THE UNIVERSITY OF KENT

EXPLORING CHALLENGES AND OPPORTUNITIES OF FABRIC FIRST PRINCIPLES AS AN ALTERNATIVE TO ACTIVE CLIMATE CONTROL TECHNOLOGIES WITHIN THE DEVELOPING WORLD CONTEXT

A CASE STUDY BASED IN THE KURDISTAN REGION

By
Haval Abdullah Abdulkareem

A thesis submitted in partial fulfilment of the requirements for the degree of
Doctor of Philosophy

Kent School of Architecture and Planning

The University of Kent

2021

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

In the name of Allah, the Entirely Merciful, the Especially Merciful.

Abstract

In regions of the developing world, development and urban and economic growth have led to a rapid increase in energy consumption and the associated greenhouse gas (GHG) emissions causing serious impact on the environment. Like other regions of the developing world, rapid expansion in the cities of Iraqi Kurdistan (KRI) has occurred, predominantly driven by the large influx of internally displaced people and refugees. The demand for residential units has continuously increased giving rise to a construction boom in the region. However, the emphasis so far has been rather on poorly constructed buildings, buildings that are equipped with active climate control technologies to be inhabitable. From a fabric point of view, poor thermal efficiency is a common feature that they are generally characterised by, no matter how new or old the buildings are. The increased reliance upon such technologies across the built environment has caused an increased rise in energy demand and has put an extreme strain on the capacities of the energy sector in Iraq, an oil-rich but powerless country. Residential buildings alone are responsible for nearly 41% of KRI's energy consumption and over 66% of KRI's total electricity consumption.

This research explores the challenges and opportunities of the fabric first approach within the residential context of the KRI as a potential solution and investigates how important it could be in freeing people from the increased reliance on energy to maintain a reasonable standard of thermal comfort. The investigations go through a sequence of phases starting from the initial exploration of the cultural context to the development and assessment of fabric first-based upgrading propositions.

The study finds that with upgrading the efficiency of the entire building envelope following the principles of fabric first, one can create a situation where the level of indoor thermal comfort is necessarily improved with a significant reduction in cooling/heating demand and CO_2 emissions.

Acknowledgements

From beginning to end, my gratitude is to The Lord, who blessed me with this task. Through His Strength, by His Knowledge and in His Grace are all things accomplished. O Allah, I am the needy servant at Your door, and You are the most generous of hosts.

This piece of work has made it to the end with the support of many, to whom I owe heartfelt thanks. First of all, I am grateful to my first supervisor Professor Henrik Schoenefeldt, the source of inspiration for me and many others. There are indeed no words that can express the great deal of thanks that I owe him. It is he whose knowledge and insight into the subject matter steered me through my PhD journey. Further, I would like to extend my heartfelt gratitude to my second supervisor Professor Marialena Nikolopoulou. The conversations and meetings I had with her were absolutely necessary for me to think critically and undertake my investigations thoroughly.

I would also like to acknowledge all the stakeholders for their willingness to impart their knowledge on the mainstream construction culture in the Kurdistan region and matters relating to energy efficiency in the built environment. Also, this thesis would not have been complete without the kind families who allowed me to carry out my investigations in their dwellings and provided the required data.

I am also thankful to Mr Jawdat Mohammad for giving the opportunity to put my research into practice and design his own two-storey house based on the fabric first principles. Despite all the challenges we faced due to the pandemic, he and the construction team were remotely taking my instructions and patiently implementing them on the ground.

Also, my deepest thanks and great gratitude to Canterbury Muslim Community for the support and kindness they have shown over the course of my research. My appreciation also go for the University of Kent for their financial support and my present and past colleagues at Kent School of Architecture and Planning for their advice and company.

Last but not least, I am indebted to those who are the reason for my existence in this life, my parents (Abdullah and Asyah). Mum and Dad, no words can express the feelings and love I have for you. Also, thanks to my brothers (Reveng and Chalang) and my sisters (Sheheen and Dereen), my partners in the love of my parents, for their support and help on all matters related to my studies.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Overview

In regions of the developing world, development and urban and economic growth have led to a rapid increase in energy consumption and the associated greenhouse gas (GHG) emissions causing a serious impact on the environment (Iwaro and Mwasha, 2010). As the population grows and urbanisation increases, more growth in energy demand is experienced. Compared with 1989, the statistical review of world energy (BP, 2020) shows that primary consumption in 2019 has increased by 244 exajoules (EJ) recording the highest ever figure (i.e. 582 EJ) as of today. If the growth continues at the same rate, it may exceed even 1,000 EJ by 2050. However, data shows that developing countries lead this global energy consumption growth by being responsible for nearly 58% of it. This gives cause for concern and raises questions regarding challenges with energy production and supply, fossil fuel combustion and the related environmental problems (e.g. climate change and air pollution), etc.

Like other regions of the developing world, rapid expansion in the cities of the Kurdistan Region of Iraq has occurred. This has been predominantly driven by a large influx of internally displaced people and refugees due to instability and the lack of basic services, e.g. clean water and electricity, in other parts of Iraq. This is besides the Syrian conflict and ISIS crisis which led tens of thousands of Syrians to flee their homes and seek asylum and safety in northern Iraq. The migration of people from rural areas to cities for social and economic imperatives has also been experienced over the last two decades (KRG Ministry of Planning, 2012). Compared to 2000, according to estimates from the Ministry of Planning, KRI's population in 2015 has nearly doubled, estimated to be nearly around 5.5 million with 1.8 million refugees (Kassamani, 2018). Consequently, the demand for residential units has continuously increased leading to an imbalance between demand and supply, one of the major challenges the region faces. According to a Joint Report by the KRG Ministry of Planning and UNDP, in order to meet the demand across all income levels, 30,390 housing units need to be built annually if a unit will be occupied by each household. Moreover, renovating or replacing sub-standard and inadequate residential units with new ones was estimated to be required for about 25% of the existing households (i.e. 283,000 units). This means that 28,300 units from the existing housing stock have to be renovated or replaced annually over 10 years. In response, the Kurdistan Regional Government in association with the Board of Investment (BOI) has launched a number of housing programmes which have led to a construction boom in the region and opened the road for local and foreign real estate developers to tackle the crisis.

However, Standards guaranteeing the quality and energy efficiency of the built environment have not been imposed in the available building regulations in Kurdistan (KRG Ministry of Planning, 2013) nor at the national level in Iraq (RCREEE, 2015). Design and construction practices are not subjected to any obligatory requirements that concern sustainability and energy efficiency. This is, in fact, a common issue in most of the nations of the developing world in which the legislative environment shows a very modest interest in energy saving (Iwaro and Mwasha, 2010), an issue that accelerates energy consumption rates substantially upward. As a consequence of the absence of such obligatory requirements in the country, poor energy and thermal performance becomes a common feature that buildings are generally characterised by. Thermal bridges, air infiltration, and lack of thermal insulation and effective shading are amongst the common weaknesses associated with the building fabric making the building liable to high thermal transmittance. They cause buildings to consume excessive amount of energy and rely heavily upon HVAC systems, introduced to enable the control of the indoor environment and provide thermal comfort to inhabitants at their finger tips. This is something that has led buildings to be the main contributor to the region's primary energy consumption and the associated CO_2 emissions (IEA, 2012). According to government data, residential buildings alone are responsible for nearly 41% of KRI's energy consumption and over 66% of KRI's total electricity consumption (Kassamani, 2018).

As the cities grow and the number of buildings increases, hence, installing mechanical means of heating and cooling widely takes place. The higher the air temperature in summer, the more the increase in energy consumption is recorded for cooling. And the lower the air temperature in winter, the more the increase in energy consumption is recorded for heating. This puts an extreme strain on the capacities of the energy sector in Iraq, an oil-rich but powerless country. Indeed, Iraq's insufficient power supply is considered as one of the key barriers to its social and economic development, and power outage has been experienced over many years despite the billions of dollars that have been wasted in that sector (IEA, 2012). Such a crisis has made people living in absolute poverty to experience extreme hardship over cooling and heating seasons. To overcome such a long-standing crisis and fill some of the electricity supply gap, the majority of Iraqi households supplement the public network with an alternative source of supply, either a private household generator or a shared generator operating at neighbourhood level (IEA, 2012). Power cuts also take place in the Kurdistan region, even though the power supply is more reliable there than the rest of Iraq. Electricity supply from all sources was reported to be around 12-16 hours per day, and thus many existing dwellings experience both overheating and overcooling throughout the year.

The level of indoor thermal discomfort and high rates of energy consumption will most likely continue if the way that buildings are constructed and designed is not changed and if the poor performance of the existing ones is not improved. With these issues, careful consideration to alternatives becomes imperative, and urgent steps that minimize energy demand need to be taken. There are opportunities to considerably reduce energy consumption in the Kurdistan region. This could be through upgrading active climate control technologies, and/or renovating the existing housing stock and constructing new homes in compliance with modern-day energy efficiency approaches that are appropriate and can be adapted to the climate and socio-technical context of the region.

Many developed countries, especially in Europe, have introduced energy-policy programmes aiming to accomplish nearly zero-energy homes. In central Europe, for instance, the early 1990s saw the introduction of one of the fast-growing standards which is the German Passivhaus standard as an approach towards achieving ultra-energy efficient buildings (Cotterell and Dadeby, 2012). It is a very advanced and ambitious version of the fabric first approach that prioritises the performance of the building envelope over the use of mechanical means of heating and cooling. It gives the components and materials that make up the envelope careful consideration, maximises the level of insulation and airtightness across the building fabric, and avoids thermal bridges to minimise the amount of energy required to maintain thermal comfort. Its application has spread rapidly across European countries and beyond, largely to new build construction, while such an implementation has been very limited in hot climate regions, especially developing countries where such an issue is lagging behind.

1.2 Research Aims, Hypothesis, and Objectives

This research intends to investigate the application of a fabric first approach within the residential context of Iraqi Kurdistan (KRI) as a potential solution and explore how important it could be in freeing people from the increased reliance on energy to maintain a reasonable standard of thermal comfort. The study attempts to revisit the Passivhaus principles to develop a realistic model to upgrade the existing building stock in a way that is appropriate and feasible for that part of the world across the socio-economic spectrum. This is in the light of limited economic resources, locally available skills, construction methods and materials.

The underlying assumption in this research is that: *"The rise in energy consumption associated with the use of heating and cooling technologies can be addressed by shifting the focus towards the efficiency of the fabric following fabric first principles."*

In order to fulfil the research aim, the key objectives are to:

1) Understand the principles of fabric first approach, the viability of applying the Passivhaus standard in different climates, and the challenges of adapting it to other contexts.
2) Define the underlying factors that could determine the nature of fabric first approach in the Kurdistan region in terms of the materials used, skills and technical solutions needed, and regulatory interventions.
3) Get an in-depth insight into the energy and thermal performance, nature of the architectural fabric, and role of technology and behavioural factors of a sample of dwellings to form the basis for computer-based models and building fabric upgrading scenarios.
4) Understand the needs of socio-economically distinct households when applying fabric first principles.
5) Develop a range of building upgrading propositions firmly guided by the principles of fabric first and the understanding of the cultural context and the socio-economic considerations that impact the people's lives in the case studies.
6) Develop validated simulation models for a sample of selected dwellings to perform parametric analysis.
7) Test the aforementioned propositions on the validated models and analyse their impact on the indoor thermal environment, energy use (primarily heating and cooling load), and reduction of CO_2 emissions.

1.3 The study area

This thesis is based on investigations conducted on the housing stock in the Kurdistan region, an autonomous region covering around 40000 km^2 with a population estimated around 5.5 million. The vast majority are Kurds making up around 17% of Iraq's population. It is a largely mountainous region located in the northern part of Iraq (36.41° N, 44.38° E) bordering Turkey, Syria, and Iran and comprising the country's four northernmost governorates: Sulaymaniyah, Halabja, Erbil (the capital), and Duhok (see Fig. 1.1). Being part of one of the riskiest states across the world and surrounded by states opposed to their aspirations, the Kurdistan Region has been increasingly susceptible to political instability and uncertainty for generations. However, despite that, it is considered the safest part of Iraq. And under the Iraqi constitution of 2005, the region's government (the KRG) has the right to exercise judicial, executive, and legislative powers in accordance with the constitution, except in what is listed therein as exclusive powers of the federal authorities (Abdallah et al., 2015).

Figure 1.1 The map of northern Iraq (source: USAID/OFDA)

The region has a semi-arid climate, with hot dry summers and cold, wet winters. The mean daily temperatures range from 32 °C to 36 °C and 4 °C to 11 °C during summertime and wintertime respectively. This is with occasional daily minimum temperatures falling below 0 °C in winter and occasional daily maximum temperatures exceeding 45 °C in summer. Therefore, buildings are normally in need of both cooling and heating services where both are responsible for most of the primary energy use. The former is highly dependent upon the use of electricity, while the latter relies heavily upon the use of kerosene.

Most of the electricity is generated in the conventional way through burning fossil fuels. There are mainly two sources of supply: the national grid and shared generators (or small stations) operating at neighbourhood levels. The first is considered as the main source of supply and is highly dependent on governmental support. However, owing to extreme pressure on its capacities as a result of increased demand driven mainly by population growth, mismanagement, transmission and distribution system bottlenecks, and some other major barriers explained in (IEA, 2012), the produced electricity through the national grid is not enough to meet the demand at peak. This is especially so during hot and cold periods. Households often experience power failure throughout the day. In 2018, for instance, the average electricity supply through the national grid was limited to nearly 13 hours per day (General Directorate of Duhok Electricity, 2018). This creates difficulties for the majority of households to keep their homes at right temperatures during both cooling and heating seasons.

The second is privately owned by Independent Power Producers (IPP). At the cost of people's health, these private generators have been distributed all over the region to fill some of the electricity supply gap that is experienced. With more than 6000 generators throughout the region, they are considered amongst the main sources of noise and air pollution which has a severe impact on human immune, neurological and respiratory systems. Despite that, they supply electricity at considerably higher prices (i.e. approximately 1 USD per 4 kWh) creating a major deterrent for many households across the region and limiting the operation of heating and cooling technologies when necessary. In terms of kerosene, every year, each household receives from the government through a subsidy programme 200 to 400 litres of kerosene as a mean of heating at a minimal charge of 0.16 USD for a litre. In most cases, however, such an amount does not meet their need, and thereby they have to buy extra from the market at considerably higher prices.

1.4 Thesis structure

Besides this introductory chapter, as illustrated in Figure 1.2, this thesis includes 8 chapters outlined as follow:

Chapter 2 focuses on the general theme and uses the review of existing research to understand the principles of fabric first approach, the viability of applying the Passivhaus standard in different climates, and the challenges of adapting it to other contexts. This is to provide the background knowledge needed to construct the tools and framework of the research presented in Chapter 3 and the technical insight needed for developing fabric first-based modelling scenarios presented in Chapter 8.

Chapter 3 presents the research philosophy and methodological framework, including research design and methods, employed in undertaking the required investigations to fulfil the aims and objectives of this research.

Chapter 4 and 5 establish the contextual background of the mainstream construction culture in the KRI and the possible problems that are faced there to understand the context and define the underlying factors that would determine the nature of the fabric first approach in the region in terms of the materials used, skills and technical solutions needed, etc. These two chapters are mainly based on data collected through investigations using a questionnaire survey followed up by in-depth interviews with key stakeholders engaged in the building industry.

Chapter 6 and 7 present summertime and wintertime investigations carried out on a sample of dwellings. This aimed to get an in-depth insight into their energy and thermal performance, the nature of the architectural fabric, the role of technology and behavioural factors for the development of computer-based models and building fabric upgrading scenarios that are culturally embedded. These two chapters are mainly based upon data collected from four case study dwellings.

Chapter 8 presents the modelling process of two of the selected case study dwellings in detail and analyses the impact of upgrading their building fabric through a range of contextual propositions firmly guided by the principles of fabric first and the understanding of the cultural context and the socio-economic considerations that impacts the people's lives in the case studies.

Chapter 9 concludes the research and provides a summary of the main findings followed by a set of recommendations, limitations of the study, and future research

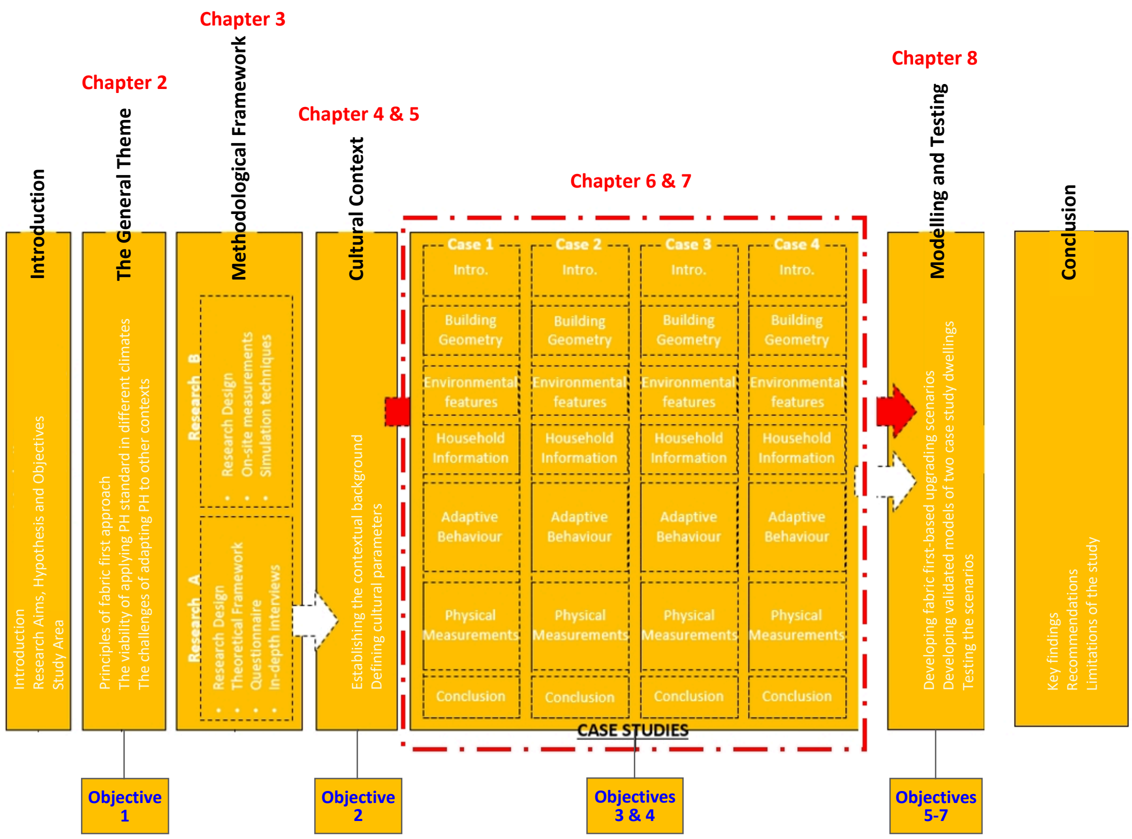


Figure 1.2 Thesis structure (author)

Chapter 2

Towards the contextualisation of the fabric first approach

2.1 Overview

In response to the increased contribution from buildings to global final energy consumption and the associated GHG emissions and the growing threat of climate change and global warming in the past decades, buildings' energy efficiency has become high on the agenda of many countries around the world, especially developed countries. This has led to the emergence of some promising approaches and standards making a building's energy efficiency as their overriding objective. This is to create greener, more sustainable and resource-efficient buildings and thereby offset the increase in energy use and substantially reduce their impact on the environment. Among the most widely adopted approaches is the "fabric-first" approach. Using the review of existing research, this chapter introduces the principles of Passivhaus/fabric first approach and explores the viability of applying the Passivhaus standard in different climates, and the challenges of adapting it to other contexts. This is to provide the background knowledge needed to construct the tools and framework of the research presented in Chapter 3 and the technical insight needed for developing fabric first-based modelling scenarios presented in Chapter 8.

2.2 Fabric first approach

The core concept of this construction line of creating environmentally optimised buildings lies in prioritising the performance of the building envelope over the use of mechanical means of heating and cooling. It gives the components and materials that make up the envelope careful consideration, maximises the level of insulation and airtightness across the building fabric, and avoids thermal bridges to minimise the amount of energy required to maintain thermal comfort (see Fig. 2.1). One of the very advanced and ambitious versions of fabric first approach is the Passivhaus standard developed by Wolfgang Feist in the early 1990s in Germany (Cotterell and Dadeby, 2012). In reliance on such a set of principles, the standard aims to keep the primary energy demand considerably low, i.e. ≤ 120 $kWh/m^2.yr$, while providing comfortable thermal conditions all year round (Feist et al., 2005). The interest in this standard grows as concerns about climate change increase. Across European countries and beyond, in fact, building in accordance to Feist's approach is on the rise. As of June 2021, there were over 65000 certified PH buildings all around the world (Passivhaus Trust, 2021). The vast majority are located in Scandinavia and German-speaking states experiencing lower temperatures most of the year, countries that are highly advanced in terms of building technology (Fokaides et al., 2016).

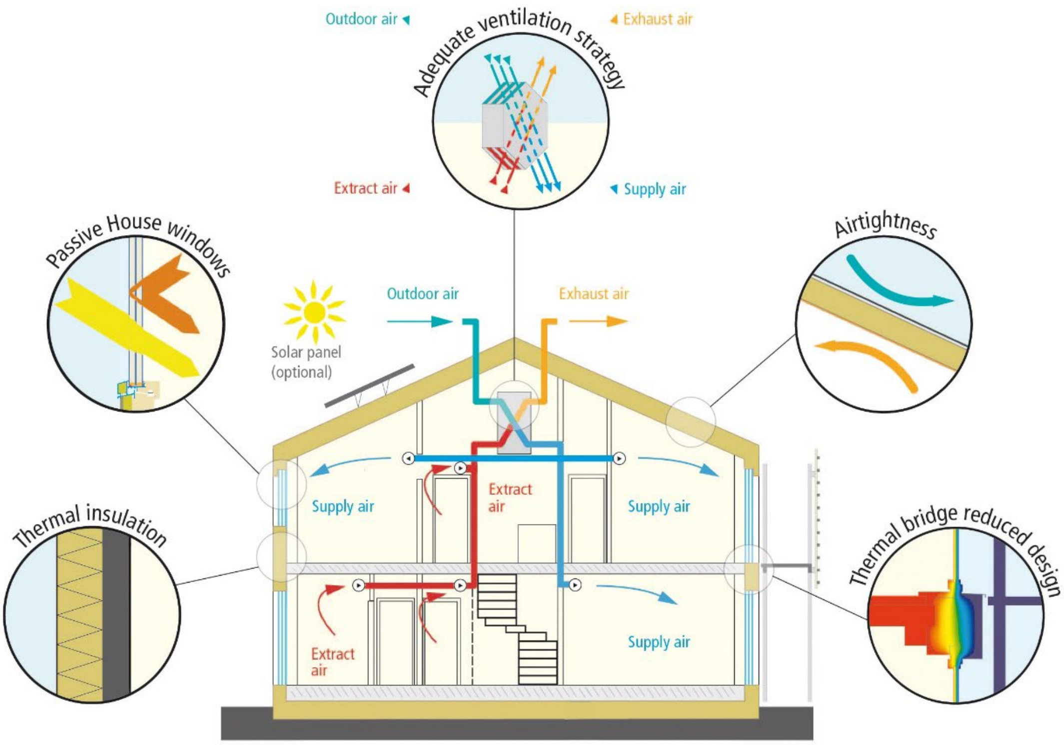


Figure 2.3 Passivhaus principles (Passive House Institute, 2015)

According to Schnieders and Hermelink (2006), the term ''Passivhaus'' refers to a construction standard that can be met using a variety of technologies, designs and materials. It is basically a refinement of the low energy house standard. Buildings built in accordance with this standard assure a comfortable indoor climate in summer and in winter without needing a conventional heat distribution system. Amongst the requirements, the U-value of opaque building components (i.e. external walls, floor, and roof) and the one of windows should not be greater than 0.15 and 0.8 W/m^2.K respectively. Also, it is essential that the building's heating load does not exceed 10 W/m^2, an amount that is roughly equivalent to an annual space heat requirement of 15 kWh/m^2.yr (see Table 2.1). Such a target can be met by heating the supply air in the ventilation system using MVHR, i.e. mechanical ventilation with heat recovery. The approach is cost-efficient because, following the principle of simplicity, it relies on optimizing those components of a building which are necessary in any case: the building envelope, the windows and the ventilation system. Improving the efficiency of these components to the point at which a separate heat distribution system is no longer needed yields savings which contribute to financing the extra costs of improvement.

Table 2.1 The criteria of Passivhaus (Passive House Institute, 2015)

Criteria	The limit
Primary energy demand	≤ 120 $kWh/m^2.yr$
Space heating demand	≤ 15 $kWh/m^2.yr$ or 10 W/m^2
Space cooling demand (In climates where active cooling is needed)	≤ 15 $kWh/m^2.yr$ or 10 W/m^2 with an additional allowance for dehumidification
Airtightness	≤ 0.6 air changes/hr @ n50
Thermal comfort	Must be met for all living areas during winter as well as in summer, with not more than 10% of the hours in a given year over 25 °C

The standard has been named ‘‘Passivhaus’’ because the ‘passive’ use of incidental heat gains—delivered externally by solar irradiation through the windows and provided internally by the heat emissions of appliances and occupants—essentially suffices to keep the building at comfortable indoor temperatures throughout the heating period. It is a part of the Passive House philosophy that efficient technologies are also used to minimize the other sources of energy consumption in the building, e.g. electricity consumed by household appliances. The target, as indicated earlier, is to keep the total primary energy requirement for space heating, domestic hot water and household appliances somewhere below 120 $kWh/m^2.yr$ (Schnieders and Hermelink, 2006).

2.3 The viability of applying the Passivhaus standard in different climates

As stated earlier, this 'fabric first' approach to construction and design has been adopted much more in Scandinavia and German-speaking states experiencing lower temperatures most of the year than other regions. As the attention to reducing the environmental impact has risen across the globe, nevertheless, adapting the standard to different climate conditions has begun to be investigated. This is something that brings up a fundamental question: can the same strategy offer high levels of comfort for different climates? In this regard and in order to evaluate its validity and feasibility under diverse climatic conditions, a number of projects were launched across Europe, such as Passive-On and CEPHEUS (Khalfan and Sharples, 2016), which are highlighted in a later section. Also across the literature, there are many pieces of research in which the Passivhaus thermal and technical performance has been assessed under diverse climatic zones, including Southern, Central and Northern European countries.

Relying on the most used building performance research methods, i.e. monitoring the indoor environment and Post Occupancy Evaluation (POE), the indoor environment of Passivhaus buildings was found to be highly comfortable by a number of studies (see e.g. Schnieders, 2003; Feist et al., 2005; Schnieders and Hermelink, 2006; Mahdavi and Doppelbauer, 2010 and Tuohy et al., 2011). In respect to comfort and energy indices, the performance of more than 100 occupied PH buildings were comprehensively evaluated in Central Europe, mainly in Switzerland, Austria and Germany. This was part of an EU-funded demonstration project called CEPHEUS (Cost Efficient Passive Houses as European Standards). High levels of thermal comfort and energy savings even under summer conditions, inhabitants' satisfaction and the Passivhaus's functional viability at all studied areas are demonstrated by this project. Indoor temperatures exceeding 25 °C, i.e. a fixed threshold that indoor operative temperatures of a PH building should not exceed for more than 10% of the occupied hours per year, were rare. Even though the measured space heat demand was above the calculated one by the Passive House Planning Package (PHPP) in a number of buildings, it was still 80% less than the required one in conventional new buildings (Schnieders, 2003). For this, Schnieders recommended the uptake of this approach in other climate regions. However, such a recommendation could be slightly misleading since it is based too heavily upon data from PH buildings in those cold climate countries.

A comparative study was conducted in Vienna to evaluate the performance of two low-energy flats in comparison with the performance of two Passivhaus flats which were built on the same site and at the same time. Both typologies differed in terms of the ventilation system and thermal insulation level. A user-operated system is used to naturally ventilate low-energy flats, while controlled ventilation is in use in the other apartments. Reasonable thermal performance in all apartments is demonstrated in the outcomes of this study. However, a slightly better indoor environment with a 35% reduction in electrical consumption and a 65% reduction in heating load were accomplished in PH flats (Mahdavi and Doppelbauer, 2010). Perhaps the higher level of thermal insulation in PH apartments gave rise to such differences.

A similar procedure was undertaken in Linköping, Sweden to carry out a research project, where several newly built Passivhaus dwellings were compared to conventional ones in terms of energy use and indoor environment relying on a post-occupancy survey, physical measurements and simulation tools. Even though energy consumption in line with the predictions and good thermal comfort in PH dwellings were demonstrated through the empirical investigations, some complaints were revealed through POE. They were exclusively indicating an exposure to high indoor temperatures during summer, something that was likely attributed to the lack of external shading (Rohdin et al., 2014). This emphasises the role of solar shading in avoiding overheating over the cooling season.

Another comparative study was conducted by Touhy et al. (2011) where three houses, i.e. a 1950s dwelling, a Low Energy House (without MVHR), and the first Scottish Passivhaus, were monitored and assessed. Again, the findings indicate that a thermally comfortable indoor environment accompanied by low energy consumption are successfully provided in the Passivhaus building over the heating season.

In another post-occupancy evaluation in Scotland, the environmental characteristics of 4 certified PH houses that depend upon MVHR system for heating and ventilation were monitored for a 24-month period accompanied by occupant surveys and interviews (see Sharpe and Morgan, 2014). The degree of occupant satisfaction with the performance appeared to be generally high across all the houses with indoor temperatures being slightly higher than expected thanks to occupant behaviour.

Nonetheless, it should be noted that all the mentioned studies so far in this section were concerned with buildings located in countries experiencing cool to cold climates, places where usually the need for cooling indoor spaces is insignificant over the summer period. In such locations, in fact, the temperatures are very often below the minimum indoor temperature threshold requiring buildings to have high levels of insulation to maximise heat retention. Consequently, this scenario may change for Passivhaus buildings in other regions that sometimes, or quite often, require cooling. And this has been asserted by other researches that indicate the potential of summer overheating in Passivhaus buildings even in Central Europe.

For example, a comparative study was conducted in Austria to compare the performance of a social PH housing complex with a similarly built low-energy one. Eighteen PH apartments as well as six low-energy ones were under investigation. The indoor environmental data were measured by employing data loggers, and the inhabitants' degree of satisfaction was assessed via two surveys which used focus group discussions, interviews and written questionnaires. In spite of showing a high degree of inhabitants' satisfaction in the PH apartments in the summer of 2010, the average yearly hours with temperatures ≥25 °C amount to 20.6% (exceeding by far the PHPP criterion) versus 6.8% in the LE housing. Note that the PHPP calculations predicted only 3.5% of overheating hours. Such a performance gap, according to the research, is probably attributed to the fact that external shading devices (with a reduction factor of 50%) were planned but never implemented (Rojas et al., 2016). In realistic terms, however, considering 25 °C as overheating is very ambitious and more energy intensive when compared to other criteria, e.g. CIBSE static or adaptive criteria, where higher temperatures are allowed.

In Slovenia, moreover, collecting and analysing measurements from a single-family Passivhaus dwelling of a wooden frame construction were carried out by Mlakar and Strancar. Their primary focus was placed upon investigating indoor overheating across the house over hot summer periods, a phenomenon that frequently takes place in southern Europe but is not quite usual in Germany. The authors indicated that an increase of a few K in indoor temperatures takes place when in two consecutive weeks a Passivhaus building is exposed to hot weather.

They concluded that keeping the indoor environment thermally comfortable during hot summer days needs the following strategies: minimising internal heat gains, intercepting sunlight from western and southern openings via strict shading, and allowing night-time ventilation by opening windows (Mlakar and Štrancar, 2011).

Apart from the above studies, in milder climate countries of Northern Europe, summer performance and overheating potentials in buildings built to PH standard have been investigated in numerous studies (see e.g. Larsen and Jensen, 2011; Brunsgaard et al., 2012; McLeod et al., 2013; Ridley et al., 2013; Guerra et al., 2013; Ridley et al., 2014; Sameni et al., 2015; Toledo et al., 2016 and Finegan et al., 2020). Some found higher indoor temperatures than predicted and observed a sort of correlation between the overheating risk and the increase of airtightness and insulation levels.

Based on in-situ measurements, a Danish passive house performance in terms of thermal comfort, indoor air quality and energy use had been investigated over the period of three years in a study carried out by Larsen and Jensen (2011). The collected measurements were analysed in comparison with the indoor environment Danish Standards established in CR1752 (category B) that specifies 23 to 26 degrees Celsius as an acceptable range for summertime DBT. Although external shading devices were installed on 'southern and partly eastern and western windows,' summer overheating was reported in the outcomes of this study. During the winter season, in addition, the house experienced insufficient heating (Larsen and Jensen, 2011). However, what is worthy to notice is that during the design phase in the PHPP model none of the mentioned shortcomings was indicated. In this regard, the authors conclude: "The main focus during the design process is left at saving energy not at assuring a comfortable indoor environment," (Larsen and Jensen, 2011, p. 1420). However, one could claim that weaknesses in installation and operation of services, building envelope's construction and detailing or occupant behaviour might have given rise to the gap between the actual performance and the predicted one.

A similar approach was used to carry out a study in London to appraise its first certified PH dwelling, called Camden Passive House built in 2010 with a super insulated and airtight prefabricated timber frame, in relation to energy and thermal performance. The detailed measurements for the period of one year indicate that the building did not completely meet the energy and thermal comfort targets. This is because the house used 4kWh/m^2 more than the total primary energy target and failed to meet BS EN 15251, PHPP and CIBSE overheating criteria even though overheating complaints were not reported by the occupants. In addition, internal gains were found to be higher than the recommended ones by Passivhaus standard. Despite such records, it is still considered as one of the ultra-low energy dwellings in England (Ridley et al., 2013).

Generally, the presence of 'performance gap' means that the measured building performance, i.e. actual, mismatch the predicted performance at the design stage meaning that the building is using less or more energy than expected [Bell et al. (2010) and De Wilde (2014)]. "Overheating is also a performance gap issue if the building models used are not able to predict the overheating risk once the building is occupied" (Mitchel, 2017, p. 2). It is not something that occurs exclusively in buildings built in accordance with the PH standard; rather, it is a common performance-related issue that other building types including low carbon ones experience (see Bell et al., 2010; Gupta and Dantsiou, 2013 and Gupta and Kotopouleas, 2018). In the UK, for instance, the fabric performance gap in new flats and houses designed to meet high thermal standards, e.g. Code for Sustainable Homes (CSH) and Passivhaus, was assessed. This is through using field tests measuring airtightness, thermal transmittance, and heat loss through building envelope along with thermal imaging (Gupta and Kotopouleas, 2018). 188 units with diverse construction systems (ranging from timber frames, traditional masonry to structural insulated panels) distributed all over the UK were selected for the investigations where only 50 of them were PH units. The cross-analysis found the gap to be common across the sample of residential units with Passivhaus ones recording the smallest magnitude of underperformance, something that indicates the robustness of the standard.

In PH buildings, in general, if the indoor temperature exceeded PHPP criterion, i.e. 25 °C, for more than a tenth of total occupied hours or if annual space heat exceeded the limiting standard, i.e. 15 kWh/m^2, the gap would take place. Generally, different factors may contribute to the performance discrepancy and they can be categorised into: those concerning the running stage (i.e. occupant behaviour), those related to the construction phase (such as poor attention to airtightness and insulation), and the factors that associated with the design stage such as miscommunication among the design team, incorrect use of modelling techniques, or using unrealistic input parameters (De Wilde, 2014). As the anticipated performance at the design stage depends normally upon historic weather data files that use long-term averages of temperature and solar radiation with no consideration to possible extreme future conditions, one would expect to have a gap between the actual and anticipated performance to some extent. Moreover, assumptions regarding occupant behaviour often lead to a mismatch between input for any calculations/ simulations and actual values for internal gain and plug loads. Technological developments can also cause a mismatch; for instance, IT-related loads are often higher than anticipated. Furthermore, the actual operation of the building is typically different from the idealized assumptions made in the design stage, both in terms of actual control settings (such as thermostat settings, operation hours, BEMS settings) as well as the broader scope of facility management (De Wilde, 2014).

With this respect, a study presents the performance of a couple of Welsh detached Passivhaus dwellings over the period of two years. Both were built next to each other, but they vary in relation to occupant behaviour, area of installed PV and area of glazing. The energy performance was found to be greatly influenced by 'occupants' electricity consumption behaviour and appliance choices.' Similarly to London's first certified Passivhaus (i.e. Camden passive house), internal gains were observed to be higher in both houses than the recommended ones by Passivhaus standard, and both dwellings failed to achieve BS EN 15251, PHPP and CIBSE overheating criteria. And this is most likely due to the large glazed area used as well as occupant behaviour. Interestingly, the risk of overheating in house 1 (i.e. the one having the larger glazed area) was found to be even greater than the one in the UK dwelling stock, as measured using BS EN 15251 (Ridley et al., 2014). Accordingly, it might be argued that having excessive south-facing glazing in a Passivhaus for passive heating might accomplish the PH target of heating under the climate of Wales even in extreme cold periods, but that may subject the house to overheating during the hot season. The fact that summer performance is greatly influenced by occupant behaviour is supported by a study conducted undertaken by Sameni et al. (2015) who monitored 25 Passivhaus apartments in Coventry during three cooling seasons and observed considerably higher indoor temperatures compared to benchmarks.

These uncertainties concerning summer overheating that surround this fabric first approach have also led a group of researchers (Finegan et al., 2020) in Northern Ireland to carry out investigations on a house built in Cork through PHPP simulations as well as a 12-month period in-situ measurements (mainly temperatures). The focus was primarily placed upon the frequency of overheating across the simulated results and the measured ones to identify the variation between these two sets of data. While the simulated assessments showed no indications of temperatures in excess of 25 °C, their real-world counterparts observed records exceeding that fixed threshold, namely in the habitable rooms. However, there is no clear evidence as to what caused such a failure in meeting the targeted performance.

Given the small sample sizes in most of these researches, however, one could consider their outcomes with respect to overheating and performance gap to be inconclusive and therefore drawing firm conclusions from their evidence seems to be difficult. In response to that, a wider study using multi-year data evaluation was conducted by Mitchel (2017) testing the presence of a performance gap in more than 100 occupied houses throughout the UK in which some of them are certified by the Passivhaus Institute. Data with respect to indoor and outdoor temperatures along with heating loads at hourly intervals were collected focusing on summer overheating and winter heating demand. As the study is meant to be undertaken over a 24-month period, the data of only 31 houses were available at the time of writing this piece of research. And according to the available measurements, the percentage of occupied hours in which indoor temperatures exceed 25 °C remained below 10% in PH dwellings except for one house where the overheating frequency slightly exceeded the standard and reached to 10.67%.

Based on GSA (i.e. Global Sensitivity Analysis) techniques and dynamic simulation modelling, furthermore, some attention has been focused on determining the possible impact of the expected future climate scenarios on the thermal performance of PH buildings in the UK. The findings showed that if there is no move towards whole life design optimisation based on minimising future overheating risks, indoor temperatures will remarkably exceed PHPP and CIBSE benchmarks by 2050 and beyond. Thus, mechanical means of cooling may become a de-facto requirement in urban Passivhaus and low energy dwellings in the UK within the next 30-40 years. In particular, the risk of overheating (OT frequency above 25 °C) was shown to be highly dependent upon the solar transmission reduction provided by a full external shading device, as well as the glazing to wall ratio on the South façade. The findings also showed that thermal mass played a clear role in reducing the overall duration of overheating in the Passivhaus dwellings (McLeod et al., 2013).

Shedding light on a more extreme climate, the question of whether this fabric first approach to design and construction would be effective in Southern Europe has been investigated. One of the earliest studies that examined its feasibility and effectiveness is the Passive-On project. Considering comfort requirements for warmer climates, a set of modifications to the current Passivhaus criteria were proposed to ensure guaranteed results in relation to the indoor environment and energy efficiency. These consist of the introduction of an explicit limit for energy demand for summer cooling (15 kWh/m^2.yr) and minimum requirements for summer comfort where indoor summer temperatures are not to exceed the Adaptive Comfort temperature defined in the EN 15251. And to avoid using an active ventilation system, a more relaxed infiltration rate was introduced (Ford et al., 2007).

As part of the above project, a study was conducted in Marseille, where the maximum temperature exceeds 33 °C, to establish the most suitable design guidelines for an affordable passive house. The performance of a PH dwelling was assessed using dynamic simulation tools based on a design that was applied before in Hannover. Four prototypes, which differed in terms of insulation level, windows' U-value (double or triple glazing) and presence or absence of heat recovery, were tested. The outcomes indicated that none of the four prototypes achieved the PHPP overheating criteria although exterior blinds and night ventilation were used. Nevertheless, when active cooling took place to provide thermal comfort, somewhat lower energy was required in the house that had MVHR, higher insulation level and triple glazing. Interestingly, the house that has the least insulated fabric, double-glazing and no heat recovery system required less annual energy for heating than the other cases (Schnieders, 2005).

In Cesena, Italy, summertime overheating was reportedly taking place in a certified PH multi-storey apartment building called Fiorita Passivhaus. This is where Costanzob et al. (2018) measured thermal parameters of the indoor environment of one of its top-floor flats through a one year-monitoring campaign aiming to further deepen understanding and knowledge of how well such buildings perform in the Mediterranean climate in terms of indoor thermal comfort. Despite its success in ensuring high levels of comfort over the wintertime, the flat failed to achieve that and meet the design goals during the summertime. Temperatures in excess of 25 °C were found to account for 48% of the occupied hours even though the building is fitted with movable perforated sunshade panels. The authors explained this to be likely driven by MVHR not being able to deliver sufficient fresh air, something that led occupants to open windows from time to time. This is besides the fact that the examined flat is located at the top floor where its roof (despite being super insulated) is fully exposed to sun rays.

Based on simulation tools mainly PHPP, furthermore, a comparative study was carried out in Bragadiru, near Bucharest, to appraise the thermal and energy performance of the first Romanian passive office building compared to those of a standard building. For a standard building, the overheating rate and the cooling demand were found to be lower than a PH building, whereas the heating demand was found to be larger. In the Passivhaus office building, a percentage of 31% was estimated to be the overheating rate; however, this rate was decreased significantly through opening the windows at night. The outcomes also underlined that both the cooling load and overheating rate are largely influenced by the maximum acceptable indoor temperature and sources of internal heat. The authors believe that for the Romanian context the use of an active cooling system in Passivhaus buildings is important (Badescu et al., 2010). Nevertheless, the problem with such a belief is that it is based upon the performance of an office building where internal heat gains are generally quite high. And most likely, discovering a higher overheating rate and lower heating demand in the PH building is related to high levels of insulation which avoids heat flux from indoor to outdoor. Consequently, the internal loads will be gathered inside arising indoor temperatures above the comfort conditions; hence, reducing internal gains as well as increasing the ventilation rate may lead to better comfort levels.

The belief that energy demand for cooling in a PH building is largely influenced by comfort parameter settings is strongly supported by a recent study, which sought to explore that in fifteen Southern European Cities, carried out by Guillén-Lambea et al. (2017). The study shows that around 30% saving in cooling energy is attained by changing the temperature set point from 26 °C to 27 °C. However, one could argue that this strategy may not be applicable in all building types, e.g. office buildings, and not everywhere as it may cause thermal discomfort in some places, especially cold climates where lower setpoint temperatures are recommended.

Similarly, the overheating rate was found by Fokaides et al. (2016) to be significant also in the first dwelling constructed according to the Passivhaus approach in Cyprus, the warmest country in Europe where the typical summer season lasts approximately eight months. They employed in-situ measurements and simulation tools to investigate the summer performance of the house with respect to indoor conditions and energy consumption. As a result, initial overheating problems were observed over the cooling season. Interestingly, in some periods the average indoor temperatures were found to be higher than the outdoor ones. The verification of the cooling loads calculated by PHPP reveals that the internal heat loads, as well as solar heat gains, account for more than 50% of the total cooling demand. However, an average reduction of 1.4 °C of the indoor air temperature was achieved by applying an optimized strategy for night ventilation. Also, the increase of the cooling capacity of the HVAC was found to significantly improve the thermal performance of the zone.

With no doubt, providing a PH building with an appropriate cooling strategy under such climate conditions would help to avoid the potential of overheating. In this respect, a study was conducted in Portugal to examine how a Passivhaus would perform under Portugues climate conditions and assess the energy saving potential (Figueiredo et al., 2016). Using dynamic building simulation, a real detached house built in compliance with the national thermal code with the commonly used construction materials and fabric solutions there was upgraded to meet the Passivhaus requirements. A range of building envelope upgrading scenarios and passive design strategies were tested to pick the most viable one. The study found that the annual heating and cooling energy use can be reduced by 42% and 64% respectively when compared to the base case, something that emphasises the viability of the PH approach there and reinforces the need of extending it to warmer climates. The authors also concluded that most likely there would be no need for mechanical cooling to maintain the overheating frequency below 10% if passive cooling strategies were in place and, in particular, if window openings were sufficiently shaded during the summer days.

Apart from the European regions, some researchers question the effectiveness of this approach under warm climatic zones overseas which has not been very often studied across the literature [see e.g. Tubelo et al. (2014); Badescu et al. (2015); Schneider et al. (2015); Khalfan and Sharples (2016); Matsumoto et al. (2017)]. The Smith House in Urbana, Illinois is the first passive house building certified in the USA. In a field investigation, it turns out that the house was having overheating issues during the first summer. The problem was likely driven by unshaded glazed surfaces, something that the founder of Passivhaus Dr Feist himself in a visit expressed concerns over as reported by (Wotzak, 2009).

Badescu et al. (2015) assessed the feasibility of Passive Houses in Southern Hemisphere countries located at reversed latitudes and with similar climatic conditions of typical EU countries. This was through adapting the construction details of a prototype passive building built in Romania. Again, the authors found out that the thickness of thermal insulation may be decreased in warm climates like in South America and New Zealand, thus allowing for capital cost savings and construction simplifications. It was also found that the cooling demand is generally smaller in Southern Hemisphere than in Northern Hemisphere.

On the other hand, Schnieders et al. (2015) simulated the performance of a reference two floor detached house built in Hannover in very different climates, from the very cold city of Yekaterinburg in Russia to the hot-humid city of Abu Dhabi in the Emirates using dynamic building simulations. The study aimed at providing a consistent theoretical basis for the transfer of the Passive House concept to residential buildings in climates that differ fundamentally from central Europe. This work is worthy of attention because it highlights that construction freedom (e.g. selection of materials) is not limited by the Passivhaus requirements presented in section 2.2. The study shows that in Abu Dhabi, where peak summer temperatures reach up to 45 °C or even higher, it is not possible to keep the sensible energy demand for space cooling below 15 $kWh/m^2.yr$, i.e. the allowed limit by the Passivhaus standard. Despite using 26 °C as a cooling setback, the space annual cooling demand exceeded 38 $kWh/m^2.yr$. However, the researchers indicated that less amount could be achieved if the size of window openings is to be reduced to the allowable minimum size. The study also demonstrated that under such climate conditions there is most likely no need for heating supply at all, something that saves the up to 15 $kWh/m^2.yr$ that is usually consumed in buildings certified by the Passivhaus Institute for heating supply. The same conclusion with respect to the heating supply was reached when the model was tested under the tropical climate conditions of Singapore. Based on their simulated results, the researchers conclude that in general when a traditionally insulated base house is turned into a Passivhaus-based one of the same geometry a reduction of 75%-95% in the space conditioning's annual energy use can be achieved regardless of which climate region the model is situated in.

The difficulty of achieving an annual space cooling demand below 15 kWh/m^2 has been evident in another study conducted not far away from Abu Dhabi. In Dubai, Abu-Hijleh and Jaheen (2019) adopted a similar approach to investigate energy-saving potential when applying fabric first principles on a typical villa constructed according to the Dubai building code. Using the IESVE simulation tool, the authors found that a reduction of 47% of annual cooling energy use can be reached if the villa is upgraded in compliance with the PH standard, something that would result in lowering the annual energy bill by 42% to 48%. Despite that, the predicted space cooling demand did not meet the Passivhaus standard and exceeded 56 kWh/m^2. Also with such a cost-saving potential, interestingly, the authors based upon a cost-benefit analysis expected the payback period to be between 119 to 132 years depending on the local market prices. This is something that would likely push many people towards considering it as a poor investment and thereby not adopting the standard. However, no robust evidence was found in favour of such a payback-related claim.

