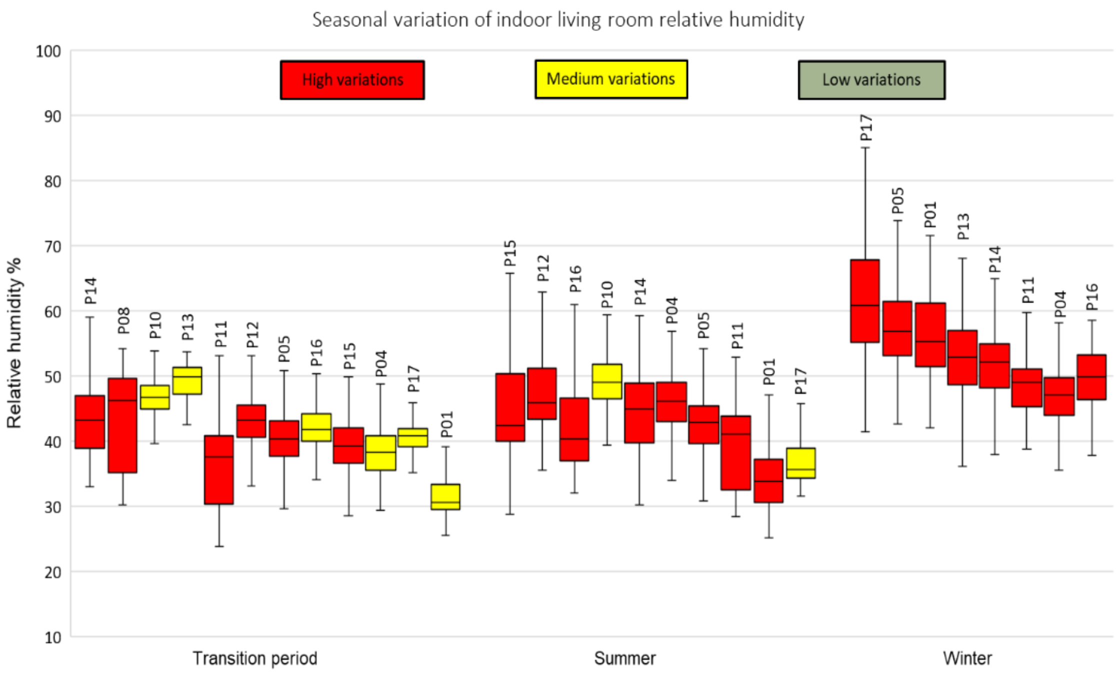


Figure 5-5 Boxplots showing the seasonal variations in humidity of the living rooms. Each box represents monthly data for each home

In the guest room, the indoor relative humidity levels were found lower than 60% in transition and summer seasons with exception of P13 (Figure 5-6). High indoor RH% levels were found above 60% in winter season and some lower RH% levels than 40% e.g.

P14 and P04 (Figure 5-6). These RH% levels of this room during transition, summer seasons and the winter can be explained by the inverse relationship between the temperature and humidity of this room. Due to the room occupancy and inhabitants' everyday practices e.g. opening windows (chapter 6). The standard deviation of this room found that the indoor relative humidity level varied more than the temperatures among all seasons and homes (Table 5-7).

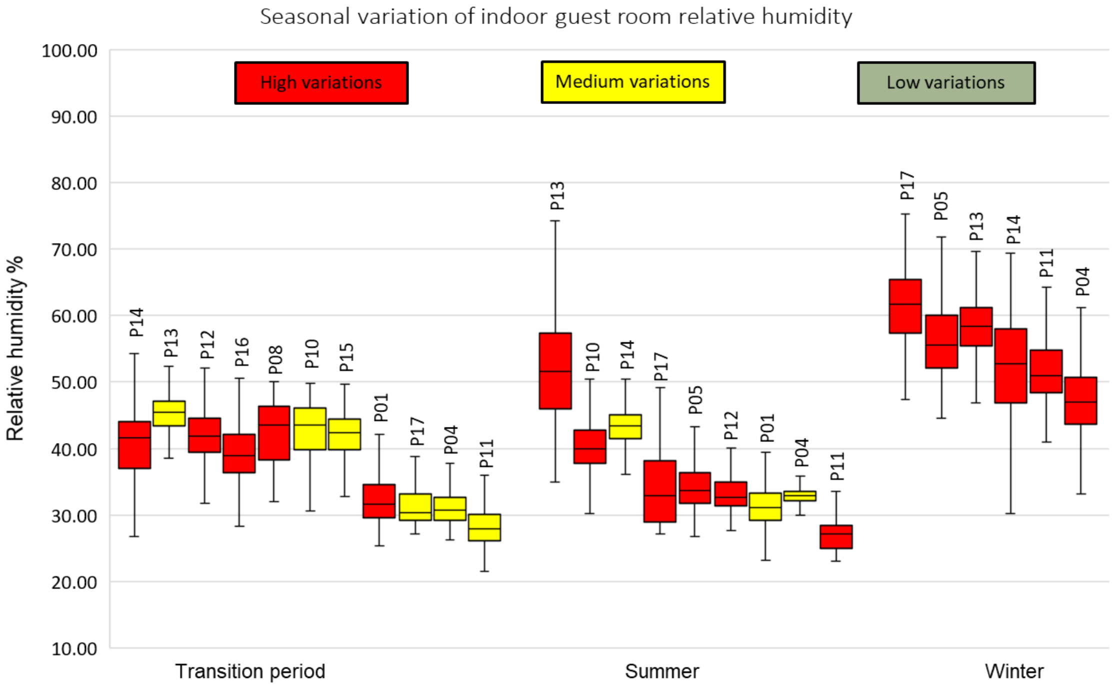


Figure 5-6 Boxplots showing the seasonal variations in humidity of the guest rooms. Each box represents monthly data for each home

Table 5-7 Relative humidity standard deviation of guest room in summer and winter

Measured months	P01	P17	P04	P05	P08	P10	P11	P16	P12	P13	P14	P15
Room Orientation	South & East	North & West	North & West	North & West	North & East	North & West	North & West	South & West	North & West	North & West	South & West	South & West
Transition period mean RH% and standard deviation	32.6% ±4.16	31.2% ±2.55	31.3% ±3.15	-	42.4% ±4.70	42.7% ±4.51	28.2% ±3.01	39.2% ±4.43	41.8% ±4.12	45.3% ±2.51	40.6% ±4.96	41.9% ±3.59

Summer mean RH% and standard deviation	31% ±3.25	34% ±4.67	33% ±2.70	-	-	41% ±5.73	-	-	34% ±6.09	53% ±8.81	43% ±2.78	-
Winter mean RH% and standard deviation	-	61.8% ±6.90	47.3% ±6.17	56.8% ±6.55	-	-	52.1% ±5.81	-	-	58.1% ±4.46	52.4% ±7.72	-

In term of the main bedroom, indoor relative humidity levels were varied in all seasons. Most of the participants' main bedroom indoor relative humidity were below 40% found in transition and summer seasons. Furthermore, lower than 30% of indoor RH was found in P01 and P11 during the transition period and in P14, P12, P01 and P11 during summer season (Figure 5-7). These recoded low indoor relative humidity levels may due to the inverse relationship with indoor temperatures of these homes. Other practices were reported (in chapter 7) may contributed to the observed high and low levels of RH% e.g. opening windows, opening the bathroom's door after showering and cleaning for ventilation. The standard deviation of the main indoor relative humidity levels was higher in this room than the guestroom across all monitored homes (Figure 5-7).

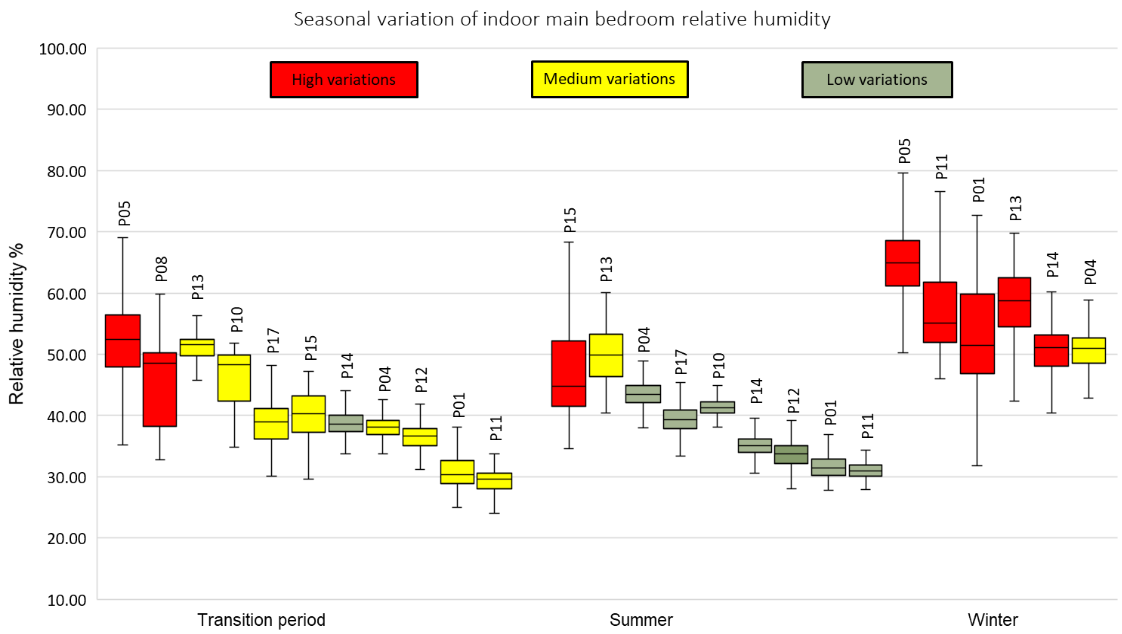


Figure 5-7 Boxplots showing the seasonal variations in humidity of the main bedrooms. Each box represents monthly data for each home

Table 5-8 Relative humidity standard deviation of main bedroom in summer and winter

Measured months	P01	P17	P04	P05	P08	P10	P11	P16	P12	P13	P14	P15
Room Orientation	South	North	North	North	East	North	North	West	North	North	West	West
Transition period mean RH% and standard deviation	32% ±2.17	38.5% ±3.71	38.4% ±2.39	51.5% ±7.22	45% ±6.20	46.6% ±4.15	31% ±1.35	-	36.5% ±2.02	50.9% ±4.40	38.7% ±1.82	40.2% ±3.80
Summer mean RH% and standard deviation	32% ±2.17	39% ±2.39	43% ±2.08	-	-	41% ±1.37	31% ±1.35	-	34% ±2.11	50% ±4.05	35% ±1.85	49% ±11.51
Winter mean RH% and standard deviation	53% ±8.91	53.8% ±5.31	51.1% ±3.55	65.6% ±5.95	-	-	57.2% ±6.19	66.9% ±5.05	-	58.3% ±5.39	50.5% ±4.35	-

For the bedroom2, it is observed that lower indoor relative humidity found among all homes below 60% for 75% of the time (Figure 5-8). The bedroom2 indoor relative humidity levels among all studied homes was found more variable than the temperature in all measured seasons (Table 5-9). It is possible that the variation of the bedrrom2 indoor relative humidity in the studied homes not only refer to the relationship with the temperature and the external weather. The variation of this room can be also affected by the participants' practices e.g. cleaning, washing, showering and ventilation, because this has its own bathroom. Household 5 has the highest indoor relative humidity level at approximately 76% in the summer season. This can be explained by the low indoor temperature of this room and also the inhabitant practices e.g. the drying cloths, ironing, cleaning and showering (chapter 7). Also, participant 8 had the highest temperature in the bedroom2 during transition period as a result this may affect the indoor relative humidity and lower it below 40% for 75% of the time. The winter indoor relative humidity levels were above 40% for approximately 75% of the time. The observed of this indoor relative humidity levels can be justified by the low recorded indoor temperatures in this room across all homes. For example, household 5 has the highest indoor relative humidity levels at 87%, this due to the low recorded temperature of this room ranged between (25°C to 20°C). According the weather station data, the maximum extreme summer outdoor temperature reached 48.5 °C with outdoor maximum relative humidity 83%. The lowest mean indoor relative humidity across all studied rooms was found in P11 guest room at 28.2% during the transition period (Table 5.9). The highest mean indoor relative humidity among all monitored rooms was captured in P05 bedroom2 in the winter season at 67% (Table 5.9).

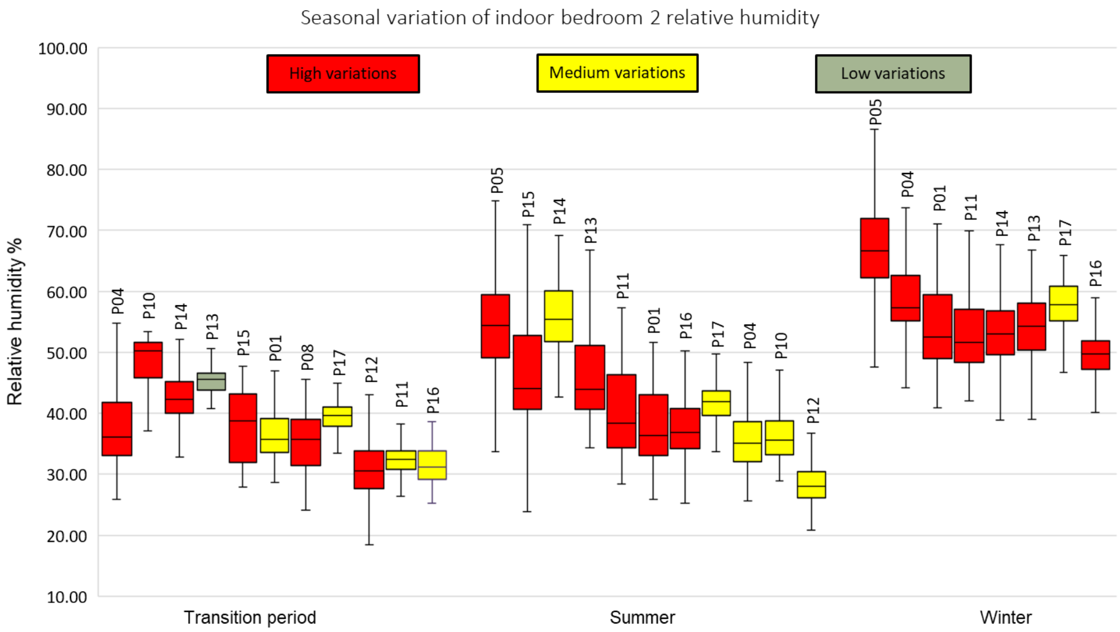


Figure 5-8 Boxplots showing the seasonal variations in humidity of the bedrooms2. Each box represents monthly data for each home

Table 5-9 Relative humidity standard deviation of bedroom 2 in summer and winter

Measured months	P01	P17	P04	P05	P08	P10	P11	P16	P12	P13	P14	P15
Room Orientation	East	west	west	west	North	South	west	South	South	west	South	South
Transition period mean RH% and standard deviation	36.3% ±3.56	39.2% ±2.42	37.4% ±5.80	-	35.4% ±4.57	47.1% ±6.80	32.5% ±2.49	31.7% ±3.20	30.8% ±4.28	45.3% ±1.96	42.5% ±4.01	37.8% ±5.95
Summer mean RH% and standard deviation	38% ±6.24	41% ±2.71	36% ±4.85	55% ±9.51	-	36% ±3.89	40% ±7.18	37% ±4.79	30% ±3.63	46% ±7.67	56% ±5.62	48% ±12.72
Winter mean RH% and standard deviation	54.6% ±7.17	58% ±3.75	58.5% ±6.39	67% ±7.83	-	-	53.4% ±6.20	49.8% ±4.66	-	54.2% ±5.23	53.7% ±7.03	-

The indoor environment was investigated through the use of building use study questionnaire (BUS). This questionnaire helps also to discover the inhabitants' satisfaction (thermal comfort, design, and needs) and identify key issues related to the thermal comfort, building design, and inhabitants' needs. The BUS questionnaire was distributed digitally to inhabitants who live in RC homes through the RC developer, the study obtained 100% return questionnaires. The answers in both questionnaires are based on Bedford Scale 1-7 scale points. The Figure 5-9 and Figure 5-10 demonstrate that the respondents are very satisfied (scale 7) in both summer and winter indoor conditions in their homes 60% and 50%, respectively. Regarding the summer and winter indoor temperatures, the respondents reported that very comfortable (scale 7) 52%, and 56%, respectively. In summer, 36% of the participants reported that the indoor temperature is about right (scale 4), while in winter, 41% reported that it is about right (scale 4). In summer, 35% of the participants reported that the indoor temperatures slightly vary during the day (scale 6), and 19% reported that it is stable during the day (scale 3). While in winter, 34% of the participants reported that the indoor temperatures were stable during the day (scale 3), and 22% of them reported that they varied during the day (scale 5).

It was reported that there was no draught issue (scale 1), and this was in both summer and winter, around 35% and 37% of the respondents. In terms of summer indoor humidity, 16% of the respondents reported that the indoor air is very humid (scale 6), and 29% reported that the is very dry (scale 2). In winter, 35% of the participants reported that the air is very humid (scale 6), and 25% reported that the air is very dry (scale 2). Furthermore, 43% of the participants reported that the indoor air is not stuffy in the summer (scale 2). On the other hand, in winter, around 32% of the respondents reported the indoor air is slightly stuffy (scale 5).

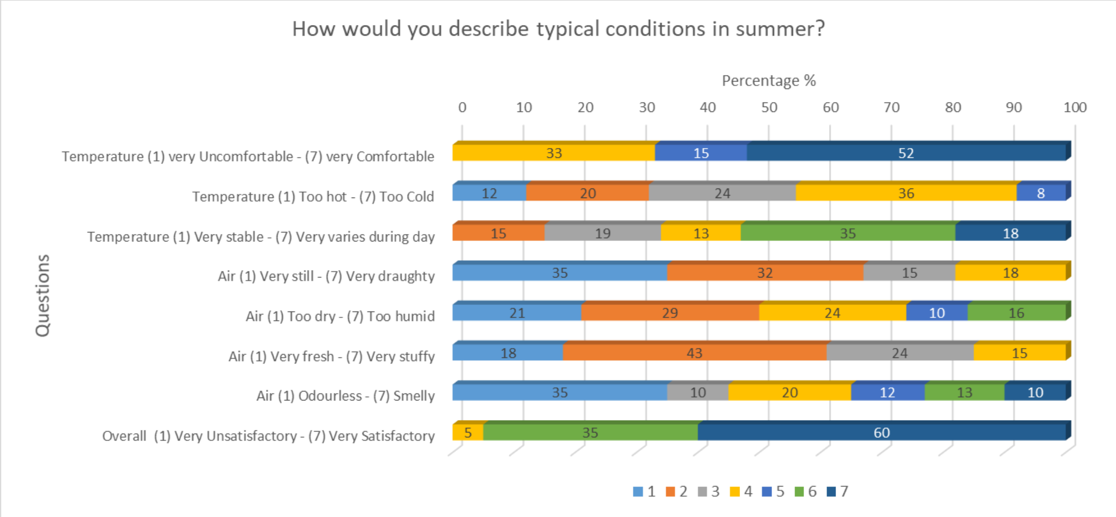


Figure 5-9 Summer indoor conditions of BUS questionnaire results

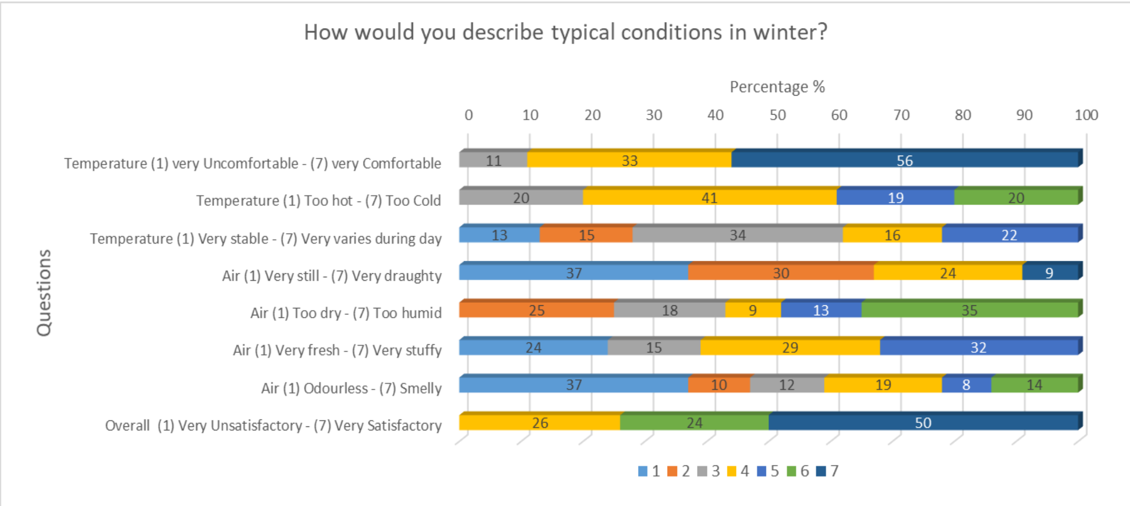


Figure 5-10 Winter indoor conditions of BUS questionnaire results

After describing the indoor environment conditions through the indoor environmental monitoring and the use for building use study questionnaire. It is found that the indoor environment varies depending on the effect of the external weather, building orientations, and the inhabitants' practices. For example, the external weather effect was more noticeable during the summer season. The physical monitoring data illustrate more variations of the indoor temperatures in summer than the indoor winter temperatures, this also can be affected by the room orientations. Also, this was seen in BUS questionnaire respondents, stating that the indoor temperatures vary during the day more in summer (35%) than the winter (22%). For the indoor relative humidity, from the physical monitoring, it is found that RH% levels vary more in the winter exceeding 60%, than in the summer (dry indoor environment). This is also observed from the questionnaire data that around 35% of the respondents rated that the winter indoor environment is more humid than in the summer (16%). This may demonstrate the inverse relationship with the temperatures. However, the variations in indoor temperatures and relative humidity levels can be also affected by the residents' everyday practices. For instance, the way they ventilate their homes during the day in the summer and winter seasons, the occupancy level of the space, using curtains/blackouts on windows (light/dark colours), cleaning practices, cooking practices, and their routines of using the HVAC system. The following section describes the energy consumption of the monitored homes.

5.3 Energy consumption

Other part of the research objective one is to identify how much energy is consumed in regulated Saudi homes; this was done by collecting energy bills from each participant. Not all energy consumption data were available, there were some difficulties having this data. It is reported that the Saudi studies (involved in the literature review chapter) and the Saudi Energy Efficiency Centre (SEEC, 2019) mentioned that deficiency in applying thermal insulation is responsible for the high energy consumption. Here, this study explores the energy consumption in RC regulated homes. Although the study investigates the energy consumption in identical Saudi homes, still it demonstrates variations in energy consumption, but compared to the average annual energy consumption of a conventional house, it shows a lower level of energy consumption due to the technology improvement. It is worth mentioning that lack of evidence on established definitions of energy consumption in Saudi domestic buildings or the Gulf Cooperation Council (GCC) countries in KWh/m^2 e.g. what is low and what is lower, based on the climate condition, culture, and inhabitants' needs, as a target to be achieved. While internationally it can be found an established definition for low energy houses e.g. passive housing, the annual energy consumption is lower than 120 kWh/m².

Figure 5-11 illustrates the annual energy consumption (KWh/m^2) of the studied homes compared with international annual energy consumption standard. The highest annual energy consumption is found in P11 at 93 KWh/m^2. The lowest annual energy consumption is noticed in household P13 at 72 KWh/m^2. Although P16 has small family size but it can be seen that this household (82 KWh/m^2) consume more energy than P08 (73 KWh/m^2), although household 8 is larger than P16. Household 8 allows more variation in their indoor environment than P16, but it is noticed that P08 consumes less than P16. Similarly, household 13 allows more variation in their indoor environment than household 4, but it is shown that P13 consumes less energy than P04. Even though the households which are falling in the same family size, it is found variation in their energy consumption. for instance, households 17 and 13 have the same family size, but P17 (87 KWh/m^2) consumes more energy than P13 (72 KWh/m^2) (Figure 5.11). These energy variations demonstrate that the participants' practices play a vital role, this is discussed more in-depth and related it to their practices (chapter 7).

It is found that the RC homes are consuming lower than actual average electricity consumption of a conventional house (156.5 kWh/m²), all these conventional houses were built with single glazing windows and no thermal insulation (Alrashed and Asif, 2014). This could indicate that improving the building envelope in Saudi homes could improve and help reducing the energy consumption.

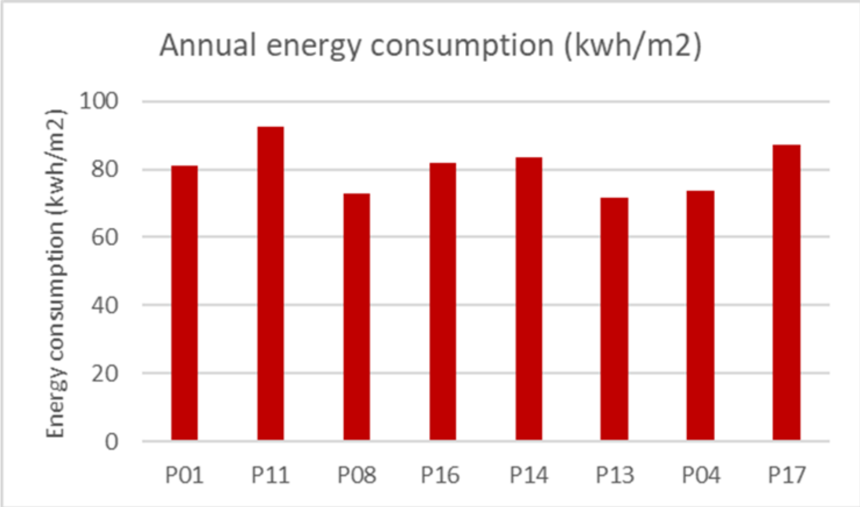


Figure 5-11 Energy consumption KWh/m2 for each studied homes

5.4 Chapter Summary

This chapter has investigated and presented the analysis of the indoor environment conditions and the energy consumption of the studied Saudi homes. The interpretations of the presented data in this chapter are illustrated in chapter six. The methodological approach that was used, the environmental monitoring, building use study questionnaire and the energy consumption bills were gathered from the participants. The results of this chapter show that from the physical monitoring and the BUS questionnaires, it is noticed that indoor environment from these methods is following similar patterns. For instance, more variations in the indoor temperatures in the summer than in the winter and more variation in indoor relative humidity in winter than in summer. In term of energy consumption, it is found that the monitored homes that have lower energy consumption than the average energy consumption of conventional house. Also, the energy data shows that some households who have the same family size it is found that the energy consumption also varies. It is observed that some households' indoor environment was more variable with less energy consumption while others low variation found in their indoor environment but with high energy consumption. This indicate that the social aspect is playing crucial role in Saudi home energy consumption. Although, the improvement of the building envelope is seen in the reduction of energy consumption comparing with the conventional house (156.5

kWh/m^2), but still the diversity seen in energy consumption between identical variables. The following chapter provides deeper understanding of the reasons contributed to these variations from social everyday practices perspective that could not be explained by the material differences. Using the four elements of practice theory offers insights on how the social everyday practices were influenced by these elements. Considering this effect (in future new dwellings) may contribute to minimise the energy demand more.

Chapter 6: Research findings on inhabitants’ practices and their experiences on environmental control interfaces

6.1 Introduction

The findings from chapter 5 have shown that even homes that are identical in layout floor plan and home size present differences in their indoor environment. The data show that the twelve homes could be categorised as low, medium or high in terms of the variability of indoor temperature and humidity.

Findings from other studies (such as Stevenson & Leaman, 2010; Steemers & Yun, 2009) have suggested that even though various building characteristics can affect the indoor environment in homes, different inhabitant’s everyday practices also play a central part. Other studies have observed significant variation in energy consumption between the identical building characteristics (e.g. floor layout, building construction and number of occupant) due to the differences in inhabitant everyday practices e.g. heating and ventilation practices (Kermeci, 2018; Tweed et al., 2013). The literature review revealed that there is a paucity of studies in Saudi Arabia or similar countries that focus on inhabitants’ practises in their homes and the relation of that with the actual energy demand.

This chapter provides detailed responses to of the two research objectives a) how Saudi inhabitants’ practices and b) their experiences of using environmental control interfaces in their homes, have contributed to the differences observed in the energy consumption and indoor environment (chapter 5). The data on the research objective (a) were gathered via interviews with the inhabitants. Data on the controls interfaces (research objective b) were gathered also via the use of the usability questionnaire and the interviews. The usability questionnaire is an inhabitant centred diagnostic tool, used to understand the user system control and testing the technology performance in relation to inhabitants’ perception. Twelve usability questionnaires are gathered from participants who’s already involved in the study. The answers in the questionnaire are based on 1-7 scale (1: is very poor and 7: is very good).

As detailed in the methodology chapter, the analysis of data collected from 12 case studies (Table 6-1), the qualitative data in this chapter was analysed using the two cycles of coding, drawing on Saldaña (2009), using deductive reasoning approach reference to practice theory and inductive reasoning approach. The two cycles of coding were carried out manually due to the language that was used when gathering the data.

Table 6-1 Interviewee characteristics (Author, 2021)

Participant code	P01	P17	P04	P05	P08	P10	P11	P12	P13	P14	P15	P16
Family size	5	4	6	7	3	5	6	7	4	6	4	1
House orientation	South	North	North	North	East	North	North	North	West	West	West	west
Gender	Male	Male	Male	Male	Male	female	Male	M & F	Male	Male	Male	Male
Age	35-49											
Type of housing	Private											
Occupation	Owners											

The chapter starts with the deductive analysed data that is structured by using the four elements of practice theory defined by Gram-Hanssen (2010): technology, institutional knowledge and rules, engagement, and know-how and embodied habits. Also, there are few emerged inductive themes from the data analysis that presents in this chapter.

6.2 The technology element

Technology is one of the practice theory elements, it was defined by some theorists as the material components and things that people use. The technology and its role in inhabitant's practices are important when considering reducing energy in homes (Gram-Hanssen, 2013). In addition, the technology element can be extended to the house lay outs, to which prefigure its use (Gram-Hanssen, 2010). Some other studies such as (Foulds, 2013), (Higginson and Thomson, 2014), (Kermeci, 2018) and (Brierley, 2021) have discussed technology as house systems and building design elements. The relation between the social practices and technologies should not be seen as material elements determining social practices. Instead, the material elements could be seen as a structure which enables and constrains practices (Gram-Hanssen, 2010). This section explores the technology element as home system, indoor environment, home design and controls.

6.2.1 Systems

Amongst all building systems, heating, ventilation, and air conditioning (HVAC) systems play a significant role in building energy consumption (Liddament, 2000; Pérez-Lombard et al, 2008; Chenari et al, 2016). The regulated Saudi homes that are studied in this research have implemented the technology of HVAC systems. This technology in Saudi Arabia is more common in non-residential buildings than in housings. As reported in the housing energy survey by the Saudi General Authority for Statistics, window air conditioners constitute the highest proportion (71.3%) of cooling/heating systems used in Saudi housingsredu (General Authority for Statistics, 2019). One participant commented on the use of the HVAC system in homes:

'It [HVAC] is a good technology, and its presence in homes is excellent because I used to see it in large places such as hospitals, schools, etc.'. P14

Each participant could draw on their experience of living in two different homes (previously conventional and currently regulated) that are equipped with different technologies. Their previous conventional homes were equipped with AC window units, and their current regulated homes have implemented HVAC systems. it is appeared from the analysed data that all interviewees reported that one of the advantages of implementing the HVAC system in homes is that the distribution of cooling through the house, such as:

'[..] the HVAC system is a very good choice to be used in houses, and I personally prefer it over AC window units because the HVAC system can cool or heat the whole floor at one preferred temperature. Every single room or space in the house is cool or warm, with no differences in indoor temperatures between the spaces'. P04

'[..] Here in the RC home, the HVAC is distributed even in the hallways, in addition to the rooms. But the previous house had AC window units distributed only in the rooms'. P12

Furthermore, some interviewees mentioned the disadvantages of AC window units and the advantages of the HVAC system in housing such as, noise, dust, health, maintenance, dripping water and scheduling feature, for example:

'[..] In terms of sound, HVAC is not noisy at all, and it is distributed over the entire place, unlike AC windows'. P15
'AC window unit openings made it easier for dust to enter the house'. P14

This participant also discussed residents' health when using HVAC systems and AC window units. in other word, the HVAC system is more convenient than the AC window units in term of interaction with it, setting the indoor environment at certain temperature and when this is achieved the system automatically turns off.

'[..] AC window units lead to health issues; for example, when you put them on, they remain on for the whole night unless someone wakes up and closes them. Sometimes, I or my kids wake up feeling unwell! But the HVAC system, when it is set at a specific temperature, for example 24°C, and when this temperature is achieved, will close automatically'. P11

The term convenience 'describes devices or services that helped save time' (Elizabeth Shove, 2003: p410). This demonstrates the significance of convenience that connected with the degree of automation with the HVAC. Another participant has mentioned that the family suffer from asthma, but since they lived in the RC homes their health has improved:

'In the previous house, we used to have air purifiers because my kids and I have asthma. So the devices were working on a daily basis. But honestly, since I lived here, we have never used it; although the area here is industrialised, we do not feel as tired as before'. P10

Also from the building use study questionnaire is found that more than 31% of the respondents feel much healthier than before. From system maintenance perspective one participant mentioned that HAVC maintenance is easier than the AC window units and it helps maintaining privacy when the maintenance occurs:

'The advantage of the HVAC is the maintenance: it is easier than the AC window unit; the technician can go up to the roof area from outside the house in order to do the maintenance. But in the case of AC window units, the technician enters my private room in order to do the maintenance or to see what the problem is'. P16

One of the interviewees mentioned that the HVAC system does not have the common issue of dripping water from outside the building as the AC window units:

'[..] Another downside of using AC window units is the problem of dripping water, which is a common problem. But here, I have never faced this problem, and I have never heard of a problem like this here; it is considered an advantage for the system here'. P14

Some participants indicated that an advantage of HVAC systems is the feature of scheduling the indoor temperature, which helps minimise one's interaction with the system during the day. Not all participants have seen this feature as an advantage due to their technical knowledge about scheduling their systems, although it was found in the home user guide booklet that the scheduling feature of the HAVC system was explained in details but the instructions are in English language (this covered in section 5.2.1). While others with different level of competences such as fluency in English (e.g. P01, P13, P14 and P15) and have learned how to schedule their systems from other sources (this covered in section 5.2.2) have found this feature an advantage for the HVAC system, such as:

'[..]The programming feature of the system is good, which means that you schedule the indoor temperature you want at the time you want, so you don't have to turn on the AC or turn it off, and this feature is not found in the AC window unit'. P13

Beside the participant's competences, one of the participants has gained the competence on scheduling the system but due to their routine, the manual use is more suitable, because the scheduling take time and need more interaction when they need to change the settings for example:

'[..] The scheduling feature in the system is not beneficial here because the routine is not fixed in this house! And it takes a long time in order to do the scheduling day by day. Let's suppose that we have a fixed routine and I did the scheduling, and for any reason the routine has changed, I need to spend more time again and redo the scheduling! Unbelievable! So that's why I said it is not beneficial; it can be, but for those who have a fixed routine that never changes'. P05

6.2.2 Indoor thermal comfort and home design

Interviewees mentioned that Royal commission (RC)-regulated homes offer a stable, comfortable indoor environment in the winter and summer seasons, contrary to their thermal experience of living in their previous conventional houses:

'From my experience living here, the RC houses are well designed'. P15

'[..] I feel that the RC built houses with a good strategy!' P01

'[..] there is a future room in the home; it is up to me if I want to build it or not. I can say that RC homes have flexibility in the design!' P04

The RC homes are built with an improvement in building envelope than a conventional house (Table 6-2). The RC developed and built the case study from scratch in 1975. Therefore, all participants who involved in this study used to live in conventional houses in different cities across the kingdom of Saudi Arabia. It is reported that 70% conventional dwellings are not thermally insulated, according to the Saudi Energy Efficiency Centre (SEEC) (Alshahrani and Boait, 2018; Alshenaif, 2015). The common building materials in Saudi conventional houses for e.g. external walls is comprised of external plaster then hallow bricks and then internal plaster (Lasker, 2016).

Table 6-2 Differences between building envelope of a Royal Commission home and a conventional home (adopted from Alardhi eat al, 2022)

	Royal commission home	Conventional home
Walls U-value	U=0.36W/m^{2}K	U=3.98W/m^{2}K
Roofs U-value	U=0.18 W/m^{2}K	U=2.75W/m^{2}K
Window U-value	U=1.8 W/m^{2}K	U=5.8W/m^{2}K

Interviewees have mentioned that due the construction materials that RC used e.g. thermal insulation have helped maintaining stable and comfortable indoor thermal comfort. All participants referred that when they turn on e.g. the air conditioning for couples of hours at certain temperature and then it turns off, the indoor environment remained comfortable. In contrast with the indoor environment of the conventional houses. This implies that the technologies used in the RC homes e.g. concrete providing thermal mass and the use of thermal insulation have contributed to reduce the operation duration of the air conditioning and the heating:

'[..] In summer, when we turn on the AC and then close it, the internal environment remains comfortable for hours. For example, the ground-floor AC is turned off at 11:00 p.m., and we go upstairs to sleep. The next day, when I wake up and go downstairs [..], I do not have to turn the AC on in the morning, because the indoor environment is still comfortable, and we only turn it on when we return from work at 2:00 p.m.'. P10

'[..]the AC here remains closed for 3 hours or even 4 hours, and the indoor environment is very comfortable. But if you did the same thing in the conventional house, it would not work at all because the cold or heat would not be preserved, so you would have to have the AC on 24 hours a day.' P16

'[..] when we turn the heating on for an hour before bedtime and then close it, the house stays warm for two days'. P12

In the usability questionnaire, the results demonstrate that 50% of the participants are using additional devices, half of these individuals use electric heaters while the other half use cooling devices, such as split air conditioning units. On the other hand, 42% of the respondents do not use any additional devices (Figure 6-1). This implies that using additional devices in some households is not strongly linked to their level of proficiency, as some of those who employ these devices typically possess high technical knowledge. Nonetheless, it is highly associated with their desire to lower their energy and electricity expenses.

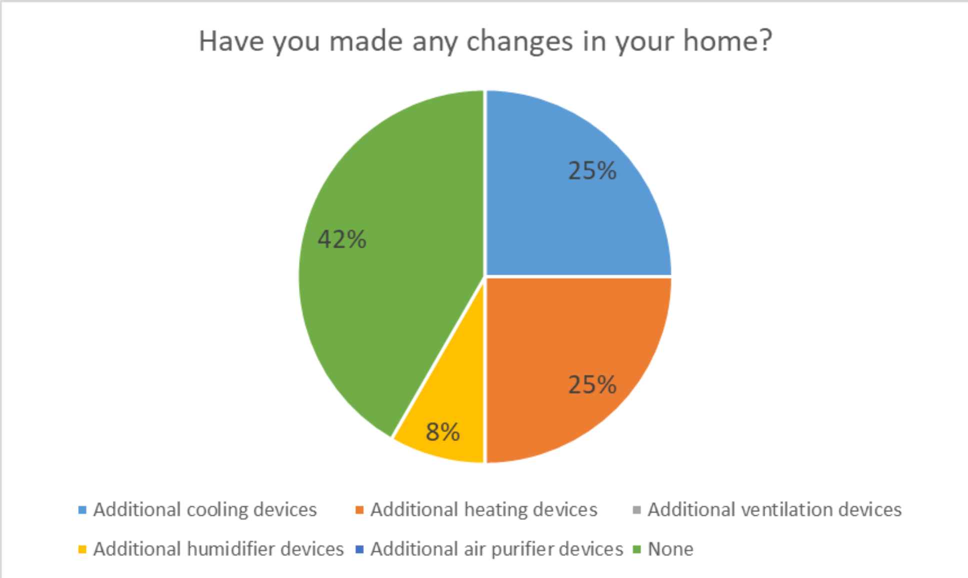


Figure 6-1 Using additional devices

It is appeared that there are different ways that the participants use to ventilate their homes e.g. using the system ventilation, opening windows, doors for cross ventilation and using the cooker hoods. In some homes the technology structure can constrain and enable social practices. For instance, some participants with higher competence than others, mentioned that they use the ventilation provided by the system e.g. P16, P14, P13, P08, P01, P10 and P15. While others the technology structure constrains them using the system ventilation e.g. P04, P05, P17 and P11, instead they rely on the use of AC, as explained by the interviewees:

‘*I turn on the fan in the system most of the time for ventilation*’. P16

‘*We do depend on opening windows when we want to ventilate a room when the weather outside is good; in summer, we depend on using the AC [..]*’. P04

During cooking time all participants reported that they do have the practice of opening the kitchen’ windows with the use of cooker hood:

'[..] We open windows from the morning to the sunset in the winter. But in the summer we just open it for an hour to an hour and a half during the cooking time only'. P05

'[..] Seasonally, we ventilate the home in summer by using the system ventilation, but during cooking we open the kitchen window for half an hour to an hour. In the winter we open windows and we leave it for a long time'. P08

Others such as P04 and P10 who have different level of competences reported that during cooking time they do not settle for using the cooker hood and opening kitchen's window but also they do open doors for cross ventilation. Household 11 reported that for safety reasons, do not use the cooker hood when cooking instead they use the window and door for ventilation, as explained by the interviewees:

'[..] Opening the kitchen window and the door and using the cooker hood'. P10

'During cooking, we don't put the cooker hood on [..]I am a policeman, I saw a lot of fires in houses, and the reason was the cooker hood with the heat exploded, so from a safety perspective, I don't let my wife use it during cooking. [..] the window and the door for cross ventilation does the job'. P11

Noticeably, it is found that all participants have the practice of opening their kitchens' windows for faster ventilation and the opening duration can be extended depending on the external weather. The potential loss of cooled/warm air does not necessarily prevent the use of windows for all residents although the use of kitchen cooker hood. And, participants referred that is not strong enough for removing cooking smells. This practice could increase their energy demand because hot air entre indoor spaces and change the level of thermal comfort as result the need for operating the system increase.

For the home design, in Saudi Arabia, homes are designed and divided into two zones, affording families the opportunity to maintain both their privacy and their social and cultural practises of gathering. This is evidenced by the Royal Commission's design for housing, which maintains privacy for its residents. From the building use study questionnaire, it is found that around 36% of the respondents reported that the daylight in their homes is about right, 15% reported that it is little and 10% reported that is too much daylight. Based on the interview data, most of the participants in RC homes are satisfied with the use of the daylight and how it maintains privacy at the same time. Daylight has an effect on the inhabitants' wellbeing e.g. psychological health (Aries at el, 2015). Also, the use of daylight could help reducing the energy use for lighting (Bannamas and Jirapong, 2015). For example, the RC has used reflective glass with heat film for the windows and doors and this support privacy for the inhabitants. Some participants reported that use the daylight instead of using artificial lights during the day time, as explained:

'The comfort and the design of the house here [RC] helped us; we do not turn on the artificial lights during the daytime due to the design of the daylight. But in the previous house, of course, the artificial lighting used to be on all the time'. P12

Some participants mentioned that one window in the bedrooms is not enough to ensure sufficient daylight during the day. Furthermore, some residents think that the window should be larger than it is and provide external shading to reduce the heat gain especially in summer:

'The lighting is insufficient on the first floor, but the ground floor is excellent. [..] because the ground floor, including the living room and the guest room, has two windows, so the lighting is good. But the rooms on the first floor, for example the bedrooms, have only one window in each room, so we feel that there is not enough daylight entering the space'. P08

'The lighting is excellent, but the thing we don't like is that the windows are not extended to the floor. [..] on the ground floor; the windows are supposed to be extended to the floor, so I can sit in the living room and see my garden without having to stand up and look at it!' P10

'I do like and prefer the daylight, but the windows here are small. They should be bigger and have external shading on them to let some light in and control it'. P05

From the building use study questionnaire 39% of the participants reported that the home layout is very good, 17% reported that the layout is about right and 25% reported that this is poor layout. Also, 35% of respondents reported that the provided spaces are about right. Around 42% of the participants reported that the facilities provided are very highly meet their needs. Some interviewees explained:

'[..] the indoor layout of this home is excellent and comfortable; the stairs are separated from the living room and guest room, and this is very good in terms of privacy'. P01

'The house layout is good, and we found it very homey! The staircase is separated from the living room and the guest room. So, I can go up or down if there are any guests in the house'. P04

While, the kitchen being open plan to the living room is not a preferred design in terms of maintaining privacy, containing cooking smells and change the level of thermal comfort which may increase the need for cooling. As result, some participants extended their kitchen and some separated it from the living room (Figure 6-2), as explained by the interviewees:

'[..] we preferred if the kitchen was isolated from the living room because of the heat that coming from kitchen reaching the living room [..]'. P08

'[..] we didn't like the kitchen overlooking the living room due to the cooking smells, especially if there are guests'. P05

Therefore, some participants who use their living room daily they made some adjustments to their homes. The adjustments involved new windows for daylight and new spilt AC units. for example:

'The main kitchen has been converted into a dining room, and a new separate kitchen has been built with a roof light.' P12

'[..] an external room was built for male guests; [..] the internal guest room is used for female guests'. P11

Figure 6-2 First-floor plan

This implies that the design of the home seems affecting the use of the indoor spaces and resulted in the adjustments that seen in some of participants’ homes, that could have an impact on their energy consumption. In addition to the home design, from the building use study questionnaire, it is found that around 39% of the respondents reported that the storages are not enough. Most of the interviewees also do not like the provided storage in their homes:

‘The layout of the house is excellent, but the storages, I feel, are not calculated well. To be honest with you, they are small and few; we can only put things that can be folded, like blankets and bedding sheets. The rooms are fitted with built-in wardrobes, and we use them as storage’. P13

Due to the insufficient storages, it is found that some participants use one of the bedrooms as a storage e.g. P08 use the bedroom2 in the second floor for storing their freezer, and it was observed from the monitoring data that high indoor temperature found in this room. This household uses this particular room because it has separate AC unit so there is no need to operate the system there as if it is in the first floor, because one HVAC unit support the whole first floor spaces. Also, participant 12 use one of the bedroom in the first floor as storage and it is reported that this room is the hottest room in the house. This household locked the duct supplying the air to this room in order to reduce their energy demand and they use a fan to cool the space. It is found that this room does not have any curtains on windows and it is facing west orientation.

6.2.3 Controls

Each of the studied homes has four control units: two on the ground floor, one on the first floor, and one on the second floor. On the ground floor, one of the units controls the guest and dining rooms, and the other one controls the kitchen and the living room. The pervious section illustrated that participants reported that the HVAC system fits well in terms of automation, scheduling, maintenance and privacy. However, in terms of the number of the HVAC units it appears that one HVAC controlling unit especially in the first floor that controls the whole first floor bedrooms, is not beneficial for some residents to reduce energy:

'[..]If one member of the family is sleeping on first floor and others are in the ground-floor living room, I end up putting the system on for both floors! I think the electricity bill will be less if every two bedrooms had one control unit'. P11

'[..] One unit controls the entire first-floor spaces; it is a lot'. P12

Due to the limited number of HVAC units, especially on the first floor, some inhabitants relied on their previous heating experience of using additional electric radiators and do not use the heating provided by the system in order to reduce energy:

'[..] because the first floor has one control unit for the whole floor, I don't want to turn on the heating to heat up the whole floor, and I only need to heat up two bedrooms!' P15

'[..] Why should I use it [system heating] to heat the whole floor when I only need to heat specific rooms, for example the main bedroom and my daughter bedroom, so that's why I do prefer using additional heaters'. P08

One resident mentioned that when he is the only one at home, instead of using the cooling in the first-floor bedroom, he uses the bedroom on the second floor because it has a split AC unit with its own control panel. This may indicate that the developer may have designed the HVAC to be one unit in the first floor assuming that all bedrooms will be occupied at the same time:

'If I am the only person in the house, why do I need to operate 10 tonnes of cooling for the whole floor when I only need one room? To save money, when my family is not with me in the house, I do sleep in the room on the second floor that has a split AC unit, and I do put the system downstairs at 26℃'. P04

The control interface between the HVAC system and the resident plays a crucial role in thermal comfort and energy consumption. The usability covers some criteria e.g. clarity of purpose, intuitive switching, labelling and annotation, ease of use indication of system response and degree of fine control and respondents can answer 'yes', 'no' or 'I don't know' (Stevenson et al, 2013; Baborska-Narożny et al, 2019). It is found that 60% the participants reported 'yes' that the HVAC control (Figure 6-3) is easy to operate. All reported that the HVAC control shows response to their actions when interacting with (e.g. putting on the AC) and 42% reported that it is not clear for them what is the purpose of this control (e.g. the system involvement of ventilation). Figure 6-4 demonstrates that 60% of the respondents reported that the location of the HVAC control helps use it when needed while the other 42% stated that it is not. It is found from the in depth interviews that participants who reported that the HVAC control location not helping when it is needed to use and is not easy to use, are those who were using their system manually such as P04, P05, P11, P12 and P17:

'[..] location does not make it flexible to use; one is in the hallway of the first floor, and it is controlling all the bedrooms on the floor'. P17

It is noticed that around 25% of the participants assessed that the HVAC control not allowing them making sufficient adjustment and it is found from the interviews that those inhabitants have retrofitted their system's thermostat. Around 42% reported that is not obvious if they should interact with the control.

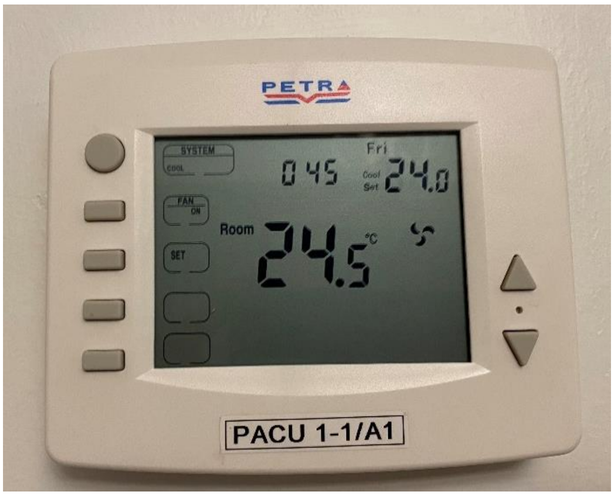


Figure 6-3 HVAC control panel participant 1 (original) (Author, 2023)

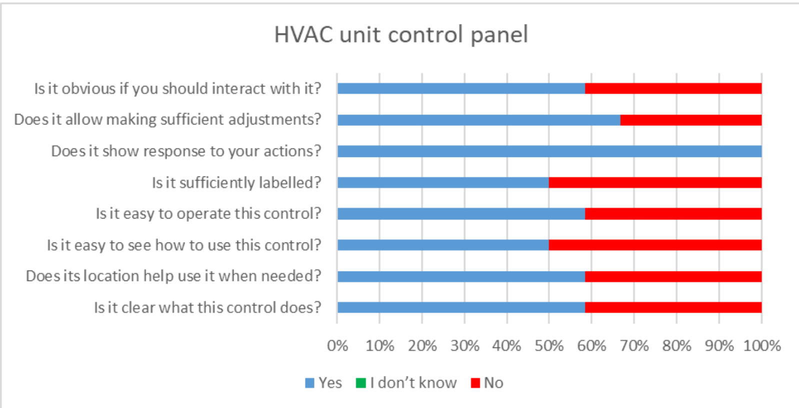


Figure 6-4 HVAC control panel

Seeking greater flexibility and convenience (e.g. in the case of emergency or travelling) in controlling the system, some participants (e.g. P08, P10, P16) have retrofitted their HAVC system thermostat and tended to use the smart control thermostat 'Ecobee' with motion sensors (Figure 6-5). Ecobee is a smart solution that can be used with many HVAC systems to help the participant controlling their HVAC systems remotely as well as set scheduling routine. It comes with a mobile App and features a user-friendly interface. Therefore, some inhabitants with their degree of competences installed it instead of the original thermostat. Reporting that using the original thermostat requires the resident to be at home in order to change the setting or put it on or off:

'I found that the provided thermostat is not useful and expensive, [..] I need to be at home to change the settings. [..] to be honest, dealing with the smart system at home is very convenient'. P16

'The previous thermostat was difficult to control; I had to be home in order to control it. [..] I remember, once, we travelled, and when we came back, the indoor temperature was 37℃! I put the AC on, and it took a whole day to cool the spaces! That night, the indoor environment started to change a bit, but I could not sleep that night [..]. The next day, the indoor environment became comfortable, as normal'. P08

'[..] the new smart controller is easy to use and very flexible, So, when we travel, we close the system, and then we turn on the AC three days earlier before coming home, so when we return, the house become very comfortable'. P10

Figure 6-5 Ecobee smart thermostat of participant 10 (retrofitted) (Author, 2023)

Participants have mentioned that the smart thermostat has motion sensors that help reminding them to turn off their system by sending messages through the app and also very convenient to control it when traveling. As explained by the interviewees:

'*The smart thermostat has motion sensors [..] So if I do not pass from the sensor area in the house, the app sends me a notification saying, "Are you away?". Then, if I don't reply, it will change the settings to the away mode and the system closes. [..].* P16

'[..]I can control it remotely via my phone, especially during travel time. When we travel, five hours before coming back home, I put on the AC so when we arrive, the indoor

environment will be comfortable. It is effective, although it is expensive in terms of installation'. P08

The results questionnaire indicated that respondents have rated the original electricity sockets at low scale of '3' and '2' (Figure 6-6). One of the participants mentioned that the provided (original) electric sockets are not practical. From the interview data, it is appeared that most of the participants have retrofitted it with European socket style (dominant in Saudi):

'The electric sockets that I had were the American socket style, and I changed them to the European socket style because it [American socket style] needs an extension for every socket, and we used to connect the machine and leave it on standby mode'. P17

A study of Guan et al (2011) showing that the households' standby electricity of the appliances represents 24% of total household electricity consumption in Australian dwellings. This implies the effect of technology in shaping the residents' practices. Moreover, in some of the residents' homes, some ceiling lights were controlled by one controller. And some of the lighting controls are not connected to any of the celling lights. It was observed during the home walkthrough that some participants used additional side lamps instead of the provided lights. This is evidenced in the questionnaire results that those inhabitants have rated the lighting controls at lower scale of '3' than others. Whereas, majority of the participants have rated the lighting controls at a high scale of '5'. The issue of having one lighting control that controls some celling lights was not observed during the home walkthrough in those who rated the lighting controls at high scale. Figure 6-6 illustrates that 60% of the respondents have reported that the lighting controls do not allow them making sufficient adjustments in term of the number of lights they need and the brightness level. In addition, 60% of the participants reported that the lighting controls are not sufficiently labelled.

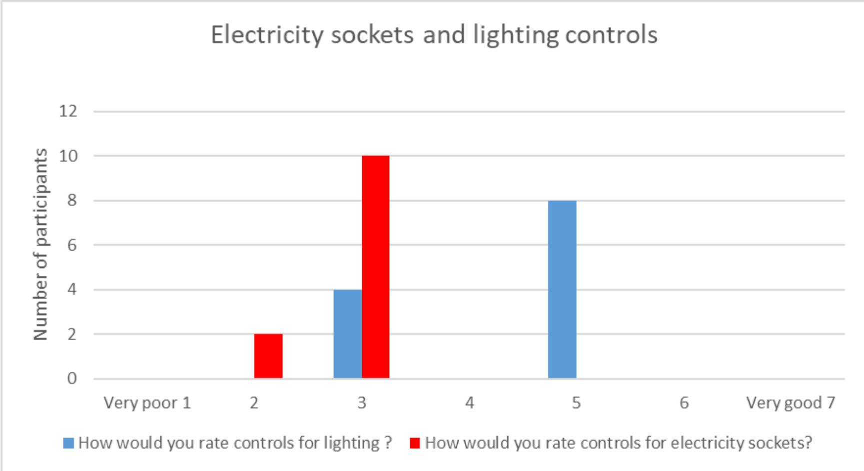


Figure 6-6 Electricity sockets and lighting controls

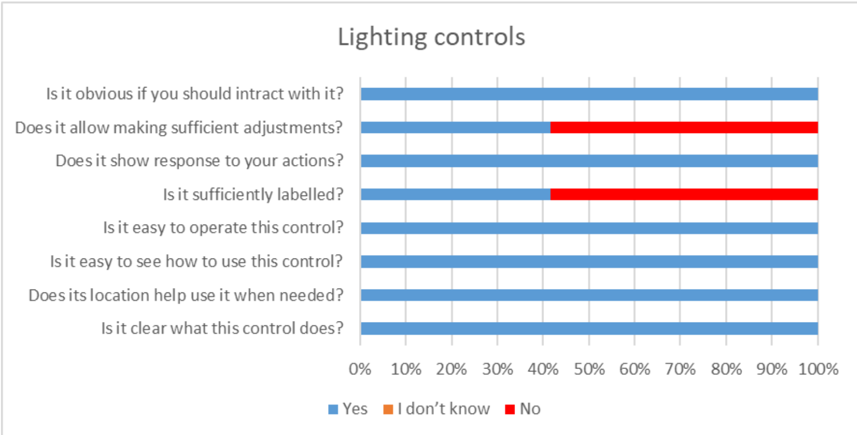


Figure 6-7 Lighting controls

The last elements of the environmental control interfaces in this section are the windows' and doors' handles and locks. A study carried out by (Jennifer Brierley, 2021) on ventilation of low energy homes in the UK found that some residents have excluded and discounted the use of windows and its trickle vents due to accessibility and the location of the windows. From the usability questionnaire, it is noticed that none of the respondents have mention any issues related to those elements in term of operation and safety especially with windows. Participants used windows and doors for ventilation whether in winter and summer seasons. This may indicate that the detailed explanations e.g. opening, closing and the company supplier in the home user guide booklet may have contributed to overcome any issue that could be occurred. It is observed during the home walk through that none of the windows have involved trickle vents. The existence of the trickle vents could support the winter night ventilation for some households who excludes the night ventilation due to noise:

'We never sleep with windows open, due to the noise, privacy, and security'. P01

'I don't sleep with the windows open, because of noise and privacy'. P05

6.2.4 Technology element summary

The above section has described the technological element that involve home system, indoor environment, home design and controls in the RC homes. It shows how the technology elements enable and constrain social practices which may affect the energy demand. For example, participants found that the implementation of the HVAC system has created comfortable indoor environment across the home spaces depending on their preference temperature. However, participants reported that they were struggling to configure the best interaction with their systems in order to reduce their energy demand especially in first year of living in their RC homes, as referred by the interviewees. As a results, some participants (e.g. P08, P10 and P16) have retrofitted their system to smart 'Ecobee' with motion sensors seeking for greater flexibility and convenience. While others (e.g. P01, P15, P13 and P14) took the advantage of the system features such as system scheduling, others (e.g. P04, P05, P11 and P17) are using their system manually. The technology element constrained these participants of using the system heating and ventilation due to the system control technicality. Therefore, they depend on AC in hot season and switch the system off in cold season, they also adopted some practices in order to reduce their energy demand. It is found that there is social practice that perform in all studied homes that could increase the energy demand e.g. the use window for ventilation even in summer during cooking, although the existence of the kitchen cooker hood. This practice may contribute to lose the cold/warm air and change the level of the thermal comfort of indoor spaces as a result the demand for cooling or heating may increase.

For the home design, some participants use the living room for daily family setting area whether for whole family or parents only (e.g. P01, P08, P12, P15, P10, P11, P04 and P05). The design of the home constrained some participants' practices and therefore they separated their living rooms and their kitchens (e.g. P13, P14 and P12). It is appeared that the idea of space separation was not only due to cooking smells and privacy but also was to reduce the need for operating the AC, because the heat transfer from the kitchen may change the thermal comfort in the living room. Because the living room was an open plan area to kitchen and any carry out practices such as cooking, washing clothes, dishwashing can effect easily the indoor environment of the living room. Participants 13, 12 and 14 not only separated their kitchens but also the HVAC system and added new spilt ACs in their kitchens in order to reduce their energy demand. The use of the AC depends on the use of the kitchen e.g. when cooking. Also, insufficient availability of storages has led some participants to use one of the bedroom as storage, no air was supplied to these rooms have contributed to change the thermal comfort level.

Although the RC has improved the building envelope of the homes aiming for energy reduction, it is found that one HVAC unit controlling the whole first floor spaces is not helping the residents to reduce their energy consumption. This indicates that the recognition of the routine complexities of domestic everyday life e.g. P11 and P05 was neglected. During heating season some participants brought in their previous practices such as the use of electric heaters in very cold days instead of using the heating system and they depend more on putting extra layers in order to reduce their energy demand. The intention of using electrical heaters especially in first floor bedrooms was to reduce the energy demand, because the first floor has one HVAC unit that controlling the whole spaces of the first floor.

The next section discusses the second element of the practice theory, the institutional knowledge and rules e.g. home touring by the developer and the home user guide. Also, it describes how the lack of information in those examples have affected inhabitants' practices of using the technologies in the way that it should be. As a result, some inhabitants tended to use other sources of gaining knowledge on their technologies from e.g. consulting professionals, neighbours and from online platforms.

6.3 Institutional knowledge and rules element

The Royal Commission (RC) is an organization and a developer of the Saudi homes that involved in this study. This organization has involved architects, electrical and mechanical engineers can act as an institution that define rules and provide knowledge regarding to the RC homes. However, the institutional knowledge and rules that explored here understood as an element which influenced practices in different ways, 'though not in any simple 'communication–change–behaviour' way (Gram-Hanssen, 2010.p184).

This element explores the guidance (home induction) that should be performed by the developer and the home user guide that is provided by the developer. This section demonstrates how inhabitants' knowledge related to the use of their home technologies have been gained.