Moving to a more practical approach in conducting building performance research where in-situ measurements were also involved alongside computer simulations, the potential of Passivhaus/fabric first approach under the current and future climate scenarios of Qatar was investigated by a group of researchers at the University of Liverpool (Khalfan and Sharples, 2016). The investigations were carried out on the first ever PH house in Qatar built in 2013 as an experimental residential project with a 200 m^2 floor area aimed to probe the degree to which this building approach would be viable in such a hot climate region. Given the extreme weather conditions, the house was fitted with an air-conditioning system to keep the indoor temperatures below 25 °C, a fixed threshold that indoor operative temperatures of a Passivhaus building should not exceed for more than 10% of the occupied hours per year. The outcomes suggested that building according to the standard would result in lower energy cooling costs while maintaining comfortable indoor temperatures. However, no specific figures were given in terms of how much saving is achieved.

There are also studies that have criticized the implementation of the Passivhaus standard in warmer climates such as in Brazil. Pacheco and Lamberts (2013) take a critical view with relation to the adoption of insulated and airtight fabrics, especially those linked with the Passivhaus standard. The authors argued that the insulated and airtight approach is not necessarily a suitable design strategy for hot climates found in the majority of the Brazilian regions.

2.4 Challenges of adapting the fabric first approach to the context of developing countries

Apart from the climatic viability of the Passivhaus/fabric first approach in different geographical areas and under different climatic conditions, understanding the associated technical and economic challenges in adopting such an approach is of paramount importance. As noted earlier in this chapter, this standard has been adopted much more in Scandinavia and German-speaking states, countries that are highly advanced in terms of building technology. And its implementation has been very limited in developing countries.

It is not clearly discussed that the same strategies taken by those developed countries may not be practical and applicable within the local construction practices in other countries, especially those of the developing world where different socio-economic and socio-technical contexts are in place. They differ in terms of the level of economic development, available information and expertise, legal frameworks, available construction materials, climate and culture. In addressing the question: "what can be a Passive House in your region with your climate?" the founder of Passivhaus Dr Feist emphasises that successful implementation cannot be accomplished by copying details from 'Central European example'; rather, they have to be developed in a way that suit geographic and climatic conditions as well as local construction practices (Feist, 2005).

Whereas some countries have decided to implement the standard as given, other countries have imported the name and the basic principles but revised the calculation method, i.e. they imported the concept but not the standard. Norway, for instance, has adopted the Passive House concept but has developed a specific Norwegian standard (i.e. NS 3700 for residential and NS 3701 for non-residential buildings). This resulted from three years of controversial discussions of the requirements for energy supply, single-family homes (which are common in Norway), and to what extent climate change mitigation should be included (Müller and Berker, 2013).

The question here: how can such a quite sophisticated approach of design and building, an approach that requires extremely high-performance components, be adapted to the context of developing countries in the light of limited economic resources, locally available skills, construction methods and materials? This could be very challenging despite being used and demonstrated in the developed countries.

In general, accepting an innovation or technology and its evolution and growth from emergence to application in a specific environment is not just based on its quality but also on the economic and social factors. And it cannot prosper unless it continues to be supported by this environment or is able to successfully adapt to changes in that environment (Guy and Shove, 2000; Rogers, 2003 and Mondal et al., 2010). In this regard, alongside the environmental performance, it is profoundly believed that social and economic issues must be at the top of the agendas of nations of the developing world when considering sustainable buildings (Gibberd, 2005; Libovich, 2005 and Ali and Al Nsairat, 2009). And this must be the case when considering the uptake of the fabric first approach in the developing world because ensuring that the local priorities and needs are met in their adoption will result in making the probability of successful application much greater.

A successful application of an unfamiliar or new construction method will probably experience problems regarding acceptability and affordability, especially at the beginning when introducing the system. Based on the literature (see e.g. Du Plessis, 2002; Du Plessis, 2007; Bhattacharya and Cropper, 2010; Liu et al., 2010; Kennedy and Basu, 2013; Mlecnik, 2013; Pitts, 2017), a number of difficulties that may impede the strong uptake of low carbon technologies are observed. Liu et al. (2010) identified a number of main barriers hindering the adoption of highly energy-efficient buildings. First of all, poor knowledge and considerable lack of awareness amongst societies of the developing world regarding the importance of low-energy buildings may be considered as a major obstacle impeding their adoption. And by only transferring technology it is not possible to reach the goal (Brown and Vergragt, 2008).

According to Dudley, E. (1993), background knowledge is needed for a community in order for an unfamiliar technology to be transferred and be used successfully, and he believes that any transfer of technology is more often to be unsuccessful without imparting this background. Hence, increasing public awareness and motivation towards energy efficiency and providing accurate and sufficient information are needed. As stated by Du Plessis (2002), this can be done through programmes aiming to educate and raise the awareness of the public, developers, politicians and government officials. Showing the opportunities of having high levels of comfort and energy savings may be influential in convincing and motivating those people to apply energy-efficient standards (Mlecnik, 2013) as they have not been implemented under local conditions causing a lack of trust. In this regard a number of stakeholders such as educational/research institutions, non-governmental organisations, community groups and media can help prepare the ground and ensure the best possible results (UNEP, 2003).

The second challenge to take up low-energy buildings lies in their overall complexity that needs to introduce new design skills and approaches, skilled personnel, new or improved materials/components and construction techniques, as well as additional supervision and inspections, to the mainstream construction industry in many developing countries. The profound impact of this factor on the rate of adopting innovation is emphasised by Rogers (2003) as he believes that the rate will be lower when innovation is more complex. Nevertheless, to construct a building according to PH standard, fully integrated design approach, appropriate skills regarding design and construction, components like high efficient MVHR, windows with high performance, airtightness solutions, low U-value insulation, other relevant materials besides software like the Passive House Planning Package (PHPP) are required (McLeod and Hopfe, 2015). This may negatively influence a certain class of labourers. This is because the technological change that uses high-level skills more intensively may hurt less-skilled workers by increasing the demand for skilled workers and simplifying tasks or allowing the outsourcing of tasks that previously were accomplished by relatively well-paid semiskilled workers (The World Bank, 2008), thereby disrupting the existing construction practices and displacing a certain class of workers.

To make a significant impact, however, innovation does not have to depend upon highly sophisticated technology or be extremely complicated (The World Bank, 2008). In this regard, Cotterell and Dadeby (2012, P. 31) pointed out that:

> *Achieving Passivhaus is not about lots of 'advanced' technology; rather, it is about changing the way we build. This means integrating design for low energy into the plans from day one, designing with an awareness of the impact of form factor, eliminating thermal bridges and radically reducing air leakage compared with standard builds, incorporating additional insulation and making use of solar gain. Once the project goes onsite, the build team needs to work in a more tight-knit, cooperative and mutually trusting way than is currently common in building projects, in order to avoid abortive work and unnecessary costs.*

In this regard, addressing questions of education and skills is necessary. There is no doubt that there are significant differences between those developed countries and countries of the developing world in respect to their mainstream construction industry (Du Plessis, 2002). For each trade in construction, for example, Germany has schools for training which are mandatory for constructors, and wide knowledge dissemination about top construction practices and delivery of suitable training through a powerful framework are provided by this kind of educational net (Cotterell and Dadeby, 2012). And despite being essential, such investments are not made in most building industries in the developing world. Hence, it could be argued that in Germany, the relatively higher skilled and better-integrated construction environment has significantly contributed to the development and widespread adoption of the fabric first approach.

Another major obstacle, which is often under debate, with respect to the adoption of energy-efficient buildings is their perceived costs related to their specific techniques and components, e.g. airtightness solutions and efficient windows. The issue of whether or not a technology is appropriate to be broadly implemented is frequently addressed from an economic point of view whether it is feasible or not. The initial costs of energy-efficient buildings are typically higher than conventional ones (Winkler et al., 2002). In the case of Passivhaus, it could be claimed that it is economically unfeasible. A study shows that a house built to PH standard costs 5-15% more than a conventional house with the same layout and size (Galvin, 2014). However, taking into account the enduring benefits (e.g. energy savings for cooling or heating) that are provided, one should see the additional costs to 'get the fabric right' as a long-term investment. The less cooling demand (or, heating in the cold climates), the more energy is saved, and the less money, including costs of maintenance and replacement, is spent during the lifespan of a building (Cotterell and Dadeby, 2012). Whilst occupants of conventional dwellings are concerned about energy costs, people in PH ones are not (Schnieders and Hermelink, 2006). Hence, the cost benefits could be even higher than that of a conventional building. This may encourage people for a strong uptake of this approach.

Nevertheless, one thing that has to be taken into consideration is that the majority of the population in developing countries have a very limited investment capacity and that technologies and materials that represent increased costs will not easily be adopted (Du Plessis, 2002). The main issue is that they have a shortage of money leading them to spend the minimum capital outlay and live in energy inefficient buildings as they cannot afford low-energy ones. In a region like Iraqi Kurdistan where the majority of the poor live in buildings that do not have heating/cooling, for instance, the economic argument of fabric first approach (i.e. cost benefits) may not help as an incentive. Therefore, the question remains as whether the application of the Passivhaus/fabric first principles would be a good investment in Iraqi Kurdistan. If yes, regardless to all the benefits that can be gained from, would it be affordable for low-income households as well?

Generally, it is agreed that by decreasing the price of new technology or product, e.g. the capital cost of the passive house, the rate of adoption is increased (Rogers, 2003 and Bhattacharya and Cropper, 2010). In this regard, Feist (2005, p. 5) strongly states that "it is not necessary that the solution shift from conventional energy demands to solutions that might be very expensive, like the Zero Energy House. It is sufficient to minimize energy use with simple systems from conventional sources." Despite the cheap labour in the developing countries, the major part of a building's capital cost is spent on used construction materials which most of them are imported from more advanced countries; thus, a notable decrease in the building's value will be achieved if locally-made materials (e.g. from the earth it sits on) were used (Ramage et al., 2010). This is besides the employ of local contractors and professionals as well as providing local maintenance will play a great role, and they will also positively influence the local economy as described by Gibberd (2005). Consequently, by using technology that is inexpensive, based on local inputs and simple to learn, a more compatible and therefore lasting solution was sought that could create value and lower costs over time (Nader, 2010).

2.5 Summary

This chapter focuses on the general theme of this PhD research and introduces the principles of the fabric first approach. Section 2.3 presents an extensive review of the research conducted on the performance of Passivhaus buildings under diverse climatic conditions, while section 2.4 sheds light on the underlying issues that pose challenges to developing countries in mainstreaming the standard. Despite the uncertainties concerning summer overheating risks and the performance gap-related issue, the vast majority agree that the need for cooling and heating is dramatically reduced when building in compliance with the standard. To date, however, studies investigating its feasibility and effectiveness under hot climatic conditions have been very limited, something that reinforces the necessity of studying the robustness of the Passivhaus/fabric first approach under such harsh conditions. Its application in the context of developing countries, however, will likely face socio-economic and technical difficulties affecting the level of investment in applying this standard, something that needs to be addressed when introducing the standard in such contexts.

Chapter 3

Methodological framework

3.1 Overview

As indicated in the introductory chapter, this research intends to investigate the application of fabric first approach within the residential context of Iraqi Kurdistan (KRI) as a potential solution to free people from the increased reliance on energy to maintain a reasonable standard of thermal comfort. This chapter presents the research philosophy and methodological framework, including research design and methods, employed in undertaking the required investigations to fulfil the research aims and objectives. The chapter starts with outlining the relevant research philosophies and how they fit with the nature of this thesis and then moves on to the detailed framework.

3.2 Research philosophy and paradigm

Before considering what methods and strategies to employ in this research, it is important to understand the nature of the research and identify the relevant paradigms that can guide the researcher in his journey. And this is a significant stage in planning and undertaking a research in general, and it is defined, "as the basic belief system or worldview that guides the investigator" (Guba and Lincoln, 1994, p. 105). It is premised on a group of practices, values, concepts and certain assumptions (Johnson and Christensen, 2008). These assumptions guide the researcher in determining appropriate research approaches, strategies, methods and techniques (Saunders et al., 2011). Different research philosophies have been identified through the literature, but the debate has been often pertinent to the adoption of either positivism or interpretivism (Saunders et al., 2011).

Positivism is built on the basis that the truth can only be learnt through the 'scientific method' relying on observations that considered quantifiable, e.g. measurements, (Collins, 2010) requiring to be analysed in a statistical manner. In researches associated with the positivist paradigm, a deductive approach is generally adopted to derive a hypothesis from a scientific theory, and then it is empirically tested and confirmed (Bhattacherjee, 2012). In this paradigm, conducting highly objective research is possible because the researcher is independent of his/her research as he/she depends completely on facts, and this leads to avoiding bias in the research outcomes (Guba and Lincoln, 1994 and Charmaz, 2006). Although generalizing the generated data and repeating studies by others can be easily undertaken for researches associated with this paradigm because of their broad dependence on quantitative approaches, thorough insights and knowledge which could be gained qualitatively might be lost. Therefore, this research could not completely follow the positivist paradigm since understanding the cultural context was central to address some of the research questions and identify the cultural boundaries that determine the nature of the fabric first approach in Iraqi Kurdistan.

According to Interpretivism paradigm, conversely, the context in which the social phenomena take place needs to be understood in order to demonstrate the truth (Collins, 2010) drawn upon subjective explanations that people assign to the phenomena (i.e. subjective perspectives of individuals involved). Each individual's viewpoint, action, attitude and expectation of the same experience, individuals' own backgrounds, the context within which they work and live, the differences between them and the interaction among them are often addressed by interpretivist researchers (Creswell, 2009). In research associated with interpretivist paradigm, unlike positivist research, theories are derived from the observed data through relying heavily upon qualitative methods and an inductive approach to theory (Bhattacherjee, 2012). Their data are known as detailed descriptions of case histories, records, correspondence, entire passages or excerpts from documents, thoughts, beliefs, attitudes, people's experience and their direct quotations, observed behaviours, interactions, events and situations (Patton, 1990). Research outcomes are prone to be biased since the investigator is significantly involved in the process of data collection and interpretative aspects of the study (Snape and Spencer, 2013). Despite the in-depth insights that can be gained using meaning oriented methodologies, e.g. in-depth interviews, due to the impact of personal values and perspectives generalizing the generated data cannot be done. Again, the research could not be completely associated with interpretivism paradigm because some of the research questions required a purely theoretical model (i.e. positivistic) to be tested under the climate conditions of Iraqi Kurdistan.

For addressing different types of research questions, nevertheless, it is believed that combining different methods and methodologies as suitable for the work would be better than falling within one single paradigm. This can be seen in a philosophy called pragmatism believing that the research question is the central determinant of the adopted research paradigm. Pragmatism argues that working within both interpretivism and positivism stances is perfectly possible within the same study (Saunders et al., 2011), so both qualitative and quantitative methods might be combined. Especially in evaluative studies, the necessity of using both methods is evident. And in the absence of this combination of methodologies, conducting a thorough evaluation is arguably not possible (Ritchie, 2013). In short, pragmatism investigators are free to use the research procedures, techniques and methods that fit the nature of their research questions (Creswell, 2009). And since the research aims required working within both interpretivism and positivism paradigms, the researcher has followed pragmatism philosophy. This is to develop a framework that could be involved in generating a culturally and climatically adaptive fabric first approach to design and building within the residential context of Iraqi Kurdistan.

3.3 Methodological framework

The research, as indicated earlier, intends to develop a framework for applying the fabric first approach to design and construction within the residential context of the KRI. Part of the research, i.e. research A, is related to interpretivism approach. This part is focusing on its achievability from a socio-economic point of view that requires a thorough understanding of the cultural context aiming to generate culturally contextualised design and technical interventions. Concurrently, another part identified as research B is purely theoretical, i.e. culturally a-contextual, and is related to positivism approach. This part is focusing on the impact of applying fabric first approach to design and construction from a climactic point of view aiming to gain technical insights and see what level of thermal comfort and reduction in energy use and CO_2 emissions could be achieved in the climate of the KRI.

For that, as indicated earlier, pragmatism approach was adopted in this research to achieve the objectives and test their viability from both perspectives. With such an approach, the researcher was able to explore opportunities and challenges related to the adaptation of the fabric first approach to the hot semi-arid climate of Iraqi Kurdistan in the light of limited economic resources, locally available skills, construction methods and materials.

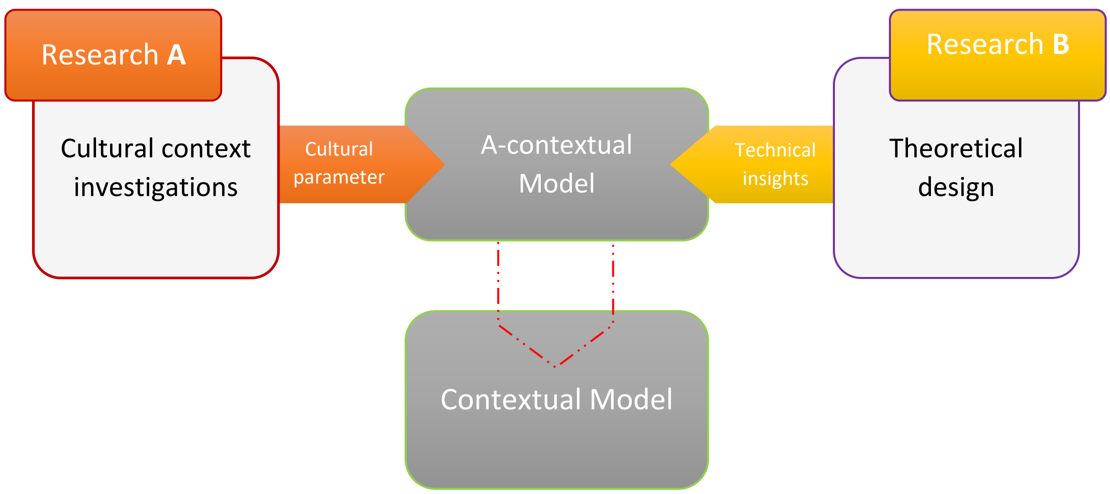


Figure 3.4 The general framework (author)

3.3.1 Research A

In order to situate the theoretical model into the context, investigations (mainly social science ones) were carried out to build a holistic understanding of the cultural dimensions (i.e. social and economic) to define what technical parameters might contribute to the development of an adaptive fabric first approach, i.e. contextual model. It is a self-contained study which sits within the context of an inductive approach where the researcher intends to build a hypothesis based on interpreting and analysing the collected data rather than presuming an existing hypothesis to be tested. Its strength lies in its ability in exploring a broad set of political, cultural, social, technical and economic factors concerning the construction sector in Iraqi Kurdistan which were not initially known to the researcher.

The study also sought to identify the areas that can be progressed to increase the potentiality of successful adoption, discover critical influences of such adoption on the current construction labour and investigate how the key stakeholders can be engaged in this process. This is alongside offering a rich context of the performance within the built environment.

At first, a thorough review on a variety of issues associated with technology diffusion has been undertaken in Chapter 2 aiming to identify from the existing research the main drivers and barriers of adapting low-energy technologies to the socio-economic context of countries of the developing world. At this stage, the researcher aimed to review relevant experiences and theories that might help to develop the research questions and instruments, e.g. the questionnaire and interview guide, as well as tackling possible knowledge gaps.

Following that, an exploratory sequential mixed methods design was employed to detect opportunities and challenges related to applying energy-efficient construction practices within the housing sector in the KRI, as perceived by the stakeholders, at three different levels, i.e. the building level, the target population and the context surrounding them. This method is necessary when a phenomenon or a concept is not clearly defined meaning that little has been written about it which needs a rigorous understanding to be built (Creswell, 2009).

To achieve the purpose of this study presented earlier, the researcher employed the following research tools: (a) questionnaire, (b) in-depth interviews, and (c) case study method (bottom-up approach).

In the first phase, initial insights with respect to questions of energy efficiency measures within the built environment were gathered through a questionnaire survey directed at key stakeholders, i.e. contractors, architects and civil engineers, at the three major cities of Iraqi Kurdistan: Duhok, Erbil and Sulaymaniyah. Then qualitative interviews were carried out as a follow-up to the initial exploration of the questionnaire results. This aimed to explore some of the themes that emerged from the survey in more depth with a smaller group of stakeholders and provide a rich qualitative context of the mainstream construction culture in the KRI and the overriding factors that generally shape its nature. In parallel, the case study method (bottom-up approach) was employed to address questions of thermal comfort and environmental control within the residential context. This was set out with the aim of providing an empirical understanding of performance within the existing building stock of the KRI. Following these three phases of data collection, data were analysed to generate inputs for the theoretical design in order to change the purely hypothetical and a-contextual modelling scenarios to culturally adapted ones. These three research tools are presented in more detail in the next sub-sections.

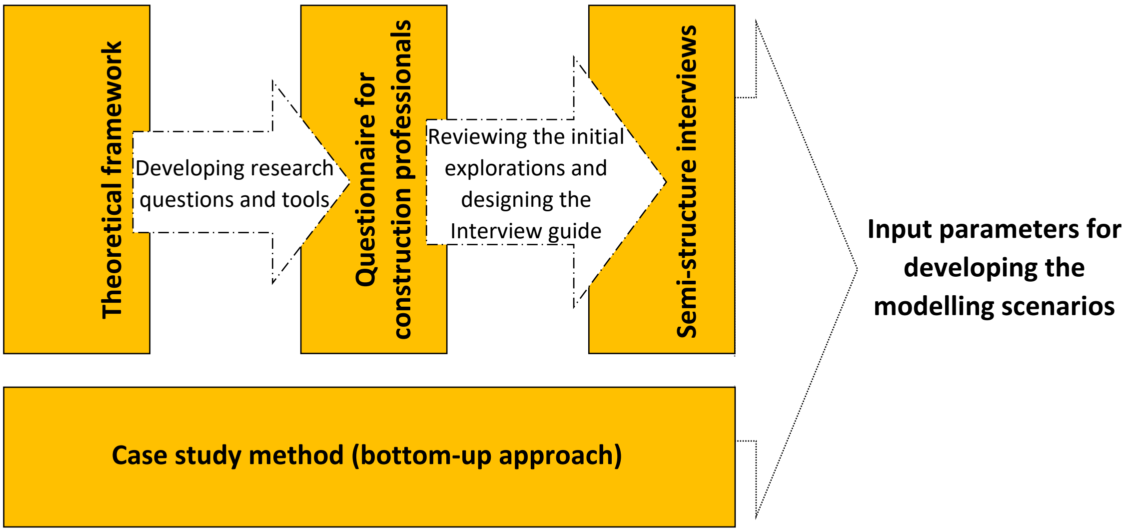


Figure 3.5 Research-A Design

3.3.1.1 Questionnaire

To gather initial data from a variety of construction professionals from different cities of Kurdistan, a questionnaire survey of 4 pages long (see Appendix A) was dedicated consisting of a group of knowledge, opinion and factual questions surrounding the research focus. "A questionnaire is a research instrument consisting of a set of questions (items) intended to capture responses from respondents in a standardized manner. Questions should be designed such that respondents are able to read, understand, and respond to them in a meaningful way" (Bhattacherjee, 2012, p. 74). It was designed using close-ended, open-ended, rating and multiple-choice questions where directions and instructions were available to avoid uncertainty in answering the questions. And to gathering qualitative responses that might supply unexpected insights, text boxes were included at the end of some of the questions. The main purpose was exploring the following key insights about the adoption of low-energy buildings, as perceived by the target group: the current status of existing construction practices, the degree of awareness and demand among the stakeholders as well as barriers, drivers and key actions for such an adoption. There were also demographic questions at the beginning to identify the education level and discipline of the respondents and their years of experience.

The research sought responses from practitioners engaged in the building industry. Due to the inability in identifying and contacting the entire target population, the researcher adopted a snowball sampling technique (see Bryman, 2016) where groups of initially identified participants via Kurdistan Engineers Union (KEU) and colleges of engineering were contacted and then requested for establishing contacts with other people from amongst their acquaintances that met the inclusion criteria. However, "The problem with snowball sampling is that it is very unlikely that the sample will be representative of the population" as pointed out by Bryman (2016, p. 203).

Prior to distributing the questionnaire, three experienced researchers at Kent School of Architecture and Planning were requested to rigorously review it in terms of the number of questions, their format, clarity, accuracy and sequencing, easiness of answering, its overall layout and the time frame needed for completion. This stage, generally, plays a significant role in identifying and eliminating the potential problems giving rise to a decrease in the rate of response (Presser et al., 2004). Following receiving their valuable feedback, the questionnaire was optimised to be further tested and refined through a pilot study. Three local architects having several years of experience in the industry and who were expected to be strong representatives of the target group were involved in filling in the pilot questionnaires, and their comments were used for further improvement to the survey instrument. Then the questionnaire was finalised and a cover letter including an invitation statement, an overview about the research and definitions of some technical words, e.g. computer-based modelling and simulation tools, was attached. Following that, it was submitted to Research Ethics Advisory Group at University of Kent to obtain ethical approval before the distribution.

To ensure a large number of practitioners getting involved, in addition, an additional Arabic version of the questionnaire was prepared and provided to avoid sampling bias (see Appendix A). This is because those who do not know English would not be able to respond to the English version. Getting a precise translation was sought via using dictionaries, i.e. English-Arabic and Arabic-Arabic, as well as consulting a specialist at University Duhok. However, slight differences might be expected across both questionnaire versions because both languages are completely different in terms of functions, structure, and vocabulary. For example, more or less might be covered by an Arabic term than its corresponding English ones.

To carry out the questionnaire survey, according to (Bhattacherjee, 2012, p. 74), it could be self-administered, group-administered or web-based survey as described below:

> ***Self-administered mail survey*** *[is] where the same questionnaire is mailed to a large number of people, and willing respondents can complete the survey at their convenience and return it. Mail surveys are advantageous in that they are unobtrusive, and they are inexpensive to administer. However, response rates from mail surveys tend to be quite low since most people tend to ignore survey requests.*
>
> ***Group-administered questionnaire*** *[is where] a sample of respondents is brought together at a common place and time, and each respondent is asked to complete the survey questionnaire while in that room. Respondents enter their responses independently without interacting with each other.*
>
> ***Web-based surveys*** *are administered over the Internet using interactive forms. Respondents may receive an electronic mail request for participation in the survey with a link to an online website where the survey may be completed. These surveys are very inexpensive to administer, results are instantly recorded in an online database, and the survey can be easily modified if needed. Furthermore, sampling bias may be a significant issue since the survey cannot reach people that do not have computer or Internet access.*

The researcher adopted the 'self-administered questionnaire' to carry out the survey in its first phase. To improve participation rates, however, both mail-based and web-based modes of questionnaires were used. Following questionnaires collection, the responses were coded and analysed through thematic analysis, and then the emerged themes were further investigated through semi-structured interviews. And for this, those who agreed to take part in an interview were asked to leave their contact details at the end of the questionnaire.

3.3.1.2 In-depth interviews

Having conducted the questionnaire survey, the researcher was ready to supplement or corroborate the results through in-depth semi-structured interviews. A key feature of in-depth interviews as pointed out by (Lewis, 2013, p. 58):

> *is their depth of focus on the individual. They provide an opportunity for detailed investigation of each person's personal perspective, for in-depth understanding of the personal context within which the research phenomenon is located, and for very detailed subject coverage. They are the only way to collect data where it is important to set the perspectives heard within the context of personal history or experience; where delicate or complex issues need to be explored at a detailed level, or where it is important to relate different issues to individual personal circumstances.*

With this in mind, in-depth interviews were planned to be undertaken to probe the initial explorations of the questionnaire survey further at a more detailed level and to enable respondents to elaborate on their answers. Accordingly, a guide was designed and developed based upon the responses and themes that emerged from the received questionnaires. And similar to the questionnaire, the interview guide was prepared in both Arabic and English (see Appendix B). Through using open-ended questions, the researcher sought to discuss the progress made to date concerning the implementation of energy efficiency interventions since the Kurdistan Regional Government (KRG) planned for the green construction practices strategy in 2012, identify the weaknesses and strengths of the current building trades and discuss the key concerns and the required actions to promote energy-efficient design in the residential sector with participants more closely. However, refinement to the semi-structured interview guide was iteratively taken place since complementary or additional lines of thought that were central to the research were brought up by participants with the progress of this phase of qualitative data collection. Therefore, the researcher might have asked questions not being mentioned in the interview guide but were picked up on points made by participants.

Purposively, the researcher chose a sample of key stakeholders, i.e. educators, policy makers and practitioners, to be interviewed at this phase of the research based on theoretical sampling. This is described by Glaser and Strauss (1967, p. 45) as, "The process of data collection for generating theory whereby the analyst jointly collects, codes, and analyses his data and decides what data to collect next and where to find them, in order to develop his theory as it emerges. The process of data collection is controlled by the emerging theory, whether substantive or formal."

Participant information sheet (see Appendix B) including invitation statement, the interview agenda, an overview about the research including the issues that were planned to be discussed and some information regarding confidentiality and anonymity was also prepared. This with the interview guide were issued to the sample participants in advance so that they get enough time for thinking about and provide more valuable contribution to the research. For the purposes of enhancing the accuracy of the qualitative analysis of the data from the interview session, moreover, with their consent the majority were recorded through a digital voice recorder. In total, the researcher conducted 15 face-t- face interviews, 2 phone interviews and 2 virtual ones which included: 3 policymakers, 2 regional planners, 5 educators and 9 practitioners. Except one interview which was undertaken in English, the rest were carried out either in Arabic or in Kurdish. Following that, the transcription, translation and thematic analysis of interview recordings took place.

3.3.1.3 Case study method (bottom-up approach)

The case study method was adopted to provide a rigorous evaluation of physical attributes, energy performance and indoor thermal conditions of a sample of dwellings over both summertime and wintertime, and examine occupants' personal knowledge of the building's thermal behaviour and measures by which comfort can be improved. Such an evaluation aimed to generate inputs, e.g. technical parameters, to the development of computer-based models and the establishment of contextual and optimal upgrading strategies for the building fabric across the residential sector.

Taking into account the socio-economic context which cannot be excluded from any in-depth analysis, it was of great importance that the sample represent socioeconomically distinct groups. This is because the fabric upgrading strategies that could fit a certain income group might not be suitable for another one owing to differences in their lifestyles, their strategies of adjusting the indoor thermal conditions, their consumption patterns, and the quality of their buildings. To identify distinct income groups, accordingly, the researcher used a framework set by a Joint Report by the Kurdistan Regional Statistics Office (KRSO) and the International Organization for Migration (IOM) based on a survey conducted on a sample of 13200 households across the three major cities of Iraqi Kurdistan, i.e. Sulaymaniyah, Erbil and Duhok (KRSO and IOM, 2018). Based on such a framework which distributed the surveyed households into eight income groups, four categories were identified to be the target of the research as follow: The first and second one account for nearly 28% and 22% of the surveyed households respectively in which the former group has a monthly income of 250,000 – 500,000 Iraqi Dinars (IQD) whilst the latter earn between 750,000 – 1,000,000 IQD. Households belonging to the former category are more likely to live in small and substandard houses where access to cooling and heating is very limited leading to poor indoor thermal conditions. On the other hand, the third and fourth group account for nearly 0.9% and 0.2% of the surveyed households respectively in which the former group earn between 2,000,000 – 3,000,000 IQD whereas the latter has a monthly income over 5,000,000 IQD (see Fig. 3.3).

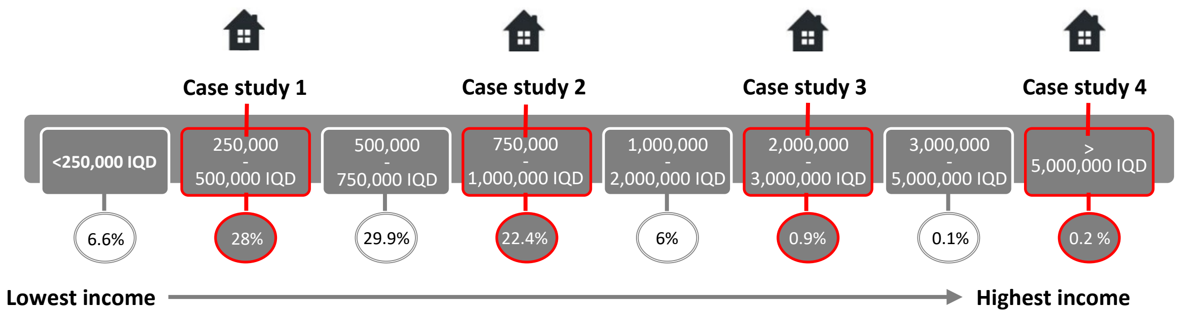


Figure 3.6 The distribution of households based on the categories of the average monthly income, and the selected groups for the research [adapted from KRSO and IOM, 2018]

Having determined the income groups, the next step was to send formal requests to a number of households within each selected group in different areas across the region to allow the researcher to undertake summertime and wintertime investigations in their houses. Several homeowners and/ or tenants agreed to take part in the study. However, bearing in mind the research resources that were available (e.g. data loggers) and the research timeframe, it was decided that one representative case study will be examined for each selected income group. Accordingly, four dwellings ranging from one-storey to two-storey buildings covering a range of floor areas were chosen. Except the first one, which was built in 1970s, the rest of the sample were constructed after 2004. The information about each one of them, including the household information and construction associated details, is presented in detail in chapter 6.

Having selected the dwellings, it was time to choose the appropriate method(s) for data collection. Throughout the literature, the typical approach in undertaking such investigations has been based on physiology and engineering-based methods and evaluations. This has been through monitoring the physical parameters, e.g. temperature and air quality, assessing how buildings actually perform in terms of providing and maintaining thermal comfort. This is besides the application of post-occupancy surveys that take occupant's viewpoint in such assessment, identify their expectations and needs, and rate their degree of satisfaction. With such an approach which has been relatively limited to the technical dimensions of environmental control and physical aspects of thermal comfort, however, one cannot rigorously understand the relationship between the inhabitants and the physical performance of the environment they occupy and the factors shaping that relationship (Leaman et al., 2010). One needs to go beyond that conventional approach and think in a wider sense with increased attention to the nature of that relationship (Cole et al., 2008).

There is a widespread belief that what people consider as a satisfactory thermal environment largely varies from one culture, place, climate or time to another (Chappells & Shove, 2005; Nicol & Roaf, 2017). And with no doubt, the human body's physiological and physical state is no longer seen as the only determinant driving the perception and management of comfort in buildings. It is according to (Chappells & Shove, 2005; Shove et al., 2008) only one element among others, such as socio-cultural context, ways of life, the building attributes, and the available measures by which comfort can be provided.

This belief can be supported by a number of field-based researches showing how influential those underlying components can be. For instance, Leaman & Bordass (2007) show that the expectations, tolerance thresholds, and thermal behavioural patterns of those living in a mechanically controlled environment undoubtedly differ from those who live in a free-running building. Also, a study conducted by Wilhite et al. (1996) compares the way households manage and control the indoor environment of their buildings in Japan and Norway. It indicates the notable impact of cultural differences and available controls which resulted in clear differences in their comfort preferences and practices. Such impact is well analysed and described by Kempton & Lutzenhiser (1992). Another research conducted in a suburb of Copenhagen by Gram-Hanssen (2010) found that even families living in the same type of dwellings could have considerably different heat consumption and behavioural patterns for different reasons, such as thermal preferences and unfamiliarity with the environmental control systems. The study examined the issue from a socio-technical angle employing a combination of quantitative and in-depth qualitative investigations and pointed up the importance of incorporating an occupants-centred approach in conducting building performance researches. Indeed, occupants' engagement in adjusting indoor conditions and its significant impact on performance outcomes is proven (Rijal et al., 2007; Hoes et al., 2009). Such engagement according to Cole et al. (2008) is shaped by a set of contextual, behavioural, cultural, psychological and physiological factors. These are alongside religious and economic ones (Humphreys, 1997). However, their degree of influence varies according to different conditions and circumstances.

In areas such as those of the developing world where the affordability of comfort is a common issue, human behaviour in controlling the environment becomes quite essential. And so considering the inhabitants as an integral part of the overall performance of the environment they occupy underlines the importance of valuing and engaging questions of human agency when studying thermal comfort and environmental control. And this is according to (Gupta & Chandiwala, 2010; Stevenson & Rijal, 2010) can be undertaken through social qualitative analysis offering intimate insights. Bringing this and methods concerning technical aspects together will form a socio-technical regime (Cole et al., 2008).

Drawing on such a regime, the performance of the representative case study dwellings is investigated relying on a close coupling of qualitative and quantitative investigations employing a combination of in situ measurements, observations, and in-depth interviews during summer and winter, four weeks for each. The methods are thoroughly presented in the following sub-sections.

3.3.1.3.1 In situ measurements

Starting with in situ measurements, data collection of the indoor thermal environment, mainly in the occupied spaces in each dwelling, were carried out. Similar to other monitoring researches (e.g. Oreszczyn et al., 2006; Hong et al., 2009; Cantin et al., 2010; Bozonnet et al., 2011; Kavgic et al., 2012; Soebarto and Bennetts, 2014), out of six thermal comfort variables that established in ISO 7730 (2006), relative humidity and indoor dry-bulb temperature were measured continuously at 5-min intervals by employing data loggers, called Tinytag Ultra 2. Its accuracy for RH and temperature is stated to be ±3% and ±0.5 °C respectively, and this is reasonable according to Nicol et al. (2012).

The place in which each logger was hung was carefully chosen aiming for ideal locations taking into account ANSI/ASHRAE Standard 55 guidelines. Householders' guidance was also considered especially in terms of their identification of the main occupied spaces and also the places where they operate portable heaters and/or air coolers within each space. Sensors were positioned away from any source of coolth or heat, e.g. air conditioner, heater, sunlight, cooker, etc. at a height of 2100 mm from the ground level where children cannot reach. This is despite the fact that it is not the ideal height, i.e. 1100 mm is recommended by (ANSI/ASHRAE Standard 55, 2010), as there might be slightly higher temperature at that height compared to inhabitant's sitting level. However, the impact of this slight increase is believed to be insignificant to the overall evaluation. All the sensors were calibrated prior to their installation, and in order to adapt to the indoor environment and avoid taking any inaccurate record, the sensors were placed two hours prior to the measuring starting time.

In addition, external air temperature and RH were also recorded beside the indoor ones at same intervals by utilising a waterproof data logger called Tinytag Plus 2– its accuracy for RH and temperature is ±3% and ±0.5 °C respectively. And to ensure the accuracy of the data, it was installed in a ventilated shelter, called Stevenson Type Screen, shielding the sensor against any radiant heat and precipitation. It is worth noting that the available 'Tinytag Plus 2' sensors for the researcher were only two. Therefore, one was installed in an area located between case-study 1&3 (see Fig. 3.4) in the city of Duhok to monitor the external conditions and provide data for both case studies, and one was installed in the English village in the capital Erbil recording data for case-study 4. And the external data for case-study 2 were acquired from the city's weather station.

Figure 3.7 The locations of one of the outdoor data loggers and case study 1&3 (Adapted from Apple Maps)

Alongside the thermal environment data collection, households' energy consumption data were collected over a period of one year starting from August 01, 2018. Additionally to the existing electric meter that records the amount of electricity that the household consumes through the National Grid (see Fig. 3.5), a smart meter was installed in each selected dwelling to measure their electricity consumption through the alternative source of electricity, i.e. a shared generator operating at neighbourhood level. On a monthly basis, readings were being documented and relevant information regarding the consumed amount of kerosene and the LPG cylinders was being obtained from the households. The annual total consumption then was calculated in kWh for each case study except case-study 2 as the household left the house unoccupied. The conversion of the total consumed amount of kerosene and liquefied petroleum gas (LPG) to kWh was based on fuel conversion factors set by Defra/DECC in 2012.

Figure 3.8 Electric meters in the examined dwellings (author)

3.3.1.3.2 In-depth interviews and observations

The in situ measurements were accompanied by qualitative data collection through semi-structured interviews with the families and tours inside their houses. This stage aimed to provide a thorough understanding of the occupants' personal knowledge about the contribution of the building itself and the available measures in maintaining thermal comfort. This is in addition to establishing a clear picture about their behavioural control actions and strategies in coping with extreme thermal conditions throughout heating and cooling seasons in the light of the constant electricity blackouts that they experience with the National Grid. This type of interview is believed to be effective as it gives more freedom to both researcher and participant to follow new leads (Bernard, 2006).

The first set of interviews was carried out during August 2018, and the second one was undertaken during the following January at their residences. The interview started with collecting some general information such as demographics, socio-economic status of the family, tenure category, period of living in their residence, year of construction, number of inhabitants and some other general data. Not only personal thermal comfort preferences, reactions and experiences that are common in post-occupancy evaluations were addressed but also the contextual factors such as historical, technical, cultural and social influences in improving thermal comfort were discussed similar to thermal comfort's cultural and social analysis (see e.g. Wilhite et al., 1996; Hards, 2013; Hitchings et al., 2015; Moore et al., 2017). Questions regarding their energy-related behaviour and consumption pattern were also addressed (see Appendix C). The thermal comfort scales were the standard 7-point ASHRAE thermal sensation scale and the 5-point thermal preference scale. The thermal sensation scale records an occupant's Thermal Sensation Vote (TSV) on a scale of (hot to cold), while the thermal preference scale asks the occupant what their preferred sensation is, from much cooler to much warmer. Since the interview was carried out in Kurdish which differs from English in terms of functions, structure and vocabulary, however, most of the interviewees had difficulties differentiating between some of the given scales, e.g. warm from hot. For that, directions and instructions were available to avoid uncertainty in answering the questions. Following each interview, the researcher was taken on a tour to carry out some observations, notes and drawings regarding the building attributes and performance as well as prompting the occupants for further elaboration on their everyday practices.

3.3.1.3.3 Thermal assessment

Following the in situ measurements, the recorded RH and air temperatures were exported to Excel to undertake data analysis and generate relevant charts and diagrams on indoor thermal conditions in the examined rooms. In this respect, the comfort temperature (T_{comf}) band needed to be identified to carry out thermal comfort analysis. Due to the absence of local standards of thermal comfort, however, international ones were employed. The residents' behavioural adaptive abilities to changing temperatures that are highlighted in a later section encouraged the use of adaptive thermal comfort models. The most broadly adopted models in such researches are the American ASHRAE 55 and the European standard EN15251. The former model, which derived from an extensive fieldwork conducted by De Dear and Brager (1998) across several countries, predicts the acceptable band of indoor operative temperature from 'prevailing mean outdoor air temperature' ($T_{pma(out)}$) and provides the possibility to be used in areas with no active cooling system and when $T_{pma(out)}$ is greater than 10°C and less than 33.5 °C (ANSI/ASHRAE Standard 55, 2013). According to this model, there is a linear relationship between T_{comf} and $T_{pma(out)}$ in which the former increases with the latter at a rate of 0.31 K per

K. Two acceptability limits of indoor temperatures are offered in this model considering the satisfaction of 90% and 80% of building users with comfort bounds, i.e. T_{lower} and T_{upper}, being 5 K and 7 K apart respectively. In order to calculate $T_{pma(out)}$, ASHARE 55-2013 (as cited in De Vecchi et al., 2015, p. 95) provides three methods as follow:

Method 1: A simple arithmetic mean of all mean daily outdoor air temperatures ($t_{mda(out)}$), calculated with 7 and 30 sequential days prior to the day in question.

Method 2: The weighting method in which the exponential value (α) was set to 0.6 and 0.8 using the exponential equation from ASHRAE 55 (2013) as follows:

$$T_{pma(out)} = (1 - \alpha)\,[t_{e(d-1)} + \alpha t_{e(d-2)} + \alpha^2\, t_{e(d-3)} + \alpha^3\, t_{e(d-4)} + \cdots]\,. \quad (1)$$

Method 3: The published meteorological monthly means for each calendar month.

In a similar way, the EN15251 adaptive model computes the allowable band of indoor operative temperature from 'running mean outdoor air temperature' (T_{rm}) using a linear equation where the former (T_{comf}) increases with the latter at 0.33 K per K rate. The standard offers the possibility to be applied in spaces with no active cooling but with a narrower temperature domain, i.e. 10 °C < T_{rm} < 30 °C, (CEN Standard EN15251, 2007). For this reason, this model could not be applied in the current research since T_{rm}, as appears in the findings, did not fall into the permissible temperature range. It could also be argued that in spite of $T_{pma(out)}$ being within the range of (10°C to 33.5°C), even ASHRAE 55 model might not be applicable in this case. This is due to the fact that cooling technologies, such as air conditioners, were operated in the houses from time to time which is not compatible with ASHRAE terms. Similarly to a number of researches conducted in hot climate areas (see e.g. Nicol et al., 1999; Wong et al., 2002; Bouden and Ghrab, 2005 and Indraganti, 2010), however, the research considers discontinuous using of such environmental controls just a further adaptive opportunity that is practiced during hot periods, unlike central cooling system that runs continuously with predetermined set points.

In order to apply ASHRAE 55 adaptive standard in thermal assessment, indoor operative temperature (T_o), which *is the average of the air temperature* [T_a] *and the mean radiant temperature* [T_r] (ANSI/ASHRAE Standard 55, 2010, p. 13), needed to be known. However, mean radiant temperature was not measured in both summertime and wintertime fieldworks as globe thermometers were not available. And thus with the absence of such a variable, the measured T_a was assumed to be a proxy for T_o. However, such supposition may not be accurate, especially in spaces having high thermal mass.

Apart from that, applying such model in sleeping spaces might be argued as illogical based on the limitation of adaptive opportunities when people are sleeping. Alongside ASHRAE adaptive model, accordingly, CIBSE static criteria were adopted in which 26 °C in bedroom and 28 °C in living space should not be exceeded greater than 1% of annual occupied hours (CIBSE, 2006). Such overheating criteria is also recommended by the Building Control Regime (BCR) developed by UNDP-Iraq.

3.3.2 Research B

This part of the study intended to measure the impact of applying fabric first principles on dwelling's thermal comfort and provide a consistent theoretical basis for such an application in a climate which is remarkably different from Germany draw on guides and criteria that have been pointed out in Chapter 2. It is a purely theoretical investigation and is considered as a parametric self-contained study sitting within the context of positivist research that adopt a deductive approach where the investigator uses new empirical data aiming to testing patterns and concepts recognized in existing theories rather than building a theory. Bear in mind that it is not just about testing, but perhaps refining, improving and extending a theory as well.

The study will focus on the fabric design rather than the whole-house design. And part of the reason is that a particular social class under the scope of this study has a very limited access to cooling and heating services. Besides, many construction experts and researches recommend that the early-stage of progress improving an entire building should be the upgrade of building envelope. It is worth noting that this study is not limited to Iraqi Kurdistan; it might benefit similar climate regions, especially those in the developing world.

At first, an abundance of literature which covers a variety of issues associated with the Passivhaus/fabric first thermal and technical performance under diverse climatic conditions has been reviewed focusing on its viability and feasibility from a climatic point of view (see chapter 2). At this stage, the researcher aimed to review relevant experiences across the world to gain technical insight, identify the possible strengths and weaknesses, and identify the most common research tools in the area. In fact, the climate difference has been one of the raised issues that architects have faced in adopting fabric first approach in different geographical areas. Studies concerning hot climate regions were very limited (e.g. Schnieders, 2005; Schnieders et al., 2015; Fokaides et al., 2016; Khalfan and Sharples, 2016 and Abu-Hijleh and Jaheen, 2019).

Quantitative methods were then used in this study to test objective theories, the framework and research aims and for giving answers by examining the interaction among measured variables using scientific techniques. The theoretical investigation was carried out and technical insights were generated experimentally through employing computer-based modelling techniques (simulation tools). Nevertheless, one should bear in mind as evident that only an approximate scenario to the actual one is offered by simulations, and this might be considered as a limitation in this piece of research.

3.3.2.1 Computer simulation

This is considered as a paradigm shift which enables engineers and designers to undertake thorough assessments for possible designs within probable real-life operating conditions to address a complex dilemma. To put it another way, it helps at the early design phase to emulate future realities. It is an opportunity to evaluate and predict the performance of proposed systems and make changes in a way that improves their performance, lead to quicker, better and cheaper outcomes and contribute in mitigating climate change and protecting environment to match the community's ambitions for sustainability (Clarke, 2007). With increasing energy and environmental awareness across the world, the use of tools to simulate building performance has widely taken place in researches and in practice at the design stage as an integral part to assess indoor thermal comfort and energy efficiency of buildings and to obtain other measurements such as energy costs, CO_2 emissions, etc., especially in nations of the developed world (Nadarajan, M. and Kirubakaran, V., 2016).

Simulation of building thermal performance using digital computers has been an active area of investigation since the 1960s, focusing on load calculations and energy analysis. Over time, the simulation domain has grown richer and more integrated, with available tools integrating simulation of heat and mass transfer in the building fabric, airflow in and through the building, daylighting, and a vast array of system types and components. At the same time, graphical user interfaces that facilitate use of these complex tools have become more and more powerful and more and more widely used (Spitler, 2006). According to Crawley et al. (2008), over the past 50 years, literally hundreds of building energy programs have been developed, enhanced and are in use. Choosing the most appropriate tool for simulation might largely be influenced by the easiness of using the tool and the building characteristics (e.g. air-conditioned and non air-conditioned buildings).

Throughout the existing research, as can be noted in chapter 2, Passive House Planning Package (PHPP) which is Microsoft Excel-based application appeared to be amongst the most common tools in assessing the application of Passivhaus principles and predicting their impact on energy efficiency and thermal comfort. The software comes with worksheets for primary energy demand, electricity demand, heat distribution and supply, and heating energy balance. These are besides the ones for summer performance, shading, and windows that were added to the application at a later stage (Feist et al., 2007 cited in Badescu et al., 2015). The PH approach of the PHI is based on local climate data and altitude, which do not care of the hemisphere. Climate data for several regions in Europe are provided. In case the passive building is placed in a region with no data provided, local climate data can be provided for the registered members of the Passivhaus community. PHPP was created for residential passive buildings design, but it may be used to design non-residential passive buildings (Badescu et al., 2015)

As it is a steady-state simulation tool assuming variables to be constant, however, the researcher opted for a dynamic simulation tool. It was therefore decided to employ an EnergyPlus-based energy modelling tool called DesignBuilder, one of the most widely utilised simulation tools in the industry for examining and predicting comfort, lighting, carbon, and energy performance of buildings [see e.g. Kulkarni et al. (2011), Cardinale et al. (2013), Wang et al. (2015), and Blanco et al. (2016)]. Offering a detailed dynamic thermal simulation and a user friendly graphical interface, the tool enables energy consultants, engineers and designers to undertake thorough thermal and energy assessments. The software allows real and accurate data with respect to construction materials, building geometry, cooling and heating technologies, and occupancy profiles to be inputted. Therefore, professionals can easily visualise possible designs, predict the performance within probable real-life operating conditions and make changes in a way that improves the performance and lead to quicker, better, more affordable, more efficient and more sustainable outcomes. Further details about the modelling process and method are presented in Chapter 7.

3.4 Summary

This chapter introduced in detail the relevant research philosophies and methodological framework developed to fulfil the research aims and objectives, along with the reasoning behind the selection. As indicated earlier, the investigations have to go through a sequence of phases starting from the initial exploration of the cultural context to the development and assessment of fabric first-based upgrading propositions where each phase requires its own research instrument(s) to be accomplished. As a result, the research follows the pragmatism philosophy where different methods and methodologies can be combined as suitable for the work. The next two chapters will present the results of two early phases of the investigations and will establish the contextual background of the mainstream construction culture in the KRI and the possible problems that are faced there concerning the application of energy efficiency measure.

Chapter 4

Energy efficiency and the built environment: Questionnaire Results

4.1 Overview

In this chapter, the researcher presents the initial data collected from a group of professionals working in the construction industry in the Kurdistan region through a questionnaire survey of 4 pages long (see Appendix A). It was distributed in March 2018 targeting 110 practitioners using a snowball sampling technique described earlier in section 3.3.1. The chapter aims to offer some initial insights with respect to questions of energy efficiency measures within the built environment and the level of awareness, demand and interest amongst not only the construction professionals but also the clients. The data are then used in designing and developing the interview guide for further investigations presented in the next chapter aiming to define the underlying factors that could determine the nature of fabric first approach there.

4.2 Questionnaire Results

4.2.1 Profile of respondents

Out of 110 practitioners surveyed from different cities of the KRI, i.e. Duhok, Erbil and Sulaymaniyah, a total of 77 respondents who represent various firms including: architecture (29 respondents), civil engineering (19 respondents), contracting firm (16 respondents), and project management (10 respondents), filled the questionnaire. This corresponds to a 70% response rate which is reasonable (see figure 4.1). The majority received their degrees from Iraqi

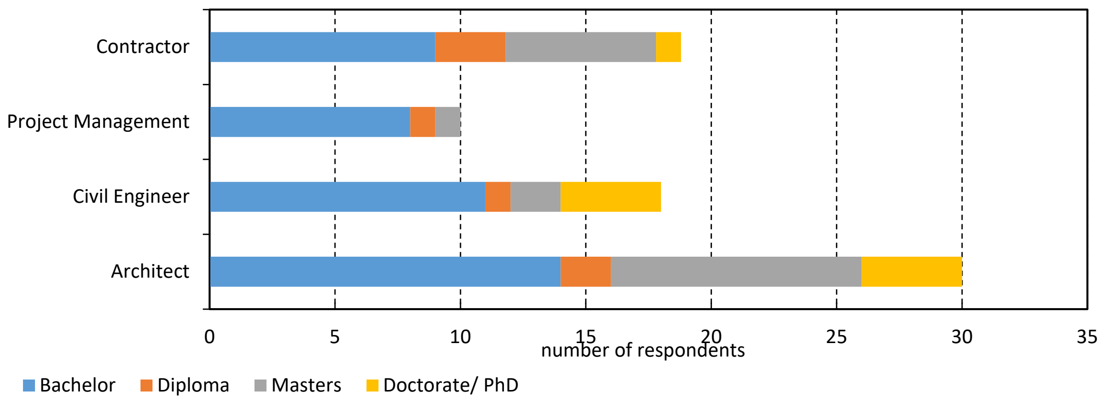


Figure 4.9 Profile of participants (author)

Universities, whereas 22 of them studied in countries like UK (9 respondents), USA (3 respondents), Malaysia (3 respondents), Turkey (2 respondents), Australia (one respondent), France (one respondent), Poland (one respondent), Czech Republic (one respondent) and Syria (one respondent). Their average experience in the construction sector is around 14 years with about one third of the participants having worked for more than 15 years in the building industry (see figure 4.2). Responses are varied and reflect the own experiences of practitioners and their opinions on adopting low-energy buildings in Kurdistan. A number of respondents show very limited experience and knowledge in relation to that.

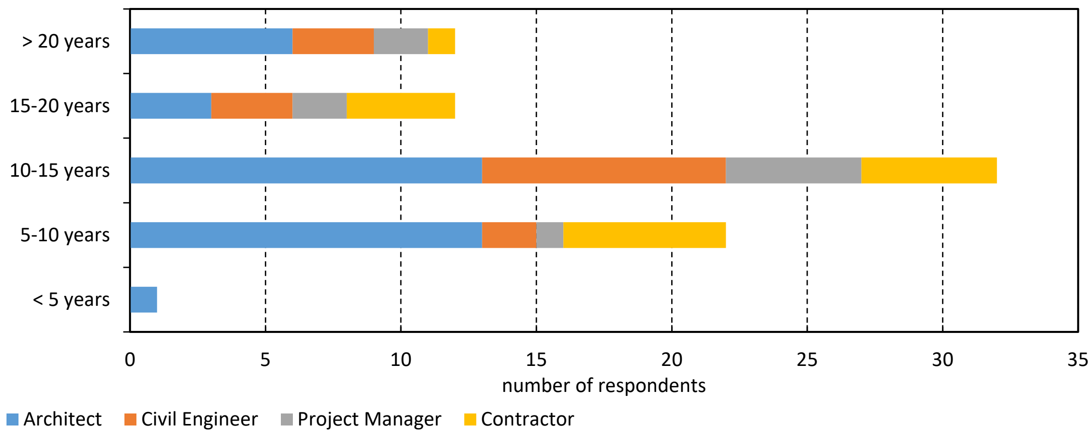


Figure 4.10 The average experience of the respondents (author)

4.2.2 Degree of awareness, interest, and demand in energy efficiency

Practitioners were asked if they are aware of the green strategy set by the Kurdistan regional government (KRG) in 2012 with respect to mainstreaming eco-friendly construction practices. And a text box followed the question in order to allow respondents to explain the reason(s). Out of all the 77 respondents, interestingly, only four claimed that they are aware of the strategy, whereas the rest showed a lack of awareness. Poor communication channels and lack of enforcement were revealed to be the main reasons why the vast majority of practitioners have no idea about such a strategy. And this is highlighted through the following illustrative quotes: "Despite the importance of environmentally friendly building strategies, there are still no serious actions by the KRG on the ground (no enforcement)"; "There could be attempts by the government in this regard. But due to the poor communication between the government and the private sector, these policies have not been circulated by the Kurdistan Engineers Union (KEU) not in the form of an official guidebook nor even through undertaking seminars or conferences raising this issue," and "It is the lack of an effective role of the Engineers Syndicate and the competent authorities in enacting laws and legislations to guide those working in the building sector." These highlighted claims were worthy of further investigation through in-depth interviews with policymakers which will be discussed in the next chapter.

Moreover, respondents were asked to rate the level of demand and interest in energy efficiency measures amongst their clients. Their answers ranged on a five points scale from "very low" to "very high" as shown in figure 4.3. The demand for such measures was rated as low by 24 respondents and very low by 12 respondents. The most often cited reasons for not desiring low-energy buildings can be categorised into the following: the lack of energy awareness, high capital cost and financial constraints, the lack of appropriate standards, and insufficient technical knowledge and tools. And these are highlighted through the following illustrative quotes: "They generally lack energy awareness. They spend a lot of money on the building appearance (aesthetic elements) and when it comes to comfort issues they go for air conditioning systems to cool or heat their buildings"; "Because of the costs of materials, components, and skills needed for low-energy buildings, clients will need to spend more money than what one would normally spend on a conventional building..."; "... Some are in need of basic supply for shelter and have no or very limited budget; therefore the concern about energy efficiency, in my opinion, will not gain the priority for these people..."; "We lack sufficient technical knowledge and tools compatible with energy-efficient buildings" and "... The competent authorities do not have any effective guidelines, policies, and strategies to drive people towards that." In addition to that, other reasons were given by several respondents such as political instability across the region and Iraq, low energy prices, lack of financial support in the form of grants or subsidies, lack of suppliers and companies working strongly in introducing these ideas and techniques (poor supply chain), and lack of demonstration projects. All these barriers, according to the respondents, exert an impact on the likelihood of investment in energy efficiency. Out of all the 77 participants, interestingly, only three of them indicated that the level of demand and interest is very high and 10 of them indicated it as high.

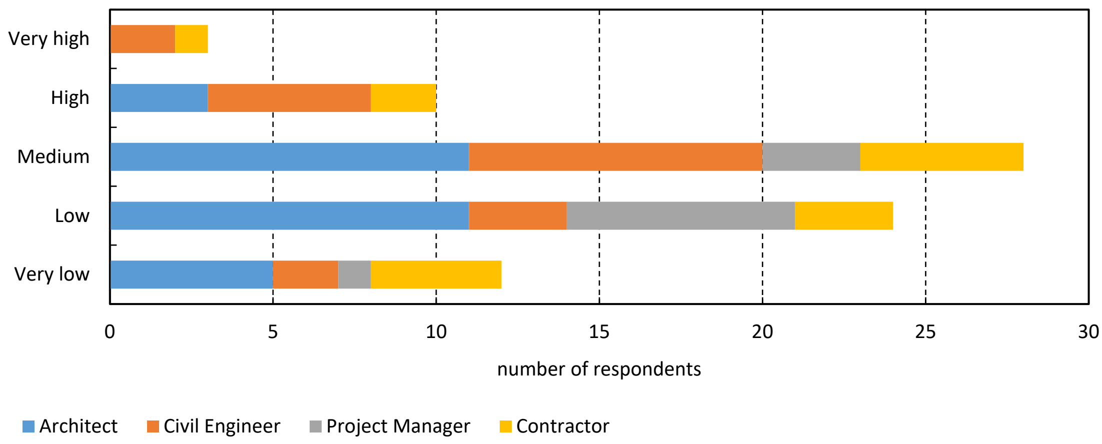


Figure 4.11 The level of demand and interest in energy efficiency measures among clients (author)

Energy and money saving, indoor comfort, power outage, and increase in energy prices were the most often cited motivations for demanding low-energy buildings. And this is illustrated through the following quotes: "Due to the harsh climate conditions, i.e. excessive heat over the summer period and extreme cold over the winter period, besides high rates of energy that is consumed to provide comfort"; "The constant power outage is leading people to look for other alternatives that decrease their energy demand and reduce energy consumption," and "The government keeps increasing the energy prices, and they [clients] often experience electricity outage leading to indoor discomfort." In addition to these motivations, one respondent highlighted the significant role of existing relatively low-energy apartments in encouraging people to go for energy-efficient solutions rather than conventional ones, and he stated that "Since the adoption of some energy efficiency techniques in few housing complexes that show better performance, people have been more interested in these buildings."

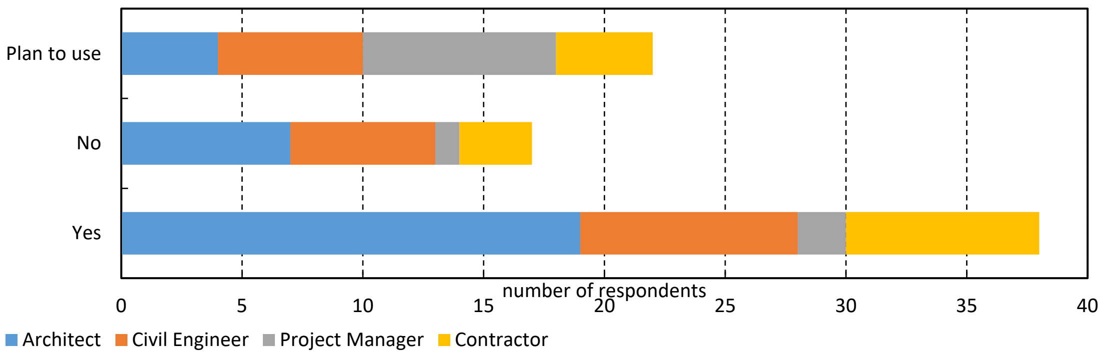


Figure 4.12 Current status of applying energy-saving measures (author)

In addition, practitioners were asked if their firms use energy efficiency methods and techniques. The responses show that about 22% of the respondents do not use energy efficiency measures, while about 27% plan to use. And the rest of the participants claimed that they apply the methods and techniques (see figure 4.4). Out of 37 practitioners who acknowledged their use of energy efficiency measures, interestingly, 19 are architects. Those engaged in adopting energy efficiency measures were asked to identify the type(s) of building that they use the measures for. The residential building is shown to be the most common type associated with that. Through open comments, the responses show similarities amongst the practitioners regarding their methods and techniques, and the most cited ones can be summarised under the following themes: building envelope insulation, passive design techniques, and energy-efficient equipment. Multi-layered walls and roofs including the insulating layer such as polystyrene or glass wool and double glazed windows were the most given technical interventions at which to reduce heat transfer in buildings. Passive techniques such as shading, vegetation, orientation, and window size were also reiterated by several respondents. Moreover, Underfloor Heating System and Air Coolers as energy efficient equipment in addition to using construction materials with higher thermal resistance than of concrete blocks that are available in the local market such as brick and Autoclaved Aerated Concrete block (AAC) were indicated by some respondents. Other measures such as spatial arrangement in accordance to sun path, energy-efficient lights, thermal insulation paints, Standing Seam Cladding, Styrocrete Cladding, and solar panels were shown by few respondents.

Out of 7 factors listed in the survey, furthermore, respondents were asked to identify the most important one that they consider when opting for building materials (see figure 4.5). A text box followed the question in order to allow respondents to explain the reason(s). The answers were diverse. The most important factor was identified by 23 respondents to be durability, whereas thermal properties of the material was considered as the most important one by 22 respondents. Extending building life and reducing the cost of maintenance were the most stated reasons behind choosing durability while avoiding heat loss and heat gain was the main reason for considering the latter factor. The following are two illustrative quotes: "The quality and durability of building materials will increase the life of building which is considered as one of the main priorities among the clients," and "We have really harsh climate conditions in both summer and winter, therefore we seek to use materials that have an excellent thermal resistance to the outdoor climate conditions."

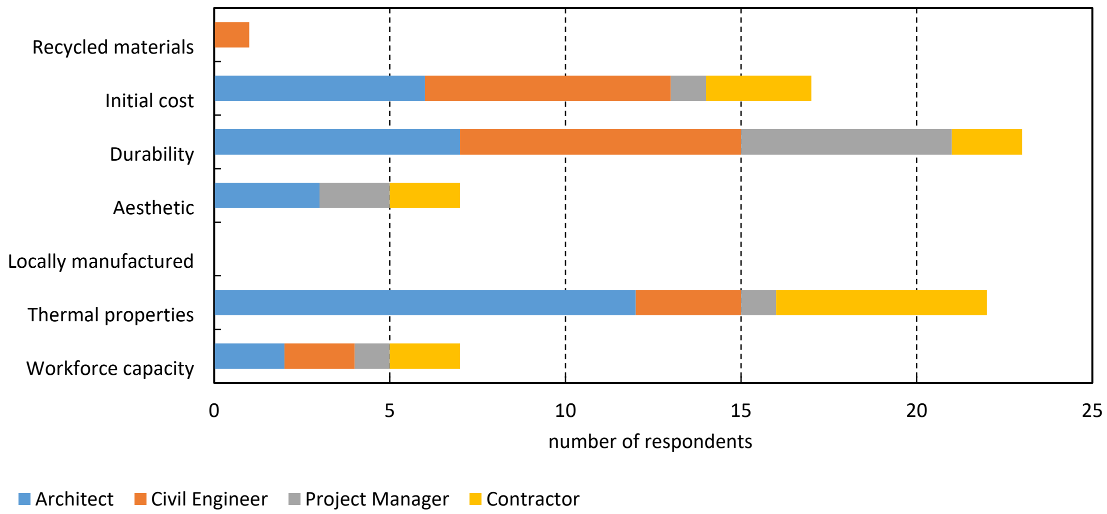


Figure 4.13 Key determinants in deciding which building materials to use (author)

According to the other 17 respondents, the initial cost was considered as the most important factor when choosing building materials predominantly because of budget constraints. The following are two illustrative quotes: "... Due to the social class differences among the clients, however, we sometimes have to pay attention to the initial cost as well" and "Initial cost hinders our work in achieving the better quality that we seek for in terms of thermal performance, aesthetic and even durability." Further, several respondents highlighted the role of technical capacities available among the local workforce, i.e. the labourers' skills, in choosing building materials. This is shown in the following quotes: "There are many materials and techniques, but the lack of skilled workers usually drives you to avoid some of these materials and techniques," and "Most of the labourers are unskilled with limited productivity, using a material which is unfamiliar to them might cause a delay in the implementation period [construction delay]." Then the participants were asked to rate the importance of the 6 factors listed in the survey when choosing building materials, and a five points scale was used from "1: least important" to "5: very important" as shown in table 4.1.

Table 4.2 Degree of importance of six determinants in deciding which building materials to use (author)

Factors	Degree of importance quoted by 77 respondents 1	2	3	4	5	Total respond	Mean	Rank
Durability	0	4	8	29	36	77	4.26	1
Thermal properties of the material	6	7	7	29	28	77	3.86	2
Initial cost	1	11	12	34	19	77	3.77	3
Aesthetic	4	9	10	38	16	77	3.69	4
Locally manufactured	26	12	16	16	7	77	2.56	5
Recycled materials	32	20	11	11	3	77	2.13	6

Moreover, practitioners were asked if they use computer-based modelling to estimate building's energy and thermal performance at the design stage. Their responses show very limited experience and knowledge in relation to that. Out of all the 77 respondents, only seven claimed that they use it. The lack of know-how, incentive and legislation were stated through open comments to be the predominant reasons for not being engaged in using the programs. This is highlighted through the following illustrative quotes: "... There are no training courses in relation to these programs"; "Neither the authority nor people encourage us to use such tools to estimate the energy and thermal performance at the design stage"; "Design fees that are given by the client do not cover the cost and effort of using such programs and providing such estimations" and "Lack of stakeholders' interest to have these estimations, and the authority has not set any regulations in this regard forcing designers to consider these issues." Further, the lack of researches highlighting the importance of simulation tools was also pointed out by one respondent. On the other hand, several respondents claimed that undertaking such estimations is not part of their responsibilities. Apart from that, IES-VE (one respondent), Revit energy analysis (three respondents), and Hourly analysis program (one respondent) were indicated to be used by those who claimed the use of computer-based modelling.

4.2.3 Feasibility of mainstreaming energy efficiency standards

Practitioners were asked if it is time for the housing sector in the region to apply energy efficiency standards. The overwhelming majority, i.e. 98.7 % of participants, believed that to be the right time. And this is predominantly to: save on electricity bills, tackle power outages, and the increased energy demand that the region is currently facing, improve indoor comfort conditions, and protect the environment as pointed out by the majority of respondents. The following are three illustrative quotes: "The region is suffering from the lack of electricity; there are deficiencies in electrical generation, transmission and distribution ..."; "... The majority of the existing housing units are not habitable in the absence of electricity, and people spend a lot of money and consume a large amount of energy for heating and cooling (air-conditioning)" and "For its long-term importance in the housing sector whether at the level of the tenant or the landlord or at the state level instead of spending a lot of money in providing energy for this sector each year." Further, few respondents indicated other reasons that fall into the following areas: population density, energy prices, and climate change. On the other hand, the only respondent, who believed that the time has not come yet to adopt the standards, explained that "Still we have more serious problems in urban design, and municipality regulations, and we are way far from this stage."

Participants were asked to indicate the main drivers for mainstreaming energy-saving measures within the built environment. A list of potential factors, which according to relevant literature are the most common ones in promoting investment in energy efficiency in buildings, was given. And respondents were allowed to tick all that apply. Besides, a text box followed the given drivers in order to allow respondents to add other drivers if they wish. Reducing energy consumption and improving indoor comfort were revealed to be the most important drivers, whereas reducing operating cost (energy bills) and improving health and safety were found to be the second and third most important ones respectively (see table 4.2). Under the 'Other' option, reducing noise pollution from private electricity generators and air conditioners' compressors as well as promoting local production of relevant materials and components as a new investment were also indicated by some respondents.

Table 4.3 Drivers for mainstreaming energy-saving measures within the built environment (author)

Drivers	**Responses**	**Total respond**	**Rank**
Reducing energy consumption	65	77	1
Improve indoor comfort	65	77	2
Reduce operating cost/ lower energy bills (cost benefits)	62	77	3
Improve health and safety	46	77	4
Reduce carbon footprint (protect environment)	44	77	5
Satisfy inhabitants' needs	28	77	6
Other	3	77	7
No benefits	0	77	8

Furthermore, participants were asked to indicate the main barriers impeding the adoption of energy-efficient buildings in the Kurdistan Region. Again a list of potential barriers, based on the literature, was given, and respondents were allowed to tick all that apply. Additionally, a text box followed the list of barriers in order to allow respondents to add other obstacles if they wish. The lack of public awareness (lack of client demand) was found to be the most critical barrier, while the lack of government initiatives was the second highest response. Further, high capital investment and insufficient technical knowledge and skills were found to be the third and fourth critical barriers respectively (see table 4.3). Under the 'Other' option, other barriers were added such as lack of financial support in addition to lack of relevant knowledge among policymakers, and one pointed out that, "KRG is still in the development phase and lacks basic knowledge of adopting energy-efficiency buildings."

Table 4.4 Barriers for mainstreaming energy-saving measures within the built environment (author)

Barriers	Responses	Total respond	Rank
Lack of public awareness (lack of client demand)	65	77	1
Lack of government initiatives	60	77	2
Initial cost investment	53	77	3
Insufficient technical knowledge and skills	45	77	4
Available construction materials	30	77	5
Too complex to implement	6	77	6
Other	2	77	7

The respondents were asked if introducing energy efficiency standards, which might require new skills, is going to be a challenge for the existing construction workers who have not learned those skills. A text box followed the question in order to allow respondents to explain the reason(s). The results show that 44 practitioners out of 77 believe that it is not going to be an issue since the construction workforce learns and adapts easily in addition to the presence of advanced construction companies, i.e. international companies, in the region that can act in this regard. Three illustrative quotes: "They adapt very quickly to new techniques in order to increase their involvement in the building industry with better pay and prospects"; "It is possible to provide a specialized staff who can train laborers periodically to provide the required competence" and "There are foreign companies in Kurdistan such as Turkish and European companies which are very advanced and can provide the skills." Further, few respondents strongly believed that carrying out some successful pilot projects will encourage the construction cadres to learn the relevant techniques within a short period, especially if the demand for such buildings increased in the market. On the other hand, adopting energy-efficient buildings was believed by 33 respondents to be a challenge for the current building labour predominantly due to the lack of skilled craftsmen and the shortage of vocational institutes and training courses. Two illustrative quotes: "The workforce in the region is accustomed to a particular pattern of construction which is somewhat easy for them ..." and "Most of the local construction labourers use traditional construction techniques and there are no institutions seeking to continuously develop their skills." Nevertheless, there was a shared view among the majority of both groups that in order for such adoption to be successful, it is significant to introduce practical and applicable techniques and train the workforce.

Lastly, respondents were asked to indicate the key actions that have to be undertaken to increase the likelihood of adopting low-energy buildings (see table 4.4). Multiple choices were allowed. Raising public awareness was found to be the most important action (69 respondents). One respondent stated in this regard that, "... We can establish the standards but if they do not get acceptance from people, then their adoption will most likely not be successful." Educating and training the workers and introducing new or improved materials and components were indicated to be the second and third important actions respectively.

Table 4.5 Key actions to increase the likelihood of adopting low-energy buildings (author)

Key actions	**Responses**	**Total respond**	**Rank**
Raising public awareness	69	77	1
Education and training	53	77	2
Introducing new or improved materials and components	45	77	3
Establishing standards	41	77	4
Providing demonstration projects [Projects built to prove the viability of energy-efficient buildings]	40	77	5
Providing financial support	36	77	6
Increasing cost effectiveness	24	77	7
Other	2	77	8

4.3 Summary

This section displays some initial explorations with respect to the current status of energy-saving measures in construction and design processes being undertaken across the KRI, the extent to which practitioners are aware of such measures, what impedes/drives their use, and what needs to be done so that such measures take a firm root and become successful in the marketplace. The findings reveal that for sure the energy efficiency movement has not yet gained momentum within the construction sector where all the public, the market, and the existing legislative environment show a very modest interest in energy saving. The results raise some key questions in this regard which require further investigations and form the basis of the qualitative findings presented in the next chapter. These include but not limited to questions associated with the socio-economic status of the target population, ecological consciousness and energy literacy within the community, regulatory measures and the political landscape, construction supply chains, and technical capacity and the quality of those engaged in the construction sector. In the following chapter, these key themes are discussed with a group of stakeholders more closely through in-depth interviews to provide the researcher with detailed information and a deeper understanding of the context. This in turn will help in defining a socio-technical framework that could later be involved whether in formulating the required policy instruments, e.g. support programs, or in generating well-developed and socio-technically contextualised energy-efficiency measures.

Chapter 5

Mainstreaming energy-efficient building practices in Iraqi Kurdistan: The underlying issues

This chapter extends and supplements the early explorations of the questionnaire survey presented in the previous chapter and teases out the little-known areas that emerged. These include but not limited to the key drivers behind the modest interest in energy efficiency among the public, market and existing legislative environment. This is besides the role of education and policymaking in building a roadmap that nurtures the ecological consciousness within the community and makes energy-saving one of the building construction's pillars. The chapter discusses these themes in detail and in the form of a socio-technical framework provides a rich qualitative context of some of the keys to managing and increasing the likelihood of adopting energy efficiency standards in general and the fabric first approach in particular across the built environment in the KRI. The chapter is based predominantly on qualitative data collected from a group of key stakeholders through semi-structured Interviews carried out in April 2018 (see Appendix B for full interview transcripts). The interviewees included policymakers, regional planners, educators, real estate developers, and practitioners (see section 3.3.1.2 for full details about the sampling process).

Based on the findings, the underlying issues that pose challenges to the industry in mainstreaming energy-efficient building practices in Iraqi Kurdistan are grouped into the following:

5.1 Economic barriers

A matter of some concern raised by the interviewees which deters stakeholders, mainly the clients, from shifting towards an energy-efficient built environment in Iraqi Kurdistan is the additional up-front costs required for implementing energy efficiency measures regardless of their many benefits. Generally, the prevailing construction practices in the region cost less when compared to their more environmentally conscious counterparts that require uncommon approaches of design, technical skills, additional time and effort, appropriate construction materials and technologies, etc. The interviewees believe that this causes hesitation and notably influences the design and construction decisions and the desire of having more energy-efficient buildings. This is in the light of a complete absence of mandatory energy efficiency standards and government grants.

There is no question that for the majority of people, the initial cost determines most of the construction details. Even if they wanted to implement energy-efficiency methods and techniques, affordability would remain the key factor in deciding what methods and techniques to use and whether or not to be used. In this respect, a contractor stated:

> *Many know that a significant amount of heat comes in through the roof and they know that something like a green roof or insulation layer is important to avoid that heat. But they think of the initial cost of these features first without taking the life cycle costing into account, so they just don't go for it. They think that if they wanted to sell the house after some years, prospective buyers would assign no value to these additional expenditures in their house and they will not be ready to pay more money for such measures*.

For people with limited income in particular where there are often tight budget constraints, such higher build costs perhaps make the installation of energy-saving measures beyond the bounds of possibility. They normally aim to keep the capital cost as low as possible. In this regard an architect whose most clients are people with very limited investment capacity asserted that implementing such measures is not within the priorities of those clients at all. "They hardly afford the cost of substandard homes, so how can they afford to pay for such measures. This is nonsense. There must be some economically viable ways to do so," the architect said.

These cost-related concerns influence not only the construction nature of self-build homes but also large-scale housing development projects which are built across the region. As they are normally built by profit-driven companies in which their priority is to reap greater cash out from the society, they are highly unlikely interested to invest in energy-efficiency and adopt the measures unless the government force them to do so. Their decisions are reportedly dependent on market preferences and commercial basis that aim to improve sales and increase the profit margins – build to sell. This is with no or little consideration to future needs and the environmental impact of their decisions and choices they make. In this regard, a regional planner stated that, "This is not surprising because you know at the end of the day they [volume housebuilders] are not the ones who will occupy those units and they are not the ones who are going to suffer from things like overheating or high energy consumption. So how would you expect them to build efficient homes?"

5.2 Energy awareness among KRI people

Despite the cost-related constraints, the level of environmental awareness and energy literacy among KRI people seems to be not high enough to drive this transition within the built environment. "People awareness of energy-efficiency and environmental issues is way low. Many of them are still not used to switch off their lights when they go to bed; they are still not used to think of the economic and environmental consequences of such behaviour," says a policymaker. This according to a number of practitioners can be clearly noted among wealthy clients where finances are not a major concern. "Having worked for wealthy people for years I realised that it is more about lack of awareness among people rather than affordability. I have had many clients with no financial barriers at all, yet they were not giving importance to energy efficiency and the demand for such measures amongst them was low," says an architect. When considering designing or buying a property, it is believed that their decisions are fundamentally driven by the visual appeal, aesthetics and the overall spaciousness rather than functionality or environment-related aspects. The lure of fancy often leads them to ignore fundamentals. In this regard, a housing developer stated:

> *Potential buyers tend to prioritize aesthetics above all else. When they come to view a house, they focus on the visual appeal of the exterior and the interior. Things like oversized spaces, High-End Finishes and Exquisite Decorations are very important for them* […] *I understand this may not be in favour of your research and what you are trying to achieve, but indeed, we do not too often receive buyers who really focus on how well our units perform in terms of energy saving.*

Such lack of environmental awareness among KRI people is believed to be attributed to a number of factors:

5.2.1 Political Instability

The first one is related to the high uncertainty of the political system and its inevitable impact on the way individuals think and plan. Being surrounded by states opposed to their aspirations, the KRI has been increasingly susceptible to political instability and uncertainty for generations. A series of destructive events and long-running armed conflicts have been taking place in and around the region, e.g. the systematic destruction of Kurdish villages during the mid-1970s, Iraq-Iran war (1980-88), the Kurdish genocide (1988), the Gulf War (1990-91), civil war between rival Kurdish factions (1994-97), the US invasion of Iraq (2003), the post-Saddam sectarian tensions (2003-present), the war against al-Qaeda and Daesh, the deteriorating humanitarian situation in neighbouring Syria (2011-present), the recurrent Turkish bombing campaigns on Kurdish territories, etc. (see Fig. 5.1). All these catastrophes have generated a widespread human suffering and have undeniably impacted and are continuing to impact people's psyche, way of life, beliefs, attitudes and future decisions they make – a key reason why people generally seem to be short term thinkers as indicated by a number of interviewees. In this regard, a policymaker stated:

> *Short-term mentality is actually dominating the construction industry. No one would set out to build a house to operate optimally for, let's say, the next 20 years because they believe that the region is vulnerable to external threats from their neighbours at any moment. This is besides their constant fear concerning the long-running conflicts amongst the main political parties. So you could say that psychologically and also culturally people are not prepared for long-term thinking and I believe shifting to energy-efficient homes surely needs long-term thinkers.*

Figure 5.14 Some of the major events around the region from the 1970s onwards

The security and peace challenges and the fragility of the region being part of one of the riskiest states across the world have, perhaps understandably, prompted people to adopt short-term and cheap solutions in their buildings at the expense of quality. In this regard, a regional planner pointed out:

> *When you have doubts about your future, of course you will prefer cheap and quick solutions that serve you now without taking future needs into account [...] Let me make it simple for you, when you want a good health you will do workouts every day and maintain a healthy diet and then you will enjoy the benefits as you age. But if you know that your life is in high risk and you may die in the next few years then you will not do that. So similarly to that, with the harsh political landscape that we have, there is no reason for people to think of long-lasting solutions when they build.*

Such presence of political upheaval along with widespread corruption have also left the built environment with little political attention. The increased levels of future uncertainty have likely shortened policymakers' horizons in building a roadmap and undertaking necessary steps to shape the future of construction in the region and developing well-targeted programs and policies that make energy-saving one of building construction's pillars. "Part of the reason why the government has not worked effectively so far on this matter [i.e. energy efficiency and environmental policies] is that the priority has always been given to other vital issues that the region experiences such as political instability, safety and security, economic downturn and so forth," says a policymaker.

5.2.2 Energy pricing

Despite the political instability, another key factor which has left the investment in energy efficiency in the built environment with little public attention is the lack of economic determination due to improper pricing of energy services provided by the government. Energy costs being generally low in this country have not incentivised people to give too high weight to energy saving in their buildings and reduce their consumption. "Being one of the world's largest oil reserves lead people to rely on the cheap oil and inefficient active systems to provide indoor comfort without thinking of energy consumption and its drawbacks. They argue that they have the cheap energy, so why should they think of alternatives" says a regional planner. This indicates how underpaying lighting, cooling, and heating services, to some extent, blunts or wipes out any intention people might have to invest in energy efficiency. In an attempt to explain the impact that improper pricing of energy services might have on occupants' behaviour, an architect stated:

> *I think energy costs have not been supportive to drive people to think of energy-saving and cultivate that awareness. I remember when I was studying in the UK I stayed for some days at a friend's house and one day my wife forgot to switch off the bathroom light and then immediately my friend's little daughter started shouting and saying "turn off the light; turn off the light; it costs money." So you see how her reaction was driven by energy cost, why? Simply because it is expensive. But when you know it is very cheap then why would you think of saving. For instance, when you know the difference in energy bill between consuming energy in an extravagant way and consuming it in a thrifty way is a matter of let's say 10 or 15 USD, then you would not be keen to save.*

This is believed to be an important factor driving people's energy-related behaviour, and its impact can be clearly noted across the region. One apparent example showing how unconscious people are about energy use could be the way people place exterior lights all over their dwellings. They are placed extensively and left ON for hours without even being needed. "You see buildings with tens of exterior lights. It is staggering. If that was costing people a lot of money, I believe they would not do that and waste their money," says an architect. Such a matter has also emerged from the qualitative investigations carried out on the case studies where households, especially lower income ones, were found to irresponsibly and extravagantly consuming the cheap energy, i.e. the one from the national grid, to adjust their indoor conditions [see Chapter 4 and Abdulkareem et al. (2020)].

The impact of energy pricing on clients' attitude towards energy saving can be further noted following an announcement made by the government in 2017. The announcement indicated that there will be policy reforms with respect to electricity in the region aiming to increase the prices and tackle meter tampering and any form of power theft. This, according to a number of architecture firms, has caused a kind of displeasure amongst people. But meanwhile, it evidently resulted in a notable change in client views concerning building design towards seeing energy saving as something worth spending time and money on. As a result, the demand for energy saving measures began to surface and clients began to ask for measures that reduce their consumption, such as introducing sufficient daylight to avoid the ongoing running of artificial lights, insulating the building envelop to reduce heating/cooling loads etc. An architect stated: "Clients have started looking for the possible ways that would increase the energy efficiency of their buildings. They started to use double or triple-pane windows instead of single ones. Even the window frames, people are looking for the types that have a thermal barrier to avoid any form of heat losses around window frames." All this has been reportedly driven by the potential increase in energy prices.

5.2.3 Building Legislation

The absolute absence of mandatory energy efficiency standards is another key factor leaving the investment in energy efficiency in the built environment with little public attention. Despite the government's claims to closely consider sustainable development, the protection of the region's environment and the preservation of its natural resources in line with international environmental laws, the building sector has gained no tangible result out of such claims. There is still no Energy Conservation Building Code and regulation in the KRI in which homebuilders, design professionals and real estate developers comply with. This has left design and construction practices across the region not to be subjected to any obligatory requirements that concern sustainability and energy efficiency as a consequence of the construction permit issuance process not being subjected to such requirements. There are only 3-4 pages of general recommendations, e.g. recommended construction materials and colours, available within the Iraqi housing standards which were set in 1982 concerning environmental design, but they are hardly considered by KRI's architects and engineers.

In underlining the impact of such a legislative matter on design and construction practices in the Kurdistan region, an architectural educator pointed out that even when some of their graduates go to the field and try to apply what they have learned and implement measures that minimise energy use, their ideas are often rejected by clients. "They would tell you that your ideas are good, but they have not been imposed or even recommended by the local government so why would we apply such techniques," says the architectural educator. The situation, according to the interviewees, will probably continue as it is if no regulations are established. One cannot deny that architects can play a significant role in increasing energy and environmental awareness among their clients, but with no government interventions, they alone cannot take the responsibility of pushing clients towards the adoption of energy-efficient designs. In this regard a design professional pointed out:

> *When the municipality does not have such requirements and does not give due consideration to the energy performance of buildings, you as a designer cannot force your clients to spend more money on energy-saving measures. But if there were regulations and strict enforcement then people will have no choice except complying with these regulations because in this case if the design doesn't comply with the established standards when you apply for the Building Permit then the application will be rejected by the municipality and they will not allow you to build.*

In the KRI, in general, there is a lack of legal authority to impose demands guaranteeing the quality and efficiency of the built environment. Within the region's laws, in fact, there is no legislation or a certain article that seeks regulating, mandating, or specifying requirements and regulations for the design, construction, and installation practices. Municipal committees that are responsible for issuing construction permits and approvals carry out their evaluations depending generally on their personal knowledge and capacities. And design and construction professionals mostly rely on the knowledge and skills gained at university as well as their experiences and preferences. "Some architects focus on improving thermal and energy performance of buildings for better living conditions while others are not interested in that; they pay for instance more attention to aesthetics," says a contractor.

To address the gap, municipalities have taken some modest steps and developed and issued a set of ordinances, i.e. a bundle of instructions which have an ad hoc nature, for architects and engineers to rely on when designing and constructing buildings. However, these ordinances are not regionally unified as each municipality develops its own ones with no coordination with their counterparts in other cities. And generally, they are not comprehensive enough to bridge the gap arising from the absence of building regulation and codes. They are restricted to some simple spatial and accessibility requirements, fire safety measures, construction site safety rules and some basic zoning restrictions, e.g. building setback, floor area ratio (FAR), height of buildings (number of stories), etc. And despite their simplicity and limitation, the competent authorities have been evidently unsuccessful in enforcing them. "Within one neighbourhood, you see buildings with different design patterns, different construction materials, and different colours which have resulted in a kind of visual pollution," says an architect. Such failure in enforcing those municipal ordinances, according to a number of practitioners, is highly attributed to the weak review process when issuing building permits and the poor government oversight at the implementation phase as a result of the lack of qualified inspectors. In this regard, a regional planner gave an example that shows how poor the building inspection is in the region and stated:

> *Permit drawings that are submitted by some design professionals to obtain a building permit, especially for small buildings, are most likely different from the ones that are implemented on the ground. What they do is that they try to make ideal drawings that comply with the available ordinances to obtain a building permit and then do whatever they or their clients want even if it does not meet those instructions.*

To tackle these issues, more recently, a team from UN-Habitat in partnership with the KRI's Council of Ministers through a project funded by UNDP-Iraq has been developing a Building Control Regime (BCR) to be established in the region. Advancements are being made and the final draft is currently under review for government approval. And its overall objective is to develop applicable and practical building codes concerning safety, health, construction quality and energy-efficiency within the built environment. This is in a way that suits the socio-technical and socio-economic context of the region and provide implementation plans, both short-term and long-term ones.

In a conversation, which revolved around the nature and progress of their project, with one of the key members of the team, however, the researcher was told that the codes are not as developed as their international counterparts. This is owing to the constraints and challenges that the Kurdistan region experiences. The proposed energy efficiency code, for instance, sets out to build a floor allowing a gradual introduction of energy efficiency measures into the built environment. "Whilst the Energy Performance of Buildings Directive requested the EU member states accomplishing the target of 'nearly zero energy building' for every new building by 2020, this goal is highly unlikely to be feasible in our region […] Our current situation drives us to act in a simplified way to introduce less stringent criteria and measures that can be straightforwardly managed by parties engaged in the construction industry," the team member said. Therefore, the code proposes a two-step implementation phase with less ambitious targets as follow: The first phase is characterised by limited but easy to apply requirements to be applied in the first 5 years from the issuance of this code, a period where parties engaged in the construction industry develop their capacities and prepare for the second phase which tends to impose more strict, advanced and ambitious requirements and measures after those five years.

5.2.4 Conformity to the norm

Conformity to the norm is another factor leaving energy-saving measures with little public attention. Instead of being more individualistic in designing their own homes, people are generally bound by design and construction patterns that are most prevalent within the industry and thereby are most marketable. They seem to be sceptical of change and often look for the same things and blindly copy the choices of others. "Sometimes you get a client (a family of two) with requirements that are just like those that a family of ten normally demand […] When you explain and try to convince them with different or maybe new ideas, they would still prefer something that they have seen on the ground and a design that is similar to what others have built even if it has lots of shortcomings," says an architect. Another one stated: "When a client comes with a north-facing plot, you know the problems with such plots with respect to winter sun, so I tell them that instead of having a front garden or front yard, we can do a backyard which will help to have south-facing windows so that you get the desirable sunlight. But many reject the idea saying that the houses next door haven't done that so why would we do." This underlines the tendency to imitation among the KRI people and how an agent is affected by choices others made. This factor, according to a number of local design professionals, was also a key driver behind the increased demand for double-height central living spaces over the last few decades despite the difficulties households experience in heating and cooling such a space. "You can almost say that double-height living space was often one of the main requirements amongst clients without even knowing the pros and cons of such a space. And when I was asking for the reason, they were often saying that they have seen it in a house and they like it," a design professional said.

Since low-energy designs have not yet made their way to become a trend in Iraqi Kurdistan, there is a widespread belief that adopting such a design approach which is quite different from what people used to could be a risk in the sense that the public might assign no value to such measures. "For many people, it sounds like gambling on something that is new, uncommon and unproven. You know there is that concern in which you start to question what if these buildings [energy-efficient ones] fail to deliver what they are promising," said an architect. This level of uncertainty, according to a number of practitioners, is partly driven by the shortage of demonstration projects and concrete examples on the ground demonstrating the significant benefits of energy-efficiency measures which in turn could have encouraged stakeholders to adopt them. "People need to see what these energy-saving measures can really do and perceive the added value; otherwise, it is difficult to persuade them verbally […] the better the visibility, the greater the public awareness, certitude and trust," says an engineer. This could have shortened the time that energy-efficient designs make their way to be a growing trend within the industry. Such an impact has started to be noted to some extent in recent years following the construction of some of the relatively low-energy housing developments where high quality windows and thermal insulation were used within the fabric. People reportedly started hearing from the residents of these housing developments how they consume less energy whether in winter or in summer while having a relatively pleasant indoor environment. And such features, according to the interviewees, prompted many people to move and settle in those housing units.

5.2.5 Lack of environmental education

Additionally to the aforementioned factors, the lack of energy awareness among people from educators' point of view is to some extent correlated to the lack of environmental education in the KRI's educational institutions. Educators believe that education in the region is not playing an effective role in nurturing the ecological consciousness and responsibility within the community. This is besides its failure in strengthening the capacity of the young generations and reshaping their value systems in such a way that they enthusiastically support the transition toward an energy-efficient and sustainable built environment and make choices which limit environmental harm. "Educational institutions should have instilled in each member of the society the values, attitudes and knowledge needed to catalyse such a transition and secure an eco-friendly future. But unfortunately these things are almost not given due weight in our institutions," says an educator. This is why there was a general belief amongst them that it will probably take at least one generation, with of course some environmental education initiatives, for this transition to boost and be a nationwide interest.

Understandably, when individuals are not exposed to such knowledge and principles over the school years and when they are not developing a deep understanding of the impact of energy consumption on region's economy, environment, and on the energy systems in general, then the degree to which they respond to such issues and take the required measures would perhaps be less. Such an influence, according to design professionals, can be noted among clients who lived and/or took their studies abroad in western countries being more cosmopolitan in their ideas. They seem to be increasingly passionate about energy saving and most willing to insulate their homes, especially if they are financially secure enough to do so. "They focus a lot on details related to the thermal efficiency of the design and comfort aspects and even sometimes they show you examples of techniques that they have seen abroad and ask you to apply them in the design of their houses," says an architect.

5.3 Technical complexity and the mainstream construction industry

Technical complexity embodied in designing and constructing low-energy buildings has emerged as another barrier that could slow down the diffusion of such buildings within the built environment. Such a barrier according to a number of interviewees makes parties involved in design and building phases reluctant to adopt such a detailed approach and reliably fulfil this transition and as a result lengthen the time that energy-efficient building design makes its way to be a growing trend within the industry. The interviewees ascribed this primarily to the following factors:

5.3.1 Technical and environmental knowledge amongst building professionals

The first one is related to the degree to which building professionals are aware of low-energy design and construction methods which are obviously much more complex and detailed than the conventional methods they regularly utilise. And thus, they require more rigorous technical background knowledge, higher levels of thought and holistic understanding of the whole system including the way measures are put together and work together. And this is seen as a challenge for the majority of indigenous design and construction teams as they are reportedly not up to the required standard from a technical and environmental angle and lack the necessary skills. "We have a shortage of adequate skills. We actually have designers who lack some basic technical knowledge which architecture students were being taught in the 1970s and 1980s [...] Does everyone [every design professional] know enough about energy efficiency and how it can be optimised or even calculated? Does everyone really understand the building physics? Or does everyone understand for instance how heat transfers into and out of the building and how that must be controlled? I guess the answer would be NO," a regional planner said. Such a statement is not surprising; it can be supported by data collected through the earlier questionnaire where in one of the questions practitioners were asked to identify the measures that they use to improve the energy efficiency of a building. And a number were referring to some poor conventional construction techniques, e.g. external walls built with hollow concrete blocks, as energy efficiency measures that they normally utilise.