6.3.1 Guidance

From the literature review it is found that the technological element has taken more attention in Saudi studies related to home energy demand. This does not mean that this study overlooks the technology element, as the above section has described how technological structure can constrain and enable inhabitants' practices which may affect the energy demand. As stated by (Shove, 2003.p397) that 'the social and the technology change are different sides of the same coin'. Meaning whenever there is a technological shift, it inevitably leads to changes in social. For example, the RC homes construction, it is referred by all interviewees in this study that it helps them reducing the duration of operation of the HVAC system unlike the AC windows. However, some other participants have mentioned that limited offer technical knowledge led to misusing the system ventilation or scheduling the system. Even from the building use study questionnaire results, it is found that more than 49% of the respondents reported that they control the system cooling more than the system heating and ventilation 35%

and 33%, respectively. This implies the importance of the home induction to the households. Unfortunately, this could not be investigated further because the respondents' details were removed from the questionnaire according to the RC developer.

Residents do not seem to have had an initial introduction to their new homes. The interview and the usability questionnaire highlighted that they received no verbal detailed instructions on using the home system. The interviewees mentioned that they had received only detailed written information, which did not appear to be useful for future reference for some of the residents:

'It [the guide] is very complicated, and there are a lot of technical things in there. I haven't read it yet, and it takes a long time to read it. The need here is the practical side, not the theoretical side, of using the home system and how to use it in order to save energy and money'. P05

'For the washing machine and the dryer, I used their manuals, and it did help, but the system did not really'. P01

The first language of participants in this research is Arabic. However, the home user guide provides no translated instructions for non-English speakers, as the interviewees explained:

'*[..] there is a user guide, but I have not read it yet. There is a lot in there, and it is not encouraging me to read because it is written in English. I know little English, but I have not reached that level of technical knowledge in English!'* P11

'The manual has technical information and is written in English. It should involve the Arabic language, which would help'. P17

A conducted building performance evaluation study by Palmer et al (2016) on several UK housings projects, it is found that one of the housing project the system control was imported in German and no translated was provided.

One of the residents sought some explanation from the technician on using the HVAC system during system maintenance. However, this resident reported receiving minimal verbal instructions and no detailed explanation from the technician:

'I was instructed by the company technician to leave the HVAC system on auto mode, and that's it'. P17

Aside from the language that is used to explain the instructions, the home user guide contains a large array of technical information, including civil/architectural, mechanical, and electrical details (Figure 6-8). Although the guide presents photos to help the residents, the latter still require a moderate level of technical understanding with clearer photos and texts to aid them in using the system.

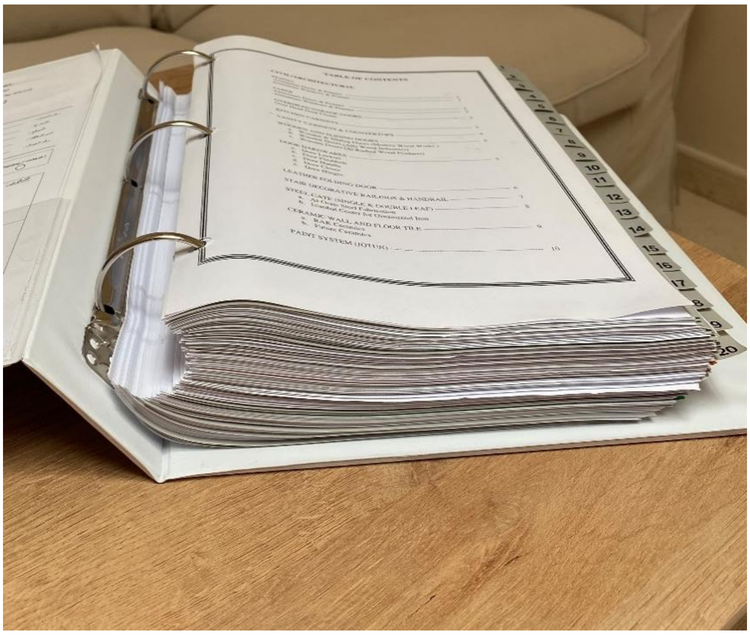


Figure 6-8 Home user guide (Author, 2023)

Based on the data provided above, it is presented that the housing developer provided a detailed written booklet about the home to the new residents as a communication method, but no verbal, online, or video instruction was offered (Menon and Foster, 2017). The residents suggested that verbal instruction is needed:

'Educating the residents on using the home system/appliances and providing them with knowledge, for example that this is highly efficient and that this is less efficient, and so on, and the features of the technology that is provided in the house'. P16

'The RC should have educated the resident on using the home system and explained the advantages that the system contains in a practical way, so it can help the residents reduce their consumption'. P11

It was found that the home user guide includes full details of the suppliers of all technology and appliances provided in the home, such as the HVAC system, washing machine, and dryer, allowing the residents to communicate directly with the suppliers when they encounter any maintenance or other issues in their home, especially once the home warranty expires.

6.3.2 Knowledge gained from other sources

As discussed in the sub section above, that the formal provision of information with the house was inadequate for nearly all participants. Furthermore, in the technology element section demonstrates that some households manage their system well, and are confident to introduce modifications e.g. Ecobee. This section explains how inhabitants gain the competence and confidence that they demonstrated earlier (section 6.1). Participants who control their systems manually or by scheduling or by smart thermoset have gained knowledge on using the home system through many ways e.g. YouTube, others' experiences, consulting professionals and attained competency through trials and errors:

'*The most difficult for me was the HVAC system settings. [..], I searched for how to make the scheduling on YouTube, searching by the name of the device and model that were provided in the home user guide. I gained help from friends who had lived in RC houses before me and advised me not to let the indoor temperature exceed 30℃ or 35℃'. P16*

'[..] when I faced any problem, I used to ask my neighbours; we do have a social group. I just put in my concerns, and I got help. I learned a lot from them'. P04

'[..] I had to consult a professional to help me using the system'. P01

'By myself by trial and error'. P05

The strong built-up connections amongst the residents have helped them overcome some issues related to the home system and energy consumption. For example:

'Some said that I should schedule the system, put a smart thermostat instead of the original one, or separate the AC unit on the first floor especially'. P17

'One of my neighbours has installed an AC split system in the first-floor bedrooms, and he noticed the difference in the electricity bills, so he recommended it to me'. P15

This could help explaining why households are varied in terms of how well they understand the system. For example, the participants who consulted professionals and being able to read or search about the technology in different language (English) seemed to have greater influence on using their systems than the knowledge provided by the institution. This can be seen in the households who are operating their system through scheduling e.g. (P01, P13, P14, P15) and others through installing smart 'Ecobee' e.g. (P08, P16, P10). While other households who face language barriers and gaining from other social experiences e.g. friends and neighbours have been able to control their system manually, and acquired other practices to reduce the amount of heat entrance into their indoor spaces but not reaching that level of technical knowledge relating to their systems compared to others. For instance, the seasonal use of spaces can be seen in P17. Also, planting around the house and opening the curtains in specific time during the daytime to reduce the emitting the heat to indoor spaces e.g. in P04 (more discussion on this in the following section 6.3.3). Trees shading can reduce the solar heat gains of the exposed building façades, as a result can contribute to reduce energy demand for cooling. A study of Tsoka et al (2021) assessed the effect of trees shadings on reducing the daily solar gain of the façade surface and the reduction of cooling demand of residential apartment. The study used simulation to measure the reduction using different seniors of trees height and density. It is appeared from the study that the higher the tree and density the potential of reducing the daily solar gain and cooling demand can increase. For example, the simulation used trees of Liriodendron tulipifera (height 10m and density 1.5 m^2/m^3), Aesculus hippocastanum (height 10.5m and density 2.0 m^2/m^3) and Tilia cordata (height 10m and density 2.5 m^2/m^3) were placed with distance of 3m far from the building block. The results show that the use of this specifications led to moderate cooling energy savings in first floor apartment by 13 %, 14 % and 15 % respectively, and the daily solar radiation gain reduces by 16% (ibid).

Another aspect of knowledge is related to health and the indoor environment. From the interviews, some residents appear to operate their heating system for a few hours before bedtime. Thereafter, it is turned off due to the quality of the indoor environment, as the interviewees clarified:

'We immediately turn on the heating, but we cannot sleep and keep it on for a long time for safety and health; the internal environment is stuffy when the heating is on for a long time. We turn it on for an hour, and then it is closed'. P10

'But when it's sleeping time, I put the heating on for 1 hour; then, I close it before going to bed because I think the heating on all night can bring health issues like feeling the indoor air is stuffy'. P01

'The heating system is on before sleeping for 2 hours, and when we want to sleep, I close it. [..] because we feel that the indoor environment is stuffy, the oxygen is low, and we also don't like sleeping in a very warm place'. P13

6.3.3 Institutional knowledge and rules element summary

The section illustrated that there was a lack of formal verbal home induction from the royal commission to their residents. This was evidenced from the interview and the usability questionnaire that participants have received no verbal detailed instructions on using the home systems. The interviewees mentioned that they had received only detailed written information as a communication method, but no sign of video instruction was offered by the institution. It is appeared that the use of the home user guide was hindered some participants from its benefits due to the language that is used (English) with no evidence of provided translated instructions for non-English speakers. Furthermore, the high amount of driven technical information and the quality of the picture provided hindered the use of the home user guide for some participants. Much of participants' work with the appliances comes from informal learning and know how rather than through the formal knowledge provided.

This can explain reasons that households are varied in terms of understanding their system. For example, the participants who consulted professionals and they are able to read or search about the technology in different language (English) seemed to have greater influence on using their systems than the knowledge provided by the institution. This can be seen in the households who are operating their system through scheduling e.g. (P01, P13, P14, P15) and others through installing smart 'Ecobee' e.g. (P08, P16, P10). While other households (e.g. P11, P17, P04, P12 and P05) due to the language barriers they gained knowledge from other social experiences e.g. friends and neighbours have been able to control their system manually. The section showed how these householders develop a knowledge to create thermal conditions that help reducing their energy consumption, but not reaching that level of technical knowledge relating to their systems compared to others. For instance, the seasonal use of spaces can be seen in P17. Also, planting around the house and opening the curtains in specific time during the daytime to reduce emitting the heat to indoor spaces e.g. in P04. Another aspect of knowledge is related to health and the indoor environment. It is appeared that some residents use the heating for a couple of hours before bedtime then it is turned off due to the quality of the indoor environment. The next following section explains the inhabitants' thermal practices that they do seasonally in order to minimize the need for operating their systems as result reduce their energy demand.

6.4 The engagement element

6.4.1 'Things' for comfort

In this section, thermal comfort is understood as 'the activities householders undertake to heat and cool their bodies and homes' (Strengers, 2010 p.7313). The participants were asked about their daily thermal comfort practices, such as cooling, heating, and ventilation, to create a comfortable indoor environment. A particular practise holds meaning to the people performing it, and a goal or reason guides this practise (Gram-Hanssen, 2013). However, the same practise can hold different meanings for different people and can therefore influence the practise in different ways. For example, for cooling practices, all participants reported that they rely heavily on air conditioning in the summer. However, they mentioned that they use a range of tactics and non-technological practises beyond the installed HVAC system to maintain a comfortable environment. The concern of high electricity bills, as mentioned by all interviewees, has driven them to undertake certain practice. Such as employing different sources of cooling, to reduce their electricity bills by mitigating the amount of time in operating the air conditioning but not a replacement of the cooling system in the summer, such as swimming, taking a cold shower and having cold food and wearing less layers:

'One of the practises that we do when the weather is hot is that we go to the beach to swim, not only for sports but also to feel cool and stay away from technology'. P14

'Wearing fewer layers of clothing, eating ice cream, and drinking cold drinks'. P01

The government of Saudi used to subsidy energy, but after the 2030 vision launched, as one of its aims is to reduce the subsidies resulting in higher tariff. The new tariff in Saudi Arabia is still the lowest among the world (Ouda et al, 2017), residential consuming 1-6000Kwh (0.18 SR/kwh), consuming more 6000 Kwh (0.30 SR/kwh) (SEC, 2017).

Other practices related to the orientation of the home, in the summer, some interviewees use blackouts on windows to reduce the heat gain e.g. households 1 and 11 use dark colours blackouts on windows (black). Also, household 4 use (white) blackouts on the windows and planted around the house (around 4.5m trees height) to provide shading and minimise the heat gain for the indoor spaces to reduce the AC usage time. In addition, Household 5 reported that they use (white) blackouts on their windows and they open and close them for a portion of the day depending on the orientations. Explained by the interviewees:

'[..] Externally, planting around the house not only for the nice look but also to provide shading and reduce heat coming inside, means we don't need to put the AC on'. P04

'[..] in the summer, we use blackouts on the windows when the temperature is high during the day, for example in the living room, guest room, and dining room, because the orientation there is facing east, and they remain closed until after 12:00 p.m., when I do open them. And I put curtains and blackouts on the windows facing the southern orientation until 3:30 p.m., and later I open them and leave them until sunset. We do this in order to reduce the heat coming inside and the need for operating AC at less than 24℃'. P05

One participant uses external shading screens on the windows of the rooms they sit in daily. And one resident reported keeping the curtains drawn in the summer to avoid the heat:

'Using external shading from the outside on the upper windows from the bottom of the window to the half only'. P13

'Most of the time, the curtains are on day and night in summer'. P01

It is noticed that not all practices that were performed may decrease the energy demand as intended. For instance, using or depending on artificial lightings most of the time during the daytime or in one of the studied homes this practice was performed during daytime in the summer season. A study of Aldubyan and Krarti (2022) showing that 11.2% of the annual household's energy consumption for lighting. This is due to the type of lighting is used, e.g. incandescent and fluorescent lamps are the most commonly used lighting in Saudi households as well as the operation duration (ibid). From the building use study questionnaire of the present study, it is found that more than 14% reported that the artificial lighting is a lot, 29% reported that it is about right and 15% reported that is little. Interviewees reported that they have replaced their lighting system and used lighting emitting diodes (LED). The practice of not using the daylight during the daytime in summer season not only due to the external weather, but could imply that the shading for windows need to be addressed especially in heat gain orientations in order to enable the residents to use the daylight.

Instead of adjusting the system, changing the temperature, or even turning the AC on or off and affecting other family members' thermal comfort, one participating family mentioned that they switch places in the living room according to their individual thermal comfort:

'[..]when we are sitting as a family in the living room, the people who feel the heat can sit in this place, and the people who feel cold can sit in the place that is under the AC. In the house, we exchange places according to the thermal comfort in the living room'. P12

Operating the air conditioning in the place that the residents sit does not necessitate them to do it, as an interviewee clarified:

'The AC in the dining room, we don't put it on; we just open the door between the living room and the dining room so the air can pass into the room'. P11

It appears that families use daily spaces differently depending on their comfort requirements and the materials of the living rooms differs:

'Putting two living rooms in the house is not only for the sake of change. The use of these rooms varies according to the season; for example, in the summer, we use the upper room because it has a wooden floor, so you can feel cool. Even the quality of the furniture differs, so the living room on the first floor has a leather sofa'. P17

Several interviewees mentioned that they all turn off their AC systems. And the practice of varying their clothing to meet individual comfort preferences and easy to be adjusted, having warm food and using the daylight to warm the indoor spaces and to reduce energy consumption were reported:

'In winter, [..] we feel that our house is very comfortable, although outside it is cold. I did not have to use the heating here, as we rely more on wearing extra layers than heating. I rarely turn it on because the weather from year to year differs'. P14

'[..] wearing extra layers makes it easier to adjust the thermal comfort; for example, if one member of the family is wearing thick clothes, they can reduce layers in order to reach their own thermal comfort without adjusting the system by putting it on or off and affecting others' thermal comfort'. P04

'We do open windows to let some heat from the sun come into the indoor spaces during the daytime and close them before sunset. If the whole family is feeling cold, I also put the heating on at 21°C'. P01

In addition to wearing extra layers of clothing, one of the household reported that e.g. lighting a fire and seating around it was brought from the past. Also, having a BBQ in the garden they also considered both practices as sources for providing heat and reduce their need for heating system. Other household use different room for family daily seating because it has fabric sofas and carpet, and reported that this helped them feeling comfortable. For example:

'In the winter, we go out in the house garden and light a fire and sit around it to feel warm, this is something that brings me back to the past, and its smell reminds me of my childhood. [..], sometimes we also do a BBQ in the garden of the house, we do all this to reduce our dependence on technology, and these practices contribute to saving'. P14

'[..] in the winter, we use more of the room on the ground floor because the floor is carpeted, [..] and it has a fabric sofa to help you feel warm as well'. P17

One resident has built a future room (it is room on the first floor that can be built according to the inhabitant' needs) see Figure 6-9, which used to be their daily living room to reduce energy:

'[..] the new living room on the first floor has its own AC split unit with its own control, so cooling a specific area is cheaper'. P14

Figure 6-9 First floor plan

Due to the adjustments made to their home, this participant does not use the ground-floor spaces unless they have guests, as a result, the AC system there is turned off. The daily space that is used in the ground floor is the kitchen:

'[..] for saving, we shut off the AC in the guest and dining rooms, as they belong to one unit, and in the living room unit because we separated the kitchen and put a new AC split there'. P14

Other residents have trained their family members to pay attention to unused electrical appliances in unoccupied rooms in the home:

'For saving money and the environment, I trained my family that if any room is not in use, anything electric should be off'. P01

'*We trained ourselves that we don't leave anything we do not use on. And when we go out, we also turn off things like lights, extractor fans, televisions and other devices to save money, and to reduce maintenance of devices'.* P13

Interviewees also reported using specific spaces and the spaces that they do not use they turned off the AC unit to reduce energy:

'For saving money I closed the AC unit in the guest and dining rooms'. P01

One resident explained that when leaving the home, they adjust the system accordingly, even for short periods:

'When travelling, I shut down the system completely. Even if I go for a short distance, like going to Dammam, I do it. [..] to save money'. P11

To reduce energy consumption, another interviewee reported operating the AC system for three days at a time and not lowering the temperature below 24°C to cool the indoor spaces:

'if we turn it on a day before, for example, it will not cool the place because the system is closed for a while, and we don't want to consume higher energy by putting it at a temperature below 24°C, like 21°C or 20°C to cool the whole two floors, so the best solution is to run it for a period of time during the day at 24°C and then it closes and so on for about 3 days'. P10

Even electrical appliance choices are driven by the desire to save money. some of participants mentioned that they assess the efficiency of a new electrical appliances before purchasing it. However, some look at the cost first due to their knowledge that these appliances not affecting more the energy consumption, such as:

'Cost, quality and efficiency'. P05

'*[..] when I want to buy white goods such as the freezer and refrigerator, we pay more attention to their efficiency because they will be on all the time'.* P10

Opening the windows in summer allows hot air to enter the home, and the hot flow of air could increase their indoor temperatures. All residents mentioned that they open the kitchen window for ventilation during cooking only for a few hours and then close it along with the cooker hood. By contrast, in winter, they reported opening windows more for natural ventilation. One resident reported opening other rooms' windows not only in the winter but also in the summer, especially during cleaning:

'We also open windows weekly during the cleaning time, for example when washing the flooring tiles, to avoid excessive humidity'. P15

In winter, some residents leave their windows in the main bedroom open only at night for natural ventilation, while others restrict the use of natural night ventilation due to privacy and noise:

'We never sleep with windows open, due to the noise, privacy, and security'. P01

'Of my bedroom, I wish to leave it open, but I cannot due to the noise'. P17

6.4.2 Engagement element summary

The engagement with the home and its systems appears to be driven by people's financial concerns as a results it is found that some practices performed in the studied homes were historical and new adopted practices which may have affected their energy demand. In the summer season, the use of AC cannot be replaced due to the desert weather. however, it is found that participants brought in some practices from their previous experiences e.g. swimming, taking cold shower, wearing less layers and having cold food. All these practices were performed in order to minimise the need for cooling as a result reduce the energy demand. Others reported that they use blackouts on windows for a portion of the day to prevent the heat from entering the indoor spaces depending on the orientations e.g. households 4 and 5. Planting around the house (around 4.5m height trees) to provide shading and reduce the heat entering the indoor spaces. This was observed from the environmental monitoring that this household (4) have low variations of indoor temperature and the lowest energy consumption compared with participants who are using their system manually. Furthermore, one of the participants (e.g. P13) has used external shading screens on windows of the rooms that daily use in order to reduce the solar gain and minimise the time need for operating the AC. It is noticed that not all practices that were performed may decrease the energy demand e.g. the use of artificial lightings during the daytime in the summer season most of the time. It seems that some participants ignored the health benefits that the daylight offer to the inhabitants or the use of it can reduce the energy demand for lighting. However, this implies that the shading for windows need to be addressed especially in heat gain orientations. Also, opening kitchen window for ventilation in summer during cooking only for a few hours and then close it along with the cooker hood and extractor fan, was found in all studied homes. This practice may have contributed to change the level of thermal comfort in e.g. living room and as a result increase the energy demand for cooling. While in winter, the time of opening windows for ventilation is extended from morning until sunset or even for couple of nights (e.g. P01, P04, P11 and P16). But in some households opening windows for ventilation during sleeping in winter time was restricted by security, privacy and noise. One of the household practice that may have contributed to increase their energy demand and the observed variations in the indoor environment is the opening windows while cleaning even during summer season. One of the household reported that instead of adjusting the system and affect others thermal comfort they exchange places e.g. when they are seating the living room. It is found that not always necessarily to operate the AC in the place that the family use, alternatively passing the air from the living room to the dining room e.g. household 11. Moreover, household 17 using different spaces at home according to the seasons. Participants reported when they leave their home for period of time they put on the curtains on windows to reduce the heat gain. One of the household reported that they operate the AC three days earlier at 24°C not lower than this to consume less energy for cooling. In winter, all participants depend on wearing extra layers, having warm food and having BBQ as source for heating. And it is found that the use of daylight increased to warm the indoor spaces and reduce the energy demand for heating. Educating the family members to switch unused equipment was referred by several interviewees. Also, assessing the electrical appliances before purchasing by its cost and its efficiency. The next following section explores the know-how and embodied habits of participants e.g. their daily routine, cooking, laundry and hospitality habits in which may affect their energy demand.

6.5 The know-how and embodied habits element

The element of know-how and embodied habit is an important element of practices associated with the energy demand and indoor environment. Different residents have different habits, which in turn may contribute to different levels of indoor environment and energy consumption. Inhabitants' habits that were found in this study are often based on their experiences from previous home or childhood. For example, the adoption of using additional electrical heaters from pervious home are found e.g. in P15 and P08. On the other hand, some habits were found new in most of the homes and have been performed only since the inhabitants lived in their current homes. This section illustrates the inhabitants' habits related to their home systems and energy consumption e.g. do it your self-habit (DIY), cooking, laundry and hospitality habits. It is found from the undertaken home walkthrough that all the studied homes were supplied with electricity and no gas source was found. Shifting from the material home and the system and interfaces of the HVAC to the broader patterns of habit and routine that are supported by the thermally comfortable indoor environment. Providing the inhabitants occupancy patterns and their routine to enable interpreting it with the findings from chapter 4 related to their indoor thermal comfort.

6.5.1 The do-it-yourself (DIY) habit

All the residents that were interviewed have adopted the new habit of cleaning their systems' filters regularly, either themselves or through technicians. The relatively DIY task of cleaning the filters enhances the system's performance. This new habit was gained for some of the inhabitants from YouTube, from company website for others and the technician. This approach assumes that inhabitants comprehend that the system requires regular filter cleaning and are aware when such a clean is due, as explained by the interviewees:

'In the summer, I noticed that the system needs more maintenance in terms of cleaning the filter because it is working most of the time, and I realised that its performance

improves after cleaning the filter; this happens 2 to 3 times a year and is carried out by the technician'. P15

'I do the maintenance by myself, like cleaning the system filter and changing lights. However, if there is a serious problem with the AC, I call the technician to fix it. In fact, I used to call the technician to clean the filter for me, but each time I learned something from him until I was confident in doing it myself and saving 500 Saudi riyals. I clean it 2–3 times a year, and it depends on the weather; if we have some dusty days, yes, I do clean the filter immediately the next day'. P14

'Cleaning the system filter, and the technician does it for me, and at the same time he checks if there is something that needs maintenance or not, and this is done every 6 months'. P12

6.5.2 Occupancy patterns and routinized practices

The goal of investigating residents' occupancy patterns to interpret the indoor environment with these occupancy patterns in the four measured rooms. It appears that all participants' homes are generally occupied for 24 hours of the day and are rarely empty at weekdays. By contrast, on weekends, especially Friday, which is usually 'family day', families go out in the afternoon and return home at night around 11:00 p.m. or 12:00 a.m. Inhabitants use the four measured rooms differently. One resident uses the living room more often than other room: This participant uses the system manually at a certain temperature during the day due to their unfixed routine:

'I put the temperature in the system on the first floor at 24°C *all the time, whether sleeping time or not. While on the ground floor, the guest and dining rooms have a temperature of 28*°C *because we don't usually use it. And the kitchen and the living room are at 24*°C *from 1:00 p.m. to 10:00 p.m., but in the winter the AC is off for 3 months'.* P05

As part of their daily routine to turn off any electrical appliances that are on before going upstairs to sleep:

'*Before going to sleep, my wife and I go room by room and check if any electrical equipment is on, and we do close it and unplug it even'.* P05

Another family also has an unfixed routine; hence, the use of the system and the space varies greatly. The husband is a policeman and has variable work shifts:

'*I have different work shifts; one day I go to work in the morning from 6:00 a.m. to 2:00 p.m. Another work shift is from 10:00 p.m. to 6:00 a.m. The third working shift is from 2:00 p.m. to 10:00 p.m.'*. P11

Houses can sometimes be empty on weekdays and occupied on weekends. Residents are in the habit of turning off the system before going out, even for short periods. They prefer setting the system at one specific temperature, regardless of whether it is daytime or night-time:

'The indoor temperature, both floors on 24°C *during the day. On the ground floor, from 10:00 a.m. to 11:00 p.m., the AC is on at 24*°C*. On the first floor, from 11:00 p.m. to 3:00 p.m., the AC is on at 24*°C*. When we don't need the AC or are leaving home, my wife or I close it manually'.* P11

One participant has a constant routine on weekdays, leaving home from 7:00 a.m. and returning at 3:00 p.m. This participant lives on his own, and the only spaces he uses on the ground floor are the dining room and the kitchen. This resident mentioned that these are the rooms which he usually occupies and in which he has the guests. He has a smart system; any adjustments to it are made remotely through an app on his phone. The system on the ground floor turns off at 7:00 a.m. when the resident leaves for work, turns on from 11:30 a.m. to 12:30 p.m. over a break time before turning off again, and is finally on from 4:00 p.m. until midnight. The first-floor system is on from 12:00 a.m. to 7:00 a.m. Even for spaces on the ground floor that are not used, the resident has automated the system such that when the temperature reaches 35°C, the system will turn on immediately. The interviewee explained the seasonal temperature settings as follows:

'In summer, autumn, and spring, 24°C *because I don't like to feel hot, and at bedtime I prefer 21*°C *degrees'.* P16

On weekends, this participant stays at home most of the time, and he mentioned that the ground-floor AC is on from 3:00 p.m. until 1:00 a.m. One of the residents has a fixed routine and uses the system manually according to their family's use of space. The resident reported that their house is empty on weekends because the family stays at their farm house every weekend and returns home on Saturday evening. Their daily temperature is adjusted as follows:

'[..] The ground-floor unit is on from 7:00 a.m. to 10:00 p.m. at 24°C. On the first floor, the AC is on from 9:00 p.m. until 7:00 a.m. at 24°C. In the case we travel, I don't close the AC unit in the spaces we use daily; I just put the indoor temperature at 26°C, so when we come back, we don't want the space is hot'. P04

Another family has a stable routine throughout the week, and they reported that their house is never empty except on Friday, which is family day. The participant has built a future room and uses it as a new daily family living room. They use the original living room on the ground floor when they have female guests and the guest room when they receive male guests. The kitchen has been extended, and the system downstairs is on when the participant uses the kitchen downstairs. When they leave their home, the temperature is set at 27°C unless they travel for a long time and turn off the system. The daily temperature is scheduled as follows, according to the interviewee:

'The ground floor has temperatures ranging from 25.5–24°C *during the time we use the spaces. When nobody is using the ground floor, the temperature is changed to 27*°C*. The first-floor temperature was 25.5–23*°C *and the same thing happened when we didn't use the floor; the temperature changed to 27*°C*. But the new living room on the first floor has its own AC split unit with its own control; the temperature there is 23–24*°C*'.* P14

Participant 12's home is never empty, even on weekends. Family members' different ages result in different routines. During the week, the family uses the living room only in the afternoon from 4:00 p.m. to 6:00 p.m. Before 4:00 p.m., family members remain in their rooms to work. As the resident described, the daily temperature in their house is complicated and all floors are occupied during the day:

'The temperature in our house is unscheduled and complicated, the temperature ranges from 28–25°C during the day [..]. 24°C is lowest daily temperature during the daytime at the weekend, after we return from work during the weekdays and at bedtime, [..] we shut off the system when travelling'. P12

Another resident has a constant routine; their house is not empty on weekdays except on Friday, which is family day, and they use different spaces at home for daily sitting as a family, with a uniform temperature of 24°C during the day. To create a comfortable environment, this inhabitant uses one of the bedrooms on the first floor as a living room in the summer and the dining room as another living room in winter due to the types of furniture in each room. They explained that they use the system manually depending on the space occupied and the daily temperature:

'[..] the temperature is fixed at 24°C during daytime and night-time. [..] Most of the day in the summer, the AC is on; it closes if it reaches the required temperature of 24°C'. P17

Due to the design of the living room, one family uses the space daily from 2:00 p.m. until 11:30 p.m. In any occupied space in the house and during the daytime and night-time, they prefer a uniform temperature of 24°C, which is never lowered unless they have guests. Sometimes, the participant's husband uses the room on the second floor as an office and uses the AC split accordingly for a few hours. Their system in the house has been changed to a smart system, which is used daily as follows:

'From 9:00 a.m., the AC is on, on the ground floor, and it is off at 11:30 p.m. First floor: from 11:30 p.m., the AC is on at 24°C and is off at 7:00 a.m.'. P10

Another family operates the AC in all ground-floor rooms on weekdays. The living room is used as the parents' sitting area and the dining room as the children's sitting area – both rooms are equipped with televisions. The daily scheduled temperature varies during the day and even when they leave home for a short or long period, as the inhabitant explained:

'[..] The temperature on the whole ground floor spaces is 23°C from 9:00 a.m. to 6:00 p.m.; after that, it turns off completely. For the first floor, the temperature is at 25°C during the daytime, except from 8:00 p.m. to 8:00 a.m. the temperature changes and becomes 20°C because we prefer to sleep in a cold environment. But when leaving home for a long period of time, I close off the system'. P15

Another family opts for a temperature schedule during the week. The family uses two of the bedrooms on the first floor as the daily living room – one for the parents and one for the children – and the downstairs spaces when entertaining guests. This family has separated the kitchen from the living room, and the kitchen is equipped with a new AC split unit. As a result, the ground floor has three AC units instead of two. The only daily space used on the ground floor is the kitchen, for cooking and doing laundry. The resident explained the daily temperature schedule as follows:

'The temperature on the ground floor [kitchen] is 24°C day and night, and the AC in the living room is closed because I separated the living room AC unit from the kitchen. Also, the guest room and the dining room's AC is closed, [..]. The temperature on the first floor is 24°C during the day, but when bedtime comes, it is changed to 23°C from 10:00 p.m. to 7:00 a.m., and then it returns to 24°C'. P13

When the family leaves their home for a short period, the temperature changes to 26°C. However, for longer periods, such as more than 10 days, the resident turns the system off completely.