Imagining a widespread adoption of energy-saving measures might be difficult if these key stakeholders are not very well familiar with and lack the required knowledge and expertise. And one should not forget their significant influence on construction decisions and choices that clients make. In this regard, an architect stated: "If I have no strong background on for instance something like thermal insulation or let’s say airtightness, then when a client requests a design of course I will not draw his/her attention to such aspects and will unlikely opt for an airtight and low-energy construction method."

This unfamiliarity and lack of environmental knowledge amongst design teams is believed to be driven to some extent by the quality of architecture and construction education at KRI's universities where environmental and technical knowledge is paid no close attention to. Even though architecture curriculum include technical-based subjects where students gain knowledge about building technologies, environmental design and other issues related to sustainability, these areas of knowledge are generally ignored and are not translated effectively into practice.

To identify the reason(s) behind that, the researcher interviewed educators across various architecture schools. The prevailing design and construction trends within the building industry are found to exert a considerable influence on what architecture students focus on over their university years. Students reportedly look at the building industry and see what the most common trends are and the skills and areas of knowledge needed to stay competitive when they graduate, and thereby place the highest emphasis on that. When students find that what generally matters for clients are purely aesthetics and visual effects, they keep their focus on that over their university years. In this regard an educator stated: "If students knew that energy-efficiency, thermal comfort, functionality of building and these aspects are key requirements among clients, developers and construction companies, then they will surely give due consideration to them and build up the necessary skills in accordance to that so that they can be prepared to practice in the field."

Apart from such an industry influence, educators agreed that in the curriculum there is compartmentation and a lack of horizontal integration. "Design tutors never ask students in design studio to consider for example environmental aspects or apply what they learn in technical subjects. And you can say that the assessment is purely based on how their designs are architecturally developed," an educator said. Another one pointed out that, "When a student knows that his/her design will not be downgraded if it is not developed environmentally, he/she will most likely ignore the environmental aspects." This is additionally to the fact that there is a shortage of tutors who know enough about those areas of knowledge and can confidently inspire students to apply them in their designs and translate them into practice in the future when they graduate and practice in the industry. "Most of our educators are not even interested in environmental design and energy saving," a professor said.

In underlining the consequences of such an educational matter on the way architects generally design and build in the Kurdistan region, a well-known local architect talked about his experience in the field and stated:

> *I could be an example; I had worked for several years with a big construction company where I was involved in designing and constructing many projects where some of them were very strategic projects like Family Mall* [It is a well-known shopping centre in the region]*. And sadly all the work had been without assigning value to their thermal and energy efficiency. Why? Because my team and I were not aware of these issues. But since I went abroad and took some courses in sustainable architecture and environmental*

design, my design approach has significantly changed. Now, I find myself guilty of not thinking of energy performance of all those projects, especially the Family Mall one as it is a mega project and energy consumption there is incredibly high. If we were aware of energy-efficiency measures and their importance at that time, we would have surely developed a much better design.

5.3.2 The current fee levels

Despite the aforementioned factor, there are designers who have adequate technical and environmental competency and possess the necessary skills but the potential increase in design complexity still makes them reluctant to integrate environmental thinking and methods into the current construction practices. And this is primarily driven by the current fee levels for the profession discouraging them to make more effort. "It is difficult to make more effort and spend additional time to ensure the quality and efficiency of a building design when you know it is not going to be rewarded or appreciated enough. Of course there are clients who give you the kind of credit that you deserve but they are not too many," an architect said. In general, the amount of cash that design professionals get for the services they provide, according to the interviewees, is significantly low. This is when compared to the level of thought and the incredible amount of time, work and coordination that goes into producing a building design. Such a fact makes it increasingly hard for those designers to work harder and expend more effort to push the boundaries of building design and carry out energy and thermal comfort analysis and calculations to generate well-developed and socio-technically contextualised measures. "You almost feel like you are not interested or committed to the long-term success of the building project," an architect said.

In the light of having no mandatory fee scales set by the Kurdistan Engineers Union (KEU), the fear of losing clients, according to the interviewees, is the key reason those qualified designers hesitate to raise their rates. In this regard, an architect pointed out that in the KRI the architect is normally chosen on the basis of how cheap his/her rates are. And he continued by saying: "If you increase your fee in accordance with the success and considerable value that you add to projects, most clients will likely go elsewhere to have one of those crude and repetitive designs at a lower cost." And this fear of losing clients, in turn, drives some of them to turn their backs on the quality and efficiency of their designs and resort to outdated and less detailed construction methods which require much less effort and time investment. This is besides reusing design solutions from previous projects without undertaking major changes.

5.3.3 The quality of the workforce

Another pressing issue that might pose a particular challenge to the industry in mainstreaming energy-efficient building practices is the quality of the workforce. Finding qualified construction trades workers needed to ease this transition within the construction sector, according to the interviewees, is not an easy task. This is because the KRI's local construction workforce is generally not involved in any form of systematic formal training; it is either craft skills inherited from forefathers or gained by trail-and-error. "We actually suffer an increasing informal labour. We often deal with people like builders, carpenters, craft workers, technicians and installers who cannot even read construction blueprints. The majority are inadequately educated; they have entered craft careers with no or low levels of education," an architect said.

The interviewees ascribed this skilled manpower shortage substantially to the lack of skills-development strategy in the region which in turn could have imparted the necessary knowledge and skills to the labour force through vocational education and training schemes. There are, in fact, technical and vocational schools nationwide meant to create strong pathways into the labour-market, but they are not functioning as good as they should be. In the 1970s and 1980s, the key construction tradesmen were legally required to undergo formal training at those schools and prove their credentials for entry into the field of construction. But following the comprehensive economic sanctions imposed by the UN Security Council against Iraq in 1990, the government decided to remove such restrictions and let individuals get a foothold within the construction industry without joining such schools. And this decision, according to the interviewees, was entirely driven by the economic implications of those sanctions. And since that time, the country has no robust skills-development strategy and those schools have not taken the lead in providing the industry with adequately trained labour. This has been resulting in an increasing informality within the building sector, and in many cases, has led developers and construction companies to either hire a foreign labour force such as Turkish, Iranian or Syrian ones or provide some form of on-site practical training to the local workforce, especially in sizeable projects or if the building design required unusual technical skills. In this regard, an architect talked about his experience with local labourers and some of the technical issues which arose in his first attempt to build a super insulated villa in the city of Duhok and stated:

> *There were some challenging moments during the construction process. The labourers were actually finding difficulties in dealing with the design of the fabric. So the project manager and I had to stay there most of the time to oversee their work and guide them. It was indeed a very time-consuming process* [….] *One of the problems that I remember we faced was that after the installation of Rockwool insulation, gypsum board, wallpapering and all stuff, those were installing the radiant heating system were unable*

to hang the radiators on plasterboard. So we had to undertake rework across the villa and remove the plasterboard and Rock wool from the wall at different areas and then connect wall brackets with walls to support radiators and then reinstall the insulation layer, plasterboard and wallpaper again. And this caused some problems with respect to the agreed timeline as well as the budget.

This skilled manpower shortage could in one way or another determine how fast energy-efficient building practices will grow across the region. However, the level of impact may considerably vary from a city to another owing to the knowledge and skills possessed by the available workforce. In the capital, for instance, this shortage is reportedly way lower and practical skills are much more advanced compared to other areas, thanks to the level of urban growth and real estate investment into the capital. These are alongside the presence of international experienced contractors and foreign-based construction companies and labour force there creating a kind of multicultural working environment. And this has notably contributed to strengthening the skills of the local workforce and building capacities there.

5.4 Discussion and conclusion

Although the key response themes demonstrated above are based on the views of only a group of stakeholders together with a set of relevant government documents, they give a rich qualitative context of the mainstream construction culture in the KRI and the overriding factors that generally shape its nature. This is besides the feasibility of mainstreaming energy-efficient building practices and the issues surrounding it which were not initially known to the researcher. And as outlined, the underlying issues that pose challenges to the industry in mainstreaming such practices revolve mainly around the following areas:

- The additional up-front costs required for implementing energy efficiency measures,
- The level of environmental awareness among KRI people,
- The required policy instruments and government interventions,
- And the technical complexity embodied in designing and constructing low-energy buildings.

Similar barriers were echoed by other studies undertaken in different countries of the developing world, e.g. Liu et al. (2010), Abidin (2010), Alkilani and Jupp (2012), Serpell et al. (2013), Shi et al. (2013), Djokoto et al. (2014), Saleh and Alalouch (2015), Ibrahim et al. (2016) and Azeem et al. (2017). In a series of qualitative investigations carried out with a group of Malaysian construction developers, for instance, (Abidin, 2010) found that limited understanding of sustainable construction practices, cost-related concerns, and poor enforcement of legislation were the main stumbling blocks discouraging acceptance for such practices. These along with lack of policies, legislation and appropriate environmental assessment tools were likewise regarded as the overriding barriers to the Jordanian construction industry according to a study conducted by (Alkilani, S. and Jupp, J., 2012). Serpell et al. (2013) presented similar findings in Chile along with the lack of integrated design impeding green building practices to become industry-wide. In Shanghai in China, meanwhile, Shi et al. (2013) found the shortage of information and green suppliers, incremental time and additional cost to be the key issues there based on a questionnaire survey distributed to the main parties involved in the building sector. All these barriers along with others could exert a significant impact on the likelihood of whether a society of the developing world will accept energy-efficient construction practices.

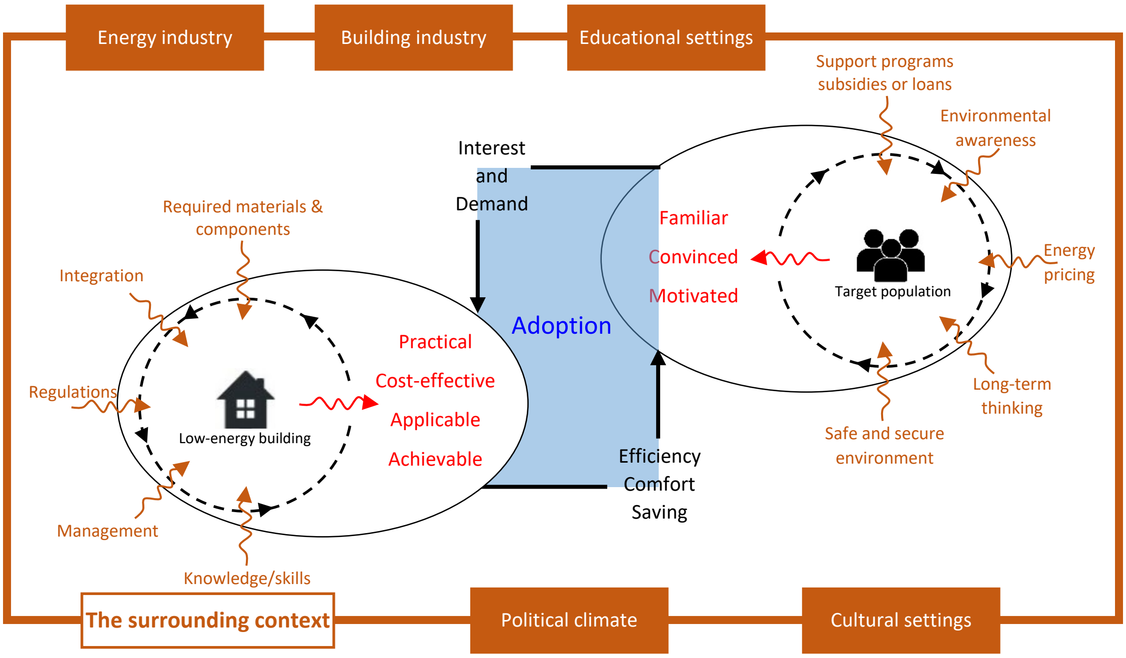


Figure 5.15 Socio-technical diagram showing variables associated with mainstreaming low-energy buildings (author)

Inspired by Wejnert's work entitled *Integrating Models of Diffusion of Innovation: A Conceptual Framework* (Wejnert, 2002), the researcher developed a framework aiming to facilitate the data analysis and define the potential parameters that need to be considered in adapting energy-efficient design solutions to the KRI context. The framework assigns the identified factors that can affect the development and implementation process and the likelihood of adoption to three different main categories (see Fig. 5.2): The first one involves the characteristics associated with the low-energy building per se such as the degree of technical disruption and complexity, and cost. This set of variables is the one that will be involved directly in the design scenarios in a later chapter. The second category contains those associated with the target population that energy-efficient building practices will be introduced to, such as personal qualities and value systems, socio-economic characteristics, status characteristics, and familiarity with low-energy buildings in general. This set of variables is further investigated in a later chapter through qualitative investigations carried out on a sample of households (See chapter 6). The last category, moreover, includes those related to the environmental context, i.e. the context surrounding the target population and the built environment, in which some of them are uncontrollable.

It is worth mentioning that all these different categories are critical to the research, but the first one, i.e. the one involving characteristics associated with the low-energy building per se, is given more priority than others as the variables are involved directly in developing the design and technical interventions.

5.4.1 Factors related to the low-energy building

5.4.1.1 Cost

The first variable related to the low-energy building per se is the cost. It is clear from the findings that if such a building approach jeopardise clients' financial viability, the interest in its adoption in all likelihood would be limited. In fact, the success of a new product/idea and its growth rate are often linked with how feasible would it be from an economic point of view (Rogers, 2003), and the debate around adopting energy-efficient construction practices is not independent of such a link [see e.g. Jakob (2006), Banfi et al. (2008), Pitt et al. (2009), Yudelson (2010), Achtnicht (2011), Tan et al. (2011), Liu et al. (2012), Hwang and Tan (2012), Dwaikat and Ali (2016), and Liu et al. (2018)].

There is no question that delivering a building with higher energy performance using advanced energy-saving solutions applied in some countries of the developed world requires more time consuming handling. This is in addition to the use of special construction techniques, components and materials, such as the use of energy efficient windows and appliances, super thermal insulation, etc. All these in turn tend to add extra direct costs to the total construction cost. Yet there is no definite answer as to how much increase in the total cost such measures cause. This is because it relies significantly upon a set of factors, such as the degree of familiarity of those engaged in the design and construction process with energy efficiency measures, site conditions, local climate, project location, and building type, which can make a noticeable difference. This is why a range of estimates can be found across the literature. In their highly cited cost analysis of 33 green buildings throughout the United States, for instance, Kats et al. (2003) found the average cost premium to fall within the range of 0.66% to 6.5% depending on the level of green standard (the higher the level of efficiency, the greater the percentage increase). In the case of Passivhaus, moreover, a detailed analysis on the economic viability of passive houses shows that the percentage increase in upfront cost falls within the range of 5% to 15% (Galvin, 2014). In a more recent study, Shim et al. (2018) estimates that meeting PH standards in a single-family house in Korea would require 1.85-4.2% additional up-front costs compared to a conventional one. However, taking into account the socio-technical context of Iraqi Kurdistan and the fact that the region is still at quite an early stage of introducing the concept of energy efficiency to the construction sector, one might expect even higher percentages than those figures. This is especially if similar solutions were to be applied and the required materials, components and expertise were to be imported.

However, emphasising the initial investment costs in making design and construction decisions while neglecting running costs is a short-sighted approach which keeps the door open to the generation of more inefficient buildings. Of course, there are additional costs associated with the implementation of energy-efficiency measures. But the question here is how significant are they in comparison to the long-term economic and environmental benefits those measures generate over building's life cycle, e.g. the savings that result from the reduction in energy consumption and lower maintenance, and improved indoor comfort level and quality of life. Multiple researches examining the economic viability of different energy efficiency upgrades have shown that these benefits along with others completely offset those additional costs and provide an implied return on investment [see e.g. Tommerup and Svendsen (2006), Dodoo et al. (2010), Mata et al. (2013), Fang et al. (2014), Preciado-Pérez and Fotios (2017), Sağlam and Corgnati (2017), and Rakhshan and Friess (2017)].

In a Danish multi-storey property, for instance, Tommerup and Svendsen (2006) carried out detailed calculations to estimate the potential savings and found that up to 76% reduction in heating demand can be achieved by installing MVHR, replacing windows and upgrading the U-value of the building fabric. The potential energy savings of these measures along with others such as decrease in indoor air temperature to 20 °C and reduction in power used for the production of hot water [see Mata et al. (2013)] were assessed in another study conducted on a sample of 1400 buildings across the Swedish residential sector. The study concluded that up to 53% reduction in the final energy demand, which corresponds to a 63% reduction in CO_2 emissions, can be accomplished by applying the selected measures. In the harsh climate of Dubai, through an investigation performed on two residential villas of different age, Rakhshan and Friess (2017) tested the viability of a set of retrofit schemes focusing mainly on improving the efficiency of fabric and AC system. They found that up to 40% reduction in cooling demand can be achieved, with the payback period falling within the range of 6.5 to 7.8 years.

As can be noted, it is crucial to not overestimate the costs associated with investing in energy-efficient buildings and overlook the earnings. But in an environment marked by an economic downturn and increased levels of poverty and inequality, the question remains as to whether their possible benefits can stimulate their adoption and outweigh the higher initial costs associated with them.

In fact, the investigations have clearly indicated that basic housing needs cannot be met by a large group of people, who according to a Joint Report performed by the Kurdistan Regional Statistics Office (KRSO) and the International Organization for Migration (IOM) represent nearly one third of the target population (see KRSO and IOM, 2018). Their investment capacity is very limited making the installation of energy-saving measures beyond the bounds of possibility. This raises the question of what would be necessary to be made to increase the possibility of delivering low-energy buildings at an affordable cost.

In light of the low manpower costs in the Kurdistan region, limiting expensive and technology-intensive energy-saving solutions which most likely require imported materials, components and maybe knowledge transfer would be necessary to meet the unmet demands of such an income group. Instead, one explores an alternative way and switches into a system that corresponds to their aspirations, a system that relies mainly upon simple solutions that can be locally sourced and maybe self-managed, a system that obviates the need for highly skilled personnel. This is a common building approach amongst environmentally oriented self-builders and architects in many developing countries (see e.g. Pearson, 1998; Steen et al., 1994; Fathy, 2010; Seyfang, 2010; Ramage et al., 2010; Sameh, 2014) who all demonstrate the possibility to build with better performance with no need for high-capital investment and sophisticated technology.

Initiatives of the well-known Arab architect Hassan Fathy in pioneering appropriate technology for Egypt's construction industry are amongst the examples (Fathy, 2010). Contrary to Western building layouts, designs and technologies, he brought back the traditional forms supported by the mud-brick technique, as appropriate technology, into existence. Fathy highlights his groundbreaking strategies regarding mass housing and documents the forceful efforts to build a forward-looking village for Egyptian peasants in his most cited work, Architecture for the Poor. By training local inhabitants, Fathy was able to engage the community in making their own construction materials and building their own village and rely on insider expertise.

Another example is the community centre of Mathare 3A in Nairobi by a group of students and researchers, who paid particular attention to adapting traditional techniques and natural materials to contemporary architecture, from Cambridge University in association with the UN-Habitat (Gatóo, 2015). The team developed a model of participatory design making the engagement of the community central to the project. The concept behind this model is explained by Dr Maximilian Bock who is the project manager; "The aim of participatory design is not to change the rich culture that already exists in Mathare, but rather to understand it deeply enough to design a space that is useful to and reflective of the community." The process included site visits by the team to make sure that the community members and users' input are reflected by the preliminary designs. A particular method was used as pointed out by a member of the team Elizabeth Wagemann, "Using wall charts, pictures, models and coloured stickers, we were able to find out what residents thought of other community centres, the potential risks to the hall, how they hoped to use the facility, and what skills they could contribute to constructing and managing it." The team also provided training to upskill the community members to be involved in the construction process under the instructions of an onsite engineer (Gatóo, 2015). In their completed design for a 15x30m building, made out of gabions filled with local or recycled stone and a floor and roof structure made from bamboo, they have managed to match what the community had imagined as well as what the complex network of other stakeholders want (Gatóo, 2015).

Another example of providing shelters with better energy efficiency and thermal comfort to low-income households through the use of natural and local materials is the work of Bill and Athena Steen, the founders of The Canelo Project which seeks to enable the community residents to build their own affordable energy-efficient buildings. In a poor outlying district of Ciudad Obregon in Mexico, Bill and Athena Steen were invited to contribute in developing its low-income housing (Seyfang, 2010). At first, in order to learn which materials can be obtained easily with better performance and lower cost, several small rooms were built. An appropriate technology that they evolved is a distinctive straw-bale (a waste from agriculture) brick with adobe plaster to build the houses which are highly insulative, made entirely of local, natural, cheap materials and are easy to work with (Seyfang, 2010). This led to a broad engagement of local people, who were simply trained through workshops and training courses, in the construction phase since neither high-level skills nor special tools were needed. Introducing straw and clay into the mainstream construction industry instead of materials like cement and rebar also resulted in saving much cost (Seyfang, 2010). Apart from the financial advantages of straw-bale buildings, there were environmental ones such as reducing waste and ecological footprint as well as saving a large amount of energy required for cooling and heating through having high levels of insulation. Besides, all involved gained a skill base for their future buildings.

Inspired by such precious legacies, the research suggests developing an effective but low-cost building envelop as an appropriate system aiming to minimise heating and cooling loads to the absolute minimum while providing higher level of comfort. This is through making maximum use of locally available materials that are inherently thermally insulating.

Among the materials that worth looking into are chopped straw and ever-present earth-based materials – cheap and readily available natural construction materials applied widely by rural and marginalised communities across the region through different traditional methods (see Fig. 5.3). These materials, in fact, have a rich history not only in the Iraqi part of Kurdistan but also in the other parts (see e.g. Smith, 1990; Bekleyen et al., 1998). Their combination provides a building material of great value and technical ingenuity, and their environmental and economic importance has been proven worldwide and throughout history (Rael, 2009). All this enables them to adapt smoothly to the context of modern-day green buildings (Minke, 2012), something that promoted even some countries of the developed world to renew interest in such materials.

A group of interviewees has strongly recommended those materials to be considered in developing technical interventions that are cost-effective and eco-friendly which would likely present a livelihood potential for the local and motivate ordinary people to utilise their creative potential. The common practiced method of application was that the mixture was poured and pressed either manually or mechanically into box-shaped moulds or wooden forms which were then left in the sunlight to dry and reach the right plasticity and then applied in the construction of external walls. Some builders used to add a small percentage of cement to the mixture as a stabiliser. One can either use them in this back-to-basics method or in a more modern way, e.g. pre-fabricated wall panels system, which would involve a sort of manufacturing process (see e.g. Gomaa et al., 2019). The latter, however, would likely require additional costs and further technical preparations, something that may not be convenient for stakeholders at the early stages. Experimentations will be performed in a later chapter to see the impact of such technical interventions in offering energy efficiency and thermal comfort and find what would be the most appropriate way of application and what can be achieved with.

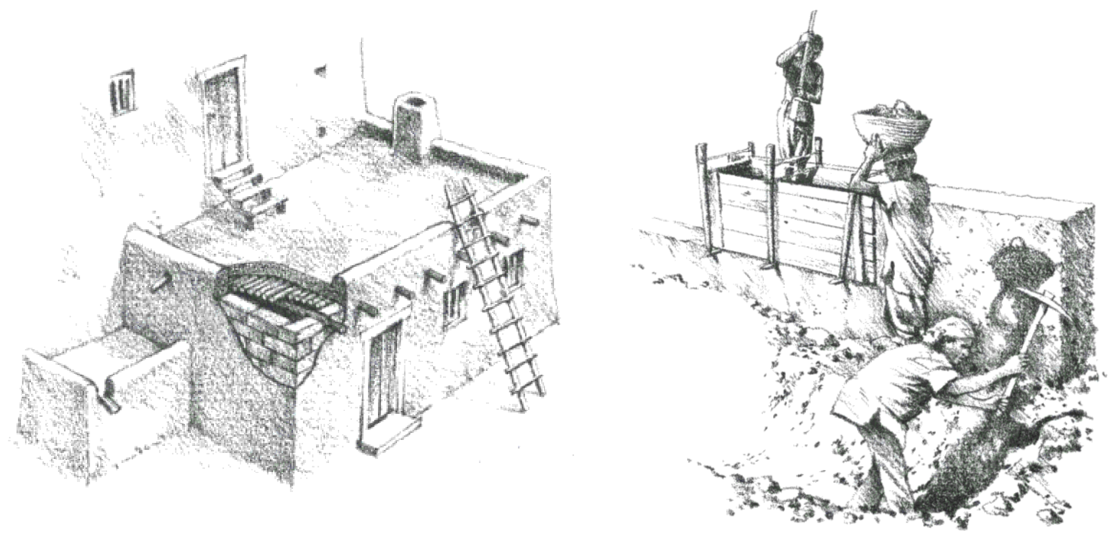


Figure 5.16 Traditional techniques of building with earth-based materials and straw

In parallel, introducing support programs in the form of subsidies or loans by the KRG would be central in this context, a policy instrument that is successfully employed in some countries of the developed world, e.g. Germany, as part of a wider committment to limit the magnitude of global warming (Galvin, 2010; Anisimova, 2011; Roseno and Galvin, 2013; Shen at al., 2016). To develop such a support program and estimate the amount of funds needed, however, cost analysis has to be undertaken within the local context. This is to answer the questions of up to how much more will the incorporation of energy-saving measures cost in the region, how would that then relate to people's income, and how realistic would it be to subsidize that and make it practical for people with limited investment capacity.

For people with better investment capacity, furthermore, one thing worth looking into is undertaking adjustments on the way construction is managed especially for those who prioritise aesthetics above all else and spend a great deal on oversized spaces, high-end finishes and decorations. Changing the direction of their focus towards energy saving and reducing the extent of such finishes can easily make even advanced energy efficiency measures within reach and surely offset the associated costs.

5.4.1.2 Technical complexity

If cost-related issues were addressed, would it be possible for energy-efficient construction practices from a practical angle to establish themselves as a leading trend across the construction sector considering the capacity of the existing apparatus and the lack of skills-development strategy? This will rely heavily upon the degree of complexity of processes associated with the design and construction of low-energy buildings, how difficult should they be to understand and implement. Should one introduce highly sophisticated solutions, e.g. ultra-low energy buildings, requiring substantial changes in the way buildings are designed and constructed? Or should one go for less complex and gradual efficiency upgrades?

Generally, delivering a building with higher energy performance as indicated earlier requires not only the use of special construction techniques, components and materials but also a different knowledge base from what the majority of parties involved in design and building processes possess. Construction teams would need to perform in a more cooperative and closely integrated way, while designers would need to pay greater attention to things like solar gain, insulation, air leakages, thermal bridges, etc. from the very first day (Cotterell, J. and Dadeby, A., 2012). This change in the way buildings are designed and constructed, according to the findings, will cause a sort of technical disruption within the industry and will likely present an issue for the indigenous practitioners and workers who are identified with a limited base of knowledge and technical capacities. Their skills might no longer be adequate to take part in such an initiative and make the most of opportunities to achieve a tangible impact unless they undergo a transition. This in turn could displace this certain class of workers and might thereby impede green building practices to become industry-wide, an issue plaguing many worthy initiatives to mainstream energy-efficient construction practices in other countries [see e.g. Liu et al. (2010) and Serpell et al. (2013)]. However, the already constructed low-energy buildings in the KRI (though very limited in number and are non-accredited) as well as the one that is currently constructed by the researcher (see Appendix E) have demonstrated that the biggest part of the work could still be performed by skilled individuals from the local design and construction teams with the use of the available apparatus. They have demonstrated that with some guidance and some form of on-site practical training at different phases of building construction, these buildings from a technical perspective can be locally within reach up to a point. And over time with the increase in the number of low-energy buildings in the KRI, the skills and experiences will certainly improve and even the cost will likely go down.

However, the concern about the skills shortage remains if those buildings are to become industry-wide practice – a mass production issue. This is why addressing questions of vocational and professional education at the national level is central. In this regard, the findings strongly suggest an upgrade in their skills, whether major or minor, through establishing a robust skills-development strategy aiming to: driving Higher Education providers (HE providers) to develop architecture and construction education in a way that can provide the industry with designers and engineers that have adequate technical and environmental competency; reactivating the role of existing technical and vocational schools; and making sufficient investments in introducing systematic programs imparting the necessary knowledge and skills to the labour force. Increasing their abilities to cope with the changes will thereby result in reducing the chances of unsuccessful adoption as well as market incertitude.

5.4.2 Factors related to the target population

This category contains characteristics associated with the target population that energy-efficient building practices will be introduced to, such as personal qualities and value systems, socio-economic characteristics, status characteristics, and familiarity with low-energy buildings in general. These are thoroughly investigated in the next two chapters through qualitative investigations carried out on a sample of households.

5.4.3 Factors related to the environmental context

What does seem clear from the findings is that shifting towards an energy-efficient built environment will not be independent of the context around, and the situational and contextual factors of various kinds will determine to a large extent the degree of success and the speed of this transition. Such a conclusion can also be noted in a number of adoption studies. In his analysis of worldwide diffusion of technological innovations, for instance, James (1993) refers to contextual factors as "externalities" and suggests that they affect the practicality and benefits of adoption, as well as an adopter's willingness and ability to adopt an innovation. Therefore, in most cases, externalities have a permissive effect, where their presence or absence largely determines the decision regarding adoption of an innovation. And similar to any other product or technological innovation, a building is constructed in a context where decisions are driven in one way or another by the characteristics of that context.

Among those characteristics is the political conditions of the region in which their impact on the likelihood of whether stakeholders will support this transition in the built environment appear to be unquestionable. This is generally consistent with researches concerned with factors driving adoption decisions [see e.g. Frost and Egri (1990), Mirza et al. (2009), Wisdom et al. (2014) and Shah et al. (2019)] placing a particular emphasis on the impact of political conditions on adoption.

From the results, it is very clear that the political conditions in Iraqi Kurdistan have not been supportive in making energy efficiency in general a nationwide interest. This is observed at two key dimensions which are: the political climate of the region as well as the norms and regulations existing within the legislative framework which determine the behaviour and decisions of the target population including clients, design professionals, construction practitioners and real estate developers. The former is deeply unstable and divided causing public distrust in the state and encourage short-termism, an endemic problem that is difficult to change, and the latter is not established in favour of energy efficiency and sustainability. Given these facts, with the exception of only a limited number of buildings, the extent of usage of energy-efficient construction practices seems unlikely to increase unless they receive political support on a much larger scale. With a proper legislative move and government interventions such as establishing and enforcing the Regional Building Regulation and its annexed building codes including energy efficiency code, there is a huge opportunity to make energy efficiency a nationwide interest in response to such a regulatory pressure. This is even despite the very fractious and unstable political climate that is currently in place.

This has been shown by prior studies worldwide emphasising the role of policy interventions in accelerating the transition towards energy-efficient practices [see e.g. Hirst and Brown (1990), Newell et al. (1999), Santín (2010), Mills and Schleich (2014), and Schleich et al. (2016)]. In their analysis of factors associated with German households' decision of replacing old incandescent lamps with more energy-efficient lighting technologies, for example, Mills and Schleich (2014) found that the replacement decision was strongly driven by the EU ban on incandescent lamps. Newell et al. (1999) in their paper entitled THE INDUCED INNOVATION HYPOTHESIS AND

ENERGY-SAVING TECHNOLOGICAL, found that the interest in energy efficiency grow faster when energy prices rise. This is also reflected within our findings underlining the influence of recent policy reforms with respect to energy pricing on design and construction decisions and stakeholders' views concerning energy consumption.

In view of these barriers in line with various innovation models and technology diffusion theories [see e.g. Rogers (2003), Wejnert (2002), Cooper (1999) and Balachandra and Friar (1997)], one could imagine how challenging the task would be for the KRI to manage a widespread adoption of low-energy buildings and bring the stakeholders on board. This is owing to the fact that some of the key determinants which lead to success in developing and introducing a new product, technology, idea, or practice to a market are hardly in place. These include but not limited to the elements associated with the innovation itself and those related to the target population and their environmental context, such as regulatory support and public interest in energy saving, etc. [further factors can be found in Montalvo (2008) and De Medeiros et al. (2014)]. This in turn can cause failure in triggering the public to invest in low-energy buildings and thereby hold back the adoption process and speed of diffusion.

To make certain that adoption will take place widely, Frost and Egri (1990) believe that having a good system, product or idea is generally insufficient. Removing those potential constraints must therefore be a key target, if the developed energy-saving measures are to take a firm root and gain momentum and success in the marketplace. Otherwise, their introduction would run into difficulties in terms of acceptability and would likely face strong resistance from the target population. Relieving the outlined barriers is however not a five-finger exercise as they explicitly take us beyond the building scale and what a research team can have control over. They involve political questions as well as issues related to education and culture which have to be addressed in the long-term through a strategic alliance with collective efforts from all key players across the building sector and beyond.

Chapter 6

Case studies

6.1 Overview

Assessing energy and thermal performance and understanding the nature of the architectural fabric, and role of technology and occupants' behaviour in a sample of dwellings are among the objectives of this research. This is to generate inputs, e.g. technical parameters, to the development of computer-based models and the establishment of contextual and optimal upgrading strategies for the building fabric across the residential sector. This chapter introduces the selected dwellings while the next chapter presents the investigations and analyses the collected data to fulfil the objective.

This chapter provides descriptions, e.g. physical attributes and household information, of four case studies where each one represents a socioeconomically distinct group of households (see Fig. 6.1). The first and second group, according to KRSO and IOM (2018), account for nearly 28% and 22% of the population respectively in which the former group has a monthly income of 250,000 – 500,000 Iraqi Dinars (IQD) whilst the latter earns between 750,000 – 1,000,000 IQD. Households belonging to the former category are more likely to live in small and substandard houses where access to cooling and heating is very limited leading to poor indoor thermal conditions. On the other hand, the third and fourth group account for nearly 0.9% and 0.2% of the population respectively in which the former group earns between 2,000,000 – 3,000,000 IQD whereas the latter has a monthly income over 5,000,000 IQD (see section 3.3.1.3 for full details about the sampling process).

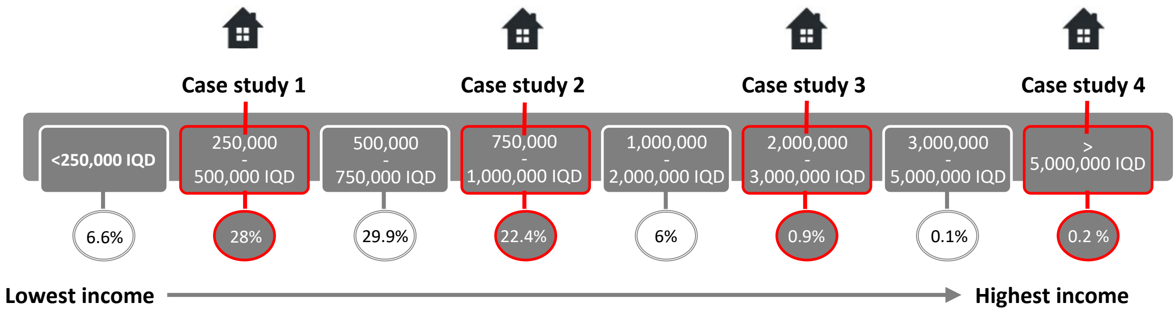


Figure 6.17 The distribution of households based on the categories of the average monthly income, and the selected groups for the research [adapted from KRSO and IOM, 2018]

The dwellings range from one-storey to two-storey buildings covering a range of floor areas (see Fig. 6.2). With the exception of the first, which was built in the 1970s, the samples were constructed after 2004 (see Table 6.1). Full information about each one of them, including the household information and construction associated details, is presented in detail later in this chapter.

Case study 1 **Case study 2**

Case study 3 **Case study 4**

Figure 6.18 Exterior views of the examined houses (author)

Like the vast majority of residential units in Iraqi Kurdistan, the four dwellings rely on two sources of electricity supply which are the national grid and a shared generator (or a small station) operating at neighbourhood level. The first is considered as the main electricity source and is highly dependent on governmental support. However, owing to extreme strain on its capacities as a result of increased demand, mismanagement, and some other major barriers explained in the background chapter, households often experience power failure throughout the day. In 2018, for instance, the average electricity supply through the national grid in the city of Duhok was limited to nearly 13 hours per day (General Directorate of Duhok Electricity, 2018). This creates difficulties for the majority of households to keep their homes at the right temperatures during both cooling and heating seasons. The second, which is privately owned, is used to fill some of the electricity supply gap that is experienced. However, it supplies electricity at considerably higher prices (1 USD per 4 kWh) creating a major stumbling block to many households across the region in operating heating and cooling technologies when necessary. Additionally to the aforementioned sources, each household receives from the government through a subsidy programme 200 to 400 litres of kerosene as a mean of heating every year at a minimal charge of $0.16 for a litre. In most cases, however, such an amount does not suffice their need. In terms of cooking fuel, like the majority of households in the region, all case studies rely on liquefied petroleum gas (LPG) which is sold in the market in steel cylinders. Those energy sources alongside the energy-related challenges that the region faces are highlighted in an earlier chapter.

Table 6.6 A summary of characteristics of the examined case studies (author)

	Case study 1	Case study 2	Case study 3	Case study 4
Completion	1974	2016	2005	2008
Location	Duhok, KRI	Chaman, KRI	Duhok, KRI	Erbil, KRI
House Type	One-storey, detached	Two-storey, stand-alone	Three-storey, attached	Two-storey, detached
Floor area	98 m^2	143 m^2	215 m^2	253 m^2
Utilised floor area	76 m^2	122 m^2	120 m^2	169 m^2
ceiling height	2.8 m	2.8 m	3 m	2.9 m
Roof type	Concrete flat roof	Concrete flat roof and lightweight metal hipped roof	Concrete flat roof	double-roof system: flat reinforced concrete roof coupled with a pitched lightweight metal tile roof
External wall materials	Cement plaster, solid concrete blocks, cement plaster	Cement plaster, solid concrete blocks, gypsum plaster	Cement plaster, solid concrete blocks, gypsum plaster	Limestone, hollow bricks, gypsum plaster
Roof's U-value	3.8 W/m^2K	2.1 W/m^2K (flat roof) and 2.7 W/m2K (hipped roof)	3.3 W/m^2K	1.3 W/m^2K
External walls' U-value	2.8 W/m^2K	2.6 W/m^2K	2.6 W/m^2K	1.43 W/m^2K
Window type	All window openings are old, steel framed and single glazed	All window openings are PVC framed and double glazed	Aluminium framed and single glazed	Sliding windows, aluminium framed and double glazed

6.2 Case study 1: A low-income household

The first case is a residential unit that represents low-income households that cannot afford to keep their indoor environment at the right temperatures neither in summer nor in winter, i.e. households living in fuel poverty. These are the households that when summer and winter approach, they struggle to have sufficient access to cooling and heating and get anywhere near meeting reasonable standard of thermal comfort. And if they do so and maintain it, their remaining income will not be sufficient to maintain access to some basic human needs. Across the region, formal requests were made to several households in low-income neighbourhoods that correspond to the research focus. In one of the oldest neighbourhoods of Duhok city, Iraqi Kurdistan (36.8° N, 42.9° E), called Gre Base, a detached house of nearly 44 years of age was chosen as a first case study (see Fig. 6.3).

Figure 6.19 The map of Central Duhok showing the location of the house (adapted from Apple Maps) with a view of the house

6.2.1 House information

It is a one-storey self-build and detached house, built in the 1970s for a low-income household. The building incorporates two bedrooms, a kitchen, living room, bathroom, toilet, and staircase leading to the rooftop (see Fig. 6.4). It also has a small basement (3.6m by 4m) basement which is rarely used for storage. One of the bedrooms, i.e. the south-facing one, is used as a storage space which will be discussed in a later section. The unit has a floor area of approximately 98 m^2 (only 76 m^2 are regularly utilised), and a ceiling height of 2.8 m. For security and privacy reasons, the house is surrounded by high solid concrete walls (see Fig. 6.5). This wall, alongside the existing vegetation, including grapevine, pomegranate, loquat, fig, lemon and orange trees

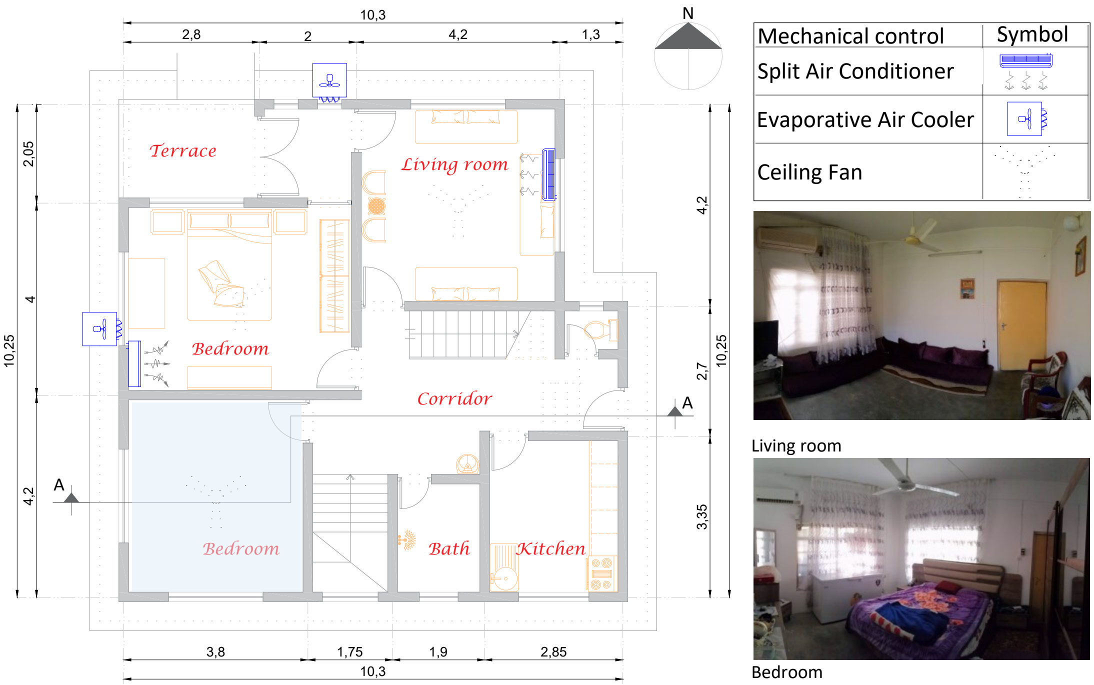


Figure 6.20 Ground floor plan (left) and views of the occupied bedroom and living room (author) (Note: the shaded bedroom is the one that is used as a storage space)

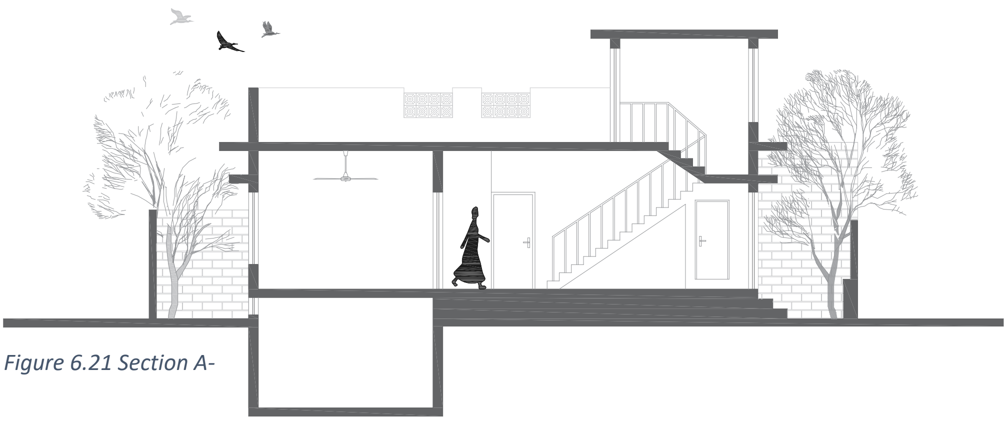


Figure 6.21 Section A-

(see Fig. 6.6), work as external shading preventing solar gains through the window openings that exist all around the house. In the meantime, the roof has no much tree cover with the exception of only a few branches hanging over allowing too much sunlight exposure (see Fig. 6.7). The windows of both the living room and occupied bedroom are equipped with curtains which are manually operated. At the very outset, the house was naturally ventilated, but afterwards, both living room and occupied bedroom were fitted with three mechanical controls which are a split-type air conditioner (in recent years), an air-cooler and a ceiling fan (see Fig.

6.4). Besides that, there were two portable kerosene heaters and an electric one which all are stored in the basement and moved to the ground floor when the heating season starts. However, the operation opportunities of all those equipment are correlated with various factors which will be discussed in a later section. In terms of power supply and like other households of the city, the electricity is supplied from the national grid as well as a shared generator operating at neighbourhood level which is used to fill some of the electricity supply gap that is experienced with the public network throughout the day.

Figure 6.22 Vegetation around the house (author)

Figure 6.23 A computer-based model of the house showing sunlight on the roof at different times of a typical summer day (author) (Note: the model does not include the existing vegetation around the house)

Poor envelope conditions are clearly observed, and the entire building envelope has insufficient thermal insulation. This influences the thermal performance of the building and thus influencing the thermal behaviour of the occupants. The main construction material used in the house is concrete. The floor is made of concrete and is in direct contact with the ground below. For external and internal walls, solid concrete blocks were used and plastered with cement mortar, and the flat roof is built of reinforced concrete. Hence, both roof and external walls have high U-value which are around 3.8 W/m^{2}K and 2.8 W/m^{2}K respectively. All window openings were old, steel framed and single glazed. Air-infiltration is significant, occurring around and through the openings. To seal gaps, avoid leaks and reduce air-infiltration, packing tape was used around the frames (see Fig. 6.8). It is worth mentioning that in late November 2018 and prior to conducting the winter's fieldwork, the living room was partially renovated by a charity donor and its old steel windows were replaced with new PVC framed ones. This will be explained further in section 7.2.2.

Outside

Inside

Figure 6.24 The quality of the north-facing window of the living room (author)

6.2.2 Household information

A family of two (a 62-year-old housewife with her adult son) lives in the house. Their average monthly income is around 300-350 USD and thereby adapting to conditions below the level of what would commonly be considered a "normal" lifestyle. They adapt to conditions where they use environmental control technologies in a very restricted manner and in certain areas at certain times to avoid financial burdens despite experiencing unpleasant indoor thermal conditions. Six days a week (08:30 am to 05:00 pm), the son works away from home, while the lady, who is from a farming background, spends most of her time at home taking care of the house and the vegetation around. On Fridays, they often spend daytime hours in their village.

6.3 Case study 2: A working-class household

The second case is a residential unit that represents working-class households with a monthly income of 750,000 – 1,000,000 Iraqi Dinars (IQD). As indicated earlier, this income group account for nearly 22% of the KRI's population. Across the region, formal requests were made to several households that belong to such an income group and correspond to the research focus. In a village located on the outskirts of Duhok city, Iraqi Kurdistan (36.8° N, 43.2° E), called Chaman, a stand-alone house of less than three years of age was chosen as a second case study (see Fig. 6.9).