Another family also has a fixed routine with uniform temperatures during the day and night on both floors. The house is occupied on weekdays and empty on weekends. This family uses the living room on the ground floor daily and the guest room only when they have guests. One of the bedrooms upstairs, which has been converted into a sewing studio for the participant's wife, is another room that is occupied daily. This resident mentioned that the system in the house has changed to be smart and is controlled remotely. Their daily use of the AC and the temperature settings are as follows:

'In the summer, the AC is on from 10:00 a.m. to 10:00 p.m. in the ground floor living room and the kitchen area at 24°C; the AC units in the guest and dining rooms are off. On the first floor, the AC unit is on from 10:00 p.m. until 10:00 a.m. at 24°C'. P08

Participant 1 employs a detailed temperature schedule. The house is occupied on weekdays and empty on weekends. The living room serves as the daily family sitting area and the dining room as the children's sitting area – both rooms have a television. The resident reported that when leaving home for a holiday, they set the temperature to 28°C because they do not want the humidity to damage their furniture. The daily temperature schedule is as follows:

'I schedule the temperatures in the house. For example, on the first floor, when it is sleeping time, the temperature is set at 22°C from 9:00 p.m. to 4:00 a.m.; from 4:00 a.m. to 7:00 a.m., at 23°C; and from 7:00 a.m. to 1:00 p.m., I set the temperature at 25°C.

From 1:00 p.m. to 9:00 p.m., the temperature is 28°C. On the ground floor, I set the temperature at 28°C from 9:00 p.m. to 8:00 a.m. From 8:00 a.m. to 9:00 p.m., I set the temperature at 27°C; at this time, the family uses the ground floor more than the upper'. P01

The resident reported that setting the temperature at 27°C on the ground floor does not cause discomfort in the indoor environment because the fan mode is on and they can feel the air circulating. They have found that doing this is cost effective and thermally comfortable for the whole family.

6.5.3 Cooking habit

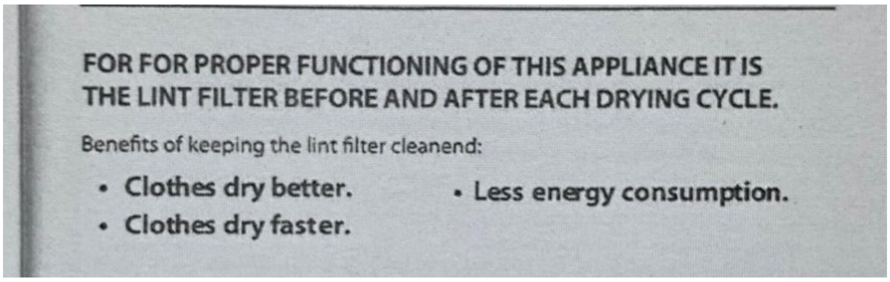
Cooking significantly influences the indoor environment and energy consumption due to the design of the kitchen as an open-plan area to the living room. When the walk through was conducted in some of the participants' homes, it was notable that all appliances in the RC homes are electric; there was no evidence of gas usage in these homes. All participants share similarities in their cooking habits: they reported cooking two to three main meals a day, with cooking durations of 20–40 minutes for breakfast meals and one to two hours for main meals such as lunch and dinner. Two of the households (e.g. 11 and 14) reported that baking occurs every day more than others, this includes the use of mixer and oven. All residents mentioned that when cooking, they use natural ventilation by opening the kitchen windows and they all also use the cooker hood in all seasons; except for P11 (ventilation practises explained in section 6.4.1). The interviewees reported that during cooking, the cooking smells permeate through the whole house because of the design of the kitchen and living room (see section 5.1 for detailed explanations of the home layout).

6.5.4 Laundry habit

Shifting from explaining the home technologies at the begging of this chapter e.g. home system, indoor environment, layout and controls to households' habits e.g. cooking, laundry and hospitality habits that have relation to energy demand. One of the households' habits that related to energy consumption is the laundry and is an essential household activity. The interviews suggest that this practise varies from one household to another. All RC homes have been designed to include a laundry room equipped with a washing machine and a dryer. The interviewees stated that, due to the size of the washing room, they cannot use drying racks to dry their clothes inside instead of using the dryer machine every time they do their laundry. Except in winter, drying indoor winter cloths such as wool, is performed. In Saudi Arabia privacy is very important not only when designing homes but also seen in performing the laundry. Culturally, Saudi inhabitants do not line dry their cloths in outdoor spaces like the western society due to privacy concern, although the weather in Saudi will help drying cloths and reduce the energy use for the dryer machine.

However, in the user guide, the section on electrical appliances states that the dryer consumes less energy, especially when the machine's filter is clean (Figure 6-10). The fact that the appliances were no longer available created a barrier for the researcher to investigate their energy rating. Residents reported that the washing machine and the dryer consume high amounts of energy:

'In the RC house, if I want to change electrical appliances, I will change the washing machine and dryer because their consumption is higher than what is currently on the market, although their quality is high'. P16


FOR FOR PROPER FUNCTIONING OF THIS APPLIANCE IT IS THE LINT FILTER BEFORE AND AFTER EACH DRYING CYCLE.

Benefits of keeping the lint filter cleanend:

- Clothes dry better.
- Clothes dry faster.
- Less energy consumption.

Figure 6-10 Instruction for dryer machine, extracted from the home user guide (Author, 2023)

Due to participant 16’s energy consciousness, he does his laundry once a week:

‘I do it [laundry] once a week’. P16

Not only the laundry habit but also paying attention to the efficiency of any devices before purchasing them, as the interviewee explained:

‘I remember when I returned to Jeddah city to visit my family there, they needed to buy a new washing machine, so I bought it for them based on its efficiency and consumption of water and electricity before looking at its brand’. P16

Rather than using the dryer machine for every wash, one resident (P17) uses it once for more than one wash:

‘Because it [the dryer machine] consumes high energy, I have to put more than one wash in the dryer and dry it all together at once’. P17

Some residents mentioned that the size of their family has shaped their habit of doing laundry daily:

‘As we are a family of six, we do the laundry every day using the washing machine and the dryer’. P11

‘Laundry we do it every day, using the dryer machine’. P14

The residents with families of below the average have different laundry habits than average and above the average family size, that the laundry is perform once at the weekend:

'*Washing and drying cloths are performed once at weekends'*. P15

'We do the laundry once at the weekend, [washing machine and using the dryer]'. P08

In fact, the frequency of doing laundry is not related to family size. Some large families do their laundry three times a week:

'The washing machine and dryer are used every other day'. P12

'*We do the laundry every other day and so on; to do that, we use the washing machine and the tumbler'*. P05

'We do the laundry two to three times a week using the washing machine and the tumbler'. P04

Two of the families have the average Saudi family size of five, but their laundry habits differ:

'We do it four times a week, using the washing machine and the dryer'. P01

'Washing clothes every day and using the dryer. My kids constantly change their clothes during the day, two to three times a day; this is a habit they acquired from their father. Well, they used to do more than that, but they have improved now'. P10

6.5.5 Hospitality habit

The interview data revealed that thermal comfort differs when residents expect visitors. This hospitality habit can influence energy consumption. RC homes have been designed with two separate spaces with two separate entrances – one for female guests and the other for male guests. The minimum indoor temperature that was found in all homes was 24°C during the daytime; falling within ASHRAE recommendation. Changing the indoor temperature to achieved good thermal comfort when having guests not only perform in Saudi culture. A mirror to this habit can be found in cold country such as the study conducted by (Sovacool et al, 2020). Discussing the thermal comfort in smart heating homes in the UK, it explores 'thermal conflict' and one of its identified form was hosts versus guests (ibid). The study mentioned that the household perform the practice of rising the temperature few degrees for their guests (ibid). in this study some participants mentioned that when they expect visitors, the AC will be on a few hours earlier, and all the internal and external lights in the entrance will be on, such as:

'Before the guests come, I reduce the temperature to 22°C so the area can be cool enough'. P05

'When we have guests, we put the AC on the same degree, and if it is needed, we reduce it to 23°C'. P08

'When we have guests, I turn on the AC at 23°C to cool the place and then increase it to 24°C'. P17

One resident turns the AC on the day before a social gathering:

'When we have guests coming, the day before, I put the AC on in the guest room at 23°C because it has been closed for a long time, so it needs time to cool the space'. P04
As mentioned above that the data was analysed deductively and inductively, after explaining the deductive themes, two Inductive themes were emerged related to the purpose of the HVAC system and one relates to its control. The limited number of the HVAC units in the studied RC homes e.g. each two rooms have one HVAC unit in the ground floor and one HVAC unit for the whole first floor spaces, it is pointed out that this limited number of HVAC is suitable for large family meaning e.g. many rooms will be occupied at the same time than small family. As referred by the interviewee:

'The AC here in this house I feel that it is good for a large family more than me as one living individual. [..]For example, I sit in the dining room, so why do I turn on the air conditioning in the rooms on the ground floor, and I only need one room in which I use'. P16

Due to the complexity of the HVAC control makes it difficult for specific age to interact with unlike the AC window units the ease of using its control allows interaction from age of 8 years and above, as mentioned by the interviewee:

'[..] From the age of 8 years old and more can control it, by putting the switch on or off and its switch control like the light switch control, it is not difficult or complicated'. P17

6.5.6 Know-how and embodied habits element summary

The section of the know-how and embodied habits element has explained varied routinized practices that people perform in their everyday lives. for instance, when, how and how long participants interact with the technologies, which in turn may contribute to variations of the observed indoor environment and energy consumption.

It is found from the households' routines that the all studied homes never be empty during the weekdays, but most of these homes can be empty during the weekend especially Fridays (family day) with exception of participant 16. However, participant 4 reported that their home is empty every weekends (Thursday afternoon until Saturday night). The routinized practices of the participants are different, some households have fixed routine (e.g. P01, P04, P08, P10, P13, P14, P15, P16, P17) and some do not have fixed routine (e.g. P05, P11, P12), this impact on the system operation duration. It is appeared that the way they interact with home and its systems is different e.g. operating the HVAC system and the temperature setting during daytime and night-time. During the cooling seasons, most of the participants (e.g. P05, P11, P16, P04, P14, P12, P17, P10, P13, P08, P01) used the AC with temperature not lower than 24°C during the day time. For household 15, reported that 23°C the preference temperature during the daytime. While during the night time temperature below 24°C is occurred in households P16 (21°C), P15 (20°C), P13 (23°C) and P01 (22°C). However, other households have unified temperature even during the night time at 24°C e.g. P04, P05, P11, P14, P12, P17, P10 and P08. When the floor not in used during the day time (first floor) and during night time (ground floor) some households increase the temperature reaching 26°C (e.g. P04 and P13), or 27°C (e.g. P14), 28°C (e.g. P05, P11, P16, P12, P10, P08, P01 and P17). Household 15 turned off the system when the floor spaces is not in use. It is reported that when participants leave their homes for approximately two weeks for holiday some participants turned off their systems (e.g. P15, P10, P13, P08, P05, P12 and P11) and some set it at higher certain temperature (e.g. P14, P16, P01, P04 and P17).

it is found in most of the participants that the living room is used as family seating area and a place where they have their guests (e.g. P01, P04, P05, P08, P10, P11, P12, P15). And some participants such as P17, P16, P13 and P14 using this space when having guests only and using different space as daily family seating area. In terms of laundry habit, performed differently in the studied homes and were affected by the energy consciousness for some participants (once to 3 times a week) and the family size (e.g. some of the above average family size do laundry every day), with exception of P10. In winter, drying indoor winter cloths such as wool, is reported by all participants.   Cooking and hospitality habits performed similarly in each home. For instance, the cooking duration, number of meals and ventilation strategy during cooking (e.g. opening windows, cooker hood and extractor fan). All participants reported that when they have guests their system's temperature will be lowered by two degrees to cool the space faster (because the AC in the guest room is off in all participants) and the entrance lights are all on.   The following section explains the triangulation of the indoor environment differences, energy consumption and the effect of the inhabitants' practices.

6.6 Chapter summary

The analysis of the thirteen interviews with residents and the conducted home walkthroughs have highlighted that all participants involved in the study deem the HVAC system to be beneficial in their homes and that it is preferred over the conventional cooling system (AC window units) in terms of air vent distribution in the entire house. According to the interviewees, this technology and the construction of the homes have helped them reach an optimal level of thermal comfort. However, the influence of the technology on the inhabitants' practises as a result of energy consumption is notable. For example, the existing system control thermostat requires several interactions, making it inflexible and time-consuming to use and created dissent that some participant prefer the AC window units because each unit has its own control panel. Therefore, the number of controlling units that are provided is insufficient and does not contribute to reducing energy consumption and electricity bills especially the first floor. Using complex plug sockets also makes it difficult to turn off appliances and they had to leave them in standby mode. Furthermore, the absence of verbal explanations and a reliance solely on detailed written information for introducing the HVAC technology to new residents appear to be inadequate. Although the technology was intended to be used by a non-technical audience, it requires a moderate level of technical understanding. The lack of translated instructions in the written booklet has further hindered inhabitants from using the system and taking advantage of its features. They have consequently adopted new practises such as separating AC units, using smart thermostats, and using specific places for daily family seating to coincide with what they were provided with. For example, P13 using the two of bedrooms on the first floor as daily living rooms instead of the living room in the ground floor, one for the parent and one for the kids, because the first floor has one AC unit that controls the whole floor spaces. And others use different spaces than the living room because the design is an open plan area to the kitchen as a result the thermal comfort level change and the need for operating the cooling/heating system increase.

The non-existent relationship between those receiving and those providing information influences how participants interact with their home systems. The strong built-up connections amongst the residents, online searches, trial and error, and consultation with professionals have contributed to residents overcoming some issues related to the home systems. For example, over time, participants have formed the habit of cleaning the system filter regularly to enhance the system's performance and to minimise its operation duration, thereby reducing their consumption and electricity bills. Although, no evidence was found in the provided written documentation for new residents regarding the process of cleaning the HVAC filter.

The chapter also explained a range of seasonal practices that residents utilise beyond the HVAC system to reduce their energy consumption and maintain a comfortable indoor environment. However, not all the participants' practices aid in reducing their energy consumption and electricity bills. For instance, participants use natural ventilation even in the summer for a few hours during cooking. This unconscious practice results in hot air entering their homes and increasing the indoor temperature, which in turn increases the operation duration of the AC to cool the hot spaces.

This example illustrates how inhabitants' ventilation and cooling practises, which are intended to improve thermal comfort and air quality, may have the opposite effect on energy consumption and electricity bills. The chapter illustrates how the inhabitants' everyday practices may affect the energy consumption in Saudi homes.

Chapter 7: Understanding the possible influences of inhabitants’ practices on energy use and indoor environment

7.1 Introduction

After, analysing the inhabitants’ practices in the previous chapter (6), shows how these social practices affected by the four element of practices’ Gram-Hansen (2010) (technology, engagement, institutionalised knowledge and rules, know-how and embodied habits). This chapter presents the triangulation of data of the indoor environment, energy consumption and inhabitants’ practices. Providing deep understanding of the possible influences of inhabitants’ practices related to the diversity presented in energy consumption and indoor environment in the studied Saudi homes. Some analysis of indoor environment is presented, attempting to explain and interpret the social context of the observed indoor variations.

7.2 Seasonal indoor temperature

Differences in the indoor temperatures among the studied homes were noticed. It is found in most of the participants that the living room is used as family seating area and a place where they have their guests. The participants’ living rooms are facing different orientations e.g. P17, P10, P04, P05, P11, P13 and P12 (south and west), P01 (north and east) and P08 (north and west). It is appeared that some participants such as P17, P16, P13 and P14 using this space when having guests only and using different space as daily family seating area. for instance, P16 is the only person who is living in the home and all his practices e.g. eating, watching and having guests are performed in the dining room. The interviewee referred to the use of this room is because its location to the other spaces in the ground floor. This room and the guest room have one HVAC unit. It is reported that the air duct supply to the guest room was locked manually so the air can only cool the space that the participant 16 uses, the reason behind this practice is to reduce energy.

Household 17 is using one of the upper floor bedrooms as daily seating area in the summer. The practice of seasonal use of their spaces in this home and minimizing the HVAC operation was performing to reduce their energy. The summer living room has different furniture and finishes that help feeling cool e.g. wooden floor and leather sofas, as stated by the interviewee:

'[..] In the summer, we use the upper room because it has wooden floor, leather so you can feel cool'. P17

Participant 13 mentioned in their routine that they use two of the upper bedrooms (located in the first floor) as daily living rooms one for the parent and one for the kids, because the whole first floor is supplied with one HVAC unit. And, separating the kitchen from the ground living room and supply the kitchen with a spilt AC unit and the AC unit in the ground floor living room is off except when they have female guests. This practice was driven by their concern of lowering their energy. Furthermore, participant 14 built the future room and supplied it with a spilt AC unit. The reason behind this practice is to reduce energy by minimizing their use of the ground floor spaces as a result the HVAC is not operated except during the cooking time. This all can explain the recorded variation of the indoor temperature the maximum temperatures in these participants' living rooms and were between 28 °C (e.g. P17) and 33°C (e.g. P14) (Figure 5-1: chapter 4).

Household 15 has the highest recorded indoor temperature in the living room among others living rooms in summer season. It is reported that living room is used daily but the HAVC system is turned off completely when the space unoccupied e.g. from 6:00 p.m. until the next morning at 9:00 a.m. in the ground floor. The indoor temperature may have been raised due to the living room's orientation towards the east and south.

Households 14, 15 and 16 have the same orientations of their living rooms e.g. south and east. However, the highest recorded indoor temperature was found in P15, this can be interpreted by their practice of turning the system off when the space is unoccupied and the use of dark (turquoise) colour curtains in their living room. Also, another practice is found that during cleaning they open windows even in summer. Whereas, P14 and P16 have light (white/ beige) colours curtains in their living room and their system in the living room is on during cooking time only, because the kitchen and the ground living room have one HVAC unit. In addition, P16 reported that the system turns on automatically when the indoor temperature reached 32°C, while P14 their system will be on when the indoor temperature reached 27°C (Figure 5-1: chapter 4).

In winter, the indoor recorded temperatures were at 20°C found as minimum temperatures in most of the participants living rooms (figure 4.3: chapter 4). This can be explaining by the effect of the living rooms orientations in P11, P05, P13, P04, P17 facing e.g. (west & south), p14 and p16 (south& east) and P01 (north & east). Also, inhabitants' practices such as opening windows during the daytime until sunset to provide warm indoor environment during night time was found in households 1, 13, 14 and 17, as reported by one of the interviewee:

'We do open windows to let some heat from the sun come into the indoor spaces during the daytime and close them before sunset[..]'. P01

Moreover, due to the homes construction material such as concrete (high thermal mass material) has contributed in creating warm indoor environment in the living rooms, absorbing the radiations due to the windows are open during daytime and release it at night. However, low indoor temperature was noticed in household 14 at approximately 17°C (Figure 5-1: chapter 4). The practice of opening windows in the ground floor such as kitchen and living room was performed but not only during the daytime also was performed during night time. This offer interpretation on the low observed indoor temperature in household 14's living room.

The internal recorded temperature of all the guest rooms have low to medium variations (Figure 5-2: chapter 4) comparing to other measured rooms (e.g. living room, main bedroom and bedroom 2). All inhabitants that involved in this study their practice of using their guest rooms performed when expecting guests only. It is reported that the HVAC unit in the guest room is closed unless participants have guests, it will be on few hours earlier at lower temperature 22°C or 23°C.

Although P11 reported that they sometimes use the guests room without putting the AC on and they cool it by opening the door between the dining and the living room to let the air pass through in order to reduce energy:

'the AC in the dining room we don't put on we just open the door between the living room and the dining room so the air can pass into the room'. P11

Even in winter the guest rooms had minimal variations recorded in their indoor temperatures. These variations were affected by the participants' practices e.g. it is reported that in the summer they close the AC in the guest room and put it on when they have guest, but in the winter they do keep the windows open even if they don't have guest for ventilation e.g. P11 and P17. Furthermore, recorded warm indoor temperatures in households' 16 and 14 guest rooms at 25°C and 26°C, respectively (Figure 5-2: chapter 4). The positioning of their rooms, facing towards the west and south, can be interpret the warm indoor environment. Also, these participants reported that their guest rooms windows have no curtains instead they had white film tint sheet.

For the main bedroom, the highest recorded indoor temperature was found in household 15 at approximately 40°C in summer. This family turns off their system when not using the first floors spaces e.g. from 9:00 a.m. until 6:00 p.m. additionally, the west facing orientation room, the use of dark (turquoise) colour curtains and opening the bedroom window may have contributed in increasing the indoor temperature (Figure 5-3: chapter 4). Although participant 14 has the same facing orientation as P15, but it is found lower recorded indoor temperature than P15 and the maximum temperature reached 27°C. This can be interpreted by use of light (white) colour curtains and setting the HVAC at 27°C so the system automatically is on when the temperature exceeds 27°C. Another, high indoor temperature was found in household 1 main bedroom and the maximum temperature reached 31°C (Figure 5-3: chapter 4). Furthermore, putting the system at 29°C in spaces that are not occupied and the south oriented room may interpret the high indoor recorded temperature. And the use of (black) blackouts on windows may contribute to this increase. Households 12, 10, 17, 4, 14 and 13 have same bedrooms' orientations north and setting their systems at certain temperature such as 27°C as a result their recorded indoor temperatures are found lower than the other households (e.g. P15 and P01). However, although household 11 main bedroom is facing north, but it is noticed that had high recorded indoor temperature at approximately 35°C. This can be explained by their practice of turning their system off when the space is unoccupied.

During the winter season, variations in indoor temperatures of the main bedrooms were noticed in all homes (Figure 5-3: chapter 4). Low indoor recorded temperature in P01, P04 and P11 were at 19°C and 18.5°C, respectively. This can be explained by the room orientations of being facing north. However, household 14 their main bedroom is facing west and it can be seen that their indoor recorded temperature was approximately at 24°C (Figure 5-3: chapter 4). Although, in the main bedroom of the household 13 faces north orientation, warm indoor temperature was found between 20°C to 23°C. This participant reported that they put the system heating on before sleeping time for two hours at 20°C.

Bedroom 2 in all studied homes (one of the four measured rooms located in the second floor) its utilization varies from households to another. The highest indoor temperatures were recorded in this room between all rooms in each home and among the households. For instance, P01, P13, P11, P17, P16, P15, P16, P12 and P14 are using their bedrooms 2 when they have guests.

In addition, the bedrooms 2 orientations in those participants are facing east (e.g. P01), west (e.g. P13, P11 and P17) and south (e.g. P16, P15, P16, P12 and P14). This can be interpreted the high indoor temperatures found in those homes in transition period and summer season (Figure 5-4: chapter 4). Besides, the inhabitants' practices in this room, other factors may affect the indoor temperature e.g. room orientation, albedo affect as well as the fact that hot air rises from down to top floors.

household 8 has the highest indoor temperature recorded in the transition period reported at 44°C, although this room is facing north. However, from the home walkthrough and the interview, it is found that this room is used as storage and it involves a food freezer. This may explain the high recorded indoor temperature in this room. Also, the low albedo of the external surface (slab tiles) of the future room is originally in dark grey colour which means more solar gain especially if the room orientation facing east, south or west. The gained heat during the day time and later more ambient temperature released. Therefore, participant 8 reported the practice of painting this room and the space of the future room with white colour in order to reduce the heat as referred by the interviewee:

'[..]I painted the bedroom 2, future room and the roof area with white paint in order to reduce the heat coming inside the house because the bedroom 2 is used as storage and we put the food freezer there'. P08

The practice of painting the future room with white colour was also evident in household 10 (Figure 7-1):

'from the neighbours social group there is an engineer and he advised people to paint the future room and the roof with a white paint because it has dark grey colour and the white colour reduces the absorption of sun radiations'. P10

Figure 7-1 painted future room of participant 10 (Author, 2023)

Indoor temperature variation of bedroom 2 is found in household 10, the minimum temperature reached approximately 19.5 °C especially in the summer season (figure 5.4: chapter 4). The household practice of using this room as an office for some days a week and for couple of hours a day could explain the lowest recorded internal temperature (Figure 7-2). however, the south room orientation can interpret the high recorded indoor temperature in the transition period and the summer season at approximately 38°C.

participant 4 have mentioned that this is used as spare bedroom for sleeping when he is the only one at the home, instead of sleeping in the main bedroom and putting the HAVC unit on to cool the whole first floor. This can explain the indoor temperature variation that is found in this room, the minimum recorded internal temperature reached 25°C (Figure 5-4: chapter 4). Also, participant 5 has mentioned that this room is occupied daily for their maid. It is reported that the thermal preferences for the inhabitant who uses this bedroom 2 is different to the other member of the family, she prefers warm indoor climate. This may interpret the variation of the indoor temperature (Figure 5-4: chapter 4). The reason for the excessively high indoor temperature of 35°C during the summer could be attributed to the west-facing orientation of the bedrooms 2 occupied by participants 4 and 5. Because Saudi Arabia is located near to the equator and more heat gain from the east and the west orientations.

In winter the recorded external temperature was at 10°C, low indoor temperatures variations are found in all four measured rooms in winter season compared to the transition period and the summer season. the monitored four rooms' interior temperatures had not exceeded approximately 27°C across all homes. This very warm indoor environment can be explaining by the effect of the temperature stratification. As warm air rising upwards from ground floor to second floor e.g. some participants reported that they put the system heating on for 1-2 hours meaning the whole first floor spaces are heated. Moreover, the bedrooms 2 found facing south (P16 and P14) west (P11, P13, P05, P04 and P17) and east (P01) orientations in the studied homes, this can be considered as another reason interpreting the observed warm indoor environment.

Lower than 20°C of the indoor temperatures were recorded in all four measured rooms. The bedroom 2 had less practices performed there e.g. (P01, P16, P11, P13, P14, P17) with exception of P04 and P05. As mentioned above that participant 4 and 5 use this room while others use it when having guests. This room found facing south, west and east orientations in the studied homes. Although the orientations of this room means more solar gain, there found low recorded indoor temperature at 17°C (e.g. P01) and

19°C (e.g. P04, P11 and P16) (Figure 5-4: chapter 4). These participants reported that the winter practice of opening windows for ventilation were performed daily and even the window can be left open for several nights unlike P13 and P14, this may explain the recorded low indoor temperatures.

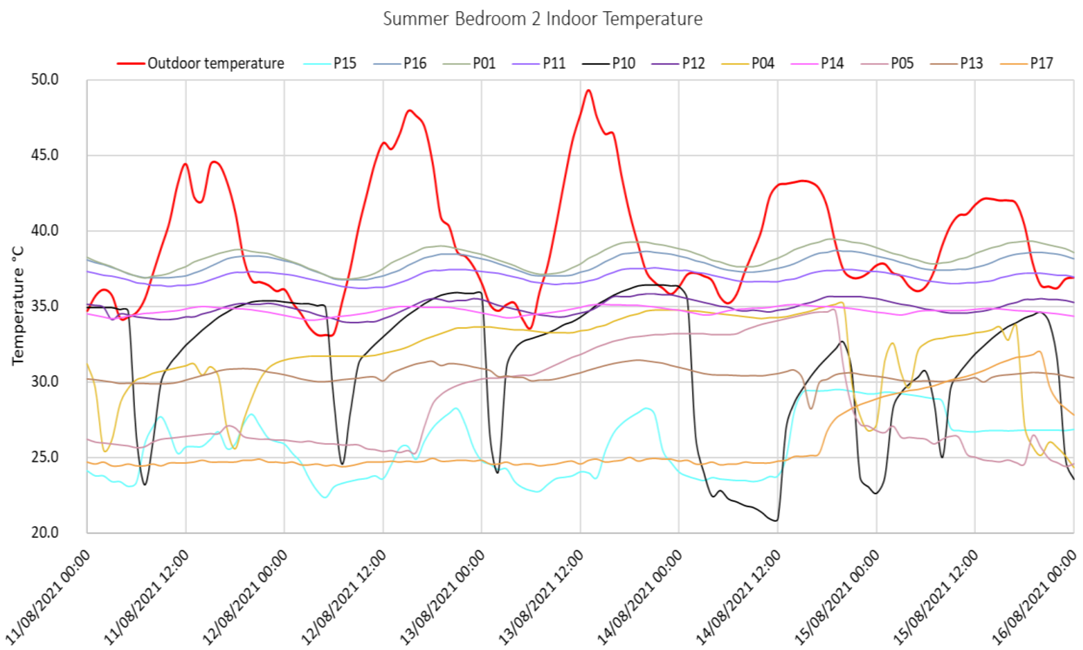


Figure 7-2 Indoor temperature of the monitored bedrooms 2 of all homes during five days of the summer season

It is worth mentioning that the noticeable variations in the indoor temperatures in most of the participants' measured rooms (e.g. living room, guest room, main bedroom and bedroom 2) during the transition period, were because participants have left their home for approximately two weeks for holiday. As a result, some participant turned off their system (e.g. P15, P10, P13, P08, P05, P12 and P11) and some set it at higher certain temperature (e.g. P14, P16, P01, P04 and P17). Participants who are not turning off their system reported that they have this practice is to avoid putting the system on for long time when they come back home.

7.3 Seasonal indoor relative humidity

According to the data collected, it was discovered that during the summer, the indoor humidity levels were low in all the rooms that were monitored in the homes. Conversely, during the winter season, high levels of humidity were observed in all the monitored rooms in the homes.

Indoor relative humidity variations are noticed in the living rooms of all participants in all seasons. In the summer, most of participants' living rooms indoor humidity levels were approximately not higher than 60% but lower than 40% (Figure 5.5: chapter 4). This might due to the use of the HVAC system, because the use of the HVAC system can help to remove excessive humidity and lower the indoor humidity level. Whereas, household 15 the RH exceeded 60% due to their cleaning practice of opening windows during the cleaning time. The weather station reported that the maximum humidity reached 83% and minimum 11.7%. Exchanging the inner air with outer air may result in variations of the indoor relative humidity. In addition, participant 12 RH level exceeded 60% (Figure 5-5: chapter 4) and it was reported that the practice of using humidifier occurs in the living room once to twice a week for half an hour as mentioned by the interviewee:

'[..] Humidifier in the living room because we feel that the weather is dry and turn it on once or twice a week for half an hour'. P12

Participants reported that they do open the kitchen window during cooking time. With the practice of opening windows during summer season, by doing so, the external weather conditions can be utilized to explain the fluctuations that were observed in the indoor relative humidity level. While, in winter data from the case study weather station showed that the winter external humidity level reached 99.2% as a maximum and 15.7% as minimum. At the same it is found that the indoor RH exceeded 60% in most of the studied living rooms (Figure 5-5: chapter 4). This can be explained by the ventilation practice of opening windows e.g. from morning until the sunset time. Due to the design of the living room being open plan area to the kitchen the indoor relative humidity level can be affected also by the practice of cooking e.g. using kettle, pressure cooker and may contribute to increasing the indoor RH level. Participants reported that more cooking practices occur in order to feel warm, as referred by the interviewees:

'There are inexpensive things we do to feel warm, such as drinking warm drinks and cooking, eating traditional warm food [..]'. P17

'[..] We rely on cooking, eating warm food and/or drinking warm drinks'. P05

Moreover, the practice of doing laundry indoor especially during winter or/and using dishwasher that all are perform in the kitchen can affect the level of indoor relative humidity. Some participants reported that the use of dishwasher is performed many times a day such as e.g. P01, P10, P12 and P14. Also, drying indoor the winter clothes that cannot be drayed by using the dryer machine e.g. wool cloths. All these practices can be used to offer explanations for the observed variations of the indoor relative humidity levels, because drying cloths indoor and using dishwasher multiple times a day release steam and moisture into the air.

For the guest rooms, all participants reported that this room is used when expecting guests, otherwise the system there is turned off. The variations of the indoor relative humidity here can be explained by the inverse relationship between the temperature and the humidity. Also, due to the ventilation practices of opening windows continually in winter may have the contribution of causing high humidity levels (Figure 5-6: chapter 4).

In term of the main bedroom, the indoor variations of relative humidity are found in all seasons. The low relative humidity levels that are found in the transition period and the summer season may due to the use of the HVAC system, as it has the ability to control the humidity levels in the home. For instance, Household 13 reported the use of the system ventilation and it is found that the RH levels fall between 40% and 60% in transition period and summer period (Figure 5-7: chapter 4). The high relative humidity levels found in P15 was high in summer season, this can be justified by their practice of opening windows during cleaning time. Whereas, in winter the indoor relative humidity levels were higher than other seasons and the HAVC system is turned off for most of the time and the reliance more on the natural ventilation was reported (Figure 5-7: chapter 4). Some participants mentioned that they turn on their heating system for only 1-2 hours before they go to bed and then switch it off. Therefore, the high recorded humidity levels could be due to the practice of opening the main bedroom's window, showering and/or cleaning practices. According to the participants, it was found that even when the extractor fan was turned on after taking a shower, leaving the door of the bathroom open for ventilation. This practice can be attributed to the fact that the moisture can get trapped in the air and find its way into the bedroom.

The purpose of using the bedrooms 2 when the participants are having guest is found the same in most of the homes. For instance, bedrooms 2 in P01, P13, P11, P17, P16, P15, P16, P12 and P14 are used for guests only. Also, household 8 as mentioned above that this room where they keep their freezer. Since the use of this room, the relation between the temperature and humidity can be used as an explanation for the variations levels of relative humidity that were observed in these participants' bedrooms 2 in all seasons (Figure 5-8: chapter 4). Another explanation for the high observed relative humidity level reaching 70% in household 15 during the summer is that their practice of weekly cleaning and opening windows during the cleaning time in all seasons may contributed in the high RH level (Figure 5-8: chapter 4). Since the case study (Jubail industrial city) is located on the Arabian Gulf coast of Saudi Arabia and it is classified with hot and humid climate. External weather may have contributed in affecting the indoor relative humidity since the external humidity reached at 99.2% as maximum and 15.6% as minimum in winter.

As reported above that this room in household 5 is used for their maid, can interpret the high relative humidity levels found in summer and winter. For example, the practice of drying cloths inside the room in both seasons are performed. Also, the practice of opening windows for ventilation is performed but only in winter. This could be the reasons explaining the high humidity levels in P05 bedroom 2. Furthermore, household 4 is using bedroom 2 many times a week, the participant reported that cleaning performed twice a week e.g. washing floors and cleaning bathroom (this room has its own). This may contribute to the observed variation in the indoor relative humidity especially in winter, the RH exceeded 60% (Figure 5-8: chapter 4).

7.4 Energy consumption

This section will demonstrate and explain the energy consumption linking it with the inhabitants' practices, their environmental control usability experiences and the indoor environment. There were some challenges in obtaining all the data on energy consumption, thus not all information on energy consumption was available.

it is reported that the Saudi studies (involved in the literature review chapter) and the Saudi Energy Efficiency Centre (SEEC, 2019) mentioned that deficiency in applying thermal insulation is responsible for the high energy consumption. Here, this study explores the energy consumption in Saudi regulated homes that are built e.g. with involvement of thermal insulation and double glazing. Furthermore, it is revealed from the data that relying on technology solely e.g. building regulated homes in Saudi is found not sufficient. Although the study investigates the energy consumption in identical regulated Saudi homes, still it is demonstrated variations in energy consumption. This shows that the social aspect plays critical role when studying Saudi home energy consumption.

It is worth mentioning that lack of finding evidence on established definitions of energy consumption in Saudi domestic buildings or the Gulf Cooperation Council (GCC) countries in KWh/m^2 e.g. what is defined as low based on the climate condition, culture and inhabitants needs, as a target to be achieved. While, internationally it can be found established definition for low energy houses e.g. passive housing the annual energy consumption is lower than 120 kWh/m^2. The findings of this study will be compared to extract the possible explanations for the observed variations in energy consumption. This will then be compared with the existing international sustainable definitions on low energy homes e.g. passive house standard in Germany, low energy house standard 2020 and 2025 in the UK.

Figure 7-3 illustrates that the residential electricity consumption in the Saudi Arabia depends heavily on seasonal and daily temperature profiles (Almushaikah and Almasri, 2021). The higher the temperature the higher electricity consumption will be.

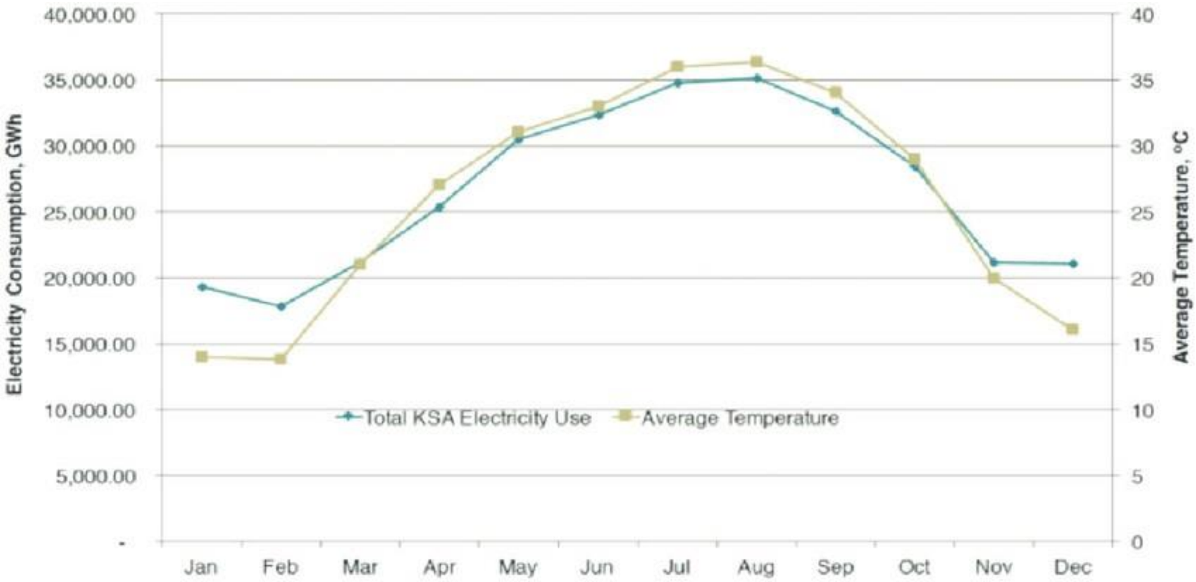


Figure 7-3 Total monthly electricity consumption in Saudi and average temperature throughout 2014 (Almushaikah and Almasri, 2021).

Surprisingly, although P16 the only person who uses the home, it is found that his energy consumption is similar to other households (82KWh/m^2) e.g. P01 (81KWh/m^2). The consumption of P16 can be explained by the use of AC system at lower indoor temperature than what is stated by ASHRAE 20°C during sleeping time for approximately 8 hours. This is not only cooling specific room but it cools the whole firs floor spaces because this floor has one HVAC unit. It can be interpreted that the consumption of P16 goes for the cooling because it is reported that he uses additional heating devices distributed in the daily used spaces e.g. dining room and the main bedroom. Household 14 consume slightly the highest than others from the same group who use the system by scheduling or smart thermostat. This household size is 6, it is reported that they use three bedrooms out of four in the first floor, meaning cooling will be supplied to even unused bedroom at temperature 25.5°C-23°C. It is found that the cooling of the theses spaces is not only performing during night time but also during the day time, because the kids stay in their rooms doing e.g. their homework during the week except Fridays. Also, in winter P14 mentioned that one of their heating practices using the heating system for the first floor spaces. This household has reported that they do bake every day and this practice involves using mixer and oven. Also, in term of cleaning practice this participant reported the daily use of dishwasher machine more than one time a day. These practices may explain the energy consumption of this household. Participant 14 has built the future room to be their daily living room and it supplied with AC split unit and also they extended their kitchen area. it is mentioned that when having guests sometimes the kids stay in the new living room. These practices of more area to be cool e.g. extended kitchen, the built future room and the use of upper floor spaces addition to the ground floor spaces when having guests, added more load to their consumption and may have contributed to the observed consumption.

The lowest annual energy consumption was found in household 13 at 72KWh/m^2 (Figure 5-11: chapter 4) compared with the households of high competency group, although P16, P14 and P13 have the same home orientation e.g. west. The size household of P13 is 4 which is less than P14 and more than P16 but still the annual energy consumption is different. The practice of using the indoor spaces is different e.g. the participant separated the kitchen from the living room and not only putting a wall but also the AC unit is separated too (kitchen has new spilt AC unit) because both spaces were used to be supplied with one HVAC unit. This mean that the HVAC system in the living room will be on and cool only this area when they have female guests. Also, the HVAC unit in ground floor that supply the dining and guest rooms are turned off and it is on when having male guests. This participant also tries to minimize their energy consumption and use all the first floor spaces, two as bedrooms and the other two are used as living rooms one for the parents and one for the kids. The windows of these living rooms have external screen shading to reduce the heat coming from the south orientation. The cooling and heating spaces are the same and beneficial especially at night time when their kids are sleeping. This may explain their annual energy consumption being lower than others. This participant mentioned that when they use the heating system the house remains warm for two days; this implies that the heating is not something use every day during the winter time.

P01 and P08 households use the same indoor spaces in term of family daily seating area e.g. the ground floor living room. In addition, both participants have the same layout of the living room and the kitchen being open plan area, meaning no changed was found in their indoor spaces. Even the homes orientations in both households have the same e.g. east, have different annual energy consumption e.g. P01 (81KWh/m^2) and P08 (73KWh/m^2). The observed annual energy variations for both households can be interpreted by the setting temperatures of their system. For example, P01 during the sleeping time the AC temperature at 22°C but during the day time from 8:00 a.m. to 9:00p.m. at higher temperature 27°C. however, P08 set the AC at uniform temperature during the sleeping and the daytime at 24°C. In winter, participant 1 use the system heating in the ground and first floors depending on their use of spaces. While, household 8 use additional heating devices, one in the living room, one in the main bedroom and one in their daughter's room, and both households operate it before bed time for 1 hour (P08) and 2 hours (P01) then it is turn off. Also, participant 1 mentioned that their kids sometimes participate in adjusting the AC system, which might have contributed to increase their energy consumption, as referred by the interviewee:

'[..] Now my kids are not young anymore so they also participating on using and adjusting the system sometimes. So, anytime they feel discomfortable instead of informing me or their mom, they just do it by themselves'. P01

Household 11 have the highest annual energy consumption among all studied households at 93KWh/m^2. The family size is 6 and they use three bedrooms of the first floor out of four similar to P14. They use their system manually with temperature at 24°C during sleeping and daytime. Due to their unfixed routine, the ACs in the ground floor and first floor spaces are on during the daytime. The father has different work shifts e.g. one of his shift finishes at 2:00 p.m. and when he comes home he sleeps, meaning the first floor spaces are all cooled because it has HVAC unit on. It is referred by the same participant that this technique of using one HVAC unit in the first floor is not helpful in term of reducing their energy:

'[..] The first floor has one control unit that controls the whole floor, so it became very difficult to reduce energy and bills. If one member of the family is sleeping on first floor and others are in the ground-floor living room, I end up putting the system on for both floors! I think the electricity bill will be less if every two bedrooms had one control unit'.
P11

Also, another reason that may contributed to the high energy that this participant has built additional place '*khimah'* located outside the house for receiving male guests and supply it with AC split (Figure 7-4). Also, this household reported baking occurs every day and this practice includes the use of the mixer and the oven (putting it on half an hour earlier). baking practice takes about an hour and half including the preparation time, this might influence their energy consumption. the heating in this family is used for 1-2 hours at 22°C -23°C (within the suggested winter indoor temperature by ASHRAE) in first floor, this may explain the high energy consumption compere to other households' consumption. For their ground floor spaces, they depend on wearing extra layers and it is reported that because the kitchen is open to the living room it provides some heating especially during cooking time.

Figure 7-4 Example of 'Khimah' for welcoming male guests

Another household who is using their system manually and has high energy consumption among to all studied households is participant 17 with exception of P11. The family size of this participant is 4, meaning two rooms of the first floor are used as bedrooms one for the parents and one for their boys and they also use one of the room in the first floor as their summer living room. Therefore, the AC unit in the first floor spaces is on daily whether daytime or sleeping time at temperature 24°C. The AC in the ground floor is on during the cooking time, and when they travel they leave their system in the ground floor at 28°C because they don't want their stored food to be damaged by the heat. This might explain their annual energy consumption 87KWh/m^2. household 4 is one of participant that using their system manually and it has the same family size of P11 (6). Their AC operate sometimes especially during weekdays on both floors. This family use the living room as family daily seating area but when their kids have some work to do they stay in their bedrooms because have involve offices. Operating the air conditioning on both floors during the weekdays at 24°C and during the sleeping time at 22°C, may explain their annual energy consumption. however, it is noticed that this participant has the lowest annual energy consumption among the households who use the system manually. P04 annual energy consumption 74KWh/m^2 is surprisingly similar to P08 (73 KWh/m^2) who use the smart system. It can be understood from the annual energy consumption of P08 and P04 that is not necessarily smart technology can help inhabitants reducing their energy consumption.

The P04 annual energy consumption can be justified by their practice of using the daylight e.g. at specific hours a day, leaving the curtains on and planting outside the house to prevent heat and add more shading for the building. Also, the occupancy of this household is different to other studied households, their home is unoccupied during weekends, it is reported that they go to their farm house instead. When they leave their home everything is turned off. This household also reported that their children were trained to turn off any electrical equipment that they do not use:

'[..] The whole family trained to close any electrical equipment they don't need in order to save money'. P04

This participant with his technical knowledge of separating the AC system in the first floor will help reducing energy:

'In the future, I will change the system on the first floor to split AC units so I can control it depending on my needs and save money. I think the energy consumption will be reduced because the house construction is good'. P04

Although P11, P17 and P04 have the same home orientation facing north and using their system manually, it is noticed variation in their energy consumptions. Another practice that is found in all studied households is that the practice of opening windows during cooking even in summer although the existence of the kitchen cooker hood, interviewees referred that they are not strong enough to remove the cooking smells. This practice may have contributed to lose the cold/warm air and change the level of the thermal comfort of indoor spaces as a result the demand for cooling or heating may have increased.

One of the study mentioned in the literature review conducted by (Aldossary, 2015) was focusing on the technological aspect in hot and humid climatic region. Two typologies were used the study comprises of three conventional houses and three flats. The study involved comparison between the actual annual consumption and after retrofitting. It is found that from the study that the conventional houses real annual consumptions were from 165.2 KWh/m^2, 115.2 KWh/m^2 and 110.3KWh/m^2. The actual average electricity consumption for conventional houses was 156.5kWh/m^2, the conventional house was built with single glazing windows and no thermal insulation (Alrashed and Asif, 2014).

Aldossary et al study suggested that retrofitting the houses by involving thermal insulation, installing shading e.g. external shutters for windows, installing PV solar and replacing the single glazing windows with double glazing. The results showed that the annual energy consumption reduction ranged between 21% to 37% e.g. 123.7 KWh/m^2, 72.5 KWh/m^2 and 75.5 KWh/m^2. Despite, that the retrofit results were simulated the suggested solutions e.g. thermal insulation and double glazing are already existed in the RC homes, the annual energy consumption in the present study is lower than the actual annual energy consumption in (Aldossary, 2015) study but still the present study demonstrates variations in energy consumption.

As previously stated, there is no benchmark for energy consumption in sustainable homes in the Middle East or the Gulf Cooperation Council (GCC) countries, making it impossible to evaluate the outcomes of this study. Therefore, the present study findings of energy consumption in KWh/m^2 will be compared with the international low energy standards. It can be seen from Figure 7-5 that RC homes achieved lower annual energy consumption than the passive house standard in Germany, low energy house standard 2020 in the UK and Low Energy house standard in Czech Republic.

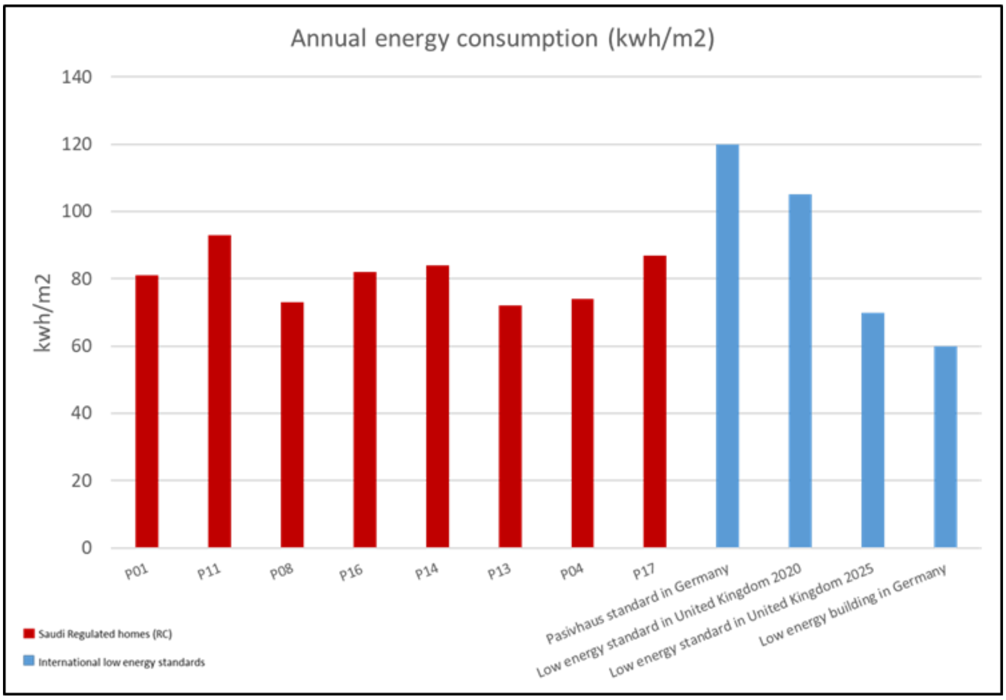


Figure 7-5 Energy Consumption in kWh /m² with International Standards

7.5 Key Findings

The improved technology (building envelope) of these studied homes has shown clearly how the energy consumption was reduced comparing with the average Saudi conventional house (Alrashed and Asif, 2014). A study of Alaboud and Gadi (2022) shows the thermal performance of Saudi conventional residential building and after it was retrofitted (e.g. adding thermal insulations). Their retrofitting results show that by improving the building envelope, can reduce the cooling demand annually by 36.2%. The findings the conducted study explain the variations that contributed to effect on the energy consumption such as building orientation (absence of external shading in heat gain orientations), home design (kitchen being open plan area to living room). In addition, the external weather (e.g. ventilation by opening windows) and inhabitants' everyday practices (how they use their homes and its systems).

The indoor environments affected by the external weather during measured seasons e.g. transition, summer, and winter. Low variations of the indoor temperatures across all studied homes and rooms are found in the winter season. Furthermore, medium to high variations of indoor relative humidity levels were observed in all rooms across all monitored homes. The cross-case findings are following the same pattern e.g. it is found that more humid indoor environment in the winter than the summer (dry environment).

The architectural design (e.g. the kitchen being open plan area to the living room & the room orientation) of the studied homes has contributed to the observed variations in indoor environments when the cooking occurs. The data show that inhabitants' ventilation practice e.g. opening the kitchen window during cooking was common practice across all studied homes even in summer. As a result, the demand for the cooling increase especially for those who use the living room every day as family seating area. This also could imply that the ventilation system not strong enough as referred by the participants. Furthermore, emphasizing the need for testing the system performance before the inhabitation stage. Studies of Foulds (2013) Kermeci (2018) show a mirror practice of opening windows for ventilation found in cold countries resulted in increasing the heating demand.

The occupancy in the measured four rooms was differ among the participants. For instance, all the participants reported that the system unit in the guest room is closed whether they are home or not and it is occupied when having guests only. The rooms that are used more often e.g. main bedroom and living room the HVAC system there is on even for those who do not use it for family daily seating place. Because there is one HVAC unit control the kitchen and living room. It is found that both rooms (main bedroom and living room) have low to medium variations with exception of household 15. Whereas, the bedroom2 have the highest indoor environment variations due to the purpose use of this room.

The success or failure of domestic technologies depends fundamentally on how they are used by residents (Hargreaves et al, 2018). The interpretations highlighted that the absence of formal knowledge (home induction), mutual conversations between the households and the developer, and the presented amount, level and language (e.g. English for non-English audience) of information in the home user guide affected the inhabitants' practices of using their systems. A study by Palmer et al (2016) on several UK housings projects, demonstrated that one of the housing project its system control was imported in German and no translated was provided.

Participants' interactions toward their home energy were related to the level of competences they have due to their level of education. For example, engineer participants use their system through e.g. scheduling and smart thermostat (retrofitted their systems), whereas others (who are not engineers) use their system manually.

It is observed that although the energy consumption was reduced in the studied homes, the data noticeably varies between the homogeneous studied homes in some cases even between the same households' size, the home orientations and the way they use their systems (smart, scheduling and manual). For instance, participants 4 and 11 have the same family size and both controlling their systems manually but their energy consumption significantly varies 74KWh/m2 and 93KWh/m2, respectively. Another example, household 17 and 13 share the same family size but P17 consume more energy than P13 around 87KWh/m2 and 72KWh/m2, respectively. It is appeared that the practice of controlling the solar is occurred in households 4 and 13 especially during the summer than the households 11 and 17. Also, household 13 took advantage of two upper bedrooms in the first floor for daily seating area because the first floor has one HVAC unit supporting the whole spaces. The use of practice theory in this research reveals that how technologies changes affect the residents' practices. There are some studies e.g. (Aune, 2007; Ellsworth-Krebs, Reid, & Hunter, 2015; Rinkinen & Jalas, 2017; Madsen, 2018) discuss how changes in technologies influence on residents' comfort practices.

The coefficient variation of the annual energy consumption between the identical homes is 15% and the differences in energy (between the highest and the lowest consumers) found of a factor of 21 KWh/m^2. This implies that the interpretations of this study provide the support to claim the importance role of inhabitants' practices in the variability of energy consumption and this was explored by the use of practice theory, that could not be explained by the material differences solely.

The findings demonstrated that participants' practices affected more by the technology and institutional knowledge and rules elements. For instance, the implementation of one HVAC unit that support the whole first floor spaces. Resulted in the use of the upper bedrooms as daily family seating area, some build another additional rooms to suit their needs related to the system. Others, using indoor specific spaces seasonally and one use the bedroom2 (has separated AC unit) in second floor increased when one member of the family being the only one who is using the home. Even the other historical practices (e.g. wearing extra layers, swimming, having cold food, using additional electric heaters) found performed seasonally in a way to reduce their energy demand.

7.6 Chapter Summary

The discussion chapter has explained the variations observed in the consumption between the studied identical homes, and explained the possible influences of social practices based on the four element of practice theory (technology, engagement, institutionalised knowledge and rules, know-how and embodied habits). Exploring different aspects that affect the energy demand e.g. building orientation (absence of external shading in heat gain orientations), home design (kitchen open plan area to living room). In addition, the external weather (e.g. ventilation by opening windows) and inhabitants' everyday practices (how they use their homes and its systems). The chapter explains the inhabitants' practices contributed in the energy variations especially between not only identical homes but in some cases between the same household size, level of education and home orientation. The inhabitant practices were investigated through the use of practice theory that offered a deep understanding of the residents' practices that could explain the observed variations and potentially consider in domestic policy for improving current and future residential buildings.

Chapter 8: Research Conclusion

8.1 Introduction

The increased concerns about the high energy demand in Saudi domestic buildings has led to this research. The review of literature shows that a number of Saudi energy studies have advanced understanding of domestic energy use but that they have concentrated on the technical elements of the building, such as the fabric performance, thermal insulation, and the integration of renewable energy sources. Moreover, these studies relied heavily on predicted energy consumption. This thesis was undertaken to address the gap identified in relation to the problem definition that there is a lack of knowledge on what underlies the causes of the energy demand in Saudi residential sector e.g. variations in household energy use between houses that are the same. And the gap between technical predictions of house energy use and the realities of household energy use. There is a growing range of literature from different geographical locations (e.g. Strengers, 2010; Gram-Hanssen, 2011; Strengers and Maller, 2011; Foulds, 2013; Madsen, 2018; Larsen and Gram-Hanssen, 2020) using social practice theory and producing insights of inhabitants everyday practices and their consequences for the domestic indoor environment and energy. The present study made a contribution to knowledge of understanding the households' energy demand in Saudi Arabia, as a new cultural geographical context, by investigating the inhabitants' practices and the actual building performance (indoor environment and energy use). The main theoretical contribution in this study is developing detailed understanding of the ways in which inhabitants' practices relate with energy demand in Saudi homes, and expanding the literature on domestic social practices. Furthermore, using post occupancy evaluation mixed methods to study the performance of Saudi regulated homes has provided complementary data. It is found a number of domestic energy studies use indoor environmental monitoring within practice theory oriented research (e.g. Foulds et al, 2013; Gram-Hanssen, 2014; Kermeci, 2018). In this study, the indoor monitoring method contributed to explaining how social practices related to indoor environment.

The findings from this research highlight that understanding the inhabitants' practices helps identifying some issues, across issues of technology, engagement, institutionalised knowledge and rules which need to be deemed important for improving future and/or current housing developments in the same or similar climatic regions of the kingdom. The insights drawn from this study about the inhabitants' practices and their influence on energy need to be considered as 'designed for', rather than 'designed out', by housing professionals (Cherry et al, 2017).

This chapter provides an overview of key findings for each of the research questions. Based on the findings of this research some suggestions for further research are presented. Also, the faced limitations of the research are discussed. The chapter provides some recommendations for the developer Royal Commission, policymakers, and energy suppliers. Finally, it discusses some insights of social practices for Saudi domestic policy. The following research aim and objectives were adopted in this thesis:

Aim: To understand the role of inhabitants practices of the energy use of Saudi homes in order to provide recommendations for future home building projects.

Objectives:

1. Identify how much energy has been consumed in a selection of regulated homes.
2. Evaluate how a selection of regulated homes are performing in relation to thermal comfort.
3. Understand the usability of environmental control interfaces of selected regulated homes.
4. Explain the influence of inhabitant everyday practices on energy consumption and the indoor thermal environment.

8.2 Overview of key findings in relation to research objectives

8.2.1 Research objectives 1 & 2

Identify how much energy has been consumed in a selection of regulated homes and evaluate how these selected homes are performing in relation to thermal comfort.

Based on the research gap that mentioned above, the research made a contribution to study the actual building performance (indoor environment and energy use) in Saudi homes. The research assesses real thermal comfort conditions, including air temperature and relative humidity, alongside energy consumption, to achieve the stated research objectives (Chapter 5). Energy consumption data were gathered by collecting and analysing the actual annual energy usage (KWh/m²). Additionally, the thermal conditions of twelve dwellings were monitored over an eight-month period to capture seasonal variations. Each dwelling was equipped with four monitors deployed in different rooms to account for all orientations.

Previous Saudi existed studies (section 2.4) such as (Aldossary, 2015) focuses on enhancing the technological aspect of the residential buildings by retrofitting solutions for upgrading the building envelope (e.g. adding thermal insulation, double glazing and external shading) to reduce the energy consumption. Applying these solutions can reduce the annual energy consumption and range between 21% to 37% for each property. The suggested retrofit solutions provided in the study of Aldossary (2015) (e.g. adding thermal insulation and double glazing) are already existed in the RC homes. It is found that the annual energy consumption in the present study is lower than the annual energy consumption in (Aldossary, 2015). Another study of Alaboud and Gadi (2022) shows the thermal performance of Saudi conventional residential building and after it was retrofitted (e.g. adding thermal insulations). Their retrofitting results show that by improving the building envelope, can reduce the cooling demand annually by 36.2%

The present study shows that the improvements in the building envelope has contributed to provide comfortable indoor environment. The building use study questionnaire results show that around 50% and 60% of participants are satisfied with the overall thermal comfort in their buildings in winter and summer seasons, respectively. However, through the environmental monitoring, variations in indoor thermal comfort of the twelve studied RC homes were noticed.

The monitoring data (Chapter 5) indicates that rarely occupied spaces, such as Bedroom 2 and the guest room, exhibited mean indoor temperatures exceeding the recommended ASHRAE standards during transitional periods and extreme summer conditions. For living rooms, the average indoor temperatures during the summer ranged from a minimum of 23.5°C to a maximum of 29°C for participants who regularly use this space as a family seating area. These temperatures varied significantly compared to other rooms, such as Bedroom 2, the guest room, and the main bedroom. In winter, the data revealed minimal variations in the mean indoor temperatures across all measured rooms in comparison to the more pronounced fluctuations observed during the transition and extreme summer periods. Winter temperatures across all homes and rooms fell within the range of 20°C to 24°C. The variations in the indoor environment across the three seasons highlight the potential need for improved window shading, particularly in orientations vulnerable to heat gain, which may have contributed to the elevated indoor temperatures during the transitional and summer months. This, in turn, affects energy demand, with rising temperatures leading to increased electricity consumption (Figure 7-3, Chapter 7). Regarding relative humidity (RH) levels, data shows greater variability in winter, with levels exceeding 60%, while summer levels were below 30%. These seasonal RH variations may result from the inverse relationship between temperature and humidity, as well as the influence of residents' practices, such as the use of humidifiers and ventilation practices.