Figure 6.25 The map of Duhok City showing the location of the house (source: apple maps) with a view of the house

6.3.1 House information

It is a two-storey self-build and stand-alone house constructed in 2016 for a working-class household. The building has a floor area of approximately 143 m^2, and a ceiling height of 2.8 m. The ground floor incorporates a guestroom that has access from the entrance for privacy reasons, open plan living area with dining and staircase that is decorated with indoor plants, semi-open kitchen, bedroom, bathroom, and toilet (see Fig. 6.10), while the first floor accommodates only the children's bedroom (see Fig. 6.11). The ground floor is provided with large south-west facing casement windows, mainly in the combined living and dining area and the guest room which is used occasionally over the summer period, when having guests. Despite having an overhang eave that is not deep enough to protect the facades, the building envelope is widely exposed to solar radiations, and the south-west facing windows are highly prone to receive direct sunlight during the summer period due to the lack of obstructions, e.g. adjacent buildings, trees, effective external shading devices and etc. For that reason, all windows were provided with internal roller blinds. The building is not free-running as mechanical controls are operated during the cooling and heating seasons to modify the indoor environment. Each space on the ground floor is fitted with a ceiling fan. And in addition to that, the open plan living area is equipped with a floor standing air conditioner and a portable evaporative cooler, which was installed indoors. The ground floor bedroom is supplemented with a wall-mounted split air conditioner as well as a window-mounted evaporative air cooler, while the bedroom upstairs is only fitted with a portable pedestal fan. However, the level of climatic control through these technologies is robustly contingent on a number of factors as described further below. In terms of electricity supply and like the first case study, it is provided by either the national grid or a shared generator operating at neighbourhood level.

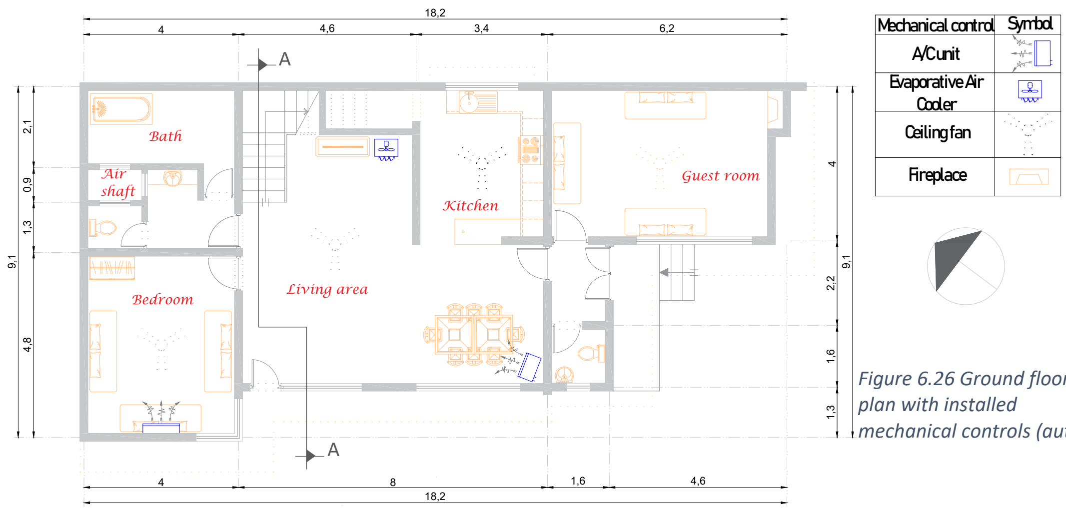


Figure 6.26 Ground floor plan with installed mechanical controls (author)

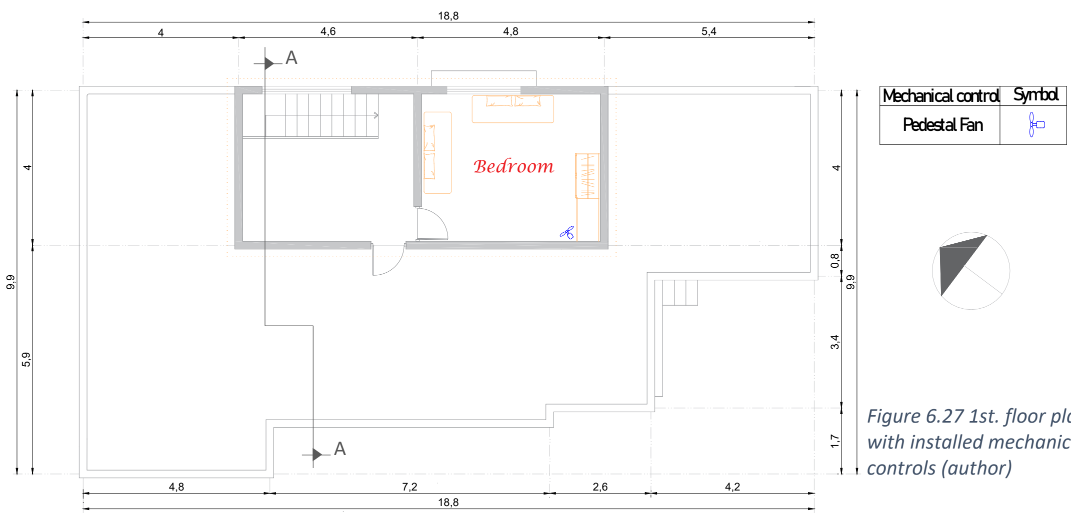


Figure 6.27 1st. floor plan with installed mechanical controls (author)

The building fabric is characterised by poor thermal properties such as critical thermal bridges. The construction elements were mainly built of concrete except for the hipped roof that covers the first floor constructed with lightweight metal roofing tiles which have a very high thermal conductivity. Solid concrete blocks and reinforced concrete were used for walls and the flat roof respectively. The external walls (see Fig. 6.12) were only rendered with cement plaster (from outside) and gypsum plaster (from inside) with no insulation layer resulting in a high U-value, i.e. 2.6W/m^{2}K, which substantially influences the building's energy and thermal performance, whereas the internal ones were rendered either by gypsum plaster or ceramic tiles such as in the kitchen and bathroom. Despite having plasterboard suspended ceiling on both floors, the roof U-values present high figures which are 2.1 W/m^{2}K (flat roof) and 2.7 W/m^{2}K (hipped roof). Moreover, with no doubt, the quality of windows is much better than the previous case study as all are PVC framed and double glazed with 4 mm glass.

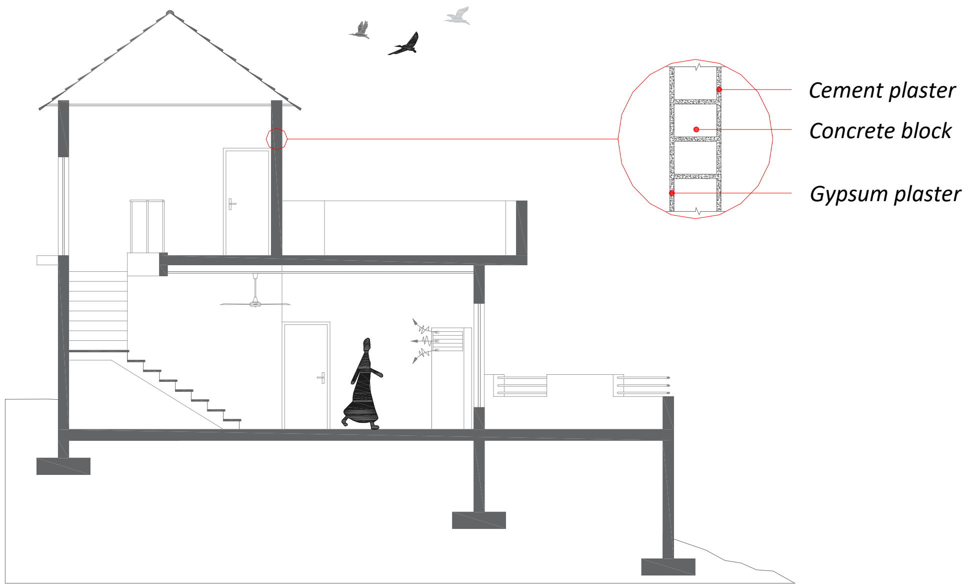


Figure 6.28 Section A-A with construction details of an external wall (author)

6.3.2 Household information

A working-class family of five (young parents with three children) lives in the house. Their average monthly income is around 700 USD and thereby striving to climb the social ladder and achieve standards of normality. Five days a week (08:00 am to 06:00 pm), the householder who is a full-time technician works in the construction sector away from home, while the wife stays at home with her little child. On normal school days, the other two children go to school. Both seem to be unhappy with the current house they are living in due to the dirt roads around the area causing difficulties for them on rainy days when going to school or playing outside.

6.4 Case study 3: A middle-class household

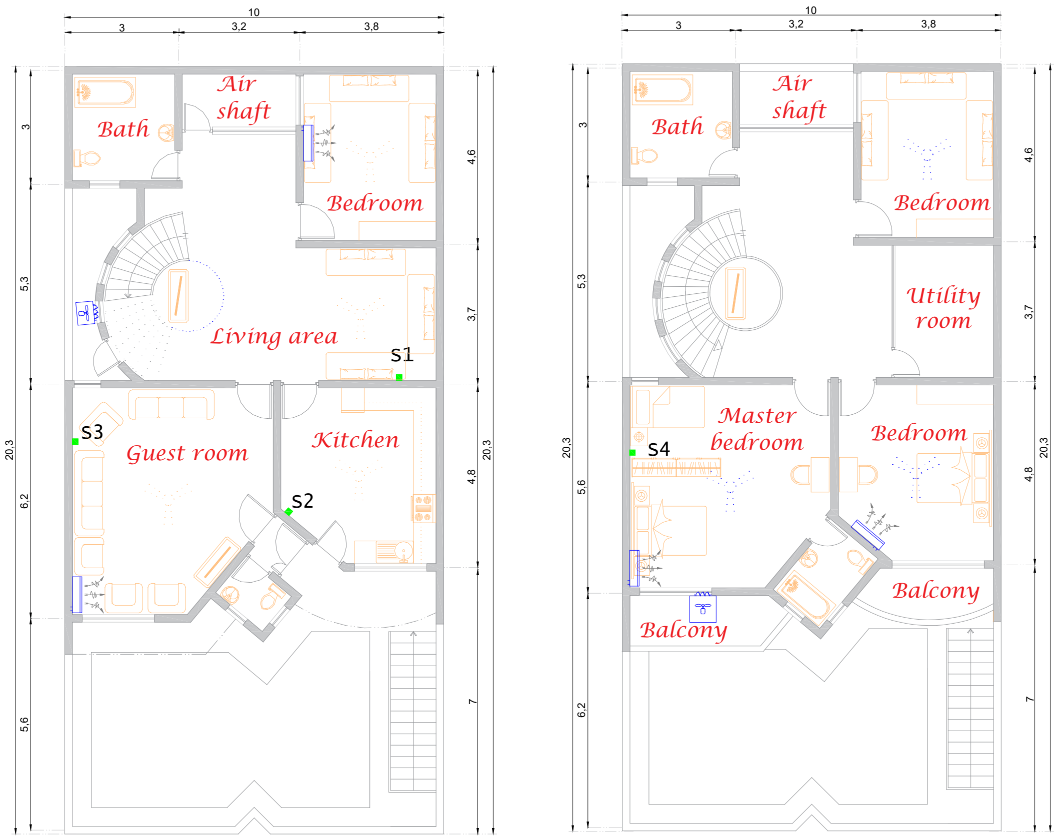
The third case is a residential unit that represents middle-class households. Across the region, formal requests were made to several households that belong to such an income group and correspond to the research focus. In one of the central neighbourhoods of Duhok city, Iraqi Kurdistan (36.8° N, 42.29° E), an attached house of nearly 15 years of age was examined as a third case study in this research (see Fig. 6.13).

Figure 6.29 The map of Central Duhok showing the location of the house (source: apple maps) with a view of the house

6.4.1 House information

It is a two-storey self-build unit elevated a full storey above the ground level to be used as a storage and parking area, and this has been a widespread approach for self-build dwellings throughout the region over the last two decades, particularly among middle-class and upper-class households. The unit is set over a plot (10m by 20m) where the south-west longer side and north-west shorter side are attached to a two-storey and a three-storey dwelling respectively, whereas the other longer side is adjacent to a plot of land which has not been built yet.

On the ground level, there is a stairway leading to the patio on the first floor which is set back from the perimeter wall around 6 meters allowing some space for the front yard. Alongside the front yard, the first floor incorporates a guest room that has access from the entrance, kitchen, large living area with helical staircase, bedroom, bathroom and toilet, while the top floor consists of three bedrooms, two front balconies, bathroom and a utility room (see Fig. 6.14). Part of the living space where the curved staircase situated has a double-height ceiling connected to the roof space where the hot air accumulates and flows out via outlets and an extractor fan, which was inoperable over the monitoring period due to a technical fault. The front four south-east facing rooms, i.e. kitchen, guest room and two bedrooms, rely on large casement windows for daylight and ventilation (if necessary) where all are equipped with curtains. Meanwhile, the living space counts on a series of vertical windows, where most of them are fixed and frosted glazed, within the curved staircase wall extended to the roof space. Despite being attached to a two-storey building from that side, i.e. south-west side, there is an air shaft which those vertical windows overlook allowing sunlight and some fresh air to be introduced, and also the adjoining building is one storey lower, thereby not entirely blocking sunlight from getting into the living area especially in summer when the solar altitude is high. Meanwhile, the rear bedroom has a window overlooking another air shaft (3m by 1.4m) which has been covered with a canopy to be used as a storage area which makes ventilation and daylight an issue in the bedroom.



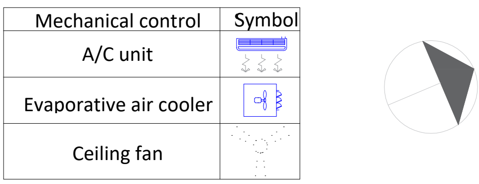


Figure 6.30 1st floor plan (left), 2nd floor plan (right) with installed mechanical controls (author)

Additionally to the ceiling fans being available in all spaces excluding the bathrooms and utility room, active cooling technologies are operated in both storeys (see Fig. 6.14). For instance, the first floor is supplemented with two wall-mounted split air conditioners (one in the guest room and one in the rear bedroom) and a window-mounted evaporative air cooler located in the air shaft serving the open plan living area. On the top floor, moreover, the master bedroom, where the young couple together with their children sleep there, has a wall-mounted split air conditioner as well as an evaporative air cooler; the other front bedroom relies on a split air conditioner, whereas the rear bedroom has no access to cooling technologies. However, their availability does not signify that all together were in use and active – two of the air conditioners, i.e. the ones in the 1st-floor bedroom and 2nd-floor master bedroom, had been suffering a mechanical breakdown over the field work period preventing their operation. In addition to the cooling equipment, there were a number of kerosene heaters as well as an electric heater which are kept in the utility room and distributed over the living spaces when heating season starts. Despite their existence, the level of climatic control through those technologies was robustly contingent on a number of factors as described further below.

The building fabric possesses similar characteristics to those of previous case studies, where poor thermal properties of the envelope being a critical issue influencing the indoor thermal environment. As observed, the construction elements were mainly built of concrete; solid concrete blocks and reinforced concrete were used for walls and the flat roof respectively. The external walls were rendered with cement plaster on the outside and gypsum plaster (from inside) with no insulation layer resulting in a high U-value, i.e. 2.6W/m^{2}K, which substantially influences the building's energy and thermal performance, whereas the internal ones were rendered either by gypsum plaster or ceramic tiles such as in the kitchen and bathroom. The roof U-value generally presents a high figure, i.e. 3.3 W/m^{2}K, and the plasterboard suspended ceiling is only available in the front bedrooms resulting in a relatively lower roof U-value, i.e. 2.1 W/m^{2}K. Furthermore, all window openings besides the kitchen door, i.e. the one leading to inside, were aluminium framed and single glazed with no thermal barrier; the main entrance door is made of solid wood while the kitchen door is made of aluminium and glass. The floor is in contact with the ground and consists of concrete, screed, and ceramic tiles.

6.4.2 Household information

A middle-class extended family of eight, where parents live with a married son, his wife and two children (6- and 7-year-olds), together with an adult son and daughter, occupies the house in which their average monthly income is around 3,000,000 IQD. Six days a week (08:00 am to 06:00 pm), the householder and his married son do stay away from home for work, and the daughter-in-law, who is a primary school teacher, with her two children go to school five days a week (08:00 am to 01:00 pm). The daughter, who is a medical doctor, works two 24-hour shifts a week at one of the hospitals; the unmarried son who has recently completed his undergraduate study also work six days a week (01:00 pm to 08:00 pm), whereas their mom is a housewife spending most of her time at home. It is worth mentioning that the family had experienced the countryside life for years before moving to this house in 2005, and the impact of this factor on their thermal behaviours will be explained further below.

6.5 Case study 4: An upper-class household

This case study is a dwelling that represents the income group that has a monthly earning above 5,000,000 Iraqi Dinars (IQD), the level that lets the households have access to air-conditioning round-the-clock. Across the region, formal requests were made to several households in new housing estates that correspond to the research focus. Among those, there was one of the new and well-known gated communities of the capital Erbil (36.19° N, 43.96° E) named English Village that has an urban form unusual for the KRI, a very western model of housing development. It contains 420 residential units which all are identical and built by a local developer in collaboration with a UK property developer. In this gated community, few households agreed to take part in the study; a detached house of nearly 12 years of age was then chosen as a fourth case study (see Fig. 6.16).

Figure 6.31 The map of Erbil city showing where English village is located (bottom) [source: apple maps]. And an aerial view of the village (top) [source: https://www.youtube.com/watch?v=jsEpXIeSGDQ]

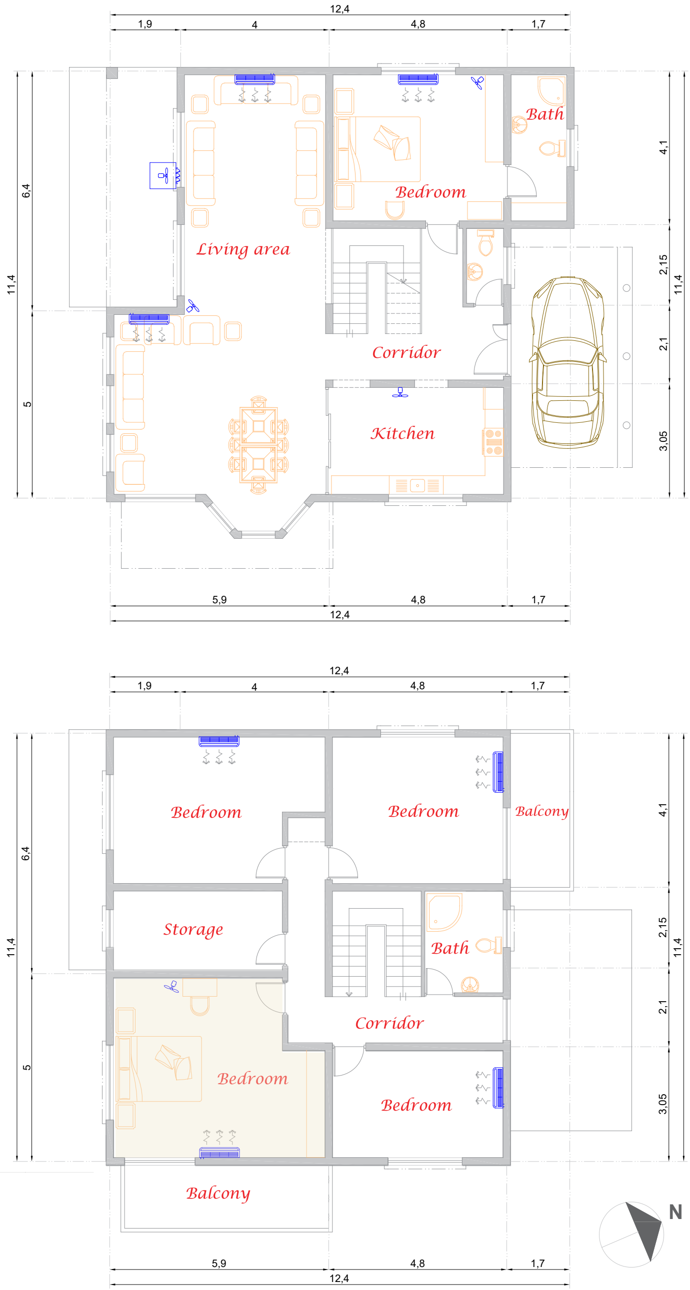
6.5.1 House information

The house is a two-storey unit with a floor area of approximately 235 m^2, and a ceiling height of 2.9 m. The ground floor incorporates an open plan living area with dining, staircase, semi-open kitchen, en suite bedroom, and toilet alongside an entrance which is connected to the

Figure 6.32 The site plan of the English village showing the location of the selected dwellings (source: apple maps) with an aerial and front views of the house

garage, while the top floor consists of four bedrooms, two balconies, storage, and a bathroom (see Fig. 6.17). The ground floor is used primarily and since the house is oversized for such a small family, i.e. a family of three members, only one bedroom is used on the first floor, and the rest are unoccupied. Both floors were provided with sliding windows all around the house where some of them are floor-to-ceiling windows, mainly in the combined living area with dining and those overlooking the balconies on the first floor.

The presence of neighbouring houses from SW, NW and NE directions makes the windows, especially the ground floor ones except those in the front SE façade, less prone to receive direct sunlight. For privacy and protection against sun rays, however, all windows were equipped with curtains which are manually operated. To modify the indoor environment, furthermore, the house is fitted with a combination of cooling and ventilation technologies. Additionally to a pedestal fan, for example, the open plan living area is equipped with two wall-mounted split air conditioners (the capacity of each one is 27000 BTU/hr) and supplemented with a window-mounted evaporative air cooler. The kitchen area relies on a wall-mounted fan besides an extractor fan, while both occupied bedrooms are fitted with pedestal fans and wall-mounted air conditioners (see Fig. 6.17), one for each bedroom with the capacity of 18000 BTU/hr. Moreover, the first-floor corridor is fitted with an evaporative air cooler which is located on the flat roof beneath the corrugated one and supplies cool air to the corridor through the roof vent (see Fig. 6.18). Furthermore, the unoccupied bedrooms are also provided with air-conditioners, even though they are not in use.



Mechanical control	Symbol
Air-conditioning unit	
Evaporative air cooler	
Pedestal fan	

Figure 6.33 Ground floor plan (top-left) and 1st. floor plan (bottom-left) with installed mechanical controls (author) (Note: the shaded bedroom is the one that is used on the first floor)

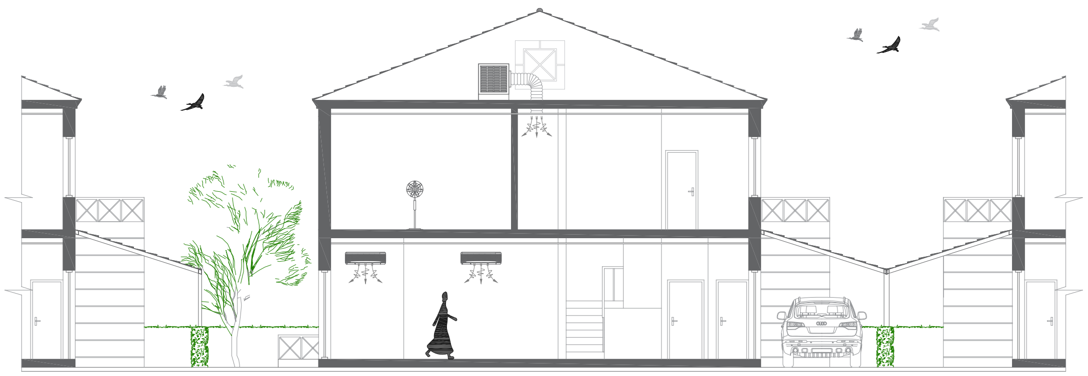


Figure 6.34 Section A-A (author)

The building fabric is characterised by relatively better thermal properties than those that exist in the previous case studies. Fortunately, the construction associated details were accessible as a few similar units in the residential development were under construction at different construction phases which helped the researcher to observe and document the relevant details. The most notable construction techniques that were found in this case study which distinguish it from the previous ones are brickwork and double-roof system. Hollow bricks (240 mm) and reinforced concrete were mainly used for walls and slabs respectively. The external walls were rendered with 20 mm of limestone on the outside and 30 mm of gypsum plaster (from inside) with no insulation layer resulting in a U-value of 1.43 W/m^{2}K, whereas the internal ones were rendered by gypsum plaster on both sides except those in the bathroom and toilet where ceramic tiles were used for rendering. For aesthetic reasons, the flat reinforced concrete roof is coupled with a ventilated pitched lightweight metal tile roof, which is highly conductive, from outside and a plasterboard suspended ceiling from inside resulting in a U-value of 1.3 W/m^{2}K. This is of course with taking into account the R-value of the cavity that exists between the three elements. This type of roof construction has been increasingly adopted in recent years all over the region, especially in the newly built housing estates. Moreover, the floor is composed of wood flooring, screed and concrete and is attached to the ground with no insulation layer in between. In terms of the quality of sliding windows, all were aluminium framed and double glazed.

6.5.2 Household information

An upper middle-class family of three (a man who is in his 50s with his two wives) occupy the house. They live in conditions being economically superior to those of previous households. Their average monthly income is around 4000-4500 USD, and they seek to live an organic lifestyle. English village was an enticing place for the household, and despite being bigger than their needs, they purchased the dwelling and moved to this gated community aiming to have amenities, e.g. 24/7 power access, the security element, spacious rooms and etc. which were lacking in their old neighbourhood. The family generally looks contented with the dwelling given that it fits their lifestyle, although they do not look very delighted with the increased amount of vehicles on the streets which resulted after some homeowners started leasing their houses to companies giving rise to unpleasant traffic.

Five days a week (08:00 am to 05:00 pm), the householder who is a civil engineer works away from home, whereas both wives are housewives spending most of their time at home. Usually, on weekends, they spend time with their relatives and enjoy nature in a resort town called 'Shaqlawa' located 51km from the capital.

6.6 Summary

Four case study dwellings have been presented in this chapter in which each one represents a distinct income group (ranging from low-income to upper-income household): two are located in the city of Duhok, one in Chaman, and one in the capital Erbil. These were selected for the purpose of undertaking assessments on their energy and thermal performance and the nature of their architectural fabric, the role of technology and occupants' behaviour, a key objective of this research. The dwellings ranged from one-storey to two-storey buildings and covered a range of floor areas. All rely on the national grid and a shared generator as sources of electricity supply. Despite the apparent differences in their socioeconomic status and quality of their houses, insufficient thermal insulation is a common feature that their buildings are characterised by. High U-values are common across their buildings' fabric. The next chapter will present the summertime and wintertime investigations undertaken in these dwellings along with their analysis.

Chapter 7

Energy performance and indoor thermal conditions of the selected houses

7.1 Overview

Following the introduction of the case studies, this chapter provides a rigorous evaluation of their energy performance and indoor thermal conditions over both summertime and wintertime. This is besides examining occupants' personal knowledge of the building's thermal behaviour and measures by which comfort can be improved. As thoroughly presented in section 3.3.1.3, the data collection process relied on a close coupling of qualitative and quantitative investigations. This is through employing a combination of in situ measurements, observations, and in-depth interviews capturing inhabitants' behavioural control actions with respect to the performance of their dwellings.

In the next sext sections, the investigations from all case studies are presented individually followed by a conclusion where key findings are highlighted to be used later in developing the modelling scenarios. It is worth noting that wintertime investigations were only undertaken in the first and fourth case study that represent the opposite ends of the socioeconomic spectrum. One of the reasons is that in early October the household of case study 2 moved to another area and left the house unoccupied. Therefore, the researcher found it pointless to carry on the investigation in an unoccupied house where there will be missing parameters affecting the accuracy of the findings.

7.2 Case study 1: A low-income household

7.2.1 Findings – cooling season

7.2.1.1 Adaptive behaviour and attitude

A semi-structured interview was carried out with the housewife on August 17, 2018, at her residence discussing their behavioural pattern in coping with summer temperatures and their energy-related behaviour. It was found that a range of behavioural control actions were being taken by the inhabitants to cope with the summer heat. These practices varied from personal adjustments, i.e. those associated with the human body, to building adjustments. Most of them were manually administrated. The former included activities like: staying away from any source of heat, drinking cold water, dampening clothes, taking cold showers and sitting or lying on the screed floor. On the other hand, the latter involved: removing carpets before summer starts, switching on the split-type air conditioners, using ceiling fans, sprinkling the roof and vegetation around the house from time to time throughout the day, washing the screed floor and opening/closing doors (including the entrance door). Such adaptations were also noted by other studies (see e.g. Nicol and Humphreys, 1998; Baker and Standeven, 1996; Wong et al., 2002; Indraganti, 2010; Langevin et al., 2013; Soebarto and Bennetts, 2014 and Moore et al., 2017).

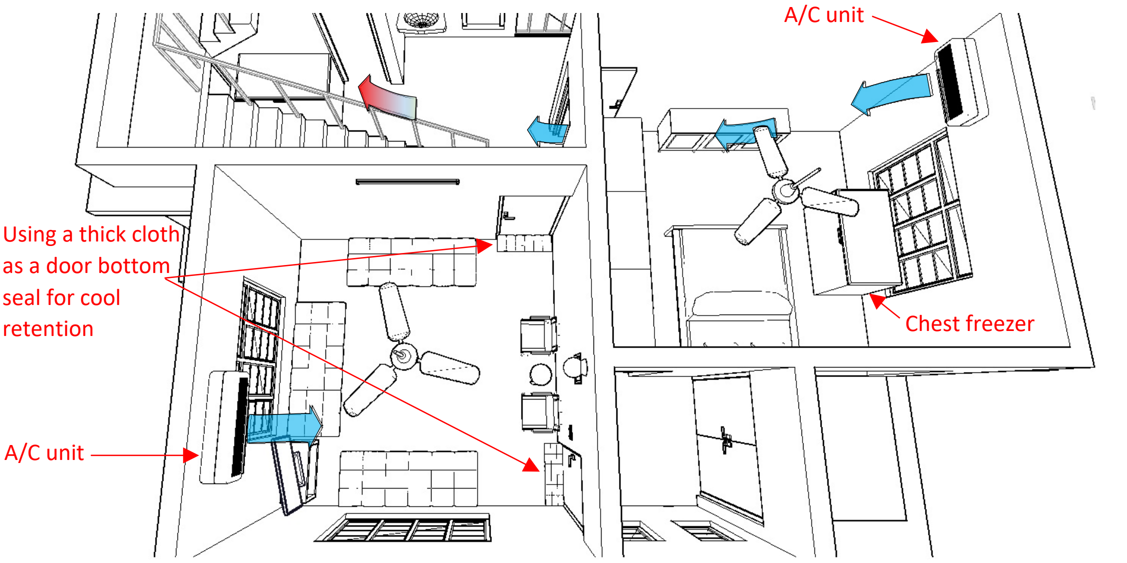


Figure 7.35 The environmental adjustments while A/C is on (author)

However, the source of power supply, economic affordability, social motive and the envelope quality were found to be the most influential factors affecting their thermal interactions with the environment. For instance, their behaviour was found to be changing with the available source of electricity supply. The operation hours of air conditioners were correlated to the availability of power from the national grid. The household used to close the doors (see Fig. 7.1) and leave the air conditioners on at the lowest possible temperature setting whenever power was supplied from the public network, and such habit was formed by low electricity prices that the national grid has offered over many years. In this regard, the housewife stated: "*Nobody is using the bedroom over the day, but the reason why I leave it* [the air conditioner] *on is that I store some food there, and energy from public network is cheap; it does not cost me a lot, so I leave it on*."

The effectiveness and easiness of running A/C might also have instigated such behaviour since an occupant just needs a fingertip on the gadget to cool the indoor environment. Nevertheless, frequent power breakdowns that are experienced with the public network hinder the continuous running of split-type air conditioners in spite of having an alternative energy source, i.e. private generator at the neighbourhood level, which unlike the national grid supplies electricity at considerably higher prices, which prevents the household from operating their A/C units. Data recorded by the installed smart meters shows that the energy consumption over the monitoring period via the private generator is about one tenth (i.e. 1.7 kWh/m^2) of the amount consumed with the public network. In this regard, she stated: "*We cannot switch on A/C to adjust the thermal environment while we have electricity from the neighbourhood generator because it costs a lot and we cannot spend most of our income on that even though we want it*." This could be a clear indication of how ease-of-use is prevented by the economy. Accordingly, the occupants resort to the other personal and environmental adjustments that are stated above to overcome thermal discomfort when that is a restriction. Particularly, the chance of operating ceiling fans (see Fig. 7.2), to create a downdraft, accompanied by some humidification techniques, e.g. taking cold showers, dampening cloths or washing the floor, is very high and their role is believed to be important in alleviating discomfort from the heat. Alongside that, a platter full of plastic cups of frozen water was observed in the living room indicating the continual drink of cold water. She commented on that by saying: "*Since I drink cold water a lot during hot periods* [when A/C goes off], *I bring several cups of ice water together from time to time to avoid going to the warm kitchen where the refrigerator is located for as long as possible.*"

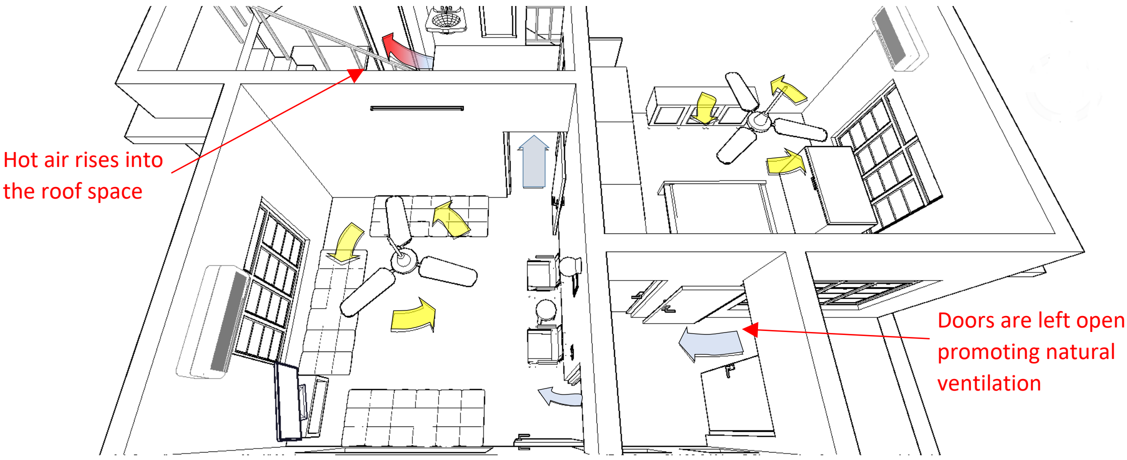


Figure 7.36 Part of the environmental adjustments at free-running mode (author)

The poor fabric conditions continued to impact their thermal behaviour. Due to the severe indoor conditions caused by heat flux through the fabric, for instance, the family decided to use the least uncomfortable spaces, thus converting the south-facing bedroom into a storage area. Furthermore, since indoor thermal conditions were further exacerbated by heat gains through the non-insulated exposed roof, the garden hose was being taken to the housetop in the late morning with leaving the faucet on for few hours to reduce that (see Fig. 7.3). This was, in fact, a longstanding cultural practice in the region (Abdulkareem, 2016). This behaviour also promoted evaporative cooling to occur around the house. While the researcher was filming this behaviour, the housewife, who had been living in a stone house in the village before moving to this house, commented on this action by saying: "*My mom used to do the same at the time* [….] *when I don't do that, we feel excessive heat coming down through the roof*."

Figure 7.37 The garden hose taken to the rooftop to reduce heat gains through the roof and promote evaporative cooling around the house (author)

Figure 7.38 The way the household deals with air leaks through the bottom of the doors (author)

In addition, a thick cloth was used as a door bottom seal for cool retention in the occupied rooms, especially when A/C was running (see Fig. 7.4). Despite the existence of openable windows in the examined rooms, adhesive tape was used around the frames to seal gaps and avoid leaks, and this impeded the occupants from opening them when they need to. The researcher also noticed a few cracked window panes which were covered by packing tape without being replaced. In this respect, when the lady was asked to identify the worst building attribute, she stated:

> *There are many which I am sure that you* [the researcher] *have already observed, but the worst one is air infiltration especially through windows. Sometimes, you can clearly hear the sounds of drafts coming through especially during windy conditions. And as you* [the

researcher] *see, I used sealing tape (adhesive tape) to prevent that, but it is not very effective.”*

Apart from that, the impression the lady gave the researcher was that their decision of using certain thermal control devices was partly influenced by non-thermal factors. In response to the social presentation of the home, the existing air-coolers were no longer used despite their significant role in respect to thermal comfort and energy saving. Despite their low and very limited income, the household felt obliged to install A/C units as an indication to relatives and neighbours of their social status. This clearly shows how a certain environmental control could be status-enhancing in that society rather than a thermal requirement. This is highlighted through the following illustrative quote:

> *We had used air coolers for years and they were good enough for us, but most of the people around us, I mean our relatives, started using air-conditioners instead of air coolers over the last years. And I don't know how to explain this to you, but my son was embarrassed and he kept pressing me to follow them and adopt A/C in our home in spite of having no money for that. So you can say it was a result of social influence.*

7.2.1.2 Physical measurements

To gain an understanding of the environmental conditions to which occupants were exposed, over the period of four weeks starting from July 25 to August 22, 2018, data collection of the outdoor and indoor thermal environment was carried out. It focused on the living room (16m^2) and main bedroom (17.5m^2) (see Fig. 7.5). Owing to the limited numbers of monitoring devices, indoor measurements were not taken in the other areas, e.g. kitchen and corridor.

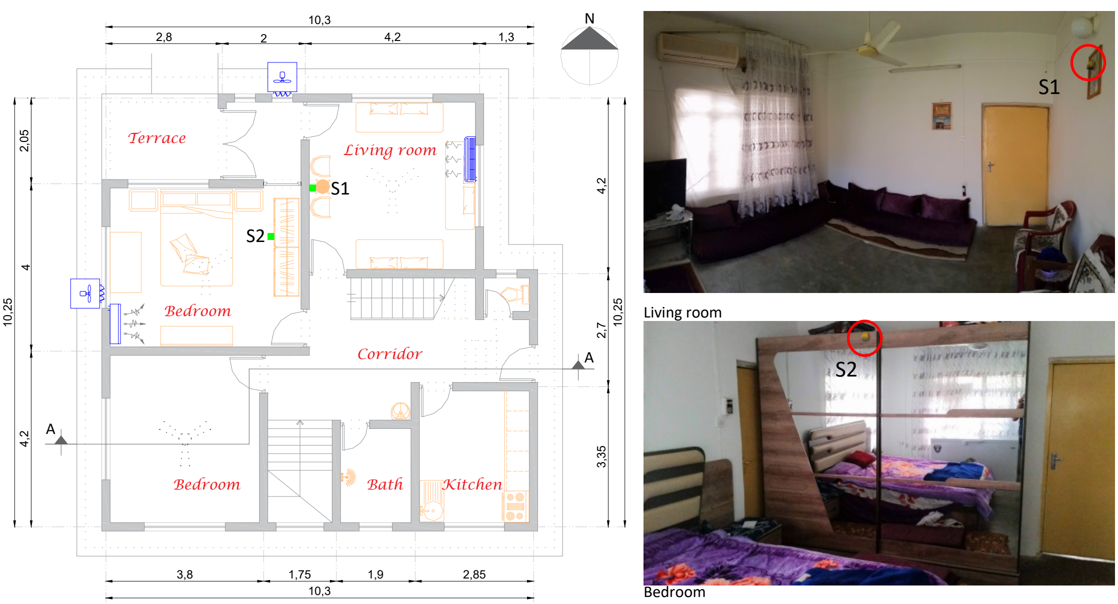


Figure 7.39 Ground floor plan (left) and views of the monitored spaces (right) showing the location of data loggers

The outdoor readings show that the mean daily temperatures ranged from 32.9 °C to 35.4 °C, whilst the lowest and highest records were 27.7 °C and 40.4 °C respectively. In addition, 'running mean outdoor air temperature' (T_{rm}) ranged from 32.2 °C to 33.4 °C. The diurnal temperature variation is found to be noticeable (10.4 K as an average). Meanwhile, the data reveals that the diurnal fluctuation of RH was from 9.4% to 42.1% (see Fig. 7.6).

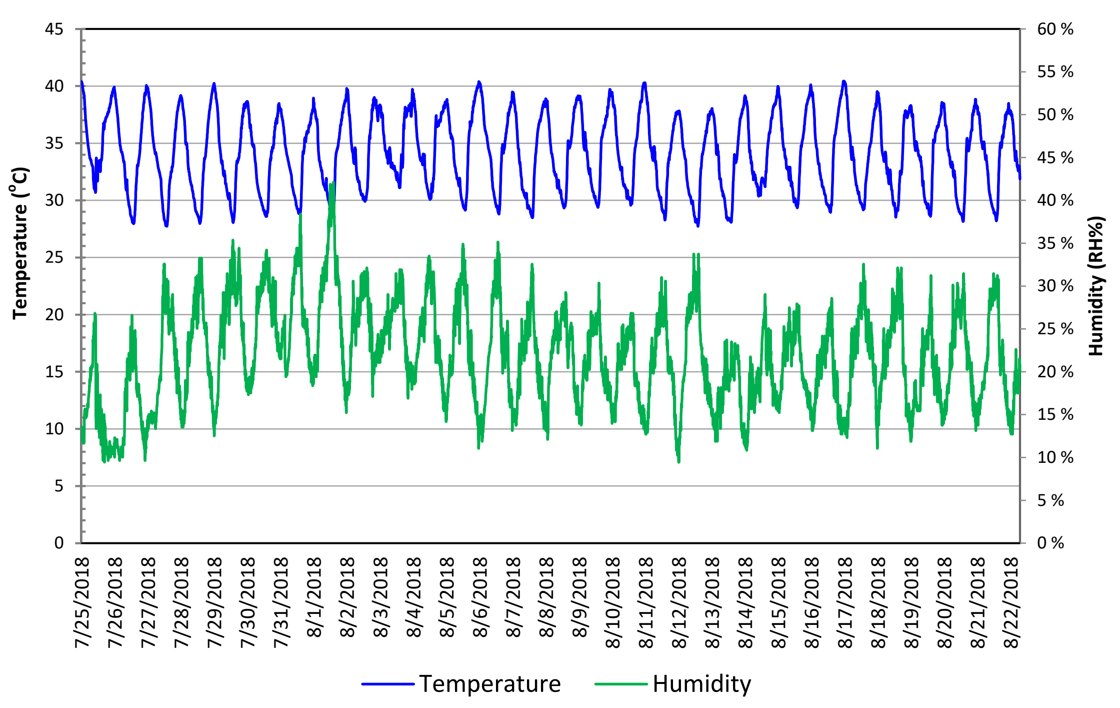


Figure 7.40 Recorded outdoor dry-bulb temperature and relative humidity (author)

Meanwhile, indoor environment data showed an apparent difference between the measurements taken in the living room and those taken in the bedroom, where the later had been generally warmer and drier (see Fig. 7.7), with the average minimum temperature being approximately 4.3 K higher and mean relative humidity 9% lower in the bedroom. This is most likely a consequence of: having a smaller air conditioner running in the bedroom, leaving the door leading to the hallway open from time to time causing heat transfer by convection, internal heat gains generated from a chest freezer installed there, sealing off operable windows with adhesive tape preventing them being opened, and lack of practising passive cooling techniques, e.g. floor washing, in that room. On average, the variation between the daily minimum and maximum temperature was around 10 to 11 K. Such variation might be expected within spaces having access to air conditioning from time to time throughout the day. At the free-running mode of the building, moreover, a fundamental correlation between internal and external temperatures is evident as shown in figure 7.8. It reveals the deficiency of the building fabric in delaying the heat transfer. This was also underlined by the occupant during the interview, stating: *as soon as the air-conditioner stops running, the indoor environment changes rapidly, I mean it becomes warm causing discomfort.*

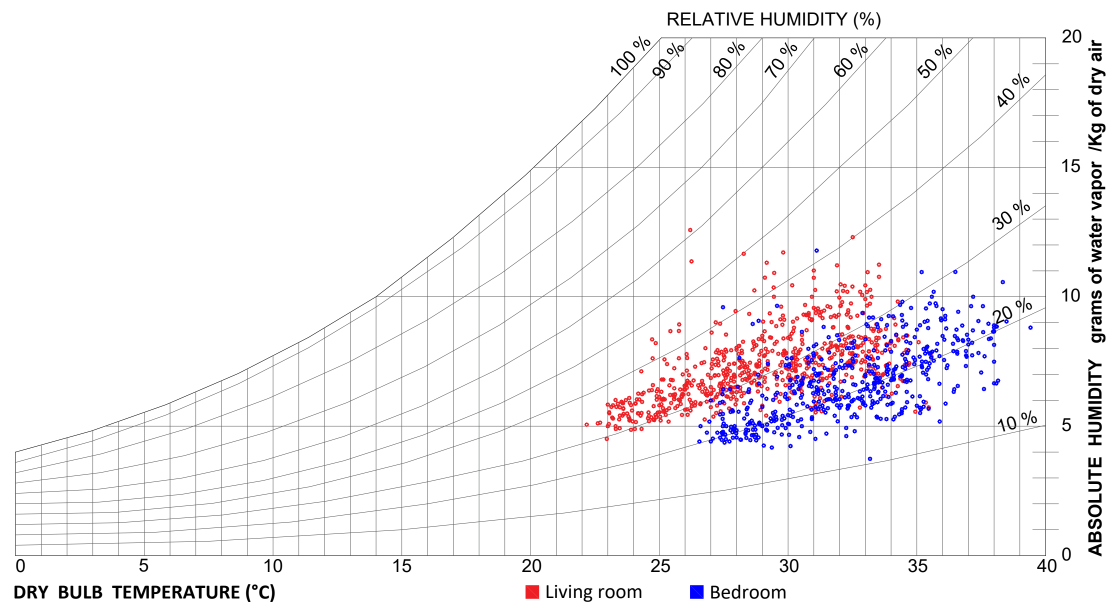


Figure 7.41 A psychrometric chart shows the internal measurements in both living room and bedroom (Note: each data point represents an hourly average of the indoor temperature and RH)

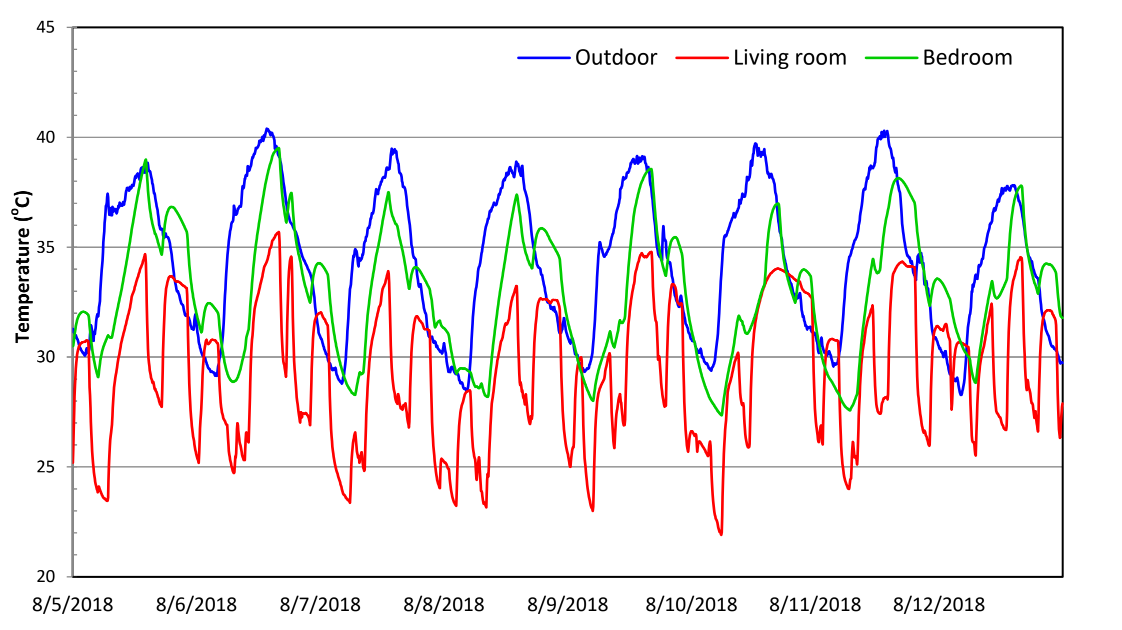


Figure 7.42 Recorded indoor and outdoor dry-bulb temperatures (author)

Overall, indoor thermal discomfort is evident in the house, and temperatures had been high reaching 35 °C and 39 °C in the living room and bedroom respectively (see Fig. 7.9), particularly when A/C was not running. In the living room, which was occupied 24/7 as the housewife was sleeping there overnight, the mean daily temperature ranged from 25.9 °C to 31.2 °C, and the peak indoor temperature, 35.7 °C, was observed to be around the outdoor temperature on the hottest day, July 26th, the day when the household received only a few hours of electricity during the day from the national grid prevented them to continually run the air conditioners.