The findings of this study reveal that the energy consumption in Saudi-regulated homes was below 100 kWh/m², significantly lower than the average electricity consumption for conventional Saudi houses, which is 156.5 kWh/m² (Alrashed and Asif, 2014). When compared to international benchmarks, such as the German passive house standard (120 kWh/m²) and the UK's 2020 low-energy homes standard (105 kWh/m²), the energy consumption in this study also remains lower. However, the data indicate inconsistency in energy usage across the studied sample. Despite the case studies being identical in terms of house size, building materials, and layout, variations in energy consumption were noted among participants. These findings suggest that energy demand in the studied homes is influenced by several factors, including building orientation (such as a lack of external shading on heat-gain facades), home design (e.g., open-plan kitchen and living areas), external weather conditions (e.g., ventilation through window openings), and residents' daily practices (e.g., how they interact with the home and its systems).

Even in the other contexts e.g. United States of America and Denmark, some studies such as Sonderegger (1978), Hackett & Lutzenhiser (1991) and Gram-Hanssen (2010) have shown variations although they use homogeneous samples. The study of Sonderegger (1978, p.313) concluded that 'the resident rather than the structure creates most of the observed variation in consumption'. Emphasising the observed variability in energy consumption among participants in the present study, cannot be solely explained by material differences, the following objectives provide deeper understanding in which inhabitant practices relate with energy demand in Saudi homes.

8.2.2 Research objective 3

Understand the usability of environmental control interfaces in Saudi homes.

The theoretical contribution of studying the technology element (e.g. home system, home design and controls) and the Institutional knowledge and rules element (e.g. home induction and home user guide) have helped to achieve the present study objective 3. Furthermore, these elements have helped to reveal some issues that have an effect on the use of home system.

For instance, the data indicate that the lack of home induction has resulted in the improper use of the ventilation system and scheduling issues. This underscores the necessity of providing formal knowledge, such as home induction, to residents. Furthermore, it was observed that the home user guide has impeded the effective utilization of home systems, particularly among participants who manually operate these systems. This challenge can be attributed to several factors, including the quantity, complexity, quality, and language of the technical information intended for residents. Additionally, there appears to be a knowledge gap on the part of the developers regarding the varying educational backgrounds of residents who rely on the home user guide, which may include differences in profession and proficiency in English; these factors can either facilitate or obstruct the effective use of the guide. Consequently, all participants had to acquire knowledge on operating their home systems informally through various means, such as consulting professionals, engaging with neighbourhood social groups, and utilizing resources like YouTube and company websites.

The success or failure of domestic technologies depends fundamentally on how they are used by residents (Hargreaves et al, 2018). The data indicate that participants' educational background, particularly in fields like engineering, influenced their use of home systems. For example, some participants with engineering backgrounds retrofitted their HVAC system thermostats, opting for smart thermostats like the Ecobee, which includes motion sensors. It was reported that the original thermostat required manual adjustments by residents physically present in the home, whereas the Ecobee’s motion sensors assist by sending reminders through an app to turn off the system, thereby reducing energy consumption. Additionally, some engineers took advantage of the system's scheduling features, allowing them to regulate the indoor environment automatically. In contrast, non-engineer participants manually controlled their home systems due to limited technical knowledge. This group tended to focus on other factors that influence energy use and the indoor environment, such as optimizing daylight use and adjusting their use of internal spaces seasonally. Furthermore, the data revealed that having a single HVAC unit to control an entire floor, particularly on the first floor, was not effective for reducing energy consumption. Families with below-average size reported that this HVAC system was more suited for larger households, while larger families suggested that the HVAC system should be divided to separately control different spaces on the first floor.

Due to this limitation (number of HVAC units), some participants e.g. relied on their prior heating experiences by using additional electric radiators rather than utilizing the provided heating system. As technologies will not always be understood and used as designed (Larsen and Gram-Hanssen, 2020). The data from the present study revealed that 42% of participants indicated that the HVAC controls were not user-friendly, and

50% reported that the controls were inadequately labelled. Additionally, approximately 25% of participants assessed that the HVAC controls did not allow for sufficient adjustments. Interview data further indicated that these participants had retrofitted their system's thermostats as a result. Moreover, around 42% of participants expressed uncertainty about whether they should interact with the HVAC controls or not.

8.2.3 Research objective 4

Understand and explain the influences of inhabitant everyday practices on energy demand and the indoor thermal environment.

To understand the variability shown in energy consumption, chapter 6 focused on the details of inhabitants practices and their influence on the energy demand. The present study addressed research aim and the gap that is found in the previous studies and it made contribution of investigating the households' practices in Saudi Arabia, as a new cultural and geographical context. The theoretical contribution of investigating e.g. the engagement and routines elements, helped to understand and explain the participants' practices that are performed in a certain way, in which may have an effect on the energy demand and thermal comfort.

The data indicate that the concern over high electricity bills, expressed by all participants, has prompted them to adopt various practices to reduce their energy costs. These practices include utilizing alternative cooling methods such as swimming, taking cold showers, consuming cold foods, and wearing lighter clothing. While these strategies help mitigate the amount of time spent operating the air conditioning, but they do not replace the need for the cooling system during extreme summer conditions.

As previously discussed in Objective 3, participants were categorized into two groups based on their educational backgrounds—engineers and non-engineers—which influenced their home system management practices. For example, some participants utilized blackout curtains on their windows for part of the day to block heat from entering indoor spaces, thereby reducing their reliance on air conditioning. Additionally, one family employed external shading screens on windows in regularly used rooms to minimize heat gain, further decreasing the need for air conditioning operation. One family noted that instead of adjusting the temperature or turning the system on or off, which could disrupt the thermal comfort of other family members, they would switch seating arrangements in the living room based on individual comfort levels. Another participant indicated that when using both the ground-floor dining room and kitchen simultaneously, they would operate the HVAC unit cooling the living room and kitchen while keeping the door open between these spaces to facilitate airflow. This approach eliminated the need to activate both air conditioning units on the ground floor, as the living room and kitchen share one HVAC unit while the dining room and guest room are serviced by another.

Moreover, the choice of daily living spaces varied according to household comfort requirements during summer. Participants reported using rooms with wooden floors and leather sofas, which helped them feel cooler and reduced their reliance on air conditioning. Practices such as varying clothing to accommodate individual comfort preferences, consuming warm food, and utilizing natural daylight to heat indoor spaces were also noted as energy-saving strategies.

All participants tended to avoid using ground-floor spaces, particularly guest rooms, unless hosting visitors, leading to the air conditioning systems in those areas being turned off. Some households practiced turning off the HVAC system when leaving home for extended periods, while others preferred to maintain it at a set temperature. It was reported that certain homes did not switch off the system to avoid longer wait times for the system to reach a comfortable temperature upon return.

Other practices that may have contributed to the variations observed in the indoor environment and the energy consumption is that opening kitchen' window in extreme summer. This negative practice allows hot air entering the home, and the limited flow of air could increase indoor temperatures, as a result, increase the need for operating the AC system and the duration time in the kitchen and living room section. It is found that all residents involved in this study mentioned that they open the kitchen window for ventilation during cooking time only for a few hours and then close it along with the cooker hood. It is reported that performing this practice, participants are looking for stronger and faster ventilation. This suggests two key implications: first, there is a need to assess the performance of the ventilation system prior to occupancy; second, effective verbal and physical communication between developers and residents is crucial. The architectural design, particularly the open-plan layout connecting the kitchen to the living room, has contributed to the observed variations in indoor environments in residential homes. As a result, some participants have opted to separate their kitchens to enhance olfactory privacy and reduce thermal fluctuations in the living room. Conversely, participants reported that their practices for window ventilation varied depending on external weather conditions. For instance, some residents opened their windows from morning until sunset during winter, while others left their windows open for several nights. Additionally, the use of dark-colored blackout curtains, tinted films, and other window coverings—particularly on the east, west, and south-facing orientations—may exacerbate heat absorption and retention, thereby increasing the reliance on air conditioning.

Laundry habits also differed among the studied households, influenced by energy consciousness and family size; some participants did laundry once to three times a week, while larger families reported doing laundry daily. Hospitality practices across all homes were found to be similar; participants indicated that the HVAC systems in guest areas (for both males and females) were activated during gatherings, along with artificial lighting being turned on several hours earlier than usual. Some participants noted that they activated the HVAC system the day before social events to ensure comfort. The next section offers several future studies on the Saudi housing energy demand based on the outcomes of this research.

8.3 Research contributions

This study has made a contribution to knowledge expanding the literature on understanding the households' energy demand in Saudi Arabia, as a new cultural context, by investigating the households' practices and the actual building performance (indoor environment and energy use) in this research, that could help to address the gap in the existing Saudi knowledge. This approach has not been undertaken to date in

Saudi context, according to existing energy studies. The interdisciplinary combination of post occupancy evaluation methods with the practice theory approach used to improve understanding of energy consumption in Saudi domestic buildings. A mixed methods approach was used to explore the social and technical contexts of Saudi homes. The Usage of the practice theory helped to understand and explore the possible influence of households' practices on energy demand.

8.4 Further research

The research has focused on investigating the inhabitants' practices and impact on energy consumption in the domestic domain. This research has suggested further studies that can be undertaken in relation to inhabitants' practices and energy consumption, such as:

- Investigating the energy consumption in domestic buildings through co-design approach. It is possible that homes will not perform as expected, both in terms of their energy and carbon (O'Sullivan et al, 2022). Engaging participants when designing domestic technologies e.g. smart technologies because 'Competences are though not static and with the integration of smart home technology in the domestic sphere, space heating practices change' (Larsen and Gram-Hanssen, 2020.p18). Exploring the effect of their engagements on the energy demand and developing methods for the participatory research that can be used for other future Saudi energy studies or housing developers. Engaging residents may reveal the gap of causes the high residential energy consumption in Saudi Arabia. It is highlighted by the study of (Shirani et al, 2022.p7) 'assumptions by professionals that consumers are passive, indifferent and disengaged may mask issues with the usability of technology'.
- Investigating the barriers to involving the post-occupancy evaluation approach to be conducted in the housing practices.
- Studying the intervention of Photovoltaics solar panels in the Royal Commission housings by the use of software simulation and what could be

the barriers that prevent this from the housing practices perceptive. Interviewing the inhabitants on how are willing to implement this in their houses and professionals' considerations and opinions of involving this practice for achieving energy conservation.

- Studying various external shading techniques to cope with climate change e.g. Roshan design (section 2.3) and its effect on reducing the domestic energy demand, to avoid excessive heat and enhance privacy.

8.5 Research limitations

Without undermining confidence in the findings outlined above, it is important to recognise the limitations of this work. As with all studies, the researcher encountered some challenges and barriers when conducted the research. It is common for qualitative research to have a limited sample size, which means that caution must be taken when drawing conclusions from the results. The use of a case-study design frame (see methodology chapter at section 4.2) to explore in depth a small number of cases, has uncovered rich data on the research topic. Due to the time limit of the research, the researcher had access only to new house typology with scheme A in order to conduct the research, although other types have a same number of bedrooms but with different house sizes and layouts. The key challenge encountered during the study was interviewing the participants as households (involving the whole family except children) but it was only possible to interview one member of the family in most of the interviews. Also, another difficulty faced during the research was gaining access to participants' utility bills so it had to present a number of bills (eight) instead of 12. Although the findings cannot be generalised to the entire population, they are nevertheless indicative and reveal knowledge that has wider significance across the field of the research (Flyvbjerg, 2006). The findings from this research could potentially be considered in relation to any other similar housing developments in the same or similar climatic regions in the kingdom of Saudi Arabia. In addition, the RC is planning to construct domestic buildings in 'Ras Al-Khair' and 'Jazan' industrial cities in the future, for which this study will be useful. Also, it is suggested that further studies to build on these findings would be of value (see suggested future studies 6.3). In terms of the methodology, in the second year when the data should be collected, the COVID-19 appeared and restricted some of the post-occupancy evaluation (POE) methods such as the use of thermal camera to identify any heat loss and gain. The use of this tool required the researcher to undertake some training, but due to the number of availability of this tool by the university and skills that are required, it has been restricted to send this tool to participants during the pandemic. Also, due to the shortage of HOBO sensors (provided by the university), the researcher had to source alternative monitoring sensors e.g. the use of smart sensors, and therefore a pilot study was conducted to calibrate the environmental monitoring sensors (original and new) and test them in use before sending them to the participants (chapter 3). The data of new smart sensor had to be sent monthly by the participants, which may have led to some of the data of some months are not available. Another limitation of the present study relates to the building use study questionnaire (BUS). When this questionnaire was published by the RC developer, it was required to remove the respondents' details from the questionnaire to ensure confidentiality. As a result, this hindered the researcher from contacting participants for gaining further information.

The following section discusses some suggested recommendations resulted from this study for the RC, and general recommendations for policy makers, that may help to enhance the domestic energy demand and reduce the impact of climate change.

8.6 Recommendations

8.6.1 Royal commission (RC)

- Improve the Handover and induction stage not only 'handing the home key' but also to ensure that the home controls are properly demonstrated to the inhabitants. providing mutual conversation between the residents and the developer such as additional training sessions about the use of their home through home visits or can be held in local community centre. This will positively affect e.g. the use of the system ventilation during summer or winter and its consequences such as health issue related to high or low indoor relative humidity level.

- Provide simple and translated home user guide to help the inhabitants understand it in order to use their home systems in a way that it should be to reduce their energy consumption.
- Separate the HVAC units on the first floor may help the inhabitants to lower their energy consumption as they will use the system according to the use of the space.
- Provide external shading on the heat gain orientations such as west, east, and south as this will help avoid the issue of overheating.
- Develop a clear and user-friendly system thermostat with not only showing the air temperature but also the indoor relative humidity level, which will increase the inhabitants' awareness and prevent negative practices such as the use of humidifiers in indoor environments that already have high levels of relative humidity.
- Utilise renewable energy for supplying electricity for homes, taking advantage of the sun availability and use e.g. solar PV systems. Saudi Arabia is located in a part of the world where the average availability of solar energy is 2200kWh/m^2 (Alawaji, 2001: Aldossary 2013).

8.6.2 Policy makers

This section describes beneficial recommendations from the outcomes of this study for different beneficiaries in the kingdom such as a National Energy Efficiency Program (NEEP). This organization was founded to discuss energy demand issues by developing various energy efficiency and conservation measures that target e.g. residential buildings. In addition, the recommendation for the housing developers in the kingdom public or/and private entities. Finally, the recommendation can be beneficial for the research organizations such as King Abdullah University of Science and

Technology (KAUST) and King Abdullah Petroleum Studies and Research Centre (KAPSARC). The recommendation as following:

- Establish a sustainable clear definition for the total energy consumption in kWh/m^2 as low or very low for housing based on the local climate conditions and culture, and incentive housing developers to meet this target.
- Incentive housing developers to involve post-occupancy evaluation (POE) as one of the stages of the housing life cycle, as it will feed the next new or/ retrofit developments.
- Incentive housing developers to engage the residents in the design stage in order to meet their needs, educate and enhance their knowledge on energy efficiency, and how this can be beneficial for reducing their future energy demand and reducing the impact of climate change.
- Incentive research organizations undertaking POE studies that may contribute in increasing public awareness related to energy in order to enhance their knowledge of energy use and efficiency.

8.7 Insights from inhabitants' practices for domestic Policy

This section was provided to present some lessons learnt from social practices in this thesis to be adopted in domestic policy. Focusing on the four elements of practice building on Gram Hanssen's elements (2010) (technology, engagement, institutionalised knowledge and rules, know-how and embodied habits) can be targeted as they could enable or constrain performing practices. The following sections are addressing each elements of practice theory providing some examples on the area that can be focus on.

8.7.1 Technology element

This thesis found that the new provision of technologies (e.g. building envelope and HVAC system) in residential buildings hinders or facilitates performing practices relevant to energy demand. The improvements made in the RC buildings' envelopes have shown positive impact on the energy consumption in the studied homes. Also, the thesis found that the provision of new technology of an HVAC system in residential buildings as one of the system efficient options, maintains comfortable thermal indoor environments for a long period of time (even after the system turns off), and to unify the indoor temperature in each space of the homes due to the distribution of the system vents, unlike the AC window units. Privacy is a main factor that is considered when designing domestic buildings in Saudi (Othman at el, 2015; AlKhateeb and Peterson, 2021). The studied homes showed various considerations for privacy, such as visual privacy achieved through the use of reflective glass with heat film on windows and social privacy ensured by providing separate entrances for males and females. However, the social practices observed in this thesis indicate that the layout of the home, particularly the ground floor design—specifically the open-plan kitchen adjoining the living room—does not adequately support olfactory privacy, which is deemed unsuitable for Saudi residential buildings. Consequently, some participants limit the use of the living room for social gatherings. As a result, certain participants have opted to utilize alternative spaces within the home or even construct additional areas, leading to an increased demand for energy. Furthermore, this thesis highlights that some participants have adopted everyday practices aimed at managing daylight in frequently used spaces. However, this practice may inadvertently heighten reliance on artificial lighting during the daytime, potentially resulting in increased energy consumption.

Designing could encourage 'what is acceptable, desirable and comfortable, while counteracting what is strenuous and forbidden' (Jelsma, 2003, p. 107). For example, isolating the kitchen from the living room is the key focus for developers as it can reduce the demand for cooling, by mitigating the variations in the indoor environment and enhance the olfactory privacy. In terms of the daylight, implementing e.g. shading devices (e.g. side fins or overhang) on windows especially on heat gains orientations. Learning lessons from the vernacular architecture e.g. applying 'Roshan' technique (figure 2.5: chapter 2). These, support the use of daylight and could help to reduce the energy demand, enhance privacy and inhabitants' health.

Technologies could be designed to explicitly link to practices. The number of HVAC units implemented in the RC homes, found not sufficient especially in the first floor e.g. one HVAC unit control all first floor spaces. Due to this, the thesis shows that one of the seasonal practices of heating, historically brought from previous conventional house e.g. the use of additional electric heaters. It is found that performing this practice seasonally not due to the misusing of the system heating but rather to reduce energy by heating accordingly spaces that occupied.

The thesis results show that the implementation of the HVAC system control in term of automation (e.g. turning on/off) could help mitigating the system operation time and impact on the energy demand. Opposite to AC window unit controls despite its ease of use but required more interactions than the HVAC (statistics showing that residents not turning off AC when a space is not used: chapter 2). This indicates that the continuous implementation of the HVAC system or other efficient systems (e.g. smart spilt AC units) in residential buildings among the kingdom, may help to impact on minimizing the operation time. However, the results of this thesis pointed out that the HAVC system control interfaces are not straightforward to use and some participants had to use the system manually the same as the old technology (AC window unit). Also, it was found through the participants' practices that the system ventilation has not been used as intended. This emphasises for engineers and developers to the urgent need for simplifications in designing domestic control interfaces. Designing technologies in terms of how they are used and experienced could help to minimise the inhabitants' confusion. The thesis show how the HVAC system controls appeared to be insufficiently labelled from the user perspective. Scripting technologies (Jelsma, 2003) in the context of social practices and relate it to energy saving, especially when the new technology is unfamiliar. Scripts 'are the structural features of artefacts encouraging certain user actions while counteracting others' (Jelsma, 2003. p106). For example, the HVAC thermostat settings could be labelled as numbers and each of the numbers has a script, to suit inhabitants' actual day activities according to the season- (e.g. '1' as 'home/ daytime'; '2' as 'night-time'; '3' as 'not at home'; '4' as 'hosting guests' and '5' as 'boost for cooking/showering'). Adding to that, the scripting can also involve e.g. the recommended indoor temperatures (23°C - 26°C) during the mode '1' and '2', and scripting that lowering the temperature than 23°C will increase the (inhabitant) energy demand. Setting '3' can be elaborated to highlight the advantages of turning off the HVAC system when the home is unoccupied from an energy-saving perspective. Energy savings can be realized even with a slight increase in thermostat temperature settings, such as adjusting by 1°C or 2°C (Alshahrani, 2018). This principle can also be applied to the other modes ('4' and '5'), following a similar approach to technology management and efficiency optimization. The thesis shows that some of the participants retrofitted the original system thermostat with smart seeking for flexibility and comfort. Therefore, it might be flexible and comfortable to enable the thermostat to be controlled remotely with consideration of scripted modes.

8.7.2 Institutional knowledge and rules

The thesis shows that the almost non-existent relationship (e.g. formal verbal knowledge) between those receiving and those providing information influences the participants' practices related to their homes and its systems. For example, the main cooling practices in the studied homes was the use of air conditioning but this perform differently. Some participants everyday use their AC system manually, some use it by scheduling and others retrofitted their system and use it remotely. It is appeared that the institution was content with written information as a communication method. Handing in a high amount of driven written information hindered the use of the home user guide. This implies that the detailed information is not an effective source of knowledge for every resident due to the language that used and the level of technical knowledge.

It is found that the language used of the written information was in English not in Arabic. In addition, the institutional jargon being used to the target audience (households), it might be understandable from the institutions but seemed to be ambiguous and easily to be misunderstood by those who it is actually for. The participants' levels of education varied significantly, influencing how they interacted with their homes and their systems. For instance, participants with engineering backgrounds utilized their knowledge to control their systems remotely through devices like the Ecobee or by employing the system's scheduling features. In contrast, non-engineers exhibited a more manual approach to operating their systems, which was shaped by their educational backgrounds and understanding of the newly introduced technology.

Although the home user guide presents photos to help the residents, the latter was not encouraging the inhabitants to engage with. However, it is found that the quality of the pictures provided there may have contributed to hindering the use of the home user guide. Furthermore, large amount of information including civil/architectural, mechanical, and electrical details (figure 6-8: chapter 6) contributed to disengagement. Another finding that the home user guide was not paying attention to how inhabitants use their home. For instance, instructions on how to ventilate their home whether by using the ventilation system or using the windows (e.g. when, how long and the consequences for doing so). The thesis shows that participants everyday practices of ventilation was through the use of windows when performing homemaking practices (e.g. cooking and cleaning) even in summer season, this practice has led to affect the indoor environment causing variations and as a result increase the demand for cooling.

Institutions could enhance the home user guide by tailoring it to the everyday practices of residents. For instance, creating two distinct types of guides could help reduce the amount of information presented and accommodate varying levels of technical knowledge, including translated instructions for non-English audience.

The first guide could focus on cooling, heating, and ventilation systems, detailing how to operate these systems and optimize the use of additional resources, such as windows and doors. The second guide could contain information related to civil, architectural, mechanical, and electrical details, allowing residents to refer to it when needing to contact a service provider or company. Furthermore, establishing verbal communication between the institution and residents through home visits was emphasized as a necessary approach by all participants. This personal interaction could facilitate better understanding and engagement with the home systems, ultimately leading to improved energy efficiency and user satisfaction.

In addition, doses of information about the home, its technologies and indoor environment through external training sessions (e.g. held in the local community) this similarly is provided for passive house residents in the UK (Kermeci, 2018). Also, institutional short videos on guiding the inhabitants and make these videos available on the institution website, this could help delivering understandable and effective formal knowledge on the home and its system (Menon and Foster, 2017).

8.7.3 Engagement element

The thesis shows that the financial concern of the electricity bills, has driven participants to perform certain practices. For instance, the HVAC unit for the dining and guest rooms was turned off, even if the dining room is used by the family, it can be cooled by opening the door of the living room to let the cool air pass into the dining room. Furthermore, some seasonal practices performed in the studied homes were historical e.g. swimming, taking a cold shower, wearing less layers and having cold food. In winter, practices such as wearing extra layers, having warm food and having BBQ as source for heating were found. Also, the use of daylight increased in winter to warm the indoor spaces and reduce the energy demand for heating. Educating the family members to switch unused equipment was referred by several interviewees.

Although the present thesis does not specifically address the socio-economic status of the participants, it highlights a potential issue for low-income households across the kingdom, who may be unable to afford energy-efficient appliances. Government economic incentives could play a crucial role in supporting these households, helping them transition to lower energy consumption. A study of Ouda et al (2017) highlight high percentages of inefficient energy of households' appliances that are used such as refrigerator 53%, oven 72.7%, washing machine 68.2%, dryer 76.3% and dishwasher 81.8%. Saudi homes still relaying on the use of AC window units and are still available on market due to its effective cost (Krarti and Howarth, 2020). In general, by doing this (government economic incentives), may contribute to increase the inhabitants' awareness of the importance of the home energy efficient appliances and its use for reducing energy consumption.

Social expectations of hosting and turning off unneeded electrical appliances can be targeted through social marketing campaigns (at work, schools, universities, and mosques) by focusing on the meanings behind of what inhabitants do. For instance, associating these social expectations with actions that consume less energy e.g. lower indoor temperatures (below the ASHREA standard) are not expected to be considered as welcoming for guests. The engagement element shows how e.g. turning off unneeded electrical appliances for some participants, the energy saving has not influenced on performing it. Some participants reported that turning off the unused electrical appliances in unoccupied spaces (e.g. lights, TVs and computers etc.) had a relatively minimal impact on the energy as the HVAC system, in which resulting in negligence. Although this represents few participants in the present study, but it could be performed by a percentage of households across the kingdom. However, considering this through the social marketing campaigns by focusing on the 'meanings' behind turning off appliances that are not needed can help in reducing inhabitants' energy.

Another important aspect to consider is the provision of smart meters, existed in some UK homes, for residents. Smart meters could assist inhabitants in identifying the energy consumption associated with their daily practices, while also increasing their overall energy awareness. The energy supplier could optimise the knowledge on energy consumption by informing the household/consumer with detailed energy information about e.g. the consumption of this month is low or is high and encourage inhabitants to reduce it. Also, how much energy goes where in the home by categorising the consumption. Provide energy advice to households in order to enhance their knowledge of energy use and efficiency.

A study of Aldubyan and Krarti (2022) showing that 11.2% of the annual household's energy consumption goes for lighting. It is found that the types of lighting were the incandescent and the fluorescent lamps, that are the most commonly used lighting fixtures in Saudi residential buildings (ibid). This thesis illustrates that majority of Interviewees reported that they have replaced their lighting system (e.g. fluorescent lights) and instead used lighting emitting diodes (LED) in order to reduce energy. This positive practice that the participants have accomplished indicates that the developer/s should target providing energy saving fixtures to help households reducing their energy.

8.7.4 Know-how and embodied habits

The thesis reveals that participants' everyday routines vary significantly; some households maintain fixed routines, while others do not. For example, having a single HVAC unit that controls the entire first floor is deemed unsuitable for participants with flexible routines. As a result, participants reported implementing new split air conditioning units to manually adjust their usage according to their routines. Also, some of participants use additional electrical heaters that brought from their previous experience.

The intention of designing the living room is that to be used for daily family seating area and receiving guests. However, it is found that the layout design of the living room (e.g. being open plan area to the kitchen) restricted the use of it. Consequently, some separated the living room from the kitchen and provided it with AC split unit and some use some of the upper bedrooms as daily family seating area. Moreover, others built additional rooms for daily family seating and for hosting guests.

The way that the institutional knowledge is presented (e.g. large arrays of technical information) has not encouraged the households especially with unfixed routines e.g. due to their working nature (shifts) have limited time to read and understand this in order to know how to use their homes' system. This show how the know-how and embodied element connected to the technology, institutional knowledge and rules and how a deficit of one element can lead to an effect on the other. It indicates for the developers that how the know-how and embodied element is need to be considered when designing technology and providing the institutional knowledge. Designing or implementing efficient home systems that support households' routines e.g. separating system units may help to reduce the energy demand. The thesis shows that how participants learned experiences from informal knowledge in order to use their homes systems. The learning by doings can be considered e.g. the home touring can involve practical interactions with the technologies rather than talking about them.

Overall, this study has contributed to international practice theory research on domestic energy use from a location that is very different to the geographical focus of most such research. The discussion of insights from social practices was provided to illustrate some interventions that could be considered and embodied in Saudi domestic policy. This can be achieved through the use of post occupancy evaluation approach after the inhabitation stage to identify issues related to energy demand in Saudi residential buildings. As this study shows its contributions to address the gap in the existing knowledge of understanding the households' energy demand in Saudi Arabia by investigating the inhabitants' practices and the actual building performance (indoor environment and energy use).

Appendices

Appendix 1- Research Project Information and Methods Guide

Inhabitants’ Practices and the Impact on Energy Demand in Saudi’s Low Carbon Dwellings

‘Research Project Information and Methods Guide'

Dear Jalmudah Resident,

If you would like to take part in this study, please sign the consent form that will be sent via email and return it to the researcher (contact details provided at the end of this guide) The following information is given to you for future reference guidance about why the research is being done and what it will involve. Please take time to read the following information carefully. Please ask me if there is anything that is not clear or if you would like more information the contact details are provided at the end.

Who I am?

I am a PhD student at the University of Sheffield. I am doing research on housing performance in Jubail industrial city (JIC). I have chosen Al-Jalmudah district to be my case study.

What is the purpose of this project?

To evaluate and monitor the physical performance of your home. In addition, I will investigate how your use of your home might affect the energy use as well as to find out what you think of your home. By monitoring the temperature and relative humidity, and checking meter readings for electricity in your home, I will be able to assess if the real performance of the occupied home meets the design targets. This measurement data will be compared with your thoughts about using your home, using a home walkthrough, two questionnaires and an interview. This information will help the Royal Commission developers, constructors and designers to understand how to build future environmentally friendly dwellings that are comfortable for the inhabitants. The key findings will be included in my PhD thesis and later will be published.

What are the benefits to me taking part in this project?

It will help you to understand how your home performs and how to use it to optimise levels of comfort whilst reducing resource use and costs. The results of the monitoring will be analysed and explained via a Webinar discussion for participants, enabling the group to learn together also about their home performance and how to improve it. This will be beneficial for the JIC community e.g. when you discuss technical problems and share your experience on solving a particular issues with others.

How long will the monitoring last?

I will monitor each home for 9 months, starting in January 2021 in order to assess both winter and summer time conditions. The monitoring tools will be sent to you in December 2020 [you need to follow the Covid-19 protocol I sent to you via email].

What equipment will be installed?

In order to accurately measure the performance of your home using simple easy to use home monitoring equipment, I need your collaboration with checking that it is working properly. The equipment will be installed on a temporary basis for 9 months, and will be removed on completion of the project leaving no trace behind.

Where will the equipment be installed?

The monitoring sensors for measuring temperature and humidity will be placed in 4 rooms in your home to capture different orientations [living room, guest room, main bedroom and bedroom in the second floor (See figure 1). The exact location of the monitoring equipment will be discussed with you directly before installing it. Below are photographs of the equipment that will be used.

Temperature and humidity sensors

Small smart sensor will be used to measure the temperature and humidity. These devices will be placed on a convenient shelf or on the table in the rooms. Any energy costs associated with this sensor will be reimbursed. The researcher has developed a visual guidance and short simple video to show you step by step how you are you going to download the data in only 15 minutes. Their most convenient location will be discussed with the residents of the selected homes.

Figure 1 Smart Sensor

Installation of equipment

The equipment is small portable and very quick to install and remove. Please note that while the monitoring is in progress you should not touch any of the monitoring equipment. When you notice any damage to the equipment or its displacement please let me know as soon as possible, so I can repair or replace any of the equipment for you. I have arranged short video on where you need to place the sensors in your home.

Ownership of equipment

The installed equipment is the property of Sheffield School of Architecture and the researcher that must be returned at the end of the study.

Other tasks

As well as making measurements, I would like to do home walkthrough e.g. how you use the specific environmental controls in your home, identifying any issues arising from this and how you use the space. Any picture is taken will be completely anonymised to de-identify you and your home. I may seek your consent to publish small parts of it, relating only to the environmental, which will be highly anonymised. It will help me to checks various heating, cooling and ventilation systems installed and addressed any issues you may have in your home. I will also ask you some questions about how you use your home and what it is like living there, from a comfort point of view.

The questionnaires will be carried out, and will take approximately 30 minutes to be completed. Towards the end of the project, you will also be asked to take part in one interview, which will take approximately 45 minutes to an hour to complete. The questions will be open ended and the interview will be audio recorded.

Approximately once every month I will ask you to download and send the sensor data. Straightforward guidance instructions on what the software is needed and how to download the data. Also, two reminders will be sent to you for downloading the data. The data downloading procedure takes only 15 minutes for all sensors.

What are the possible disadvantages and risks of taking part?

The only disadvantage of taking part in this study is the time taken for completing the two short questionnaires, interview, home walkthrough and downloading the data. There are no risks to you or your home, as all the monitoring equipment is fully removable. Some of the monitoring equipment used in this study is fairly expensive. You will not be required to pay for any damages to this equipment, accidental or otherwise, but I would appreciate your help to keep this equipment safe from harm.

Will my taking part in this project be kept confidential?

The consent form will be requested from you before collecting any data relating to your home. It is a signing sheet for all information that is collected about your home during this project e.g. if you want your home pictures to be share with others or not then your data will be kept strictly confidential. Additionally your name will not be included in any publications or anything identifying you will be removed. It will be shown what personal information concerning your occupancy, demographical data e.g. age, will be used in the study prior to its publication.

Contact for further information

If you have any further questions, please contact me by phone or email, given below.

Thanks for your collaboration,

Rawdah Alzahrani student at Sheffield School of Architecture, The University of Sheffield,

Mobile : +44xxxxxxxxxx / +966xxxxxxxxxx

E mail: ralzahrani1@sheffield.ac.uk

Appendix 2- Consent Form

Title: Inhabitants' Practices and the Impact on Energy Demand in Saudi' Low Carbon Dwellings

Consent Form

Contact for further information

Rawdah Alzahrani student at Sheffield School of Architecture, The University of Sheffield,

Mobile : +44xxxxxxxxxx / +966xxxxxxxxxx

E mail: ralzahrani1@sheffield.ac.uk

Please tick the appropriate boxes	Yes	No
Taking Part in the Project		
I have read and understood the project information sheet dated 15/12/2021 or the project has been fully explained to me. (If you will answer No to this question please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)	☐	☐
I have been given the opportunity to ask questions about the project.	☐	☐
I agree to take part in the project. I understand that taking part in the project will include completing two questionnaires, being interviewed, being recorded (audio), home walkthrough and environmental monitoring.	☐	☐
I understand that by choosing to participate as a volunteer in this research, this does not create a legally binding agreement nor is it intended to create an employment relationship with the University of Sheffield.	☐	☐

I understand that my taking part is voluntary and that I can withdraw from the study at any time before installing and starting to monitor your home indoor environment; I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw.	☐	☐
How my information will be used during and after the project		
I understand my personal details such as name, phone number, address and email address or anything identifying you will not be revealed to people outside the project.	☐	☐
I understand and agree that my words may be quoted in publications, reports, web pages, and other research outputs.	☐	☐
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I understand and agree that other authorised researchers may use my anonymised data in publications, reports, web pages, and other research outputs, only if they agree to preserve the confidentiality of the information as requested in this form.	☐	☐
I give permission for the anonymised data that I provide to be deposited in [ORDA] so it can be used for future research and learning	☐	☐
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.	☐	☐

Name of Researcher [printed] Signature Date

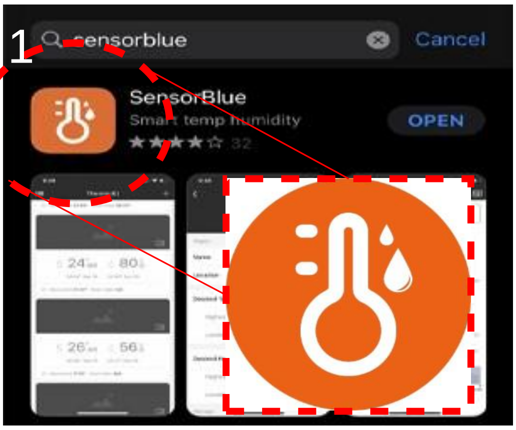
Appendix 3- Sensors Monitoring Guidance

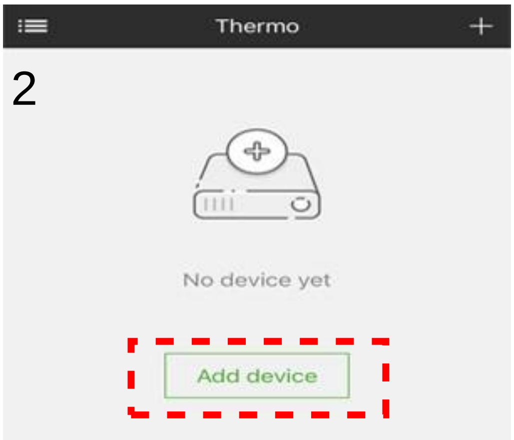
The following documents, written in Arabic, were sent to the participants along with the smart sensor kits.

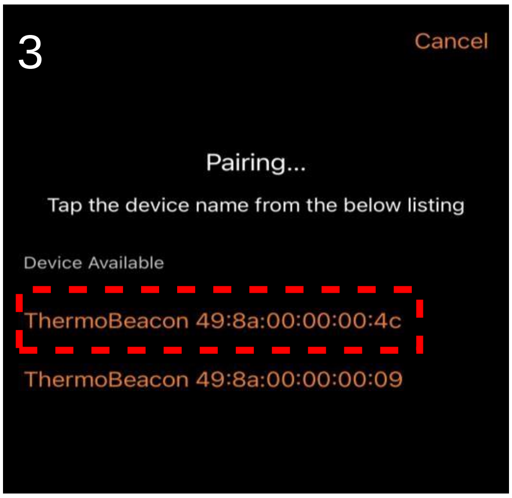
ممارسات الساكن في المنزل وتأثيرها على أستهلاك الطاقة

دليل إستخدام جهاز قياس درجة الحرارة والرطوبة

1.طريقة تحميل التطبيق:



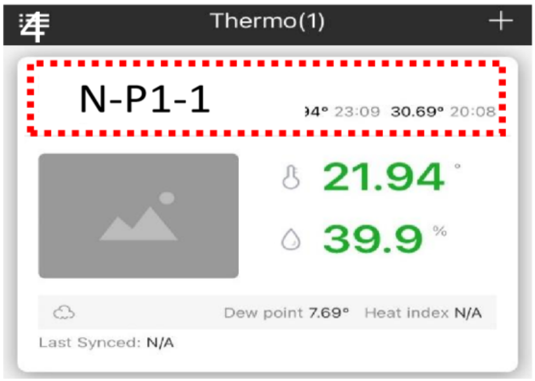




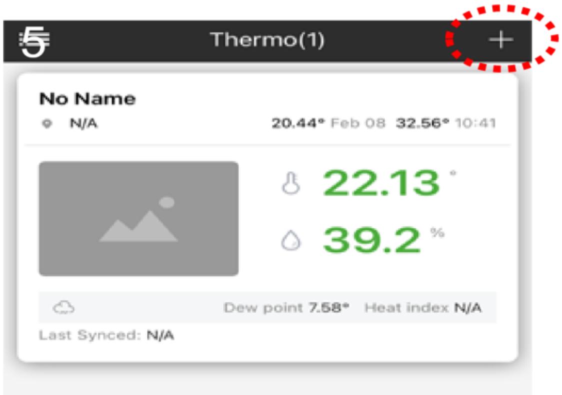
1. من خلال متجرتحميل التطبيقات " Apple store" أو "Google play" المتاح في هاتفك قم بكتابة إسم البرنامج "Sensor blue"
2. قم بتحميل التطبيق الموضح في الصورة)1(
3. بعد التحميل، إفتح التطبيق وقم بالضغط على أيقونة "Add device" كما هو موضح في الصورة)2(
4. لإضافة جهاز إستشعاردرجة الحرارة والرطوبة قم بإختيار الأيقونة " Pairing by device name"
5. بعد الضغط على الأيقونة السابقة إختر رمزالجهاز الذي يظهر أمامك كماهو موضح في الصورة)3(

)ملاحظة: رمز الجهاز قد يختلف عن الذي يظهر أمامك(

6. بعد إضافة جهاز الإستشعار في التطبيق قم بإختيار الأيقونة "Name“ وأكتب الأسماء الاتيه المرفقه على كل جهاز إستشعاركما هو موضح في الصورة (4)



7. لإضافة جهاز الإستشعار الأخر قم بالنقر على "+" كماهو موضح في الصورة (4)، وثم إتبع الخطوات رقم 5 و6



2.أين يتم وضع أجهزة الإستشعار؟

أجهزة الإستشعار توضع على رف أو طاولة بحيث لا يستطيع الأطفال الوصول إليها ويكون ارتفاع الجهاز عن مستوى الأرض (90 سم -1.6 م)

يتم توزيع أجهزة الأستشعار في عدة غرف من المنزل كما هو محدد في خرائط التصميم المرفقة والغرض من ذلك هو التقاط القراءات الصحيحة للحرارة والرطوبة داخل منزلك من جميع الجهات (الشرق، الشمال، الغرب والجنوب).

(**ملاحظة**: الرجاء عدم وضع أجهزة الإستشعار أمام النافذة أي تكون معرضة لأشعة الشمس، ولا بجانب جهاز التدفئة أو على الأرض حتى لا تتلف ولا أمام جهاز التكييف لكي تأخذ القرأة الصحيحة للمكان)

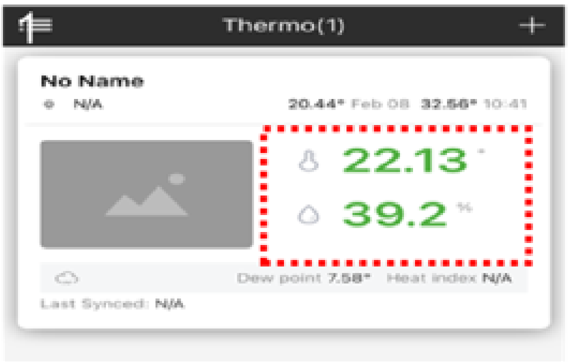
3.اماكن وضع اجهزة القياس في المنزل

الدور الأرضي

الدور الأول

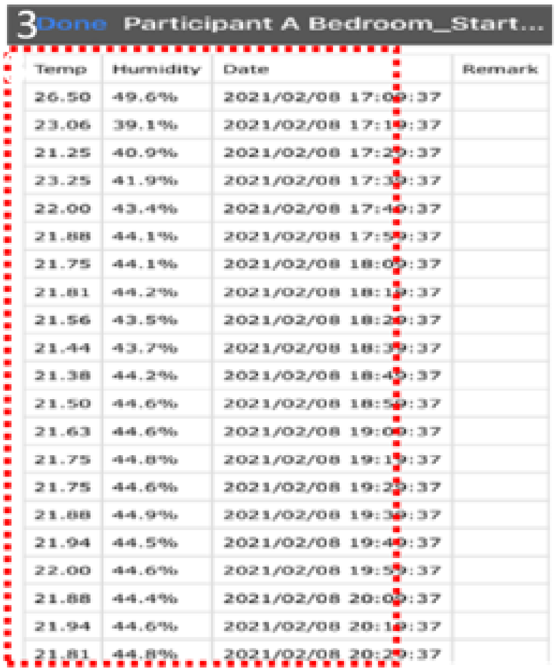
الملحق العلوي

4.طريقة إرسال المعلومات إلى الباحث:



1. قم بالنقر على درجة الحرارة والرطوبة وسيظهرلك رسم بياني يوضح درجات الحرارة والرطوبة كماهو موضح في الصورة (1)

2. أنقر على هذه الأيقونة المشار إليها في الصورة (2)
3. ستظهر لك قائمة بدرجات الحرارة والرطوبة قم بالنقرعلى الأيقونة الموجودة في الأعلى ومن ثم قم بالنقر على الأيقونة “Export-CSV"
4. بعد ذلك قم بإدخال إيميل الباحث الموضح ralzahrani1@sheffield.ac.uk

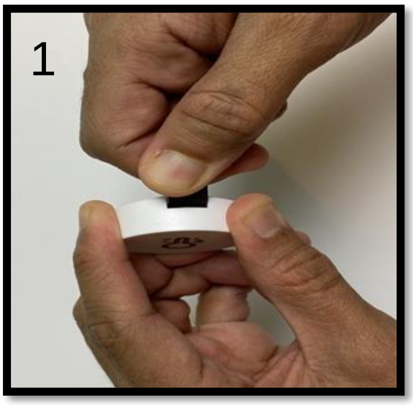


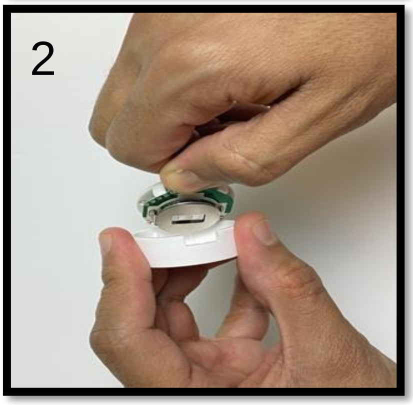
Temp	Humidity	Date	Remark
26.50	49.6%	2021/02/08 17:09:37	
23.06	39.1%	2021/02/08 17:19:37	
21.25	40.9%	2021/02/08 17:29:37	
23.25	41.9%	2021/02/08 17:39:37	
22.00	43.4%	2021/02/08 17:49:37	
21.88	44.1%	2021/02/08 17:59:37	
21.75	44.1%	2021/02/08 18:09:37	
21.81	44.2%	2021/02/08 18:19:37	
21.56	43.5%	2021/02/08 18:29:37	
21.44	43.7%	2021/02/08 18:39:37	
21.38	44.2%	2021/02/08 18:49:37	
21.50	44.6%	2021/02/08 18:59:37	
21.63	44.6%	2021/02/08 19:09:37	
21.75	44.8%	2021/02/08 19:19:37	
21.75	44.6%	2021/02/08 19:29:37	
21.88	44.9%	2021/02/08 19:39:37	
21.94	44.5%	2021/02/08 19:49:37	
22.00	44.6%	2021/02/08 19:59:37	
21.88	44.4%	2021/02/08 20:09:37	
21.94	44.6%	2021/02/08 20:19:37	
21.81	44.8%	2021/02/08 20:29:37	

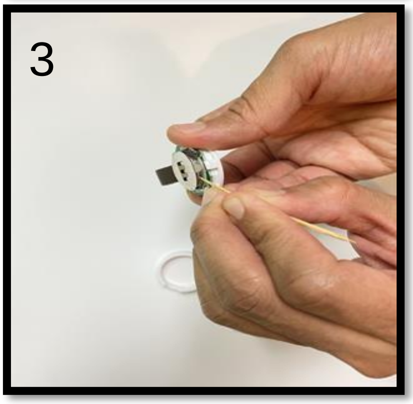
5. الطريقة الأخرى لإرسال المعلومات للباحث إتبع الخطوات من 1إلى 3 ثم أنقر على " Open-CSV" ثم أرسل البيانات من خلال الواتس اب عن طريق الرقم المتاح
6. ستصل إلى الباحث هذه المعلومات الرقمية فقط كما هو موضح في الضورة (3)

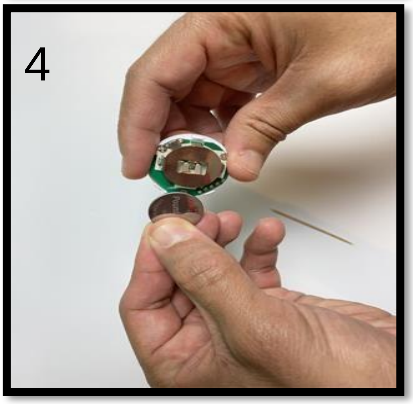
5.طريقة تغيير بطارية أجهزة الإستشعار:

1. قم بسحب قطعة الجلد البنية
2. إفتح الجهاز
3. قم بدفع البطارية ذات الشكل المستدير بواسطة إستخدام إي قطعة **غير** معدنية مثال: عود الأسنان الخشبي
4. أخرج البطارية المستعملة وقم بإدخال البطارية الجديدة مكانها (عند إدخال البطارية الجديدة ، سيضيئ الجهاز باللون الأحمر لعدة ثوان)
5. أغلق الجهاز بإحكام
6. أفتح التطبيق "Sensor blue" وقم بالتأكد أن الجهاز متصل (أي أن درجة الحرارة والرطوبة تظهر باللون الأخضر)









شكرا لتعاونكم

Appendix 4- Usability Questionnaire

Usability Tool — Domestic Controls

This survey is being conducted to help with future planning and design of domestic controls. The information collected will be treated as completely confidential. Survey reports will only use summaries of information and not reveal the identities of individuals.

Please fill in as many questions as you can. Write any further comments in the spaces provided or on a separate sheet. Thank you for your help.

Queries: If you have any queries please contact **Rawdah Alzahrani**

Email: **ralzahrani1@sheffield.ac.uk**

Who should fill this in? Anyone over the age of 18 who lives in the residence. This will normally be the person in the household mainly involved with the controls.

Please tick boxes where appropriate and fill in additional comments and information in the fields provided

Background

What is your age?	☐ Under 30	☐ 30 – 50	☐ 51 – 70	☐ Over 70					
... and your sex?	☐ Female	☐ Male							
Participant code? please write the written code on the monitoring sensor that you have									
Are you normally at home...	☐ Most of the time	☐ Evenings	☐ Weekends only	☐ Other:					
Are you in a...	☐ Detached House	☐ Semi-detached House	☐ Flat	☐ Other:					
How would you rate your skills in use of technical devices?	Very low	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	Very high
Do you have home user's guide?	☐ Yes	☐ No	☐ I don't know						
If yes, how would you rate its usability for... operating your home?	Very poor	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	Very good
securing maintenance?	Very poor	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	Very good
Did you have home handover demonstration tour?	☐ Yes	☐ No	☐ I don't know						
If yes, how would you rate its effectiveness in preparing you for... operating your home?	Very low	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	Very high
securing maintenance?	Very low	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	Very high
Do you have any special circumstances that make your ability to operate domestic controls different from the average person? Please describe any particular constraint or advantage.									

Central heating & hot water | MVHR controls | Renewable energy controls | Electricity & lighting | Emergency & Maintenance

Hot water & Additional devices

Central heating & hot water

- Overall, how would you rate controls for:

	Very poor						Very good
Hot water	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7

Tick to indicate your rating.
For additional comments please use the comments section at the bottom of page

- Are you aware of the maintenance procedure? ☐ Yes ☐ I don't know ☐ No

	Boiler control			Shower & bath controls		
	Yes	I don't know	No	Yes	I don't know	No
Is it clear what this control does?	☐	☐	☐	☐	☐	☐
Does its location help use it when needed?	☐	☐	☐	☐	☐	☐
Is it easy to see how how to use this control?	☐	☐	☐	☐	☐	☐
Is it easy to operate this control?	☐	☐	☐	☐	☐	☐
Is it sufficiently labelled?	☐	☐	☐	☐	☐	☐
Does it show response to your actions?	☐	☐	☐	☐	☐	☐
Does it allow making sufficient adjustments?	☐	☐	☐	☐	☐	☐
Is it obvious if you should interact with it?	☐	☐	☐	☐	☐	☐

- Comments on hot water:

Have you made any changes in your home?

Tick where appropriate:

- ☐ Additional cooling devices
- ☐ Additional heating devices
- ☐ Additional ventilation devices
- ☐ Additional humidifier devices
- ☐ Additional air purifier devices

Why you have made changes?

HVAC control

HVAC- Heating, Ventilation and air Conditioning

Tick to indicate your rating.
For additional comments please use the comments section at the bottom of page

MVHR controls

- Overall, how would you rate controls for HVAC?

Very poor ☐ ☐ ☐ ☐ ☐ ☐ ☐ Very good

- Are you aware of the maintenance procedure?

☐ Yes ☐ I don't know ☐ No

- How would you rate ease of maintenance for:

	Very poor						Very good
HVAC filters	1	2	3	4	5	6	7
Cooker hood filter	1	2	3	4	5	6	7

HVAC **unit control panel**

	Yes	I don't know	No
Is it clear what this control does?	☐	☐	☐
Does its location help use it when needed?	☐	☐	☐
Is it easy to see how how to use this control?	☐	☐	☐
Is it easy to operate this control?	☐	☐	☐
Is it sufficiently labelled?	☐	☐	☐
Does it show response to your actions?	☐	☐	☐
Does it allow making sufficient adjustments?	☐	☐	☐
Is it obvious if you should interact with it?	☐	☐	☐

- Comments on HVAC :

Renewable energy controls

- Which systems is your home equipped with?
  Tick where appropriate:

Solar thermal (houses)	Photovoltaic	None of the listed
☐	☐	☐

- Overall, how would you rate controls for renewable energy

	Very poor						Very good
Solar thermal (houses)	1	2	3	4	5	6	7
Photovoltaic	1	2	3	4	5	6	7

Tick to indicate your rating.
For additional comments please use the comments section at the bottom of page

- Are you aware of its maintenance procedure?

	Yes	I don't know	No
Solar thermal (houses)	☐	☐	☐
Photovoltaic	☐	☐	☐

	Solar controls			Solar switch			PV Meter			PV switch			PV converter		
	Yes	I don't know	No	Yes	I don't know	No	Yes	I don't know	No	Yes	I don't know	No	Yes	I don't know	No
Is it clear what this control does?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Does its location help use it when needed?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Is it easy to see how how to use this control?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Is it easy to operate this control?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Is it sufficiently labelled?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Does it show response to your actions?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Does it allow making sufficient adjustments?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Is it obvious if you should interact with it?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

- Comments on Renewable energy controls:

Electricity & Lighting

- Overall, how would you rate controls for electricity and lighting?

Very poor 1 2 3 4 5 6 7 Very good

Tick to indicate your rating.
For additional comments please use the comments section at the bottom of page

- Which of the following is your home equipped with?

Tick where appropriate and fill coresponding details below

- Are you aware of its maintenance procedure?

	Consumer unit	Individual light switches	Multiple light switches	TV point (aerial)	TV amplifier	Telephone point	Sockets
Which of the following is your home equipped with?	☐	☐	☐	☐	☐	☐	☐
Are you aware of its maintenance procedure?	☐ No ☐ I don't know ☐ Yes	☐ No ☐ I don't know ☐ Yes	☐ No ☐ I don't know ☐ Yes	☐ No ☐ I don't know ☐ Yes	☐ No ☐ I don't know ☐ Yes	☐ No ☐ I don't know ☐ Yes	☐ No ☐ I don't know ☐ Yes
	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No
Is it clear what this control does?	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Does its location help use it when needed?	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Is it easy to see how how to use this control?	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Is it easy to operate this control?	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Is it sufficiently labelled?	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Does it show response to your actions?	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Does it allow making sufficient adjustments?	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
Is it obvious if you should interact with it?	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐

- Comments on Electricity & Lighting:

Emergency & Maintenance

- Overall, how would you rate controls for emergency and maintenance?

Very poor 1 2 3 4 5 6 7 Very good

Tick to indicate your rating.
For additional comments please use the comments section at the bottom of page

- Which of the following is your home equipped with?

Tick where appropriate and fill coresponding details below

- Are you aware of its maintenance procedure?

	Fire alarm control	Burglar alarm control	Smoke alarm control	Water emergency stop cock	Electricity cut off point	Gate valves / water cut off points	Doors - Handles & Locks	Windows - Handles & Locks
Which of the following is your home equipped with?	☐	☐	☐	☐	☐	☐	☐	☐
Are you aware of its maintenance procedure?	No / I don't know / Yes	No / I don't know / Yes	No / I don't know / Yes	No / I don't know / Yes	No / I don't know / Yes	No / I don't know / Yes	No / I don't know / Yes	No / I don't know / Yes
	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No	Yes / I don't know / No
Is it clear what this control does?								
Does its location help use it when needed?								
Is it easy to see how how to use this control?								
Is it easy to operate this control?								
Is it sufficiently labelled?								
Does it show response to your actions?								
Does it allow making sufficient adjustments?								
Is it obvious if you should interact with it?								

- Comments on Emergency & Maintenance:

Emergency & Mainten-ance

Appendix 5- Building Use Study (BUS) Questionnaire

Housing Evaluation

This survey is being conducted as part of research into the design and management of residences. The information collected will be treated as completely confidential by the survey team. Survey reports will use summaries of information and never reveal the identities of individuals.

Please fill in as many questions as you can. For questions that are not relevant to you, please leave blank or choose or 'No response'. Type any further comments in the spaces provided.

If you wish to say more or have any queries please contact Rawdah AA Alzahrani .

هذا الإستبيان جزء من البحث العلمي وتجميع هذه المعلومات من هذا الإستبيان ستكون سرية للغاية. ويستخدم هذا الإستبيان ملخص للمعلومات التي تم تعبئتها ولن تكشف أبدا عن هويات الأفراد. الرجاء تعبئة أكبر عدد ممكن من الأسئلة. وأما للأسئلة التي لاتتعلق بك الرجاء تركها فارغة أو إختيار (لايوجد رد). أكتب أي تعليقات أخرى في المساحات المتوفرة. إذا كنت ترغب في قول المزيد أو لديك أي إستفسارات يرجى التواصل بالباحثة

This is an internet version of a standard A4 page questionnaire.

You may change the text size with the browser's View / Bigger Text (or similar) command.

(Background) معلومات عامه

الرجاء كتابة الإسم

نسأل عن الأسم حتى نتمكن من متابعة أي أمور قد تطرأ معك شخصيا

Please give your name ... (at your discretion)

We ask for names so that we can follow up any matters that may arise with you personally.

الإسم

العمر

نسأل عن العمر والجنس لأن كلاهما وثيق الصلة باحتياجات الناس في المباني

Age

We ask about age and gender because these are both relevant to people's needs in buildings.

أكثر من 30 ○ أقل من 30 ○

الجنس
Gender

...

ذكر ○ أنثى ○

الرجاء كتابة رقم المنزل واسم الشارع

Please add your address and postcode

Postcode

منذ متى وأنت تعيش هنا ... ؟
How long have you lived here ... ?

أقل من سنة ○ سنة وأكثر ○

كم عدد الأشخاص الاخرين الذين يعيشون معك في سن الثامنة عشرة أو أقل من ...؟
اختر من فضلك

How many other people live with you who are eighteen years of age or under...? *Please choose*

لا أحد ○ واحد ○ إثنان ○ ثلاث ○ اربعه اواكثر ○

كم عدد الأشخاص الاخرين الذين يعيشون معك والذين تزيد أعمارهم عن ثمانية عشر ...؟
اختر من فضلك

How many other people live with you who are over eighteen...? *Please choose*

لا أحد ○ واحد ○ إثنان ○ ثلاث ○ اربعة او اكثر ○

هل انت عادة في المنزل ...؟

الرجاء الإختيار

Are you normally at home...?

معظم الوقت ○ في المساء وعطلات نهاية الأسبوع فقط ○ غير ذلك ○

Please choose and describe below if other

التفاصيل إذا كانت غير ذلك

هل تسكن في ...؟

الرجاء الإختيار

Are you in a ...?

بيت مستقل (داخل سور) ○ منزل ملاصق بمنزل آخر ○ شقة ○ غير ذلك ○

Please choose and describe below if other

التفاصيل إذا كانت غير ذلك

هذا البيت ...؟

الرجاء الإختيار

Is this a ...?

ايجار ○ ملك ○ غير ذلك ○

Please choose and describe below if other

التفاصيل إذا كانت غير ذلك

الإقامة بشكل عام (The Residence Overall)

		1	2	3	4	5	6	7		لايوجد رد
موقع المنزل كيف تقيم الموقع بشكل العام ...؟ اختار من فضلك **Location** All things considered, how do you rate the overall location ...? *Please choose*	غير مرضي	○	○	○	○	○	○	○	مرضي	○
المساحة الداخلية للمنزل هل هناك مساحة كافية ...؟ **Space** Is there enough space ...??	لا توجد مساحة كافية بشكل عام	○	○	○	○	○	○	○	مساحة كبيرة جدا بشكل عام	○

تعليقات عن الموقع

تعليقات عن المساحة

		1	2	3	4	5	6	7		لايوجد رد
تخطيط المنزل هل تخطيط المنزل مناسب لك ...؟ **Layout** Does the layout suit you ... ?	تخطيط سيء	○	○	○	○	○	○	○	تخطيط جيد	○
وحدات التخزين بالمنزل هل توزيع وحدات التخزين بالمنزل ملاءمة لك؟ **Storage** Suitability of storage arrangements ... ?	غير كافية	○	○	○	○	○	○	○	كافية جدا	○

تعليقات عن وحدات التخزين

		1	2	3	4	5	6	7		لايوجد رد
المظهر الخارجي للمنزل كيف تقيم المظهر من الخارج ...؟ **Appearance** How do you rate the appearance from the outside ... ?	سيئ للغاية	○	○	○	○	○	○	○	رائع جدا	○

تعليقات عن المظهر الخارجي للمنزل

(Your needs) إحتياجاتك

1	2	3	4	5	6	7	لايوجد رد

بشكل عام، إلى أي مدى تلبي مرافق المنزل احتياجاتك (مثال: غرف النوم، المجالس، الصالات،دورات المياه، المطبخ، الأمان، الفناء الخارجي وموقف السيارة)...؟

How well do the facilities provided needed meet your needs ... ?

سيئة للغاية	○	○	○	○	○	○	○	ممتازة	○

الرجاء إعطاء أمثلة على المرفقات التي تلبي إحتياجاتك بشكل جيد ...؟

Please give examples of things which work well ... ?

أمثلة على الأشياء التي تعمل بشكل جيد

وأمثلة على المرفقات التي لا تلبي إحتياجاتك بشكل جيد ..؟

... and examples of things which do not work well ... ?

أمثلة على الأشياء التي لا تعمل بشكل جيد

(Special circumstances) ظروف خاصة

هل لديك ظروف خاصة تجعل احتياجاتك مختلفة عن المعتاد ...؟ الرجاء كتابتها

Do you have any special circumstances which make your needs different from the norm ...?