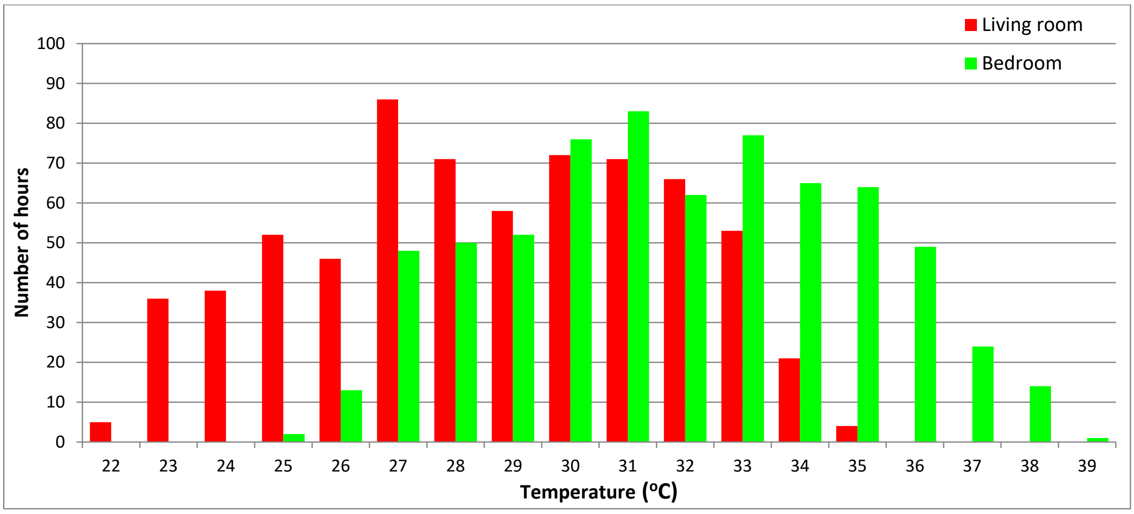


Figure 7.43 Histogram of hourly living room and bedroom temperatures (author)

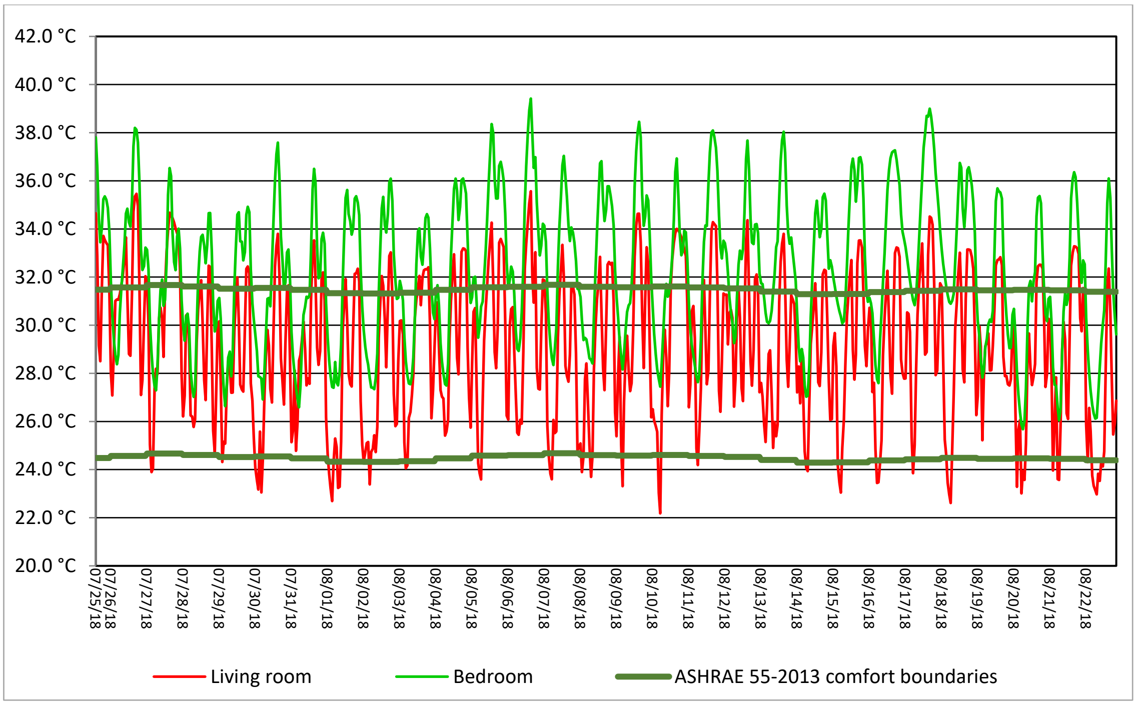


Figure 7.44 Indoor temperatures with comfort boundaries of ASHRAE 55 (80% acceptability)

Compared to CIBSE static criteria where 28 °C in living space should not be exceeded greater than 1% of annual occupied hours (see section 3.3.1.3.3 for further details), the data showed that 61% of the monitoring period, living room temperatures exceeded 28 °C (see Table 7.1). However, during the operation hours of air conditioners where thermal sensation was indicated as neutral and slightly cool over day and night respectively, the indoor environment was relatively comfortable according to the measurements. On the other hand, the bedroom experienced higher indoor temperatures where the mean daily temperature had been between 29.9 °C and 34.9 °C, and the highest recorded temperature was a degree above the outdoor temperature on the hottest day. At night when the bedroom was occupied, the mean temperature ranged from 27.4 °C to 31.9 °C; it had approximately 99% of occupied hours with records in excess of 26 °C (see Table 7.1). Furthermore, both monitored spaces failed to meet both 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria (see Fig. 7.10 and Table 7.1). These figures also correspond to occupancy evaluation which indicated the overall indoor environment as being uncomfortable. Perhaps being located under a non-insulated concrete roof exposed to high solar radiation and temperature explains those high figures to some extent. These hot conditions were accompanied by an absolute absence of opening windows due to the earlier mentioned reason. At the free-running mode, furthermore, the likelihood of indoor night-time temperature exceeding the outdoor temperature is considerable, particularly between the hours of 8 pm and 4 am. Interestingly, a degree or two were observed to be higher in both rooms than the outside during that time which might indicate the impact of thermal mass throughout the spaces as well as the limitation of environmental adjustments, e.g. opening windows for night cooling, overnight.

Table 7.7 A summary of overheating assessment in regards to ASHARE adaptive comfort & CIBSE static standards

	Internal temperature			Percentage of occupied hours above certain temperatures		ASHRAE adaptive comfort standard	
Room	Mean (°C)	Minimum (°C)	Maximum (°C)	>26 °C	>28 °C	Occupied hours above T_{upper} (90% acceptability)	Occupied hours above T_{upper} (80% acceptability)
Living room	29.07	21.9	35.7	-	61%	236 (35%)	167 (24%)
Bedroom	32.31	25.63	39.51	99%	-	133 (43%)	83 (27%)

7.2.2 Findings – heating season

Before going through the findings of the wintertime fieldwork, it is worth noting that this case study was initially proposed to be a possible follow-up pilot study to the current research in order to examine the feasibility and applicability of the research's outcomes on the ground through retrofit. Besides the physical attributes of the building and the household's readiness for any further work to be carried out in the future which encouraged the researcher to select this house among the four case studies, their harsh economic conditions would likely encourage charity donors to contribute and provide financial support to the project. In his attempts to find a sponsor for such a proposed stage, a charity donor, who prefers to stay anonymous out of religious conviction, showed his willingness to partly support the research and improve the house's conditions. And they actually accompanied the researcher in one of his visits during the summertime fieldwork to see the house and evaluate the situation. In early December 2018 and prior to conducting the winter's fieldwork, however, they executed a few significant changes to the living room without informing the researcher. The changes included: the replacement of the old steel windows with new PVC ones (double glazed), the replacement of the existing split type air conditioner with a new one with changing its location, and the provision of new furniture, a Smart TV, curtains, and a rug (see Fig. 7.11 & 7.12).

Figure 7.45 The new PVC windows of the living room (author)

Figure 7.46 The living room a. before changes b. after changes (author)

7.2.2.1 Adaptive behaviour and attitude – heating season

On January 20, 2018, the researcher held a semi-structured interview with the family discussing their thermal behaviours and strategies in dealing with winter temperatures and maintaining their thermal comfort. And in response to their invitation for an overnight stay, the researcher spent that day at their house to undertake further observations. A range of adaptive actions, which varied from personal adjustments to building adjustments, were found to be practiced by the family members to stay warm in the cold. The former included activities like: staying in the most comfortable space, staying close to any source of heat, drinking tea, wearing thick clothes and putting on toasty socks, wearing a headscarf, laying a small blanket over legs, and sleeping under heavy blankets. On the other hand, the latter involved: laying rugs before winter starts, leaving doors and windows closed, Using a thick cloth as a door bottom seal to exclude draughts and retain heat, and turning on heating equipment (i.e. a kerosene heater, an electric heater, and a split-type air conditioner). Only the living room was equipped with such heating tools (see Fig. 7.13). Despite having an A/C unit in the bedroom, it has no heating system to be used in winter.

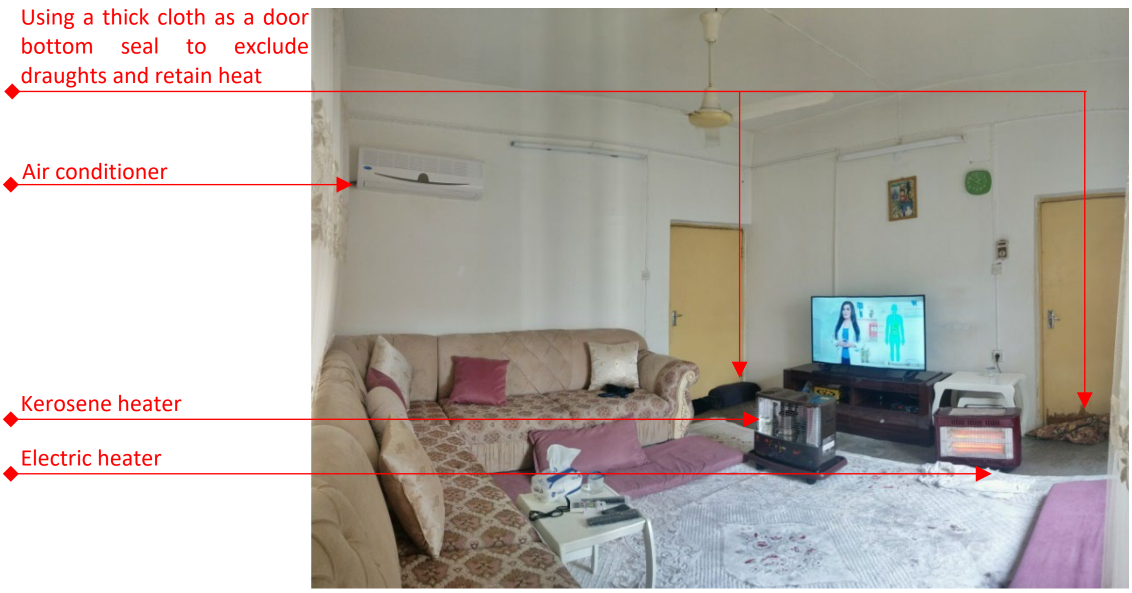


Figure 7.47 The living room with heating equipment (author)

Similar to the summertime findings, their thermal interactions with the environment were found to be changing with the change in power supply mode due to the prices being offered by the two different suppliers as explained previously. When electricity was being supplied through the national grid, the occupants were primarily relying on electric heating equipment. They used to seal the house to avoid heat loss, stay in the living room and switch on the portable electric heater and the air conditioner, and this behaviour as indicated previously was obviously formed by low electricity prices that the national grid has offered over many years. When the

Independent Power Producer (IPP) was supplying electricity, on the other hand, both tools were not operated as the household could not afford their running costs. Instead, the occupants were resorting to the use of the kerosene heater as the government does provide each family with 200 to 400 litters of kerosene every year at a minimal charge of $0.16 for a litter. However, if the given amount did not suffice, which is the most likely scenario, the family needs to buy it from oil stations at a higher charge of $0.6 for a litre. This presented a challenge for the household and forced them to use the kerosene heater in a restricted manner to reduce fuel consumption and avoid additional financial burdens despite experiencing extremely cold temperatures across the house as presented in the next section.

Figure 7.48 The teapot on the kerosene heater in the living room (author)

For that reason, they used to stay in the living room throughout the day and run only one kerosene heater when IPP was supplying electricity despite having another one stored in the basement which was only used in 'very cold days' in the bedroom as reported by the housewife. The operation of the kerosene heater was often accompanied by putting on one more layer of clothing, covering the legs with a small blanket or sitting and putting their feet close to the heater. Figure 7.13 shows how close the kerosene heater was to the housewife's sitting place. "*I feel discomfort and cannot sleep well when my feet get cold*," says the housewife. In addition to that, drinking tea was observed several times during the researcher's stay there; most of the time, there was a stainless steel teapot on the top of the heater in the living room (see Fig. 7.14). She commented on that by saying: "*The tea helps somewhat; with the first sip, your throat and stomach start getting a fleeting feeling of warmth [….] we drink it a lot and the kitchen is so cold which is why we used to make it here using one of the heaters instead of preparing it in the kitchen every time.*" However, despite all those endeavours to reduce their fuel consumption, it exceeds the amount that the government provides. On average, the household burns around 500 to 600 litters throughout the heating season. "*We try our best to keep fuel consumption within our means, but winter chills tend to defeat our attempts in the light of* *constant electricity blackouts that we experience with the National Grid*," says the housewife. This season, fortunately, the charity donor who renovated the living room filled the fuel gap and purchased two barrels of kerosene for the household.

Nevertheless, not only financial concerns but also potential safety risks associated with the use of kerosene heaters such as fire hazard and carbon monoxide poisoning restrained the usage of such technology to some extent. Multiple studies (e.g. Fisher, 1999; Abelsohn et al., 2002; Ritchie et al., 2003 and Prockop and Chichkova, 2007) have shown that health problems such as shortness of breath, difficulty in concentrating, nausea, weakness, dizziness and headache could arise from breathing kerosene fumes. With prolonged exposure, the symptoms could be more severe such as convulsions and loss of consciousness, especially within spaces that are poorly ventilated, and there is also a possibility of lung and heart failure which could lead to death. According to the World Health Organization (WHO), "*3.8 million people a year die prematurely from illness attributable to the household air pollution caused by the inefficient use of solid fuels and kerosene*." Those health concerns indeed frighten the majority of families across the region when using such heating tool regardless of the income level. In this case study, both occupants were very keen to turn off the kerosene heater before going to bed no matter how cold the indoor environment was. This is highlighted through the following illustrative quote: "*Every year as a result of leaving kerosene heaters on during sleeping times, multiple people die. A family of four lost their lives last week because of that. You know it is really terrifying, so even if I had enough fuel, I would never leave the heater on while we sleep*." The same attitude was applied to the portable electric heater as well due to a potential fire hazard. Furthermore, what also slightly bothered the inhabitants in using the kerosene heater was the daily process of refilling it with fuel especially on rainy days as the fuel barrels were located outdoor for safety purposes, around 10 m away from the entrance. This sometimes, according to the housewife, causes the person in charge to be exposed to extreme cold for several minutes when the heater needs to be refilled.

While there was a chance for the living room air conditioner to be operated at times when the national grid was supplying electricity during sleeping hours, the adult son had no other option in the unheated bedroom than wrapping up himself in a bunch of blankets. "*The blankets keep me warm regardless of the room's low temperatures, but the first some minutes after getting into my bed are tough; my teeth often chatter. Also, the problem when you get up in the morning and remove the blankets, usually, it takes me around 15 minutes to have that courage to get out of my bed*," says the son. Indeed, unpleasant indoor conditions were evident across the house with the exception of the living room which is why the inhabitants were thermally dissatisfied with the rest of the spaces. The concrete floor was so cold to a degree that the researcher found it hard to walk barefoot through the corridor; the rugs were only available in the living room and the bedroom. And to avoid touching the cold floor, a few pairs of sandals were provided in the corridor. One of the most challenging moments for both occupants is when they wake up for the dawn prayer which requires going through the corridor to the bathroom to perform Wudu, i.e. *ritual washing to be performed in preparation for prayer and worship*, since both unheated areas are usually very cold at that time. "*You need to prepare yourself for that moment*," says the housewife. As soon as she wakes up, she lights the kerosene heater straight away, takes off her socks to be able to wash her feet, and puts on a cardigan before heading to the bathroom, and so do her son. After Wudu, they return to the living room and expose themselves to the heat for some minutes to warm up and then pray their prayers next to the heater.

7.2.2.2 Physical measurements

Over the period of a month starting from December 22 to January 22, 2019, the outdoor and indoor thermal environment had been monitored. The indoor spaces included the living room and the main bedroom, and upon the household's complaints about the harsh thermal conditions of the corridor, the researcher used one of the data loggers left from case-study 2 to carry out monitoring in that space as well (see Fig. 7.15). It should be noted that the researcher could not hang the living room's data logger at the same place where summertime measurements were taken because the portable electric heater used to be run right under that position, and this could have significantly affected the accuracy of the data. This is why the data logger was installed onto another wall away from any source of heat.

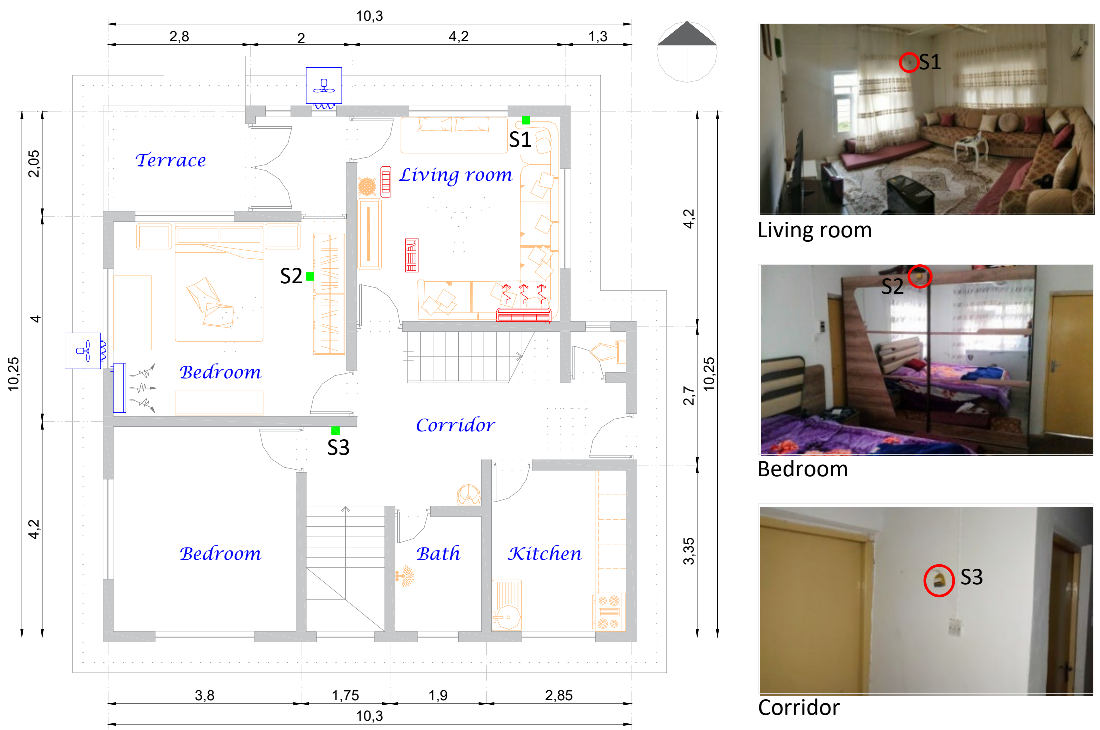


Figure 7.49 Ground floor plan (left) and views of the monitored spaces (right) showing the location of data loggers (author)

It is clear from the outdoor data that during the monitoring period the area was generally cold and wet. The mean daily temperature ranged from 4.1 °C to 10.9 °C, and the lowest and highest records were 1.2 °C and 13.3 °C respectively. Running mean outdoor air temperature (T_{rm}) ranged from 5.7 °C to 9.8 °C. On average, the diurnal temperature variation is found to be around 4.3 K. Meanwhile, the data reveal that the mean relative humidity ranged from 47% to 90% (see Fig. 7.16).

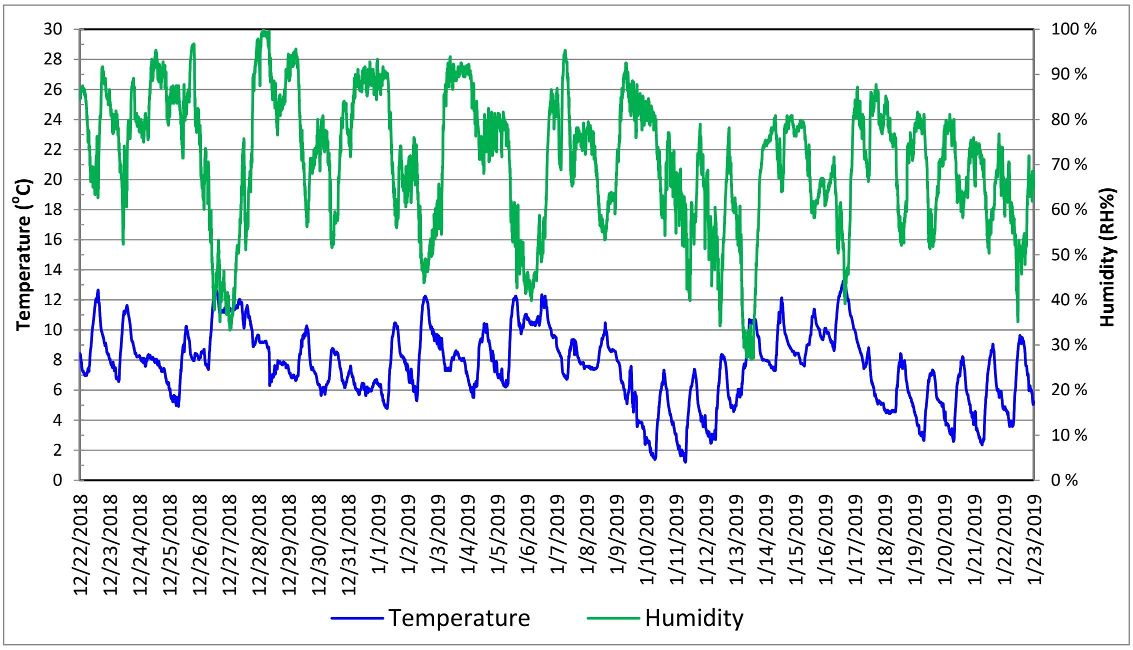


Figure 7.50 Outdoor dry-bulb temperature and relative humidity (author)

In terms of the indoor data, the mean daily RH is found to be relatively similar across the monitored areas ranging from 62% to 86%. However, a significant difference can be noted between dry-bulb temperatures recorded in the living room and those measured in the bedroom and the corridor, where the first had been significantly warmer (see Fig. 7.17 and 7.18), with the mean temperature during the monitoring campaign being approximately 8 K higher in the living room. This is primarily a consequence of employing heating equipment in the living room most of the time besides having new PVC framed and double-glazed windows there which have certainly resulted in maximising heat retention and reducing air leakages that widely takes place in the other rooms due to the poor conditions of their windows as explained previously. Their contribution in having better thermal conditions in the living room can be clearly noted by looking at temperatures recorded during sleeping hours when none of the heating tools was in use, e.g. Jan 10 (2 am to 5 am), showing up to 6 K higher temperatures in the living room when compared to the bedroom (see Fig. 7.18). This, in fact, was also underlined by the housewife during the interview, saying: "*I can tell that the indoor conditions here* [living room] *have been remarkably improved since the replacement of the windows. There are I think no more air leakages through those two windows*." In contrast to the bedroom and the corridor, the variation between the living room's daily minimum and maximum temperature is found to be large, around 8 K as an average. One could expect such variation within a space equipped with three heating tools.

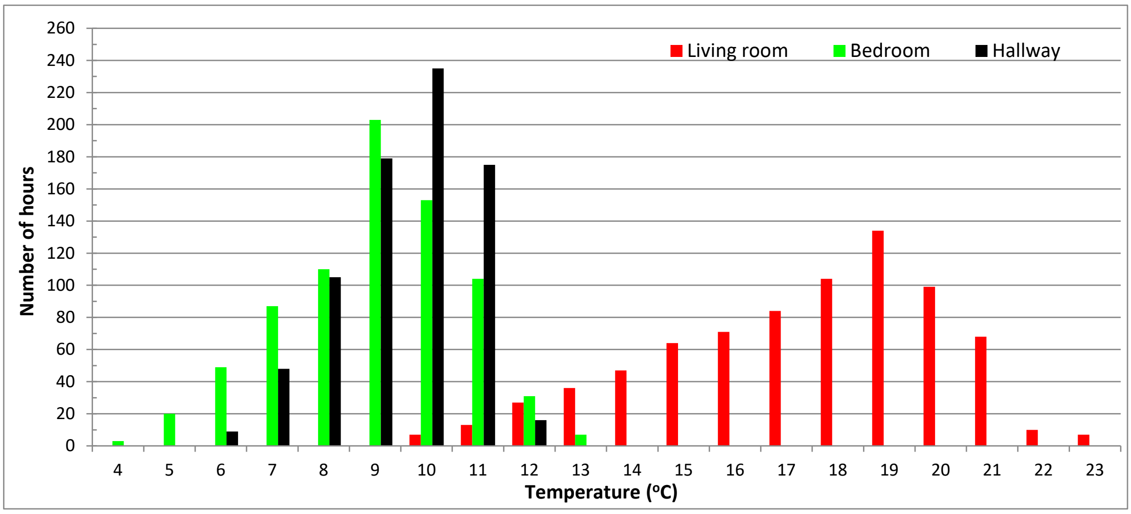


Figure 7.51 Histogram of hourly temperatures in the monitored spaces (author)

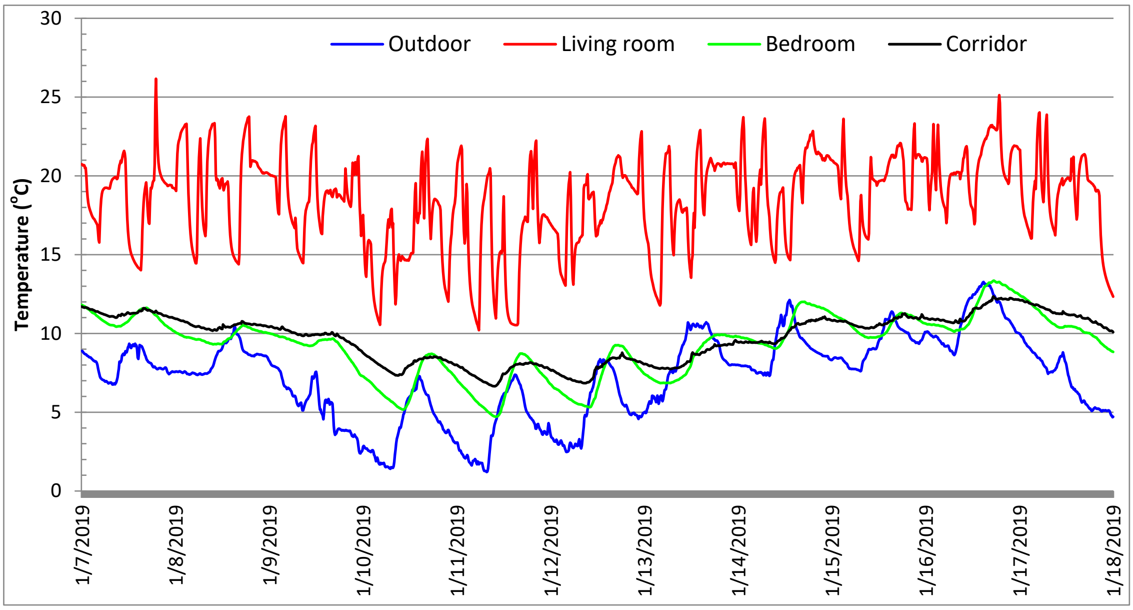


Figure 7.52 Recorded indoor and outdoor dry-bulb temperatures (author)

With the exception of the living room, indoor thermal conditions were generally adverse and far from the comfort zone, with indoor temperatures as low as 5 °C and 7 °C in the bedroom and the corridor respectively (see Fig. 7.18). Starting with the most uncomfortable space (i.e. the bedroom) as indicated by the occupants, the in situ measurements show that the mean daily temperature ranged from 6.7 °C to 11.6 °C. The lowest record, which is 4.7 °C, was found to be around the outdoor temperature on the coldest day, January 11, the day when the outdoor temperatures remained within the range of 1.2 to 7.4 °C. At night, when the bedroom was occupied, the mean temperature ranged from 6.2 °C to 11.8 °C, with all occupied hours with records below 13 °C, and these cold conditions were accompanied by an absolute absence of mechanical heating. In view of these low figures, one can easily understand the son's thermal behaviour of sleeping under heavy blankets and why he declared a high degree of dissatisfaction. It is quite understandable since at 16 °C and below, according to the World Health Organisation (WHO), "*there is an increasing risk of hypothermia developing, and also of increased respiratory illness*." In the corridor, meanwhile, the mean daily temperature ranged from 7.6 °C to 11.6 °C, with all records below 13 °C, and the coldest record was found to be 6.6 °C on the same morning when the bedroom's lowest temperature was recorded. Interestingly, the temperature fluctuation of both bedroom and corridor was noticeably following the outdoor one as illustrated in figure 7.18, and the likelihood of their indoor temperatures falling below the outdoor one was common, particularly during the daylight hours, likely due to the poor fabric conditions alongside the impact of thermal mass all around the spaces in the light of having no heating and solar gains. Up to 3 K can sometimes be observed to be lower in both unheated spaces when compared to outdoor. Those data give a further explanation of some of the qualitative findings, e.g. the housewife's behaviour of putting on an additional layer of clothing before leaving the living room and moving through the corridor. On the other hand, warmer temperatures were found in the living room which according to the interviewees was the most comfortable space. The mean daytime and the mean night-time temperatures remained within the range of 14.7 to 21.1 °C and 13.2 to 20.1 °C respectively, with no record below the outdoor temperature. However, the room did not accomplish a steady thermal condition and failed to meet CIBSE static criteria and both 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria, despite the frequent operation of heating equipment there (see Fig. 7.19 and Table 7.2). Over a quarter of the readings were below 16 °C, the degree that poses certain risks to human health according to WHO.

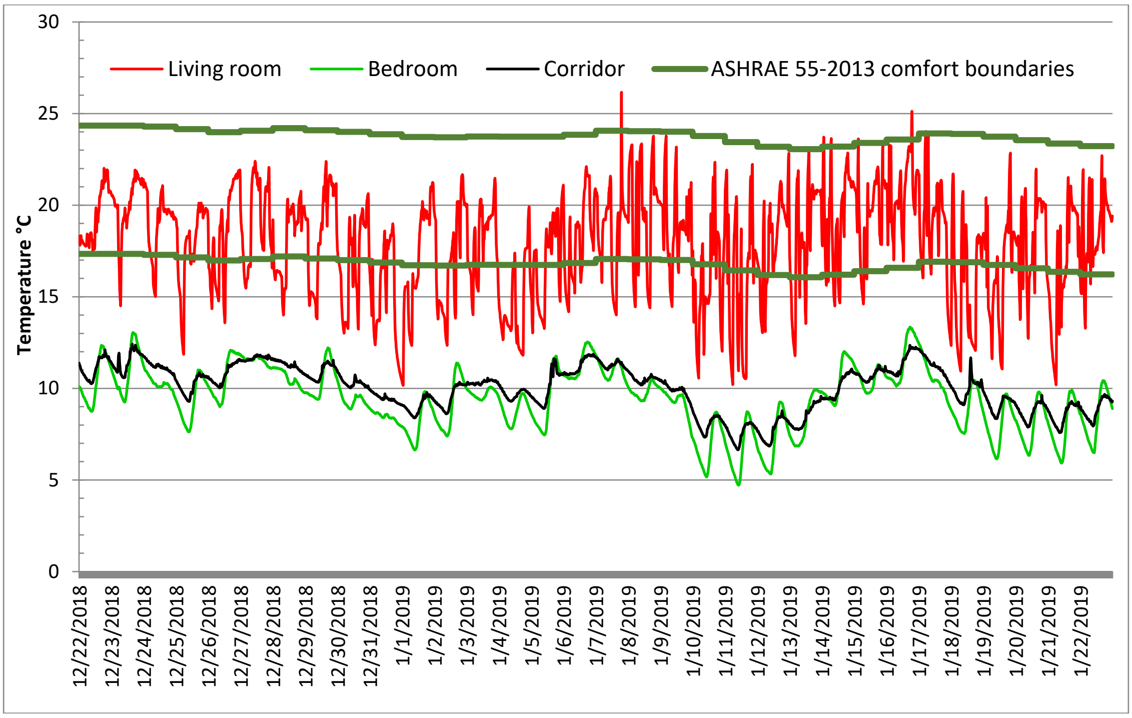


Figure 7.53 Indoor temperatures with comfort boundaries of ASHRAE 55 (80% acceptability)

Table 7.8 A summary of indoor thermal conditions in regards to ASHARE adaptive comfort & CIBSE static standards (author)

Space	Internal temperature			Percentage of occupied hours below certain temperatures		ASHRAE adaptive comfort standard	
	Mean (°C)	Min (°C)	Max (°C)	<17 °C	<22 °C	Occupied hours below T_{lower} (90% acceptability)	Occupied hours below T_{lower} (80% acceptability)
Living room (daytime)	17.9	10.9	26.16	-	97%	134 (43%)	94 (21%)
Living room (night-time)	17	10.16	24.02	48%		192 (60%)	149 (47%)
Bedroom	9.4	4.71	13.35	100%	-	100%	100%
Corridor	10	6.65	12.41	-	-	100%	100%

6.1.5 Energy consumption

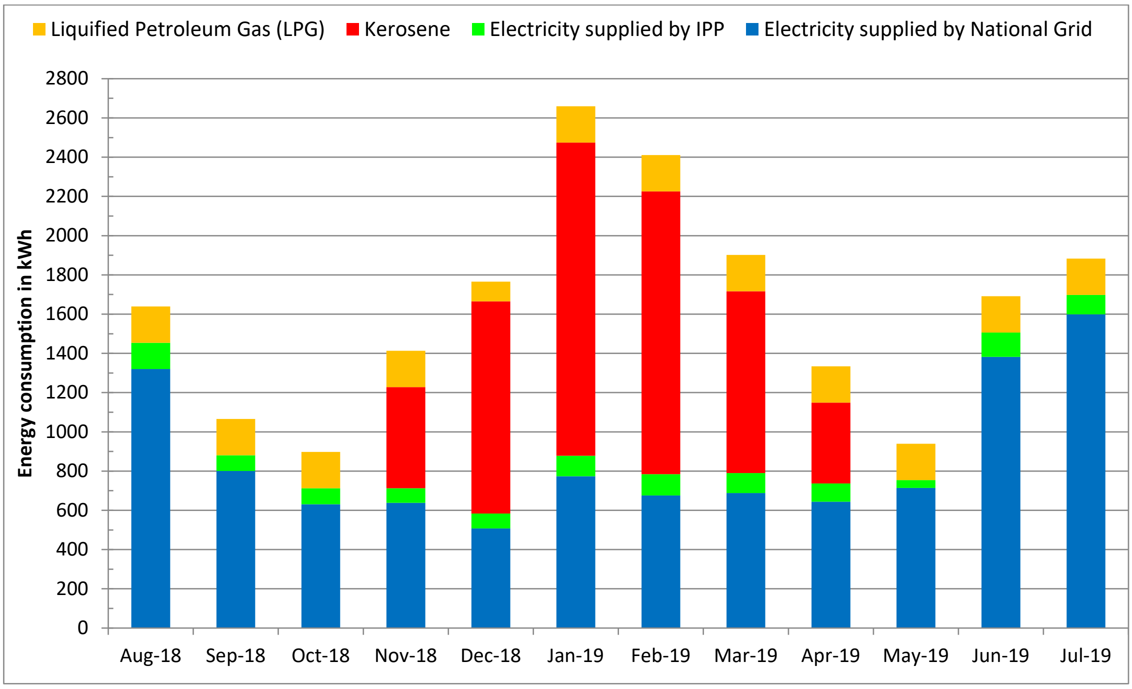


Figure 7.54 Household's energy consumption profile (author)

During the period of a year starting from August 01, 2018, the household's energy consumption data had been collected. On a monthly basis, electricity readings were being documented and relevant information was being provided regarding the consumed amount of kerosene and the LPG cylinders. The findings show that the occupants had consumed a total of nearly 19601 kWh, i.e. (258 kWh/m^{2}yr) when considering the occupied area, with January and October recording the highest and lowest monthly energy consumption respectively. The most-used source is found to be electricity supplied by the National Grid accounting for 53% of the total power consumption, while IPP electricity is found to be the least-used source accounting for 5.7% of the total consumption (see Fig. 7.20). This is despite the fact that the neighbourhood generator was supplying electricity for nearly 11-12 hours per day. This, as indicated earlier, was primarily driven by the electricity prices that the two suppliers offer in the light of their limited income.

Indeed, the latter source was exclusively used for lighting, refrigerating, powering the TV, and charging a phone. Furthermore, the consumed kerosene and Liquefied Petroleum Gas (LPG) represent 30.4% and 11% of the total consumption respectively where the former was the most-used source of energy during the heating season, and the latter was exclusively used for cooking throughout the year. It is noteworthy that the house was left unoccupied for ten days (December 6 to 16), and all appliances were off as the occupants were staying in their village which resulted in having less energy consumed during the month of December than what was expected.

7.3 Case study 2: A working-class household

7.3.1 Findings – cooling season

7.3.1.1 Adaptive behaviour and attitude

A semi-structured interview was carried out with the family on August 13, 2018, at their residence discussing questions of thermal comfort and environmental control. The interview revealed that their strategies of coping with summer heat were in a similar fashion to the previous household where a range of adaptive actions are practiced in order to prevent thermal discomfort. These include ingesting chilled fluids, showering, moving to the most comfortable space, adjusting clothes, removing carpets, turning on cooling equipment (i.e. fans, air conditioners, and evaporative air-coolers) and exposing themselves directly to the cool air, adjusting blinds and opening/closing windows. Similar to case study one, the behaviours were essentially influenced by the source of power supply, economic affordability, social motive, and the envelope quality. In this case study, however, there is a noticeable decrease in the level of human intervention as the occupants were being more inclined to rely on mechanical controls, mainly air conditioners and evaporative air coolers, than considering other adaptive measures. Before moving to the current house in 2016, in fact, the family was living in a rented one-storey dwelling which had no access to AC, but the social presentation of the home, according to the householder, has instigated to some extent their installation in the current house.

The optimum cooling role of air-conditioning as well as having free electrical power from the National Grid have led the household to resort to A/C as a first response to high indoor temperatures, whenever electricity was supplied through the national grid. The latter attribute has also lowered occupants' willingness to save energy. The occupants used to seal the house and leave both air conditioners on at the lowest possible temperature setting even during times when nobody was at home. This habitual consumption is reflected in the data taken by the installed smart meter which shows that approximately two MWh's of electricity through the National Grid were consumed by the household over the monitoring period. In this regard the householder commented:

You know, there is no bill, so why do we need to be concerned about electricity consumption? You can simply say that we switch them on when summer starts and leave them on until the end of the season [....].There are times when I feel slightly cold especially at night, maybe it sounds odd, but I use a lightweight blanket or a duvet to cover my body instead of turning it off or setting it at a higher temperature."

Nonetheless, constant electricity blackouts from the National Grid alongside high electricity prices offered by the Independent Power Producer (IPP) limit the use of such technology to certain hours throughout the day. This in turn was hindering the provision of perfect conditions, i.e. uniformly neutral and completely constant thermal environment. Upon the householder's request, indeed, the electrical system and wiring installations in the house were set up in such a way that allows air conditioners to only be operated on the national grid power mode. When the householder was asked about that, he stated: "*In the light of our limited income, energy expense is a real concern. Such electrical installation has enabled us to leave the air-conditioners running even when we are not home or while we are asleep and thereby when an outage occurs and the alternative source* [IPP] *starts supplying electricity, the A/C units stop operating avoiding costs involved in their usage.*" This shows how the economy has been central to occupants' decisions of behaving in certain ways.

When Independent Power Producer supplies energy, the other thermal control actions alternatively come into play to restore occupants' comfort. In particular, the evaporative air cooler was noted to be the second most deployed environmental control for being considered more energy-efficient and cost-effective. This obviously led the other adaptive measures, especially the passive ones, to be employed less. Although it is a mechanical control, some sort of care, such as oiling the motor, cleaning the pump, changing the moisture pads, and connecting/disconnecting the water line, were needed to provide optimal results. Nevertheless, both evaporative coolers, i.e. the indoor and outdoor ones, were being unable to cool down the indoor environment to a degree that the existing ACs would do which is why the wife and the children, who spent most of the time in the house, were slightly unsatisfied about the thermal conditions, especially over the daytime. To avoid thermal distress in hottest times, therefore, their operation was often accompanied by consumption of cold beverages, showering, and opening windows for night-time ventilation (with the exception of children's bedroom).

Apart from the fact that evaporative air coolers are generally less effective than air-conditioners, perhaps their thermal experience with the frequent use of air conditioning at the lowest possible temperature has diminished their abilities to tolerate higher temperatures and thus influenced their thermal sensation and degree of satisfaction. Such conclusion was also noted by other studies (see e.g. Brager and De Dear, 1998 and Saman et al., 2013). Presumably, a more satisfactory condition could have been met by the evaporative coolers if the water tank, which water is supplied from, was not in a sunlit area. In this regard, the householder affirmed: "*The air cooler has a very good role in fact If deployed in the* right *way, but the problem, water comes from a metal water tank located on the rooftop and it is exposed to sun heat, so the water gets warm during the day which is why I think the air cooler is not always effective*." Besides that, the researcher noted that the outdoor cooler itself was extensively exposed to solar radiation resulted in being less effective.

Apart from the aforementioned factors, weaknesses associated with the design of the building fabric, e.g. the lack of thermal insulation, inefficient shading and etc., have forced the inhabitants to interact with the indoor environment in certain ways. In response to the potential direct solar gains through the south-west facing windows due to ineffective external shading, for instance, the window blinds were often left closed throughout the day in spite of the household's desire for having a visual axis to the Mountain View and connection to outdoors. In the upper floor bedroom which has neither AC nor evaporative cooler, furthermore, the excessive heat gains through the non-insulated exposed hipped roof and façades cause unbearable indoor conditions. For that, the children spend most of their time in the living area despite their desire to play in their bedroom. An eight-year-old child said: *I like my room; all my toys and painting tools are there [.....] It is very hot so that is why I do my paintings here* [in the living space]. In this regard, the mother affirmed that getting out of the bedroom at night due to high indoor temperatures and moving downstairs to the living space to continue their sleeping has been a common behaviour among her children even though she does not like such an attitude since the living space becomes messy. In this respect, when the householder was asked to identify the worst building attribute, he stated:

> *Well, the construction quality, in general, is not that much good, particularly the roof of the first floor. I think the comfort level there, and you will probably agree with me when you look at the recorded measurements, is at its lowest because of the extreme inflow of sun heat and unavailability of cooling technologies. At the moment, honestly, we are financially unable to repair the roof, but every month my wife and I try to put some money aside to be able to purchase a cooling device for the bedroom as soon as possible.*

7.3.1.2 Physical measurements

Over the period of nearly four weeks starting from July 27 to August 21, 2018, the indoor thermal environment monitoring campaign was carried out. It focused on the kitchen (12m^2), living space (40m^2), bedroom (17.5m^2) on the ground floor, and bedroom (17.5 m^2) on the first floor (see Fig. 7.21). And because of the limited number of monitoring devices and the fact that the guest room, according to the household, is used occasionally only when having guests, indoor measurements were not taken there. Meanwhile, the external data were acquired from the city's weather station.

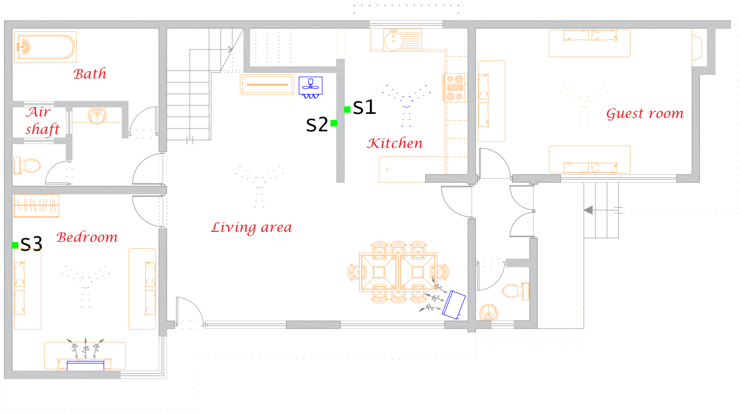
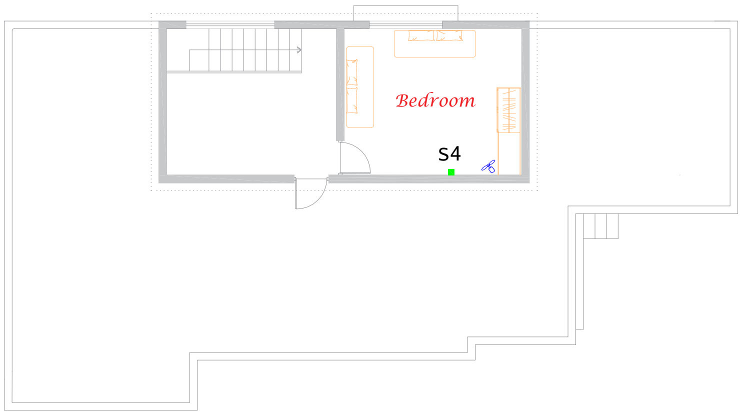


Figure 7.55 Ground floor plan (top), 1st. floor plan (bottom) and views of the monitored spaces (right) showing the distribution of data loggers (author)



The outdoor readings show that the mean daily temperatures ranged from 31.4 °C to 34.2 °C, whilst the lowest and highest records were 23.2 °C and 41 °C respectively. In addition, 'running mean outdoor air temperature' (T_{rm}) ranged from 31.7 °C to 33.1 °C. The diurnal temperature variation is found to be noticeable (14 K as an average). Meanwhile, the data reveals that the diurnal fluctuation of RH was from 15% to 57% (see Fig. 7.22).