يرجى وصف أي متطلبات معينة لم يتم تلبيتها بشكل صحيح

الراحة (البيئة الداخلية للمنزل)
(Comfort)

فصل الشتاء

كيف تصف البيئة الداخليه للمنزل في فصل الشتاء؟

إذا لم يسبق لك العيش هنا في فصل الشتاء ، فالرجاء ترك هذه الأسئلة فارغة وإكمال الأسئلة حول درجة الحرارة في الصيف

Winter

How would you describe typical conditions in winter ?
If you have not lived here in winter then please leave these questions blank and just complete the questions on Temperature in Summer

	1	2	3	4	5	6	7		لايوجد رد
درجة الحرارة داخل المنزل في الشتاء									
غير مريح	○	○	○	○	○	○	○	مريح	○
حار جدا	○	○	○	○	○	○	○	بارد جدا	○
مستقرة وثابته	○	○	○	○	○	○	○	مختلفة ومتفاوته خلال اليوم	○
الهواء داخل المنزل في فصل الشتاء									
ساكن	○	○	○	○	○	○	○	متسرب	○
جاف	○	○	○	○	○	○	○	رطب	○
منعش	○	○	○	○	○	○	○	خانق	○
عديم الرائحة	○	○	○	○	○	○	○	ذو رائحة كريهة	○
حالة البيئة الداخلية للمنزل بشكل عام في فصل الشتاء									
بشكل عام غير مرضية	○	○	○	○	○	○	○	بشكل عام مرضية	○

فصل الصيف

كيف تصف البيئة الداخليه للمنزل في فصل الصيف؟

إذا لم يسبق لك العيش هنا في فصل الصيف ، فالرجاء ترك هذه الأسئلة فارغة وإكمال الأسئلة حول درجة الحرارة في الشتاء

Summer

How would you describe typical conditions in summer?

If you have not lived here in summer then please leave these questions blank and just complete the questions on Temperature in Winter

	1	2	3	4	5	6	7		لايوجد رد
درجة الحرارة داخل المنزل في الصيف									
غير مريح	○	○	○	○	○	○	○	مريح	○
حار جدا	○	○	○	○	○	○	○	بارد جدا	○
مستقرة وثابته	○	○	○	○	○	○	○	مختلفة ومتفاوته خلال اليوم	○
الهواء داخل المنزل في فصل الصيف									
ساكن	○	○	○	○	○	○	○	متسرب	○
جاف	○	○	○	○	○	○	○	رطب	○
منعش	○	○	○	○	○	○	○	خانق	○
عديم الرائحة	○	○	○	○	○	○	○	ذو رائحة كريهة	○
حالة البيئة الداخلية للمنزل بشكل عام في فصل الصيف									
بشكل عام غير مرضية	○	○	○	○	○	○	○	بشكل عام مرضية	○

انطباعك عن نظام التدفئة

الرجاء إضافة أي تعليقات حول نظام التدفئة
Please add any comments about heating

تعليقاتك عن نظام التبريد و التهوية

الرجاء إضافة أي تعليقات حول نظام التبريد و / أو التهوية
Please add any comments about heating and/or ventilation

الضوضاء (Noise)

كيف تصف تأثيرات الضوضاء ...؟

(يشير هذا السؤال إلى الظروف على مدار السنة)

How would you describe the effects of noise ...?

(This question refers to conditions all year round)

		1	2	3	4	5	6	7		لايوجد رد
الضوضاء بشكل عام	غير مرضي	○	○	○	○	○	○	○	مرضي	○
الضوضاء الناتجه من الأشخاص بين الغرف	قليل جدا	○	○	○	○	○	○	○	كثير جدا	○
الضوضاء من الجيران	قليل جدا	○	○	○	○	○	○	○	كثير جدا	○
ضوضاء أخرى من الخارج	قليل جدا	○	○	○	○	○	○	○	كثير جدا	○

تعليقاتك عن الضوضاء

الإضاءة (lighting)

كيف تصف جودة الإضاءة داخل المنزل؟

(يشير هذا السؤال إلى الظروف على مدار السنة)

How would you describe the quality of the lighting in your home?

(This question refers to conditions all year round)

		1	2	3	4	5	6	7		لايوجد رد
الإضاءة بشكل عام	غير مرضي	○	○	○	○	○	○	○	مرضي	○
الإضاءة الطبيعية	قليلة جدا	○	○	○	○	○	○	○	كثيرة جدا	○
(كمية وجود الوهج القادم من الشمس والسماء (على الشاشات والأسطح مثلاً	لايوجد	○	○	○	○	○	○	○	كثير جدا	○
الضوء الإصطناعي	قليل جدا	○	○	○	○	○	○	○	كثير جدا	○
(كمية وجود الوهج القادم من الأضواء الإصطناعية (على الشاشات والأسطح مثلاً	لايوجد	○	○	○	○	○	○	○	كثير جدا	○

تعليقاتك عن الإضاءة

الراحة بشكل عام داخل منزلك (Overall Comfort)

كل الأشياء التي تم أخذها في الاعتبار ، كيف تقيم الراحة العامة لبيئة المنزل؟
All things considered, how do you rate the overall comfort of the building environment?

	1	2	3	4	5	6	7		لايوجد رد
غير مرضيه	○	○	○	○	○	○	○	مرضيه	○

تعليقاتك عن الراحة بشكل عام داخل منزلك

(Health)
الصحة

هل تشعر أن هذا المنزل يؤثر على صحتك بجعلك تشعر أكثر أو أقل بصحة ...؟

	1	2	3	4	5	6	7		لايوجد رد
أقل صحة	○	○	○	○	○	○	○	أكثر صحة	○

يرجى محاولة تقييم منزلك فيما يتعلق بتجربتك في استخدامه بشكل عام

Do you feel that this building affects your health by making you feel more or less healthy...? Please try to evaluate this building with respect to your experience of using buildings in general.

تعليقاتك عن الصحة

الرجاء الإدلاء بأي تعليقات حول الصحة ...؟
Please make any comments about health ... ?

التحكم الشخصي داخل المنزل (Personal Control)

ما مدى تحكمك الشخصي في الجوانب التالية داخل المنزل...؟

How much control do you personally have over the following aspects ... ?

		1	2	3	4	5	6	7		لايوجد رد
التدفئة	لا يمكن التحكم	○	○	○	○	○	○	○	يمكن التحكم بشكل كامل	○

التبريد

لا يمكن التحكم ○ ○ ○ ○ ○ ○ ○ يمكن التحكم بشكل كامل ○

التهوية

لا يمكن التحكم ○ ○ ○ ○ ○ ○ ○ يمكن التحكم بشكل كامل ○

الإضاءة

لا يمكن التحكم ○ ○ ○ ○ ○ ○ ○ يمكن التحكم بشكل كامل ○

الضوضاء

lا يمكن التحكم ○ ○ ○ ○ ○ ○ ○ يمكن التحكم بشكل كامل ○

أهمية التحكم (Importance of Control)

يرجى تحديد الأشياء التي من المهم أن تكون تحت تحكمك التام داخل منزلك

Please tick if important to you in the context of this building...

☐ التدفئة ☐ التبريد ☐ التهوية ☐ الإضاءة ☐ الضوضاء

		1	2	3	4	5	6	7		لايوجد رد
التصميم أخذا بعين الاعتبار ماسبق ذكره، كيف تقيّم تصميم منزلك بشكل عام ...؟ **Design** All things considered how do you rate the design overall ... ?	غير مرضي	○	○	○	○	○	○	○	مرضي	○

انطباعك عن تصميم منزلك بشكل عام

سمات التصميم البيئي
إذا كان لديك إقتراحات أو حلول تصميميه بخصوص توفير الطاقة والمياه في منزلك، الرجاء كتابتها هنا...؟
Environmental design features
If you have anything to add about the energy and water-saving features of your home please put them here. ... ?

انطباعك حول حلول تصميميه بخصوص توفير الطاقة والمياه في منزلك

هل هناك شيء آخر ...؟
إذا كان لديك أي تعليق آخر، يرجى وضعه هنا ...؟
Anything else ...?
If you have anything else to add please put it here. ... ?

هل هناك شيء آخر تود إضافته ...؟

		1	2		لايوجد رد
نمط الحياة هل غيّر العيش هنا نمط حياتك ...؟ **Lifestyle** Has living here changed your lifestyle ... ?	نعم	○	○	لا	○

أمثلة على تغييرات نمط حياة عملك
Examples of work lifestyle changes

العمل

أمثلة على تغييرات نمط حياتك في وقت الفراغ
Examples of leisure lifestyle changes

وقت الفراغ

أمثلة على تغييرات نمط حياتك في النظام الغذائي
Examples of diet lifestyle changes

النظام الغذائي

أمثلة على تغييرات نمط حياتك في السفر
Examples of travel lifestyle changes

السفر

تكاليف الخدمات
كيف تقارن تكاليف الخدمات الخاصة بك في هذا المنزل من ناحية (التدفئة بالغاز، الكهرباء والمياه) مقارنة بتكاليفك في المنزل السابق ؟...

Utilities costs
How do your utilities costs (for heating, electricity and water) compare with your previous accommodation ...?

		1	2	3	4	5	6	7		لا يوجد رد
(Heating) التدفئة بالغاز إن وجد	أقل بكثير	○	○	○	○	○	○	○	أعلى بكثير	○
(Electricity) الكهرباء	أقل بكثير	○	○	○	○	○	○	○	أعلى بكثير	○
(Water) المياه	أقل بكثير	○	○	○	○	○	○	○	أعلى بكثير	○

يرجى إعطاء أمثلة لكيفية تغيير نمط إستخدامك التدفئة / التبريد والإضاءة والأجهزة والماء منذ قدومك في هذا المنزل مقارنة بمنزلك السابق

Please give examples of how you have changed your use of heating/cooling, lighting, appliances and water since coming here ...

التدفئة / التبريد

التدفئة و / أو التبريد
Heating and/or cooling

الإضاءة

الإضاءة
Lighting

الأجهزة الكهربائية

الأجهزة الكهربائية
Appliances

المياه

المياه
Water

شيء آخر

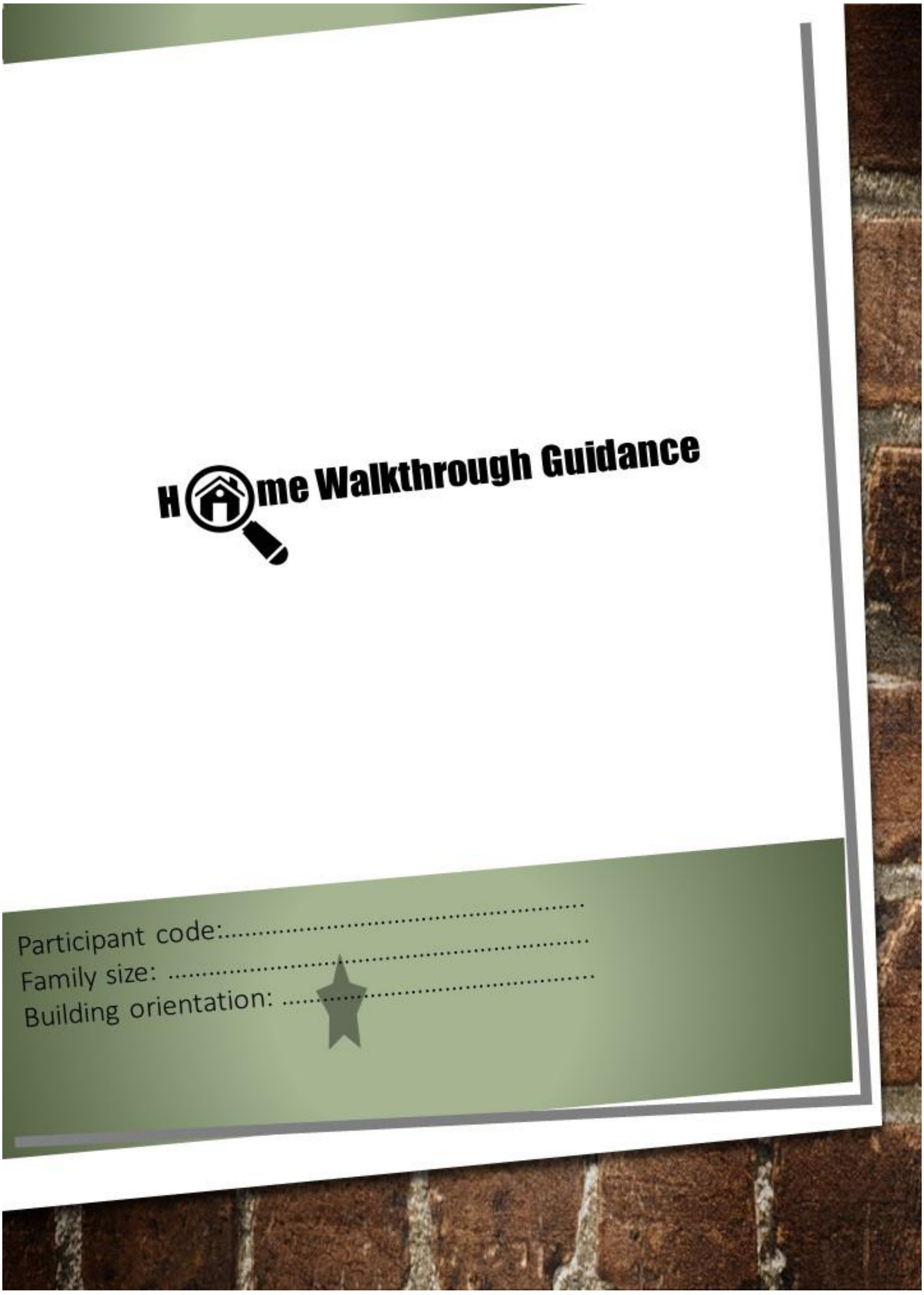
شيء آخر
Anything else

شكرا لك على مساعدتك. عند النقر فوق الزر "إرسال" أدناه ، يتم إرسال بياناتك إلى الباحثة. وسيتم التعامل مع المعلومات التي تم جمعها على أنها سرية تماما. سيستخدم هذا الإستبيان ملخص للمعلومات التي تم تعبئتها ولن تكشف أبدا عن هويات الأفراد

بعد النقر فوق الزر "إرسال" ، سيكون هناك تأخير قبل أن يستجيب النظام

إرسال الإستبيان

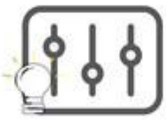
Appendix 6- Home Walkthrough Guide



KITCHEN

1. How you use the space, and where is the HVAC controller thermostat? How do you use it here? How long? When?
2. How are you using your appliances? Does it seem easy to use?
3. How well the windows open, safety and security?
4. Are there any issues relating to the kitchen's operation? And this would include: controls; lights; ventilation systems; or manual openings / vents.
5. Are there any visible signs of mould or condensation this area?
6. Do the developer / manufacturer produced user manuals help or hinder the correct use of the dwelling?
7. Adjustment?
8. Is there anything you would like to add?

1

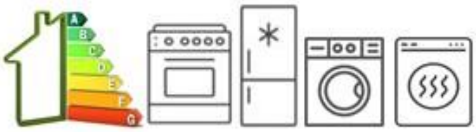


Lighting controls

2

Window & door ventilation control

3



Appliances (energy labelling)

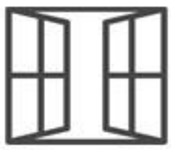
Floor :.........................
Curtains colour:.............................
Image:........................
Video:.........................
Comments:..
....

Tick box

LIVING ROOM & BEDROOMS

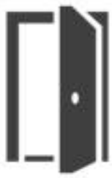
1. How they use the space, and where is the HVAC controller thermostat? How long using AC? When?
2. How are you using HVAC ? Does it seem easy to use?
3. Is it easy to tell when the filter needs changing, and is it easy to access and change it?
4. How well the windows open, safety and security?
5. Are there any issues relating to the living room & bedroom's operation? And This would include: controls; lights; ventilation systems; temperature settings; motorised or manual openings / vents.
6. Are there any visible signs of mould or condensation in this area?
7. Do the developer / manufacturer produced user manuals help or hinder the correct use of the dwelling?
8. Adjustment?
9. Is there anything you would like to add?

1



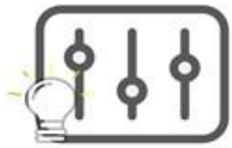
Window ventilation control

2



Door ventilation control

3



Lighting control

HVAC control thermostat

Floor :.........................
Curtains colour:..............................
Image:.......................
Video:........................
Comments:..
....

Tick box

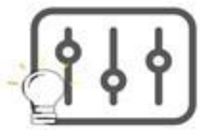
BATHROOMS

1. How are you using the controls? Does it seem easy to use?
2. How well the windows open, safety and security?
3. Are there any issues relating to the bathrooms' operation? And This would include: controls; lights; ventilation systems; motorised or manual openings / vents.
4. Are there any visible signs of mould or condensation this area?
5. Adjustment?
6. Is there anything you would like to add?

1

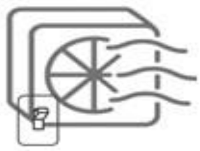
Window & door ventilation control

2



Lighting control

3



Extract fan control

Floor :........................
Curtains colour:.............................
Image:......................
Video:........................
Comments:...
....

Tick box

HALLWAYS/ STAIRS

1. Are there any issues relating to the dwelling's operation? This would include: controls programming the system and; lights; ventilation systems; temperature settings; motorised or manual openings / vents.

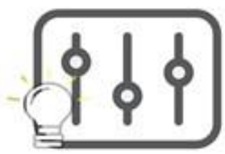
2. Do the developer / manufacturer produced user manuals help or hinder the correct use of the dwelling?
3. Adjustment?

4. Is there anything you would like to add?

1

Monthly electricity bill

2



Lighting control

Floor :.........................
Curtains colour:.............................
Image:........................
Video:.........................
Comments:..
....

Tick box

Appendix 7- Interview questions

Interview questions	Research objectives
1. How long have you been living here in this home? Who lives with you? Do you have pet? 2. Where were you living before you moved into this house? [Understand the context, e.g. house or flat, location, number of rooms] Compare the pervious home and this home in term of indoor thermal comfort (heating, cooling, ventilation, involve insulation, glazing) and electricity bills? 3. How do you feel about your home? Are there any general things you like or dislike about your home? 4. How did you find living in RC home with the implementation of new technology (HVAC)? 5. Have you changed anything since you lived in this home?	- Understand and explain inhabitant experience of living in pervious conventional and regulated Saudi homes in relation to energy consumption and thermal comfort. - Identify how much energy has been consumed in Saudi regulated homes.

Interview questions	Research objectives
1. How you cool the indoor space in the summer? Additional cooling devices? What do you do to reach the comfortable level of cooling? Why? What time of the day is cooling mostly used? 2. Do behaviours change when more people - guests/ family are in the house? 3. How you heat the indoor space in the winter? Additional heating devices? What do you do to feel warm? Why ? What time of the day is heating mostly used? 4. If you were feeling cold would you choose to turn the heating up or put on an extra layer? If you did put on the extra layer, why would that be your reaction to the cold and not turning up the heating? 5. Who is responsible for changing the settings? What is usual temperature setting? Do different people have different preferences? 6. Do you open windows: which windows/doors opened – when, why and how long? [Show them the home layout the researcher can know the location] 7. Do you sleep with windows opened/closed [e.g. in winter/spring]? 8. How you ventilate your home? (practices) Additional ventilation devices? 9. Do you use extra equipment e.g. humidifier/dehumidifier devices? 10. Have you notice any condensation mould? Where? 11. Are artificial lights used during the day time? If so, why? 12. When you leave a room, do you pay attention to switching off lights, AC and/or other equipment? Why? How about other households?	• Identify the performance of regulated Saudi homes in relation to thermal comfort. • To understand and explain the influence of inhabitant everyday practices on energy consumption.

Interview questions	Research objectives
1. Daily routines: ask about a daily routine **a**) week-day **b**) weekend [time waking up, sleeping, watching TV how long, who is setting at home most of the time/day/week] 2. Which rooms are the most frequently used? And which rooms are occasionally used? Where does the family spend most of the time? And why? 3. What are the appliances used daily? 4. Have your practices changed over time since you lived here? 5. Any other activities you do every day/ a week? 6. How often do you cook? Is this at the same time as the other household? 7. How long does it take to prepare a meal? How many equipment are used to prepare the meal? [e.g. microwave, oven, cooker, electric grill, toaster, blenders, food processor, kettle and other] 8. Does this make the space too hot? If so, how you cool/ventilate it? For how long? 9. How many times doing laundry [weekend/ every day or every other day etc…]? Drying using machine or traditional drying? If yes where inside the house [which room]? Do you use fan or you open window or non to dry cloths?	• To understand and explain the influence of inhabitant everyday practices on energy consumption.
1. Are you concerned about your consumption? Have it change since you lived here [low or high]? Why? 2. Are you interested in energy efficiency / saving? Why ? 3. What do you do about it? Or what are you planning to do about it? 4. How you normally choose an appliance based on what criteria? (brand, size, quality, cost savings, energy rating, advertisement, the ease of use) 5. Have you received any advice about your energy? Do you wish to have it?	• To understand and explain the influence of inhabitant everyday practices on energy consumption.
1. how did you learn how to use the system in your home? 2. Has anyone ever offered you any advice on how to use the systems in this house? If yes what form you got? Were you given a home user guide? 3. Do you have any problem using/interacting with the home environmental systems? If yes how did you solve it ? 4. In term of maintenance, what maintenance has been done [type and who doing it]? have you ever changed the filters? Or has anyone else? 5. Thanks for answering the questions, before we wrap up is there any thing you would like to mention?	• To understand the usability of control interfaces in their homes.

Appendix 8- Ethical Approvals

The University Of Sheffield.

Downloaded: 10/10/2023
Approved: 13/10/2021

Rawdah Alzahrani
Registration number: 190225904
School of Architecture
Programme: Phd in architecture

Dear Rawdah

PROJECT TITLE: Inhabitants' Practices and the Impact on Energy Demand in Saudi' Low Carbon Dwellings
APPLICATION: Reference Number 043038

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 13/10/2021 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 043038 (form submission date: 11/10/2021); (expected project end date: 01/12/2023).
- Participant information sheet 1096463 version 3 (11/10/2021).
- Participant consent form 1096902 version 3 (11/10/2021).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Parag Wate
Ethics Administrator
School of Architecture

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy: https://www.sheffield.ac.uk/research-services/ethics-integrity/policy
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

The University Of Sheffield.

Downloaded: 10/10/2023
Approved: 11/02/2022

Rawdah Alzahrani
Registration number: 190225904
School of Architecture
Programme: Phd in architecture

Dear Rawdah

PROJECT TITLE: Inhabitants' Practices and the Impact on Energy Demand in Saudi' Low Carbon Dwellings
APPLICATION: Reference Number 040380

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 11/02/2022 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 040380 (form submission date: 03/02/2022); (expected project end date: 01/12/2023).
- Participant information sheet 1092106 version 2 (29/10/2021).
- Participant information sheet 1092105 version 1 (25/05/2021).
- Participant consent form 1092051 version 3 (03/02/2022).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Your responsibilities in delivering this research project are set out at the end of this letter.

Yours sincerely

Parag Wate
Ethics Administrator
School of Architecture

Please note the following responsibilities of the researcher in delivering the research project:

- The project must abide by the University's Research Ethics Policy: https://www.sheffield.ac.uk/research-services/ethics-integrity/policy
- The project must abide by the University's Good Research & Innovation Practices Policy: https://www.sheffield.ac.uk/polopoly_fs/1.671066!/file/GRIPPolicy.pdf
- The researcher must inform their supervisor (in the case of a student) or Ethics Administrator (in the case of a member of staff) of any significant changes to the project or the approved documentation.
- The researcher must comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
- The researcher is responsible for effectively managing the data collected both during and after the end of the project in line with best practice, and any relevant legislative, regulatory or contractual requirements.

Appendix 9- Pilot study

A pilot study was undertaken to calibrate the environmental monitoring sensors and test them in use (e.g. people being asked to place them and download the data). Due to the shortage of data loggers provided by the University of Sheffield, alternative data loggers were secured by the researcher. It is essential to ensure all the data loggers used in this research project are calibrated to provide accurate results. Hence, a comparison study of the university's provided data loggers (HOBO) and the new data loggers (SMART) was conducted to ensure the accuracy and sensitivity of the collected data (**Error! Reference source not found.** and **Error! Reference source not found.**).

In this study, four sensors (2 HOBO) and (2 SMART) were placed in the same room next to each other for approximately 3 weeks. The data acquired from both sensors fall within the expected tolerance (**Error! Reference source not found.**). **Error! Reference so urce not found.**shows that temperature readings from all sensors follow the same pattern, with approximately 0.3 °C difference between HOPO and SMART readings. The humidity data provided by both types of sensors are also accurate, with approximately 1.5-2.0 % difference between HOPO and SMART readings (**Error! Reference source not f ound.**). The difference in the measured data by the two sensors is fractional and fall within the tolerance level. Therefore, 15 SMART sensors will be used instead of HOBO to conduct the study.

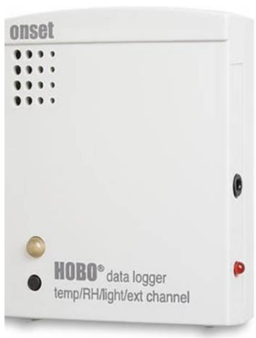


Figure 0-1 Hobo Sensor [Measurement Systems Ltd, n.d]

Figure 0-2 Smart Sensor [ORIA, n.d]

Table0-1 Sensors Technical Data (Author, 2020)

Accuracy	**SMART**	**HOBO**
Temperature	± 0.5°C	± 0.35°C
Humidity	± 5.0 %	± 2.5%

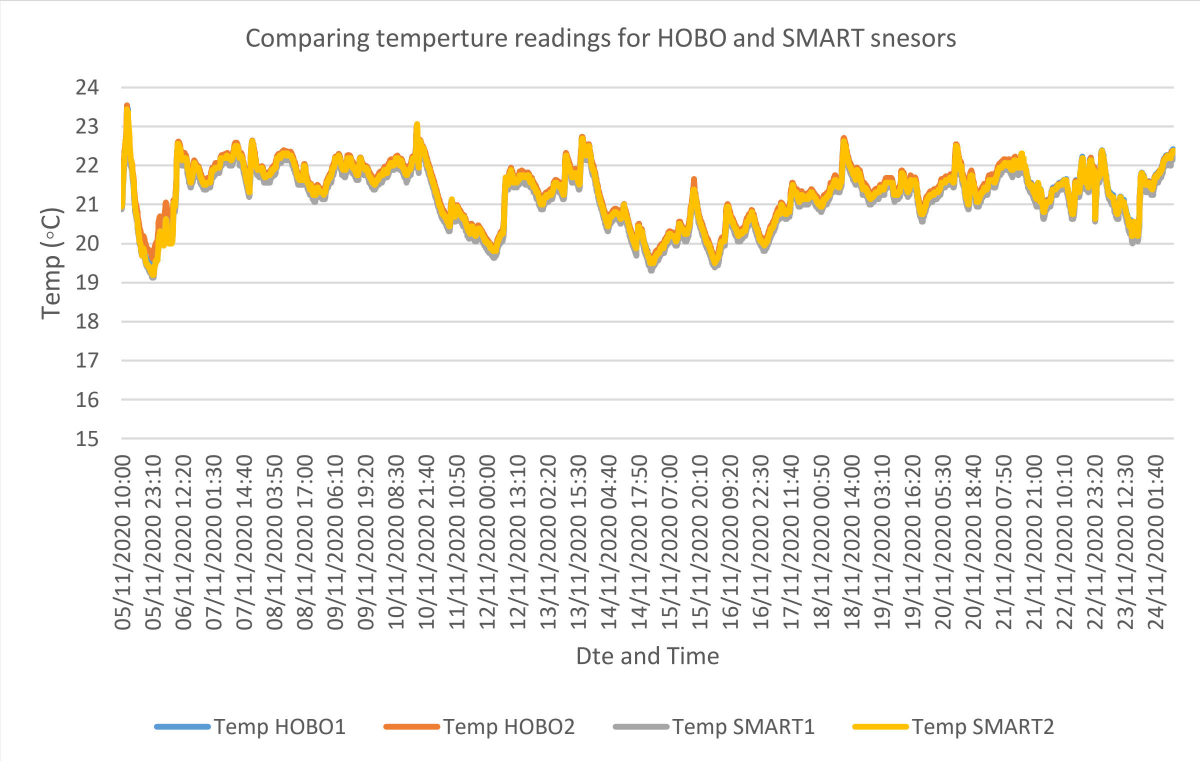


Figure 0-3 Comparing Temperature Measurements of Different Sensors [Author, 2020]

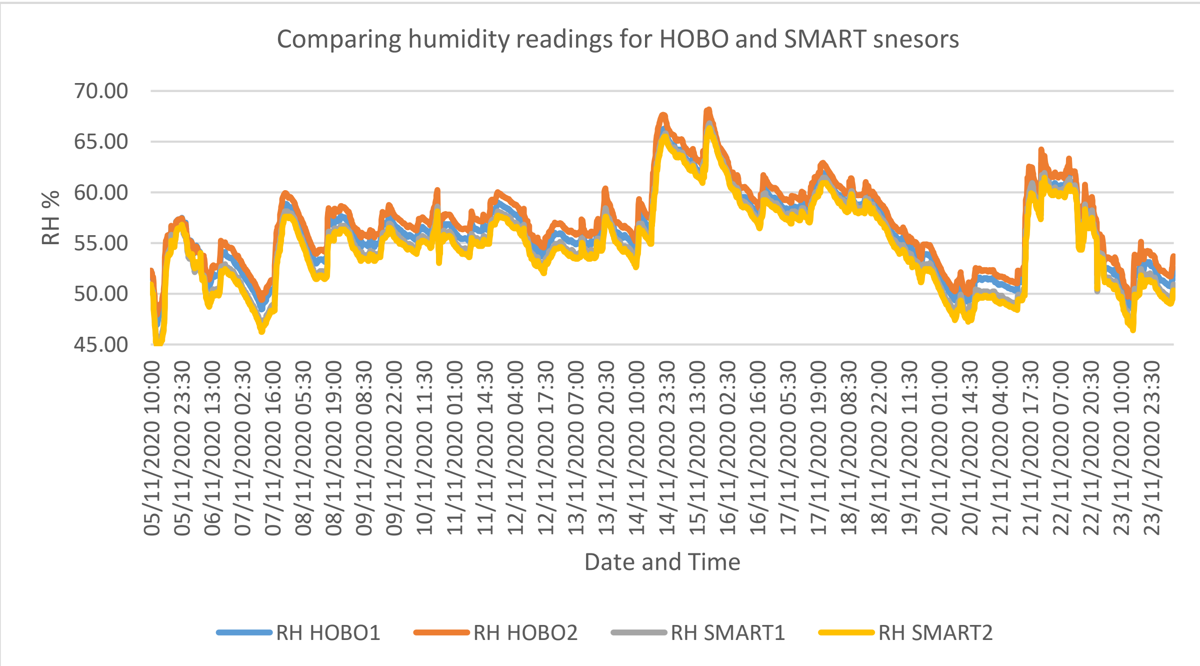


Figure 0-4 Comparing Humidity Measurements of Different Sensors [Author, 2020]

The great advantage of using SMART sensors is simplicity and being user-friendly, where data can be directly accessed via an app (available for both iOS and Android devices). Participants were able to download the app (Sensor Blue) where the data could be accessed by the researcher and collected monthly. The researcher also provided a video guide on how to use the app and export the data as a CSV file to ensure that participants understand the whole process in terms of using the app and downloading the data.

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