In the meantime, indoor environment data show a noticeable variation between the dry-bulb temperatures measured in the ground floor and those measured upstairs, where the latter are generally higher (see Fig. 7.23), with the average minimum temperature in the upstairs bedroom being approximately 8 K and 5.5 K higher than the ground floor bedroom and living space respectively. The excessive heat gains through the non-insulated exposed hipped roof, together with the unavailability of an air conditioner and/or an evaporative cooler, and the lack

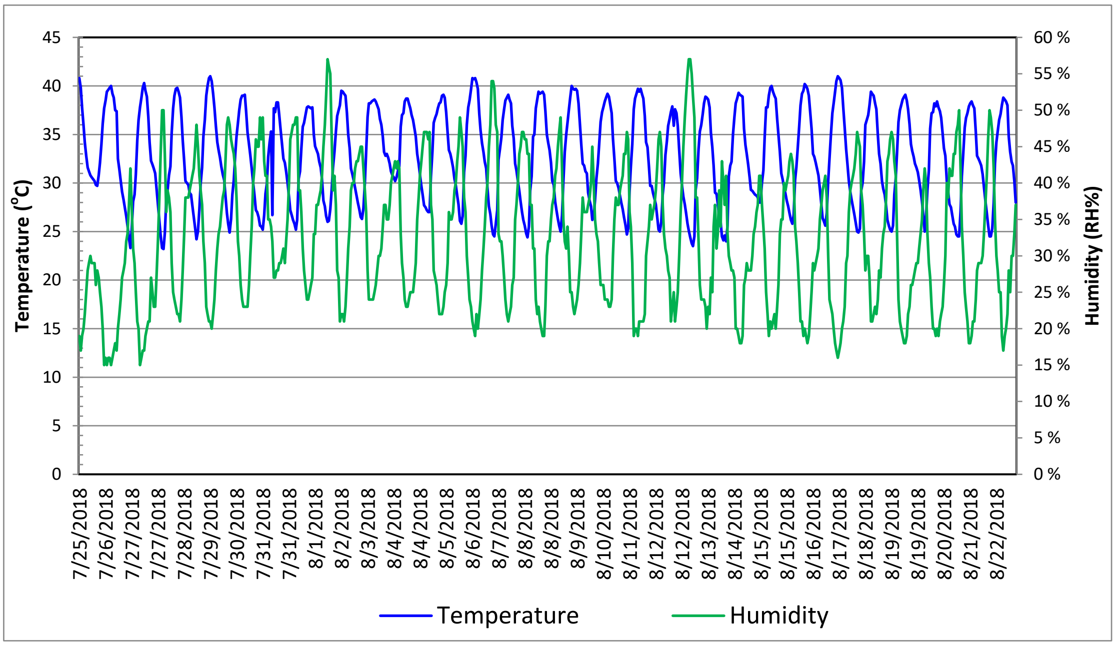


Figure 7.56 Outdoor dry-bulb temperature and relative humidity (source: weather station)

of opening the north-east facing window to avoid dust getting inside the space, all have resulted in such hotter and relatively drier (see Fig. 7.24) indoor environment there. In particular, the impact of the poor building envelope and its failure in delaying the heat transfer is evident in data analysis showing a notable correlation between internal and external temperatures, particularly in the bedroom upstairs (see Fig. 7.25). Interestingly, the variation between the daily minimum and maximum temperature is shown to be highest in the ground floor bedroom, up to 10 K, and lowest in the kitchen, about 3 K as an average.

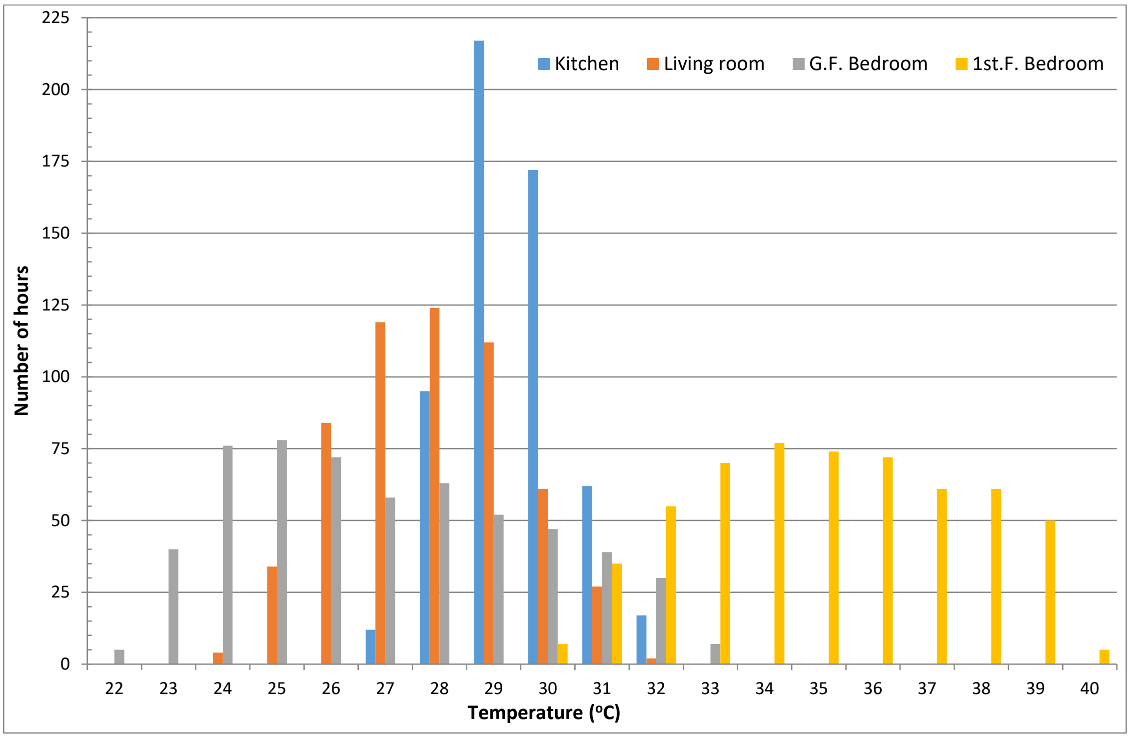


Figure 7.57 Histogram of hourly living room and bedroom temperatures (author)

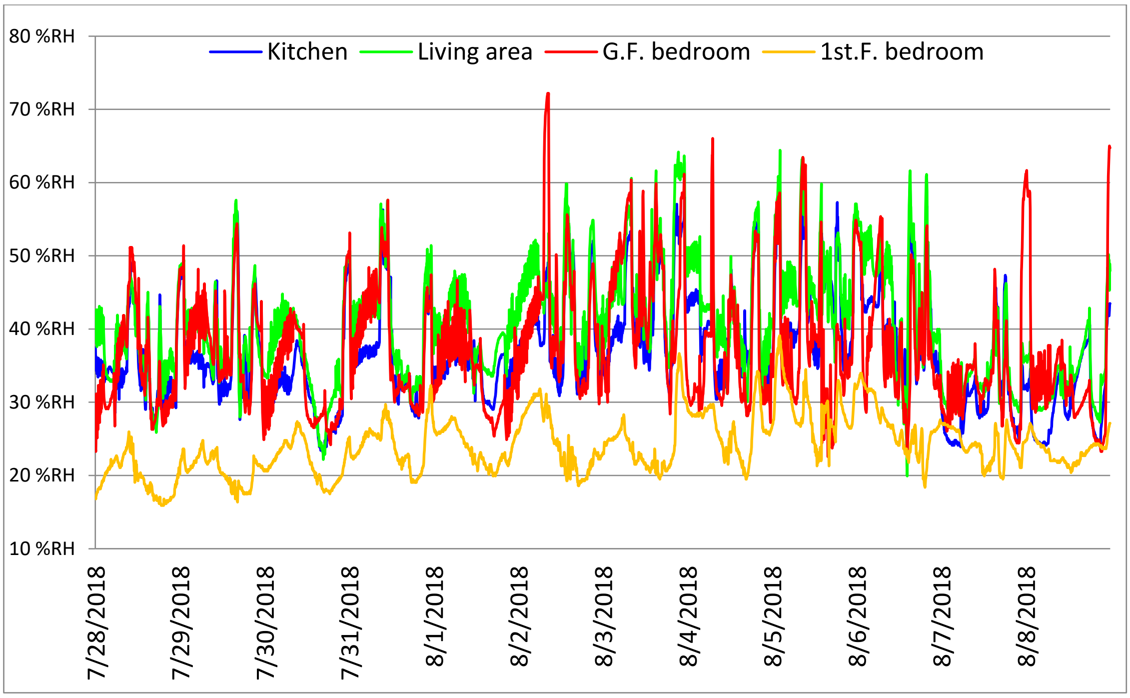


Figure 7.58 Recorded RH in all monitored spaces for a period (July 28th to August 8th)

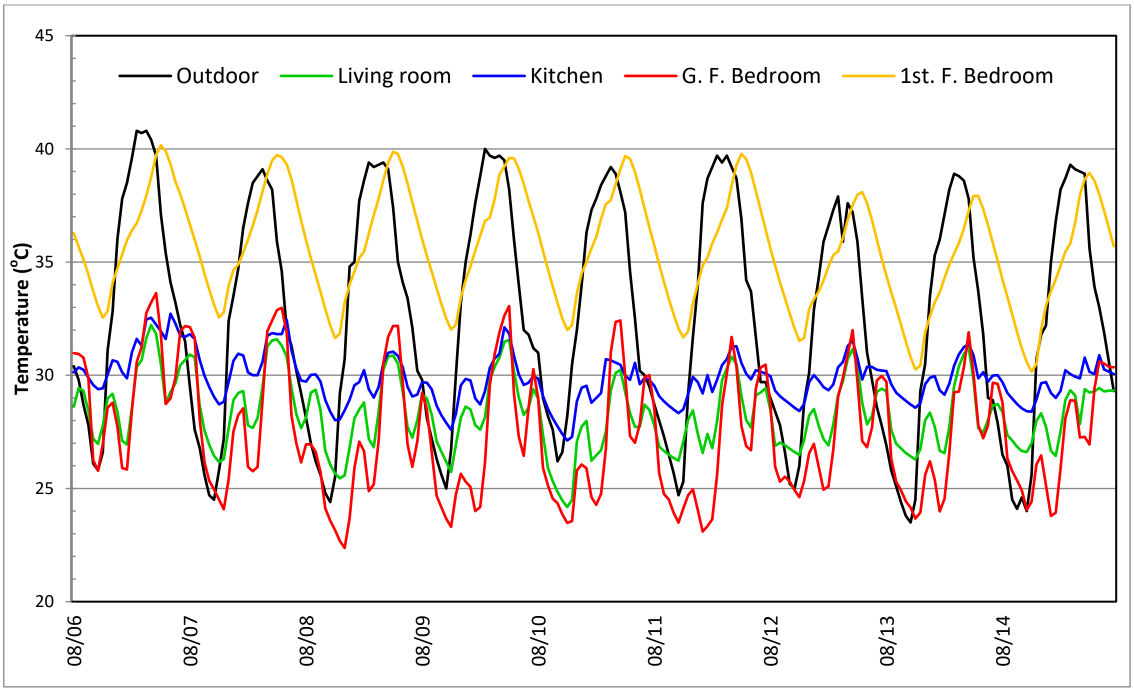


Figure 7.59 Recorded indoor and outdoor dry-bulb temperatures for a period (August 6th to August 14th)

With the exception of the children's bedroom, the house had experienced relatively better indoor thermal conditions in comparison to the previous case study. This is as a result of being located in a less dense and more elevated area where the mean temperature is one to two K lower. This is along with the operation of air coolers in the absence of power supply from the national grid, and the better quality of the window openings being more efficient. However, indoor temperatures were still being high exceeding 32 °C on the ground floor, when ACs were off, and reaching 40 °C upstairs (see Fig. 7.23). And none of the monitored spaces has met neither CIBSE static criteria nor 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria, of course with variation in their percentage of exceedance (see Fig. 7.26 and Table 7.3).

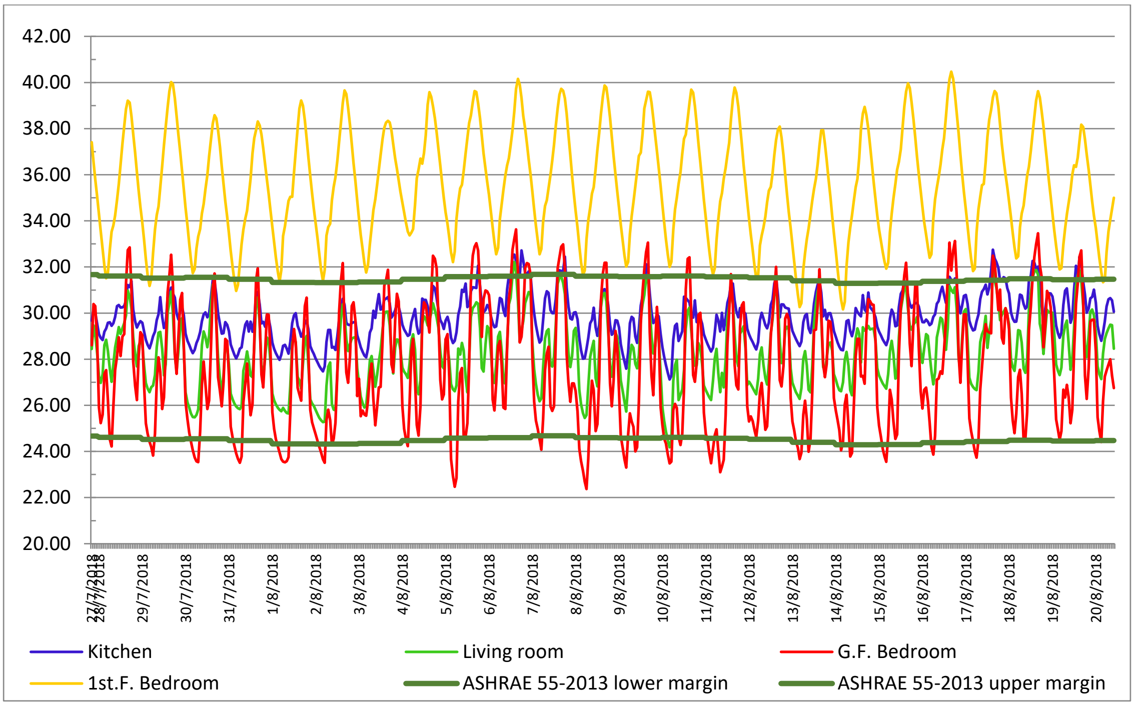


Figure 7.60 Indoor temperatures with comfort boundaries of ASHRAE 55 (80% acceptability)

Table 7.9 A summary of overheating assessment in regards to ASHARE adaptive comfort & CIBSE static standards

Room	Internal temperature			Percentage of occupied hours above certain temperatures		ASHRAE adaptive comfort standard	
	Mean (°C)	Minimum (°C)	Maximum (°C)	>26 °C	>28 °C	Occupied hours above T_{upper} (90% acceptability)	Occupied hours above T_{upper} (80% acceptability)
Kitchen	29.9	27.1	32.8	-	-	133 (41%)	34 (10%)
Living room	28.4	24.2	32.2	-	56%	50 (14%)	13 (4%)
G.F. Bedroom	27.5	22.4	33.6	54%	-	25 (9%)	7 (4%)
1st.F.Bedroom	35.6	30.2	40.5	100%	-	285 (99%)	271 (94%)

Starting with the main occupied spaces downstairs, the records show that the mean daily temperature ranged from 26.4 °C to 29.7 °C and 27.1 °C to 29.4 °C in the bedroom and living area respectively. Their highest recorded temperatures, i.e. 33.6 °C in the bedroom and 32.2 °C in the living area, were found to be around 6 to 8 degrees below the outdoor temperature. When the air-conditioners were inactive, however, indoor night-time temperatures were more likely to exceed the outdoor ones, up to 2 K, particularly between 11 pm to 5 am as the outdoor temperatures decline significantly. Despite being identified as the most comfortable rooms in the house, the bedroom has 54% of occupied hours with records in excess of 26 °C; meanwhile, the living area, which was occupied 24/7 in most of the days over the monitoring campaign as explained previously, has 56% of occupied hours with records in excess of 28 °C (see Table 7.3). Such percentages might be expected in partially air-conditioned spaces despite being supplemented by evaporative air-coolers which had been unable to significantly cool down the indoor environment. On the other hand, the children's thermal behaviour of staying away from their room could be easily understood by looking at the measured thermal parameters, mainly the indoor temperatures which exceeded the outdoor ones for 15-17 hours a day, with the peak indoor temperature, 40.2 °C, being three degrees above the outdoor temperature. The room had experienced notably higher temperatures in comparison to the living area where the children often resorted to for thermal relief; the findings show that the mean daily temperature had been between 34.3 °C to 36.4 °C. Interestingly, the peak temperature in all examined spaces was recorded in the afternoon on the same day, i.e. August 6th – the hottest day, which might be an indication of the effects of thermal mass throughout the building.

7.3.2 Energy consumption

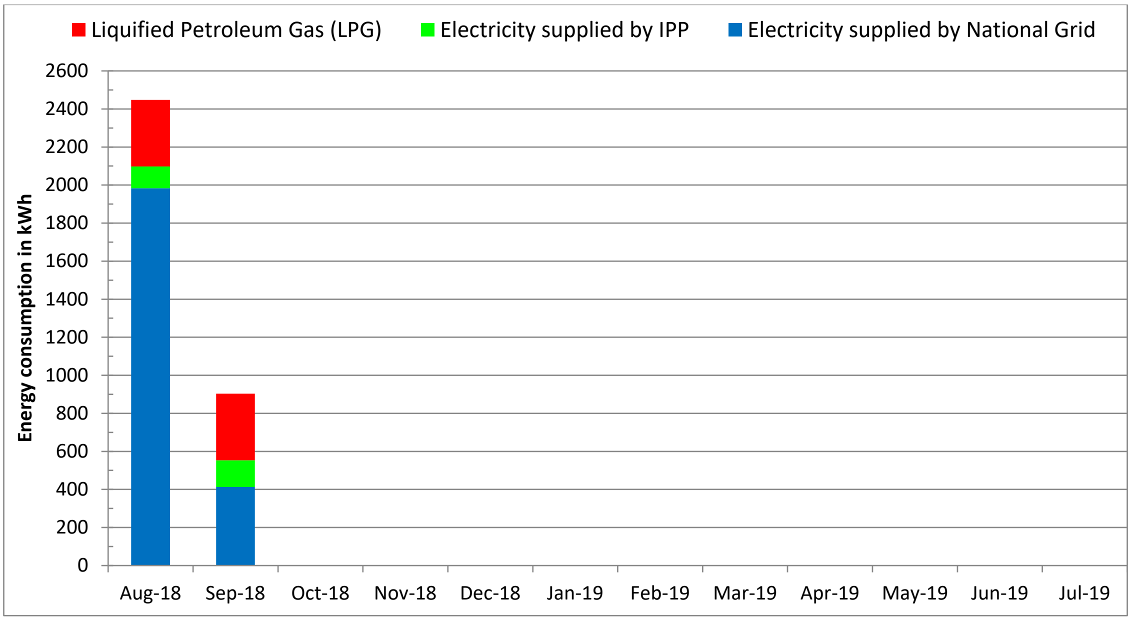


Figure 7.61 Household's energy consumption profile (author)

Given the fact that the household moved to another area in early October and left the house unoccupied, as indicated earlier in this chapter, energy consumption records were only taken during August and September, the reason why the researcher could not calculate the actual annual energy consumption per square meter of floor area. However, the collected records are well consistent with the qualitative investigations presented earlier.

The findings show that the household consumed a total of 2448 kWh and 903 kWh during the months of August and September respectively. Their inattentive and excessive consumption of electricity via the National Grid as a result of having free access to it can be clearly noted. Similar to the previous case study, it was found to be the most-used source accounting for 81%, i.e.

1983 kWh, of the total energy used during the month of August. Out of these 1983 kilowatt hours, 1705 (i.e. 86%) were used exclusively for cooling purposes. This is equivalent to 14 kWh/m^2 of cooling energy used in one month. Meanwhile, IPP electricity, thanks to the high electricity prices that the IPP offers, was found to be the least-used source accounting for 4.7% of the total consumption during the month of August (see Fig. 7.27) even though this source was supplying electricity for nearly 11-12 hours per day. Moreover, the consumed Liquefied Petroleum Gas (LPG), which was used for cooking, represented 14% and 38% of the total consumption during the months of August and September respectively.

7.4 Case study 3: A middle-class household

7.4.1 Findings – cooling season

7.4.1.1 Adaptive behaviour and attitude

A semi-structured interview was carried out with the family on August 15, 2018, at their residence discussing questions of thermal comfort and environmental control. Similar to the other case studies, the inhabitants' behavioural pattern in coping with summer heat included a range of adaptive actions being varied from personal adjustments to building adjustments. The former included activities like: ingesting chilled fluids, showering, moving to the most comfortable space, adjusting clothes, whilst the latter involved: removing carpets, turning on cooling equipment (i.e. fans, air conditioners, and evaporative air-coolers) and exposing themselves directly to the cool air, adjusting blinds and opening/closing windows and doors.

However, their choice of a certain adjustment was strongly influenced by a number of factors such as their financial conditions, source of power supply, past experiences, design-related factors. For instance, the first has been obviously influential in their choice of practising one particular adjustment over the others. With no doubt, the level of human intervention in adjusting their thermal environment was way lower compared to the first case study. As a result of having a higher income level, in fact, the mechanical controls were more likely to be involved in modifying internal conditions. In particular, the occupants used to employ the air coolers and leave them on throughout the cooling season no matter from which source the energy was supplied. This was often accompanied by leaving the internal doors open for air to travel through, using ceiling fans, and when necessary, the air conditioners were also operated from time to time on the national grid power mode in a couple of spaces. Unlike the previous case studies, in fact, the evaporative air cooler was noted to be the most practised environmental control in the house despite having A/C units installed which have not significantly affected the use of air coolers. The only periods that air coolers were not in operation were the times when occupants were not at home beside the time interval between the outage and resupply of electricity which usually takes up to several minutes every time that power cut occurs. High electricity prices offered by the Independent Power Producer (IPP) in the light of the constant electricity blackouts from the National Grid did not really limit the use of such technology. This can be noted through records taken by the installed smart meters showing that 427 kWh of electricity from the IPP supplier were consumed by the household over the monitoring period which is way higher than the amount consumed by the previous households. Apart from the continuous operation of two air coolers, such consumed amount might also be attributed to its size and the fact that more people are living in this house and thereby more energy might be consumed. Nevertheless, this was not the case with the amount consumed through the National Grid which interestingly appeared to be approximately 0.2-0.3 MWh less compared to the previous households, and this is most likely the consequence of less use of A/C as explained further below.

Despite their relatively good financial conditions, one still cannot deny the impact of cost-related concerns on their thermal and energy-use related behaviour which understandably tended to change to some degree in conjunction with the change in power-supply mode. One could clearly perceive this in a couple of attitudes. In spite of the availability of air conditioners and their undeniable effectiveness in fulfilling a desired indoor temperature, for instance, the users were less disposed to operate them in the light of the unpleasant thermal conditions that they experience over the summer period. Their likelihood of being run was primarily influenced by the availability of electricity from the national grid which unlike the Independent Power Producer (IPP) supplies electricity with considerably lower prices. In this regard, the householder who is in his late 60s stated that, "We do not have a massive wealth by the way; b*eing capable to afford does not mean that we have to waste our income on energy bills and continuous operation of A/C. One should seek a cheaper option even if it is a bit less effective*." Out of four units, in fact, only two were functioning throughout the period examined as described earlier, and the reason why the defective air-conditioners have not been repaired or replaced was voiced to be 'carelessness' in the light of having an alternative control, i.e. evaporative air cooler, which is more energy-efficient and cost-effective. The active units were the one in the guest room and the one in the front bedroom above the kitchen which is occupied by the daughter who is a medical doctor. The operation hours of the former were generally limited to the times when they were receiving guests for the sake of hospitality, whereas the latter was operated at night on her days off for a reason highlighted further below. It is worth mentioning that infrequent use of A/C was not only reflected on energy bills as shown earlier but might also be reflected on occupants' tolerance level. This because being less exposed to air conditioners raises the ability to tolerate higher temperatures as concluded by Brager and De Dear, 1998 and Saman et al., 2013.

Another example emphasising the impact of the cost factor on their energy use related behaviour is the way where both washing machine and dishwasher were being used (although it is not related to their thermal behaviour). The occupants tended to use them only during times when the national grid was supplying electricity. All these habits, according to the housewife, are attributed to the low electricity prices that the national grid offers.

Apart from the influence of the cost factor, interestingly, the inhabitants' past experiences have also governed their behavioural control actions to some degree. For instance, their life experience of the countryside still affects their current thermal behaviours. One of the daily adaptive actions that this household practises over the cooling season is moving to the front yard in the evening to have their dinner and spend a couple of hours before going to bed. This form of internal migration has been a widespread behaviour among people in rural areas until nowadays. In this regard, the householder stated, "*My wife and I began the married life in a free-running mud house in a village where life was so simple* [....] *we used to start evenings in the garden* [front yard] *where you enjoy the cool of the night air and the beautiful clear sky with plenty of stars* [....] *many things have been changed in our life since we moved to the city and this house but that habit still takes place I can say on a daily basis and we both are happy about it.*"

However, such a thermal attitude was not very welcomed by everyone, particularly their daughter-in-law, and this is highlighted through the following illustrative quote: "*I would rather choose the easiest way by switching on the air cooler instead of moving to the front yard and filling my ears with outdoor noise. It is less convenient*." She seemed to be influenced by her premarital thermal experiences as she was living in a partially air-conditioned house, where air-conditioners were run more often as she claimed, before getting married and moving to this house. She affirmed that she had suffered from unpleasant indoor thermal conditions once she moved to this current residence in summer 2010 which is why her husband installed a split air conditioner in their room right away.

Another sort of influence from the past experiences lies in the adaptive behaviour of the householder's daughter. Her thermal experiences and periodic exposure (few days a week) to an air-conditioned environment, i.e. the hospital that she works in, resulted in being accustomed to lower indoor temperature which is why the split air conditioner in her room was switched on at night on her days off as highlighted earlier. In this regard, she stated, "*The problem is that I work two 24-hour shifts a week at the hospital where the temperature I guess is around 23 °C, so you can say that my body gets acclimated to such temperature. When I come back home, which is of course warmer, I feel that I need to turn on A/C*."

In addition to the aforementioned factors, most importantly, others associated with the design of the building such as fabric and floor area were found to be affecting the indoor conditions and thereby driving inhabitants to interact with the indoor environment in certain ways. In response to the excessive heat gains through the non-insulated exposed roof and façade which cause unbearable indoor conditions, for instance, the entire top floor is left unoccupied throughout the daytime, even the master bedroom where the evaporative air cooler continuously runs, and most of their activities take place in the living area which was identified as the most comfortable space. In this context, one of the interviewees derisively described the conditions by saying: "*It* [the second floor] *gets hot to a degree that you can fry eggs*."

The reason behind such poor fabric conditions was voiced to be linked to their desire to have a big dwelling at the expense of quality when they were building this house. In this regard, the householder stated, "*In the light of the strict budget that we had at the time, we aimed to build a dwelling that can actually house a growing family where everyone can have his/her own room and also considering, for example, a spare bedroom for a future spouse and grandkids [....] we chose the quantity, I mean as many rooms as possible with large areas, over the quality without considering energy-efficiency at all*." This has been causing an unfortunate impact on the building's thermal performance and made the achievement of a pleasant indoor environment in the entire house an expensive task because the larger the floor area, the greater the cooling load. For this, out of the 215 m^2 floor area, only 120 m^2 were regularly occupied. Three family members including the householder, his wife and their unmarried son were sleeping in the living area over summer nights, and their bedrooms, i.e. both rear bedrooms on the 1st and 2nd floor, were merely used for the purpose of changing clothes and storing their stuff. In fact, both bedrooms seemed to be rather barren, and a sort of mould was observed in both areas. The reason behind such condition is believed to be the lack of ventilation since the air shaft that rear rooms are connected to was completely covered by a lightweight roof hindering both daylight and fresh air to be introduced. In addition to the limited use of those bedrooms, the guest room was also used occasionally. In this respect, when the householder was asked to identify the worst building attribute, he stated: "*I think it is too big and non-insulated demanding too much to keep all the spaces at the right temperature*."

7.4.1.2 Physical measurements

Starting from July 28 to August 22, 2018, data collection of the outdoor and indoor thermal environment was taking place. The indoor spaces included the kitchen (18 m^2), living space (40 m^2) and guest room (28 m^2) on the first floor, and master bedroom (26 m^2) on the second floor (see Fig. 7.28). It is worth noting that the outdoor data are the same as those presented in the first case study as the available 'Tinytag Plus 2' sensor was installed in an area located between case-study 1&3 (see section 3.3.1.3.1 for further details).

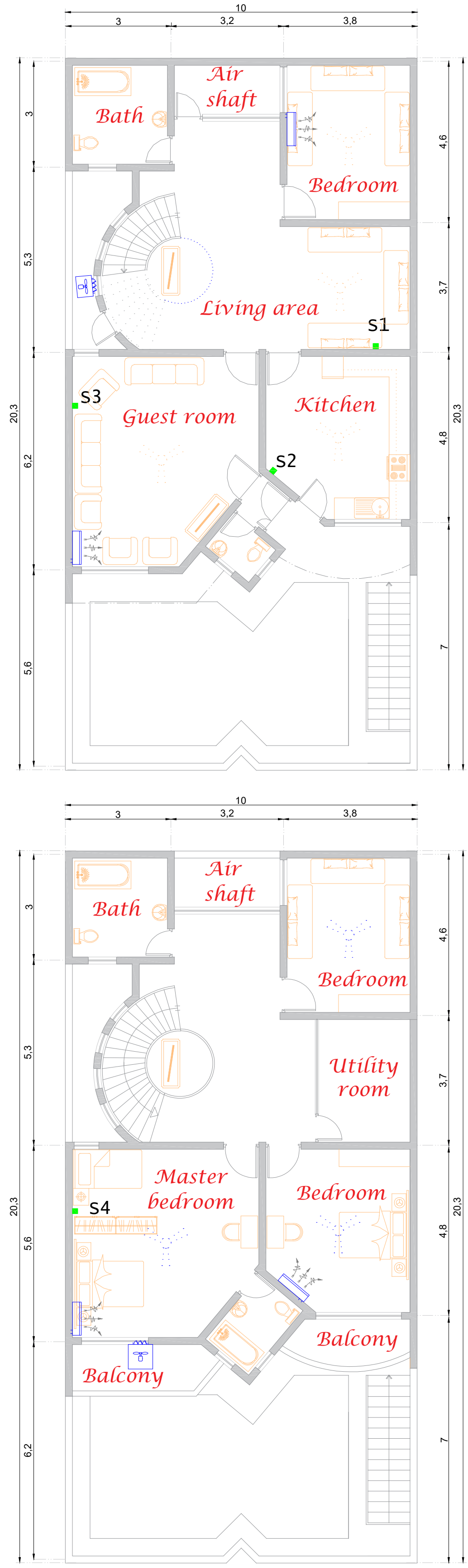


Figure 7.62 1st floor plan (top-left), 2nd floor plan (bottom-left) and views of the monitored spaces showing the distribution of data loggers (author)

As presented in section 7.2.1.2, the outdoor readings show that the mean daily temperatures ranged from 32.9 °C to 35.4 °C, whilst the lowest and highest records were 27.7 °C and 40.4 °C respectively. In addition, 'running mean outdoor air temperature' (T_{rm}) ranged from 32.2 °C to 33.4 °C. The diurnal temperature variation is found to be noticeable (10.4 K as an average). Meanwhile, the data reveals that the diurnal fluctuation of RH was from 9.4% to 42.1% (see Fig. 7.6).

In the meantime, the indoor readings show that dry-bulb temperatures measured on the first floor noticeably varied from those measured on the top floor, where the degree of fluctuation of the latter being generally larger (see Fig. 7.29). The variation between the daily minimum and maximum temperature is shown to be highest in the master bedroom, up to 8 K, and lowest in the living area, less than 2 K. In fact, records from all areas examined on the first floor show a small diurnal temperature variation, i.e. 1.2 K on average.

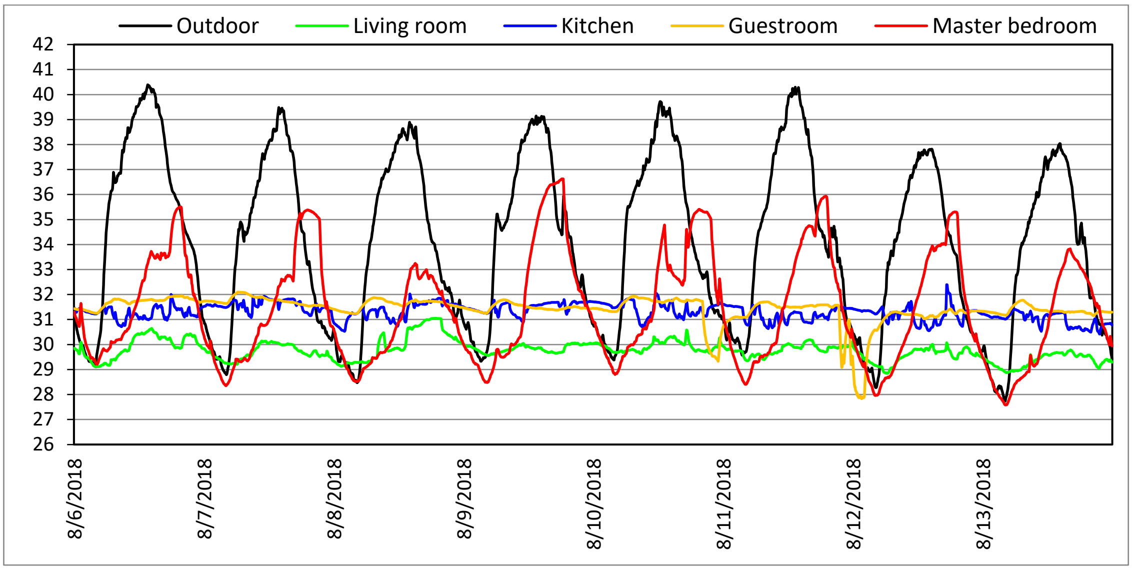


Figure 7.63 Recorded indoor and outdoor dry-bulb temperatures for a period (August 6th to August 14th)

Similar to the other case studies, indoor thermal discomfort is generally evident in the house; temperatures had been high reaching 34 °C on the first floor and exceeding 37 °C on the second floor. With the exception of the living area, none of the monitored spaces has met neither CIBSE static criteria nor the 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria, of course with variation in their percentage of exceedance (see Fig. 7.30 and Table 7.4). The living area, which was occupied 24/7 as three family members were sleeping there overnight, was the only space that met the 80% acceptability limit of ASHRAE adaptive comfort criteria, yet failed to meet the other aforementioned standards. This explains why the space was identified by all four interviewees to be the least uncomfortable space in the house and why most of their activities were taking place there. Generally, the space accomplished a rather stabilised thermal condition where the mean daily temperature ranged from 29.3 °C to 30.5 °C, with 100% of occupied hours with records in excess of 28 °C where the lowest record, i.e. 28.6 °C, is found to be slightly higher than the outdoor temperature. This is despite the availability and continuous operation of an evaporative air cooler which seemed incapable of achieving a cooler indoor environment. Such limited cooling efficiency is normally expected from an air cooler, especially when the water is supplied from a metal tank placed on the housetop and fully exposed to solar radiation which warms up the water, and this was the case in this house. Indeed, the water appeared rather warm when the researcher used his hand to undertake a rough estimate.

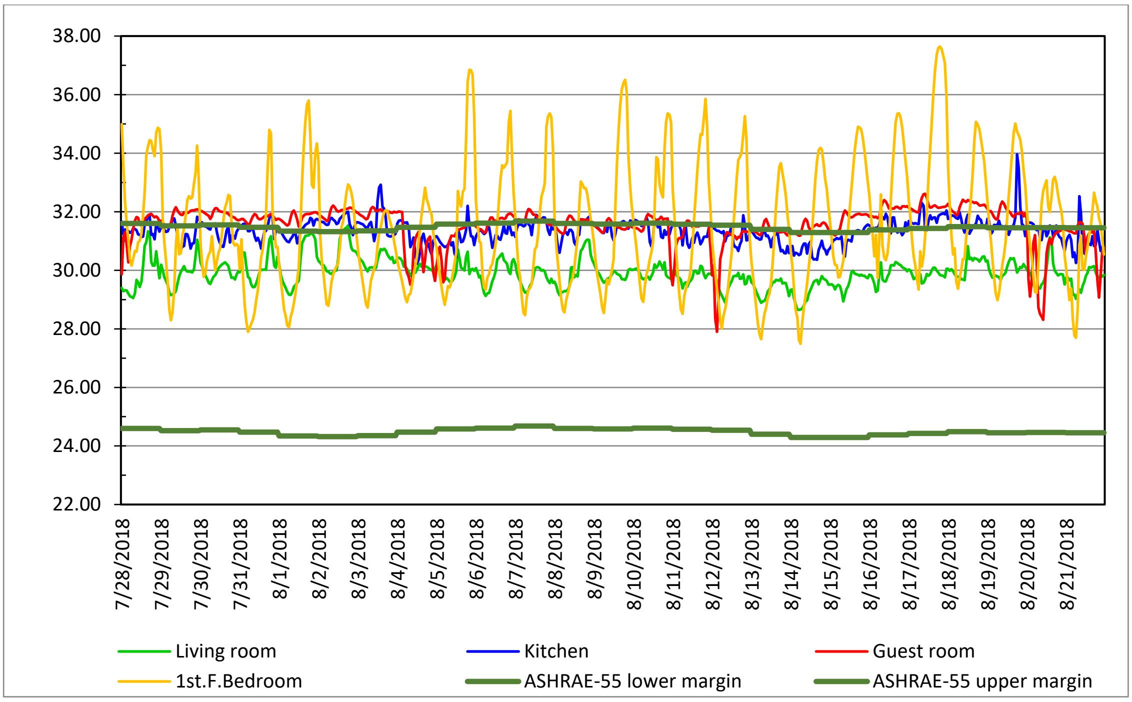


Figure 7.64 Indoor temperatures with comfort boundaries of ASHRAE 55 (80% acceptability)

Table 7.10 A summary of overheating assessment in regards to ASHARE adaptive comfort & CIBSE static standards

Room	Internal temperature			Percentage of occupied hours above certain temperatures		ASHRAE adaptive comfort standard	
	Mean (°C)	Minimum (°C)	Maximum (°C)	>26 °C	>28 °C	Occupied hours above T_{upper} (90% acceptability)	Occupied hours above T_{upper} (80% acceptability)
Kitchen	31.33	30.16	34.42	-	-	107 (35%)	50 (14%)
Living room	29.89	28.59	31.58	-	100%	60 (10%)	4 (0.6%)
Guest room	31.51	27.83	32.63	-	100%	368 (96%)	262 (68%)
1st.F.Bedroom	31.47	27.36	37.66	100%	-	124 (40%)	63 (20%)

The kitchen and guest room also accomplished a rather stabilised thermal condition where their mean daily temperature ranges from 30.7 °C to 31.8 °C and 30.4 °C to 32.2 °C respectively. As can be noted from Figure 7.30, the internal temperatures of the former had experienced frequent fluctuations within a limited range, up to 1.4 K, which is likely originating from cooking events as well as air infiltration occurring through the kitchen's front door whenever used by occupants to get in or out of the house. Meanwhile, the latter experienced notable temperature drops, up to 4 K, whenever A/C was switched on, and this can be noted on several occasions during the monitoring campaign, e.g. on the morning of August 20 when the interview was taking place at the guest room. Nevertheless, the cooling effect of such technology seems to be insignificant as the lowest recorded temperature there is found to be 27.8 °C. Such insufficient cooling was also observed by the researcher on his visit even though the setpoint was 18 °C. Perhaps this is attributed to the unit size being small, and thereby incapable of effectively cooling down a big space like the guest room.

On the other hand, the occupants' thermal behaviour of staying away from the top floor during the daytime could be justified by looking over the internal temperatures of the master bedroom which demonstrates that the space had experienced warmer conditions than the living area. Its mean daily temperature had been between 30.4 °C and 33.5 °C, and the mean daily maximum temperature there was found to be 4 K higher than that of the living space. The question then arises: why such variation had been taking place whilst both spaces use the same type of cooling technology? The reason for this variation could be rather related to their level of exposure to solar radiations as the master bedroom being located at the top floor is more exposed to direct sun rays and thereby is prone to experience higher indoor temperatures throughout the day resulting from excessive heat flux through the non-insulated roof in particular. Besides, there was a possibility for some of the hot air escaping from the first level through the staircase to enter and accumulate in the master bedroom as the door was often left open throughout the day, and this might have contributed to such higher indoor temperatures. Interestingly and despite all the numerical indications of overheating in the house, the householder along with his wife considered the overall indoor environment as being 'Neutral,' and this likely indicates their abilities to tolerate high temperatures. In contrast, their daughter and her sister-in-law plainly showed a degree of dissatisfaction.

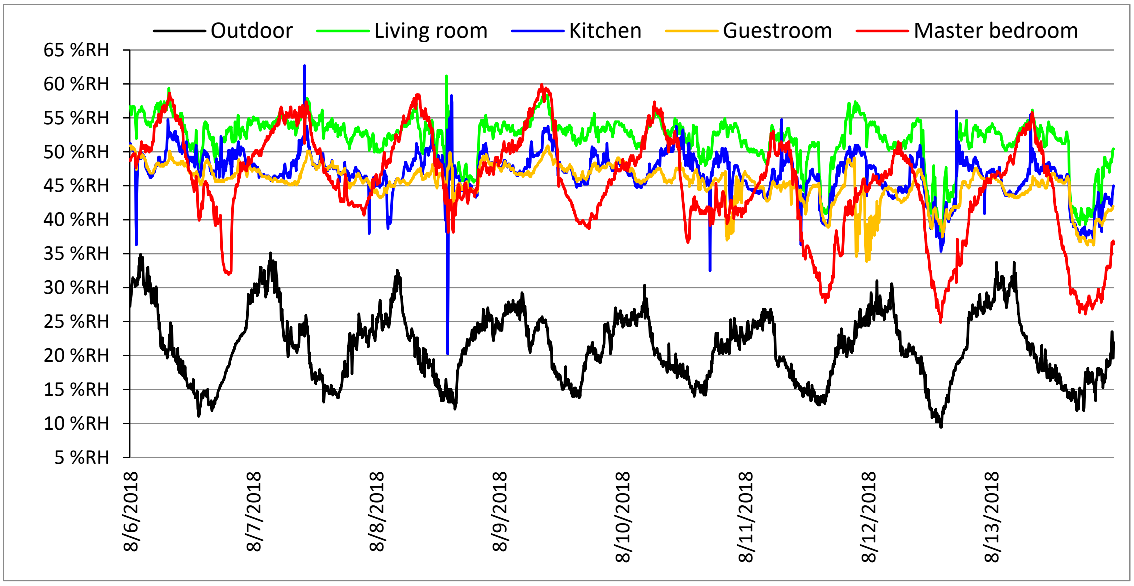


Figure 7.65 Recorded RH in all monitored spaces for a period (July 28th to August 8th)

Apart from the indoor dry-bulb temperatures, the impact of evaporative air cooler on rising the indoor moisture level is also evident through the collected data where the mean RH is found to be 52% and 45% in the living area and master bedroom respectively, whilst the outdoor one is 23% (see Fig. 7.31).

7.4.2 Energy consumption

During the period of a year starting from August 01, 2018, the household's energy consumption data had been collected. On a monthly basis, electricity readings were being documented and relevant information was being provided regarding the consumed amount of kerosene and the LPG cylinders. The records show that the occupants had consumed a total of nearly 35765 kWh, i.e. (174 kWh/m2yr). Out of these 35765 kilowatt hours, 14480 (i.e. 40.5%) were used exclusively for heating purposes in the form of kerosene which was found to be the most-used type of energy. This is equivalent to 67.3 kWh of heating energy used in one square meter of floor area in one year. Of course, being at a higher rung of the economic ladder helped the household in consuming such a large amount of kerosene. Furthermore, electricity supplied by the National Grid was found to be the second most used source accounting for 37.7% of the total consumption.

Similar to the earlier case studies, on the other hand, IPP electricity is found to be the least-used source accounting for 5.8% of the total consumption (see Fig. 7.32). This was mainly used for things like: lighting, refrigerating, powering the TV, charging electronic devices, and running evaporative air coolers over the cooling season. Moreover, the consumed Liquefied Petroleum Gas (LPG), which was only used for cooking, represents 16% of the total consumption.

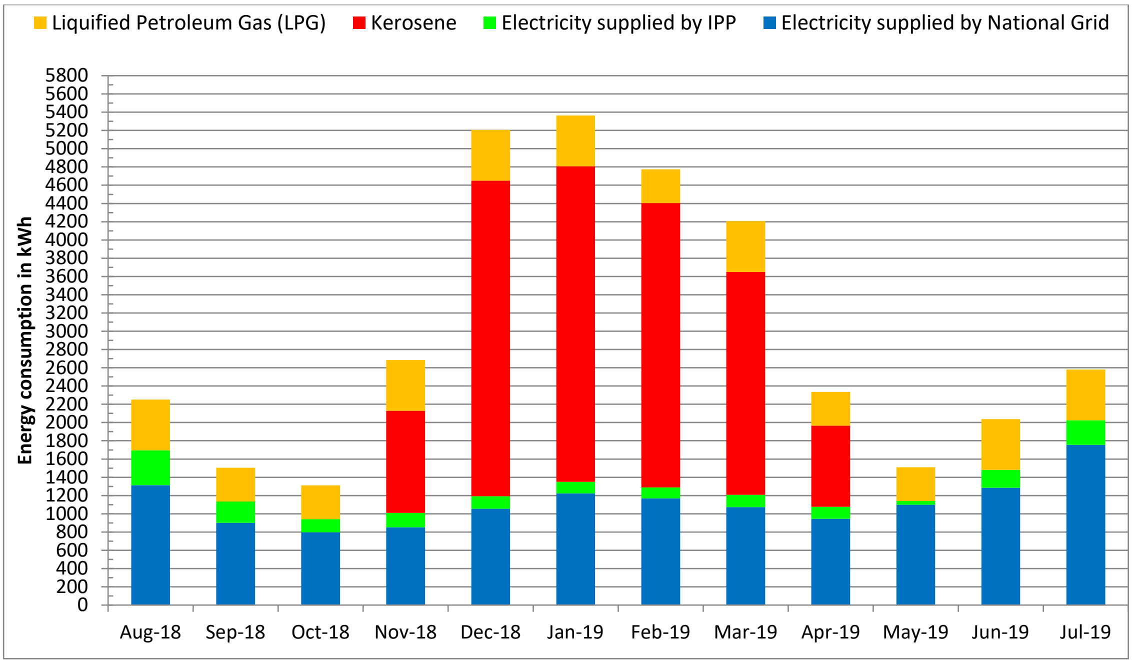


Figure 7.66 Household's energy consumption profile (author)

7.5 Case study 4: An upper-class household

7.5.1 Findings – cooling season

7.5.1.1 Adaptive behaviour and attitude

The household's behavioural pattern in dealing with summer temperatures and improving the thermal comfort level within the indoor environment was thoroughly discussed with the householder through a qualitative interview that took place on August 16, 2018. Several thermal adaptation habits came to light including: turning on cooling equipment (i.e. fans, air conditioners, and evaporative air-coolers) and exposing themselves directly to the cool air, adjusting blinds, opening/closing windows, and adjusting clothes. Nevertheless, their choice of practicing a certain adaptive behaviour was essentially influenced by their economic status, their moral principles, individual's thermal preference, and physical attributes of the building. In particular, the lack of economic pressures was found to have a potent role in configuring their thermal behavioural patterns. As a consequence of being on the higher rungs of the economic ladder, the extremely low level of human intervention compared to the other households in overcoming thermal discomfort is beyond question as active cooling technologies were predominantly used in improving inhabitants' thermal satisfaction level. In this respect, the interviewee explained by saying: "*With the extreme prevailing summer temperatures of Erbil, it is almost impossible to avoid thermal distress with no cooling technologies in hand.*" While the householder works away from home throughout the day, the ladies used to move in the morning to the living area, where most of their activities take place, and rely on one or both available air conditioners in the first place to adjust the thermal conditions. In fact, A/C units were noted to be the most practiced environmental control in the house. Among all four case studies, interestingly, this house has the highest ratio of installed A/C units per occupant, i.e. 7 units for 3 occupants, although three of them were not in use. Unlike the other case studies, energy-related expenditures were not desperately limiting the operation of A/C, and the operation hours (especially during night-time hours when occupants fall asleep) were not exclusively correlated to the supply of electricity through the National Grid. This can be noted through data recorded by the installed smart meter showing that among all four case studies, this household had the highest ratio of consumed electricity (via IPP supplier) per person, i.e. 183 kWh per occupant.

Even though high electricity prices offered by the Independent Power Producer (IPP) did not seem to be an important deterrent to this household, their thermal and energy use related behaviour was changing to some degree in conjunction with the change in power-supply mode. Out of two split-type air conditioners available in the living area, for instance, only one of them was switched on when IPP was supplying electricity and that was exclusively during the hottest hours of the day. This habitual consumption could explain why the total energy consumed over the monitoring period via the IPP supplier was about one-third, i.e. 549 kWh, of the amount consumed through the National Grid. Apart from that, the inhabitants were generally very keen to reduce their consumption of energy no matter from which source the power was supplied; whatever the electrical appliance was, it was only in use when needed. Before moving from one space to another, for example, they switch off all the appliances; the operation of bedrooms' air conditioners was exclusively limited to the sleeping hours. The householder was asked if such an attitude was encouraged by cost concerns, but he asserted that it is not so; rather it is based on their moral principles being central in their energy-related behaviours. In this regard, he commented by saying:

> *It is definitely a non-economic factor. We morally feel uncomfortable to overspend or consume something in an extravagant way, and even religiously, we are not allowed to be wasteful as the Almighty Allah 'likes not those who commit excess' as it is stated in the Holy Qur'an. So it is not just about energy but I mean in general. Even when we prepare food, we cook only as much as we need and avoid food waste.*

Apart from the aforementioned factors, interestingly, the inhabitants' thermal preferences have also governed their behavioural control actions to some degree. Different thermal preferences seemed to exist among the family members. One of the wives who occupies the first-floor bedroom, for instance, prefers lower temperatures than her husband, and therefore she set her bedroom's air conditioner on 21 °C. This was forcing her husband to put on a thicker pyjama or use an extra lightweight duvet to cover his body on the nights that he was sleeping in that bedroom. In this regard, he stated that he does not resort to turning up the set temperature as that causes her difficulty to fall asleep. The other wife who occupies the downstairs bedroom, on the other hand, prefers a warmer environment than her husband; the normal setpoint temperature of her bedroom's A/C unit is 26 °C. Again, this was driving the man to mainly adjust his clothes or sometimes reduce the setpoint temperature a few degrees while she was asleep.

Their behavioural adjustments and indoor thermal conditions were also noted to be impacted to some degree by the physical attributes of the building, e.g. the internal layout, floor area, and the quality of the building envelope. The dwelling has generally more space than needed which is why three bedrooms remained completely unutilised. Out of the 235 m^2 floor area, in fact, only 169 m^2 were regularly utilised. The extra square meters of the living zone alongside its layout which is semi-open, moreover, resulted in increased demand for cooling; accordingly, the area was fitted with four cooling gadgets as described earlier where two of them, i.e. both A/C units, an air conditioner with the window-mounted evaporative air cooler, or the pedestal fan with air cooler, were often in function throughout the day depending on how extreme the internal conditions were. And that made the achievement of a pleasant level of thermal comfort there an expensive task. Furthermore, heat gains associated with the extreme trapped heat in the attic as a result of the corrugated roof being non-insulated causes an unfortunate impact on indoor thermal conditions particularly in the first-floor rooms. All occupants, in fact, voiced that the upper floor is indisputably warmer than the ground floor. For this, the household installed an evaporative air cooler in the attic to constantly supply cool air to the space and the corridor during the daytime to mitigate such impact (see Fig. 7.33). In this regard, the householder commented by saying:

> *I am not sure if the pitched roof was originally designed to protect the concrete flat roof from sun rays, or whether it was just part of the aesthetic process, you know, to look like an English house. But if their goal was protection, then based on our living experience over almost a decade in this house, I can tell you that they absolutely failed to achieve such a goal* [....] *Without having the air cooler there, believe me, it is very difficult to tolerate the heat coming down, and all the raw food like uncooked rice, flour, and etc. that we have in the storage area* [on the first floor] *will be spoiled.*

However, the roof was not the only building fabric element that affected their thermal interaction with the indoor environment. In response to the potential direct solar gains through the south-east facing windows due to ineffective external shading, for instance, the window blinds were often left closed throughout the day. Moreover, the householder seemed to be not very pleased with the thermal properties of external walls for being low in R-value, particularly the cladding layer of limestone; he would have preferred a Styropor cladding, i.e. polystyrene panels plastered with cement which has been a common cladding technique in recent years in the region, to reduce heat gains. "*These walls* [external walls] *are not so efficient. They do not significantly help in keeping the coolth in for a long period. Right after switching off the cooling gadgets the indoor environment warms up; it does not take too long,"* says the householder.

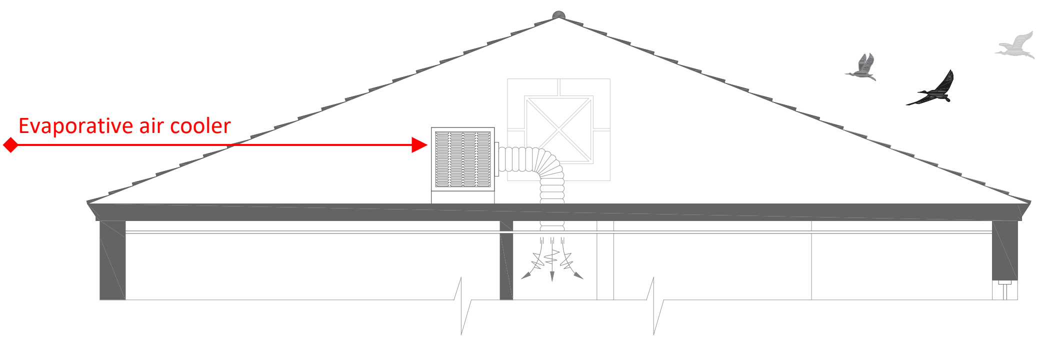


Figure 7.67 Roof and attic cross section (author)

7.5.1.2 Physical measurements

Following the research methods included earlier in this thesis, data collection of the outdoor and indoor thermal environment was carried out over the period of three weeks, starting from July 27 to August 16. It focused on the kitchen (13.5 m^2), living space (54 m^2), and en suite bedroom (18 m^2) on the ground floor (see Fig. 7.34), whilst no measurements were recorded on the first floor due to the limited number of sensors.

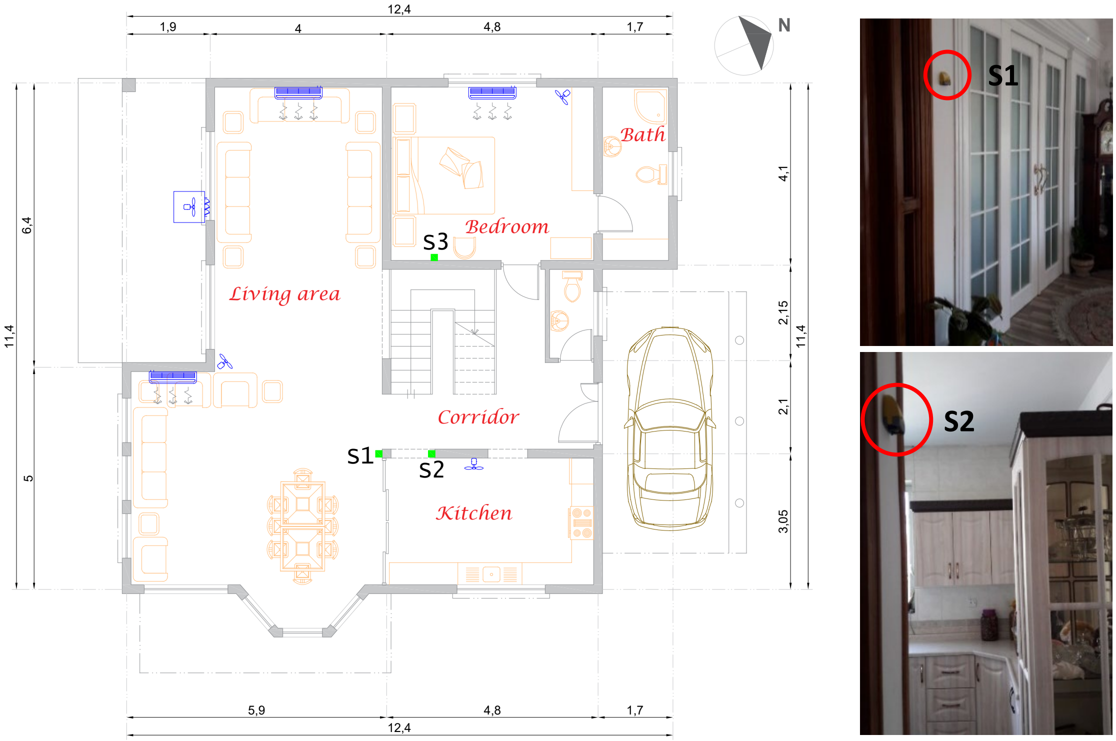


Figure 7.68 Ground floor plan (left) and views of two monitored spaces (right) showing the location of data loggers (author)

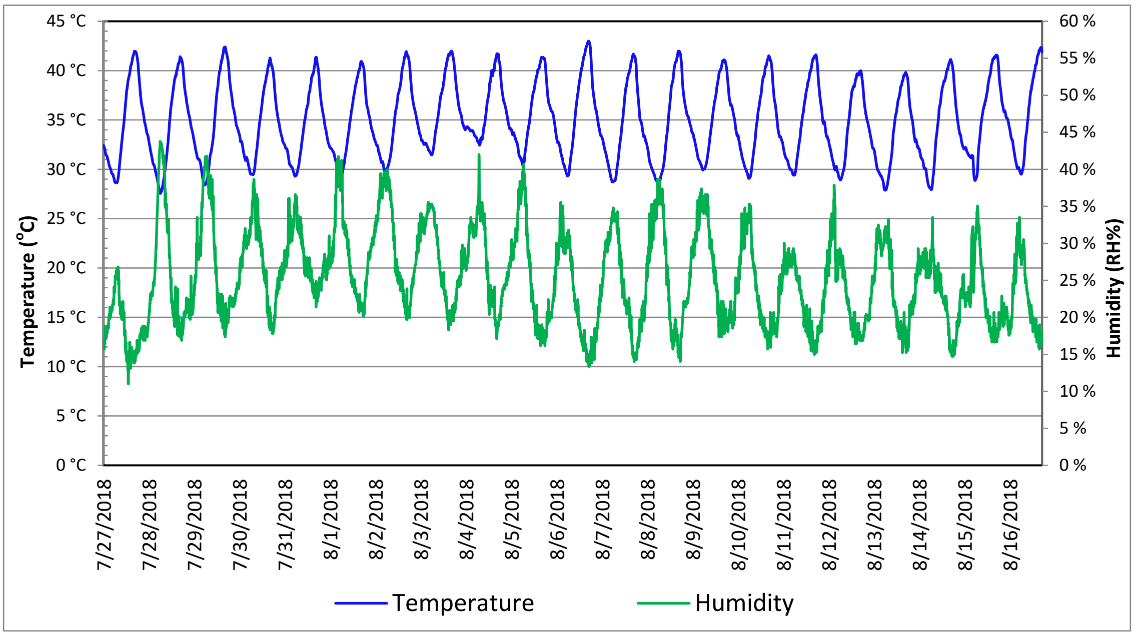


Figure 7.69 Recorded outdoor dry-bulb temperature and relative humidity (author)

The outdoor readings show that the mean daily temperatures ranged from 33.5 °C to 36.2 °C, whilst the lowest and highest records were 27.6 °C and 43 °C respectively. The diurnal temperature variation is found to be noticeable (12 K as an average). Meanwhile, the data reveal that the diurnal fluctuation of RH was from 11% to 44% (see Fig. 7.35).

Meanwhile, indoor readings show that the mean daily RH remained within the range of 34 to 50% in all three spaces (see Fig. 7.36). Despite the extensive use of cooling equipment, mainly air conditioners, together with the better building thermal characteristic, i.e. lower U-value, in comparison with the previous case studies, the household had generally experienced relatively warm indoor thermal conditions in which none of the monitored spaces had met CIBSE static criteria (see Table 7.5). This might explain why two family members, out of three, considered the overall indoor environment as being slightly uncomfortable.

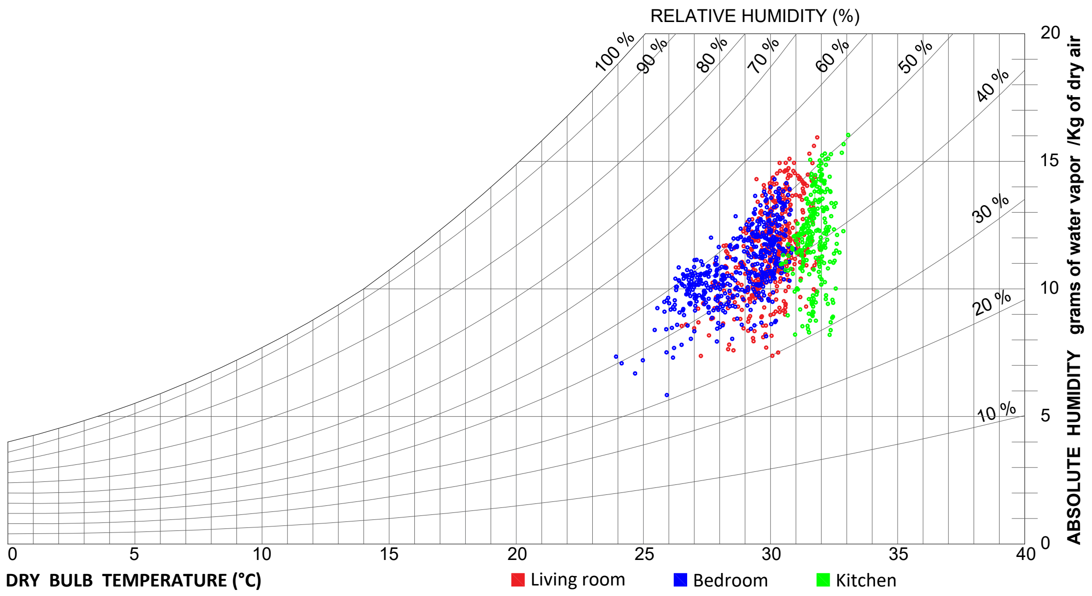


Figure 7.70 Pscychrometric chart showing indoor readings in the monitored spaces (Note: each data point represents an hourly average of the indoor temperature and RH) [author]

The variation between the daily minimum and maximum dry-bulb temperature is shown to be highest in the en-suite bedroom, up to 6 K, and lowest in the kitchen area, up to 2 K (see Fig. 7.37). As shown in the figure, the latter is found to have a rather stable thermal condition where the mean daily temperature ranges from 30.8 °C to 32.1 °C. However, it is found to be generally warmer than the other two examined spaces; its average minimum temperature is approximately 4 K higher than the en suite bedroom, i.e. the coolest monitored space. Despite being semi-open with the living area allowing heat exchange to constantly occur by convection, which can be noted in figure 7.37 showing a noticeable correlation between the temperature fluctuation of both kitchen and living area, the lowest recorded temperature there is found to be 29.8 °C. It actually failed to meet both 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria (see Table 7.5). The reason for such a warmer indoor environment in the kitchen is most likely attributed to the unavailability of effective cooling gadgets, e.g. air conditioner, apart from having a wall-mounted fan. This is together with internal heat gains resulting from cooking activity alongside possible solar gains through the south-east facing window despite having a sheer curtain.

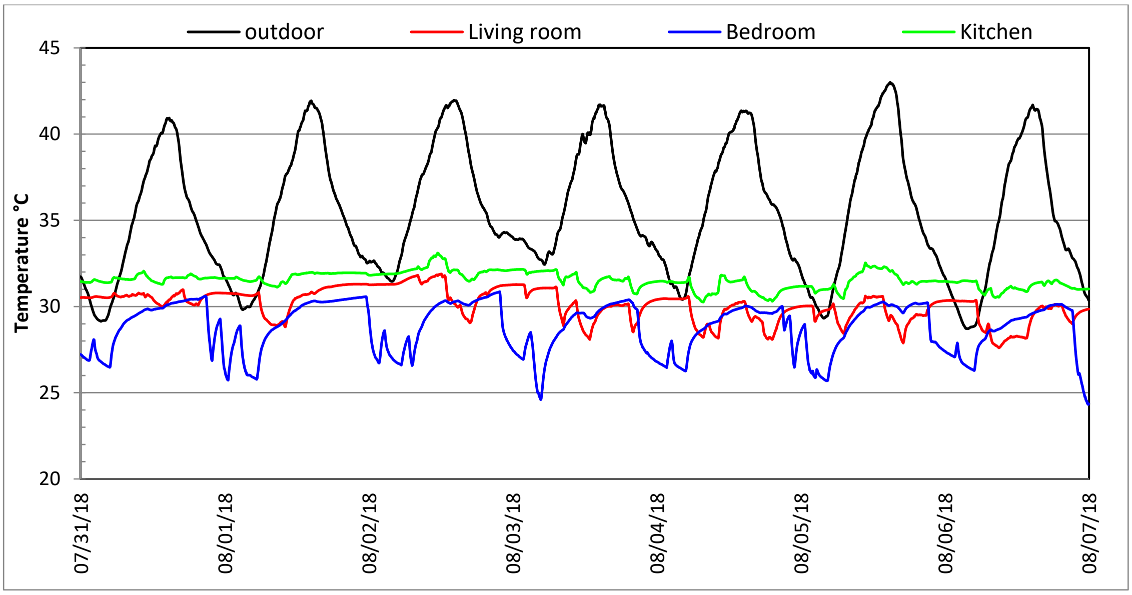


Figure 7.71 Recorded indoor and outdoor dry-bulb temperature over a period of one week (author)

Temperatures in the semi-open living area, which was normally occupied from 8 am until 10 pm, remained within the acceptability range of ASHRAE adaptive comfort criteria (i.e. 80% acceptability limit) for 96% of the occupied hours, as shown in Table 1, in the light of having one or two cooling equipment frequently in operation throughout the occupied hours as described earlier. The mean daily temperature ranged from 29.1 °C to 31.2 °C, and the peak indoor temperature, 32.1 °C, was observed to be 0.6 K below the outdoor temperature. The likelihood of indoor temperature exceeding the outdoor temperature is considerable after midnight when cooling gadgets are switched off. Interestingly, the two available wall-mounted air conditioners there were set to 24 °C, yet temperatures remained above 28 °C, i.e. CIBSE static criteria, over 94% of occupied hours (see Table 7.5 and Fig. 7.38), and the lowest record was found to be 26.4 °C. One could argue that the units' inadequacy to accomplish the set temperature is attributed to the fact that air conditioners are normally prone to lose their efficiency and power over time especially if there is a lack of maintenance. However, one should not deny: the impact of the room's layout and size being spacious (around 54 m^2) accommodating both the living and dining area. This is in addition to being attached to a staircase and a non-conditioned semi-open kitchen, where cooking takes place, allowing heat transfer to occur among those spaces through convection. This is besides the impact of high thermal transmittance of external walls, which is 1.43 W/m2 K, allowing heat to enter the space from outside through conduction which was also indicated by the householder during the interview. All these, in fact, could result in increased cooling loads and thereby causing difficulties for the units to achieve the desired temperature.

Table 7.11 A summary of overheating assessment in regards to ASHRAE adaptive comfort & CIBSE static standards

Room	Internal temperature			Percentage of occupied hours above certain temperatures		ASHRAE adaptive comfort standard	
	Mean (°C)	Minimum (°C)	Maximum (°C)	>26 °C	>28 °C	Occupied hours above T_{upper} (90% acceptability)	Occupied hours above T_{upper} (80% acceptability)
Kitchen	31.4	29.8	33.1	-	-	261 (87%)	87 (29%)
Living room	30	26.4	32.1	-	94%	56 (19%)	6 (2%)
G.F. Bedroom	28.7	23.8	31	94%	-	4 (2%)	0

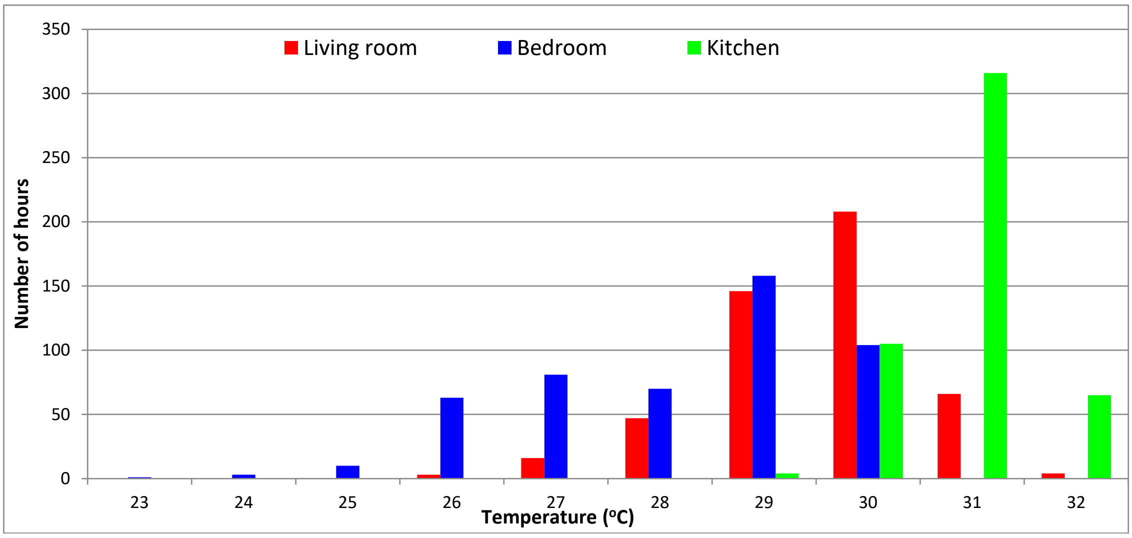


Figure 7.72 Histogram of hourly living room and bedroom temperatures (author)

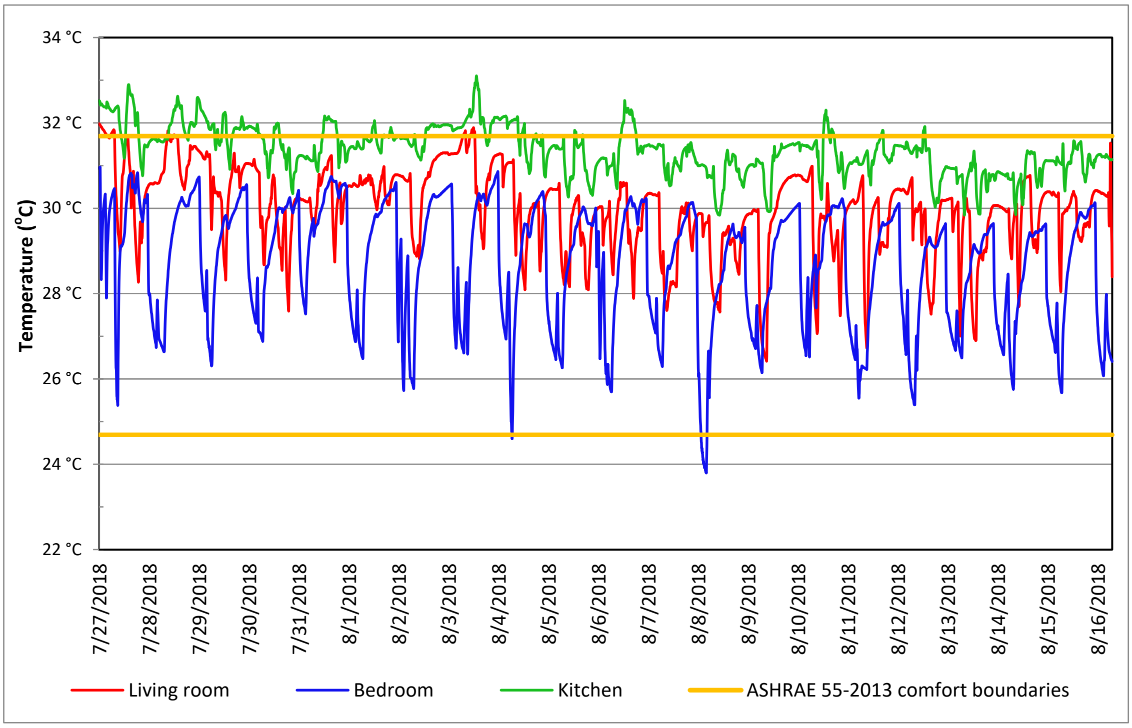


Figure 7.73 Indoor temperatures with comfort boundaries of ASHRAE 55 (80% acceptability)

On the other hand, the en suite bedroom was found to be the coolest monitored space in the house, although it relies on a smaller air conditioner (18000 BTU/hr) which was set to 26 °C. During the occupied hours, temperatures remained within the acceptability range of ASHRAE adaptive comfort criteria (i.e. 80% acceptability limit) and exceeded the upper limit of 90% acceptability for only 2% of the occupied hours (see Table 7.5). The mean daily temperature ranged from 27.9 °C to 29.7 °C, and the peak indoor temperature was found to be 30.9 °C at a time when the A/C unit was not in operation. Indeed, only during one night, i.e. one of the nights that the household stayed in the resort town, the bedroom experienced higher temperatures than the outdoor for a few hours. With no doubt, being less exposed to the direct sunlight due to the surrounding objects as well as being enclosed, which helps in reducing the cooling loads and putting less stress on the air conditioner, have facilitated the control of the thermal environment there and given rise to the accomplishment of relatively lower temperatures. Undoubtedly, cooler conditions could have been provided by the A/C unit if the occupants reduced the setpoint temperature, but the lady, who sleeps there, seemed to be satisfied with the situation as indicated in the interview. However, such thermal conditions were not very welcomed by her husband, which is why on the nights that he was sleeping there, as explained earlier, he was resorting to adjusting clothes or sometimes reducing the setpoint temperature to 24 °C as can be noted in figure 7.39 when the temperature occasionally falls below 26 C.

7.5.2 Findings – heating season

7.5.2.1 Adaptive behaviour and attitude

Their wintertime thermal comfort-related behaviours and consumption patterns were discussed during a qualitative interview held on January 22, 2019. A range of behavioural control actions was found to be undertaken by the family members to stay warm in the cold. These included: turning on heating equipment (i.e. kerosene heater, oil filled radiator, and split-type air conditioner), heating up the space beforehand, adjusting blinds, opening/closing windows, adjusting clothes, and sleeping under blankets. In general, the level of human intervention in dealing with winter temperatures was found to be low as the occupants were predominantly relying on heating technologies. This is believed to be highly driven by the economic conditions of the household.

Throughout the day, normally from 8 am until 11 pm, a kerosene heater was being run in the living area where the inhabitants prefer to stay. It was indeed the most used heating technology in this dwelling, and the limited amount of fuel distributed by the government through a subsidy programme, i.e. 200 to 400 litres, did not restrain the use of such technology. To avoid any shortage, in fact, the householder used to buy sufficient fuel for the heating season from an oil station by the end of each summer regardless of the amount that is given by the government. "*In this country where kerosene is the main heating fuel, one should never run out of it*," says the householder. The operation of the kerosene heater in the spacious living area was sometimes accompanied by turning on one of the available A/C units. This, according to the householder, was taking place on very cold days and also during the first 60 to 90 minutes of the day to quickly warm up such a roomy space which is left unheated overnight. In this regard, he stated:

> *It* [living space] *would take longer to be at a comfortable temperature by only running the kerosene heater* [….] *when we sometimes stay in Shaqlawa* [it is a resort town] *over weekends, the house gets cold as we do not leave any appliance on, so once we come back I straight away switch on both* [the air conditioner and kerosene heater] *for some time*.

However, such a mean of convection heating was not very welcomed by one of the ladies. "*I generally do not like air conditioning in winter; the air is so dry. It dries out my nasal passages, and I feel it is one of the reasons why I get flu and sinus infections*," says the lady. In addition to those heating devices, the window blinds were also being rolled up on sunny days to let sun rays reaching the space.

Each of the two occupied bedrooms, on the other hand, was relying on an oil filled radiator alongside a kerosene heater. At night, normally around 8 pm, one of those technologies was turned on to heat up the bedroom and be at a comfortable temperature before getting into bed around midnight. Their choice, however, was partly influenced by the power-supply mode as the oil filled radiators were only run on the national grid electricity. This again shows that despite their economic status, i.e. being on the higher rungs of the economic ladder, running costs-related concerns were involved in shaping their thermal behaviour. "*When you have two options in hand in which both can deliver similar outcomes, with no doubt one would go for the cheaper choice*," says the householder. Occasionally, both aforementioned thermal control devices were switched on on extremely cold days regardless of the source of power supply. However, none of the heaters was left on during sleeping hours no matter how extreme the weather was; instead, they were preferring to sleep under blankets. Before going to bed, the householder used to go around the house and make sure that all the heaters are switched off. The householder was asked if such an attitude was encouraged by cost-related concerns, but he claimed that it is not so; rather it is substantially driven by potential safety risks such as fire hazard, or carbon monoxide poisoning associated with the use of kerosene heaters. In this regard, he stated: "*You know how dangerous or even fatal it* [kerosene heater*] can be. Why would one put his/her life in danger in order to have warmer temperatures during sleeping?*" He also pointed out that there was no need for heating and energy consumption while they could stay warm under blankets. "*Regardless of how rich you are, you should not cause overconsumption. It is a sin*," says the householder.

In general, the inhabitants were satisfied with the indoor temperatures with the exception of the kitchen in which the inhabitants declared a slight degree of dissatisfaction for being cool. And this is understandable as there was no heating equipment available there apart from the cooking equipment. However, temperatures in the kitchen were obviously not as low as to run a heater in which the household can certainly afford. Instead, the ladies used to adjust their clothes and put on a robe while they work there. The only indoor variable that the occupants were highly dissatisfied with was the level of condensation being indicated as too high resulting in mould growth. This was driving them to open the windows and the roof vent from time to time every day to ventilate the house despite the heat loss that such behaviour might have caused. Also in the living room, the ladies were reportedly experiencing slightly warm conditions in the living room from time to time, especially around afternoon, something that they were dealing with through turning off the kerosene heater and opening the windows.

7.5.2.2 Physical measurements

Over the period of a month starting from December 24, 2018, the monitoring campaign was taking place in the same areas that were examined during the summertime fieldwork (see Fig. 7.34).

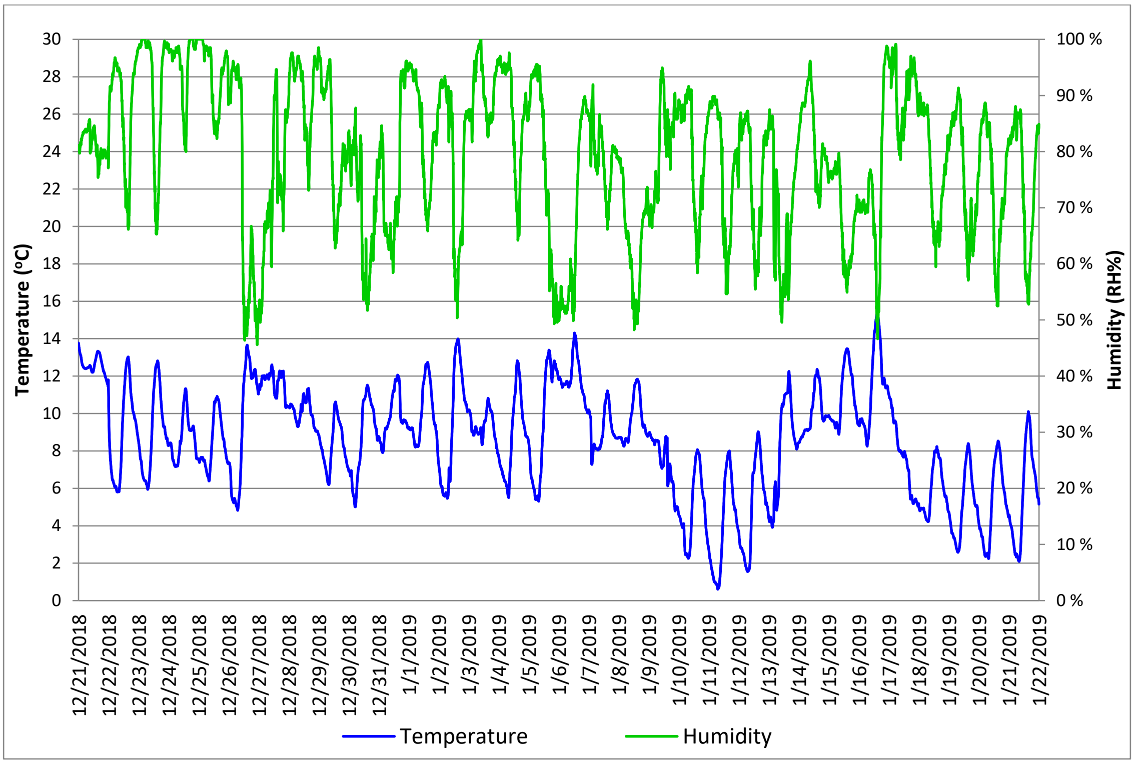


Figure 7.74 Recorded outdoor dry-bulb temperature and relative humidity (author)

It is clear from the outdoor readings that during that period the area was generally cold and wet. The mean daily temperature ranged from 3.9 °C to 11.9 °C, and the lowest and highest records were 0.6 °C and 15.4 °C respectively. Running mean outdoor air temperature (T_{rm}) ranged from 6.2 °C to 10.3 °C. On average, the diurnal temperature variation is found to be around 5.5 K. Meanwhile, the readings show the diurnal fluctuation of RH was from 46% to 100% (see Fig. 7.40).

In relation to the indoor readings, temperatures were generally found to be relatively pleasant during the occupied hours, especially within the living and sleeping spaces. The diurnal fluctuation of dry-bulb temperature is shown to be highest in the living area, up to 10 K, and lowest in the kitchen area, up to 3 K (see Fig. 7.41). Meanwhile, the mean daily RH is found to be relatively similar across the monitored areas ranging from 44% to 72%.

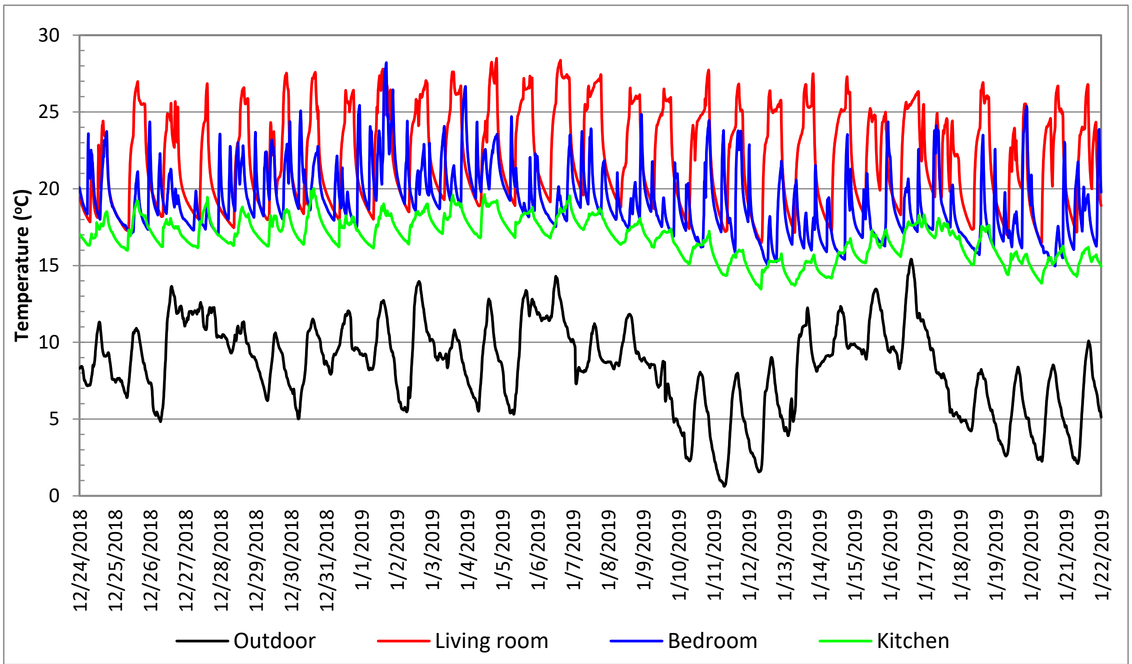


Figure 7.75 Recorded indoor and outdoor dry-bulb temperature (author)

Although the living area did not accomplish a steady thermal condition as shown in the figure, the space is found to be the warmest examined space, with even some indications of overheating. Its mean temperature during the monitoring campaign is approximately 3 K and 5 K higher than those recorded in the en suite bedroom and kitchen respectively. This is greatly attributed to the constant operation of the kerosene heater when the living space was in use along with direct solar gains through the south-east facing windows. Despite being large, the mean temperature there during the occupied hours, i.e. 9 am to 10 pm, remained within the range of 21 to 26 °C. As shown in table 7.67 and figure 7.42, all readings remained above the lower margin of ASHRAE adaptive comfort bandwidth (both 90% and 80% acceptability limits). Not only that, in fact, 67% and 54% of the occupied hours were found with records above the upper margin of 90% and 80% acceptability limits respectively. This could give an explanation of why the ladies were from time to time turning off the heater around afternoon and opening the windows. Since the heater was being switched off overnight, the space was experiencing notable temperature drops as can be noted in figure 7.41. However, no records were found below the outdoor temperatures, and the lowest reading, i.e. 16.5 °C, was observed to be 14 K above the outdoor one. It was recorded on the morning of January 20, the day when the outdoor temperatures remained within the range of 2.2 to 8.5 °C. In fact, all the daily lowest temperatures in the living space were recorded between 7 am and 9 am, the time when the space was unoccupied. One could expect this in such a space that is left unheated overnight. Also, such numerical indications could give an explanation of why the operation of the kerosene heater in the morning was being accompanied by running an air conditioner for some time as emerged from the qualitative investigations.

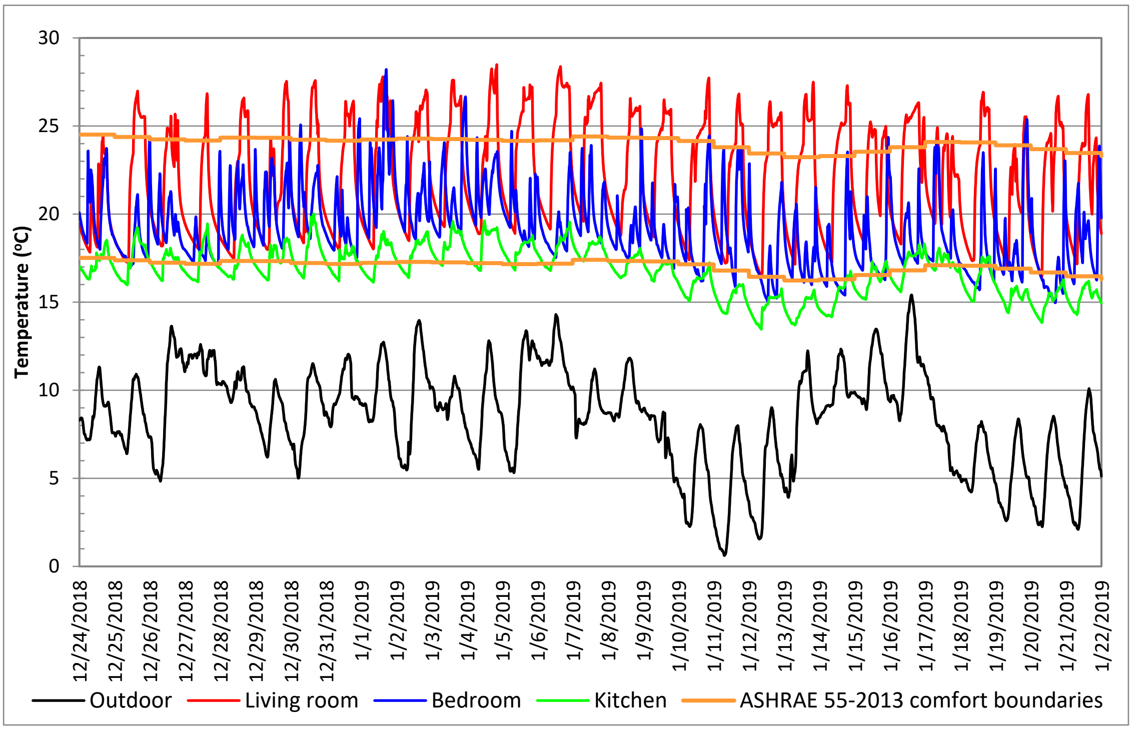


Figure 7.76 Indoor temperatures with comfort boundaries of ASHRAE 55 (80% acceptability)

Table 7.12 A summary of indoor thermal conditions in regards to ASHARE adaptive comfort & CIBSE static standards (author)

	Internal temperature			Percentage of occupied hours below certain temperatures		ASHRAE adaptive comfort standard	
Space	Mean (°C)	Min (°C)	Max (°C)	<17 °C	<22 °C	Occupied hours below T_{lower} (90% acceptability)	Occupied hours below T_{lower} (80% acceptability)
Living room	22	16.4	28.5		22%	0 (0%)	0 (0%)
Bedroom	19.2	15	28.2	8%	-	74 (26%)	9 (3%)
Kitchen	16.8	13.5	20	-	-	268 (77%)	141(40%)

In the bedroom where heating was being operated for only 5 to 6 hours a day and where no direct sunlight was reaching the space owing to the neighbouring objects, cooler temperatures compared to the living space were found. The readings show that the mean daily temperature had ranged from 16.8 °C to 22.4 °C, with notable variation between the daily minimum and maximum records up to 9 K (see Fig. 7.42). Occasionally, temperatures had slightly fallen below the lower margin of 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria accounting for 26% and 3% of the occupied hours respectively (see table 7.6). Nonetheless, no indications of thermal discomfort were reported by the householder, given that he and his wife used to stay under blankets right after turning off the heater(s). No records were observed below 16 °C, i.e. the degree that poses certain risks to human health according to WHO, during the occupied times. The coldest temperature, 15 °C, was observed to be 7 K above the outdoor temperature, and it was recorded on the afternoon, when no one was staying in the bedroom, of the same day when the living area's lowest temperature was found. On the other hand, the ladies' behavioural action of adjusting their clothes by putting on a robe sometimes while staying in the kitchen could be understood by looking at the temperature readings demonstrating that it was the coolest monitored space. The mean daily temperature had been between 14.6 °C to 18.2 °C, and the average maximum temperature is approximately 9 K lower than the one of the living area. It actually failed to meet both 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria (see Table 7.6). Such indoor conditions are expected due to the absence of heating gadgets apart from the available gas cooker. Similar to the other spaces, however, all records were found notably above the outdoor temperatures, and the lowest reading is found to be 13.5 °C being 12 K above the outdoor temperature. With no doubt, having no records below the outdoor temperature in all three spaces is attributed to the building fabric which has lower U-values compared to the other case studies.

7.5.3 Energy consumption

During the period of a year starting from August 01, 2018, the household's energy consumption data had been collected. On a monthly basis, the householder was providing a detailed excel sheet where he was recording all the required data on a daily basis. The sheets included electricity consumption from the two sources, kerosene and LPG consumption, and occasionally, information about the days/hours where mechanical control(s) were on (see Appendix D for samples of excel sheets provided). The records show that the occupants had consumed a total of nearly 26162 kWh. Interestingly, this is equivalent to 155 kWh of energy used in one square meter of occupied floor area in one year, an amount that is way less than the amount consumed by the low-income case study where a family of two was occupying the house.

The most-used source is found to be electricity supplied by the National Grid accounting for 49.2% of the total power consumption, while IPP electricity is found to be the least-used source accounting for 9% of the total consumption (see Fig. 7.43). The consumed kerosene and Liquefied Petroleum Gas (LPG) represent 26.2% and 15.6% of the total consumption respectively. Similar to the other case studies, the former was the most-used source of energy during the heating season. It is noteworthy that the house was usually being left unoccupied on weekends and all appliances were being left off.

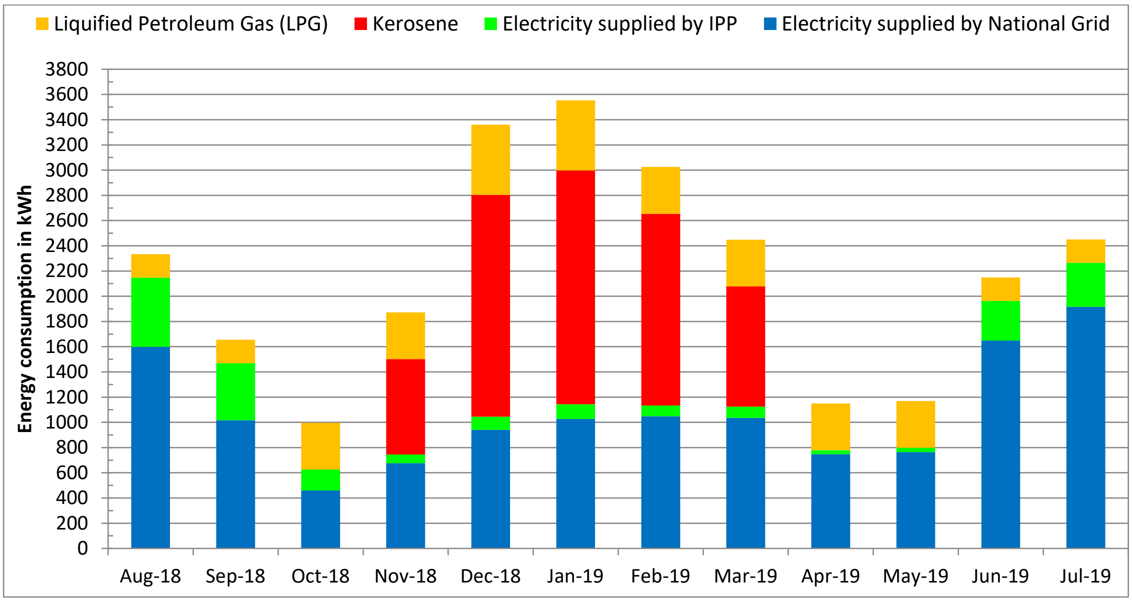


Figure 7.77 Household's energy consumption profile (author)

7.6 Conclusion

As key determinants in the functionality of buildings and the way inhabitants interact with the built environment, the questions of thermal comfort and environmental control have been addressed in this chapter employing the case study method (bottom-up approach). This is within four residential buildings of different technological standards and economic conditions. This was set out with the aim of providing an empirical understanding of performance within the existing building stock of the KRI to inform the development of optimal upgrading strategies. Unlike the typical approach across the building performance literature that is primarily based on physiology and engineering-based methods and evaluations, e.g. monitoring the physical parameters, the researcher went beyond such a conventional approach and examined the questions from a socio-technical angle as well. Increased attention has been paid to the relationship between the inhabitants and the physical performance of the environment they occupy and the factors shaping that relationship.

Consistent with other studies (see section 3.3.1.3 and Abdulkareem et al., 2020), the investigations demonstrate clearly that the way people control the environment in their buildings is not necessarily driven by the human body's physiological and physical state. It is essentially shaped by non-thermal factors, with socio-economic factors having a particular strong influence. The income, for instance, has led the human intervention in adjusting indoor thermal conditions to be at a certain level (see Fig. 7.44). In areas where households could not afford to mechanically service their buildings, the element of human behaviour emerged as an integral part of the overall performance and was much more engaged in terms of making occupants more comfortable. This is quite evident especially in case study 1 where the occupants exploited many possible adaptive measures ranging from those associated with the human body, e.g. dampening clothes and taking cold showers, to those associated with the building per se, e.g. sprinkling the roof and vegetation around the house and removing/laying rugs, to stay thermally comfortable. Meanwhile, higher-income households engaged less in adaptive behaviour as comfort was mostly dealt with using technological means. Even for those on the lower rungs of the economic ladder, technological means were becoming the first option to resort to when cost-related concerns were vanishing at times when the National Grid was supplying electricity.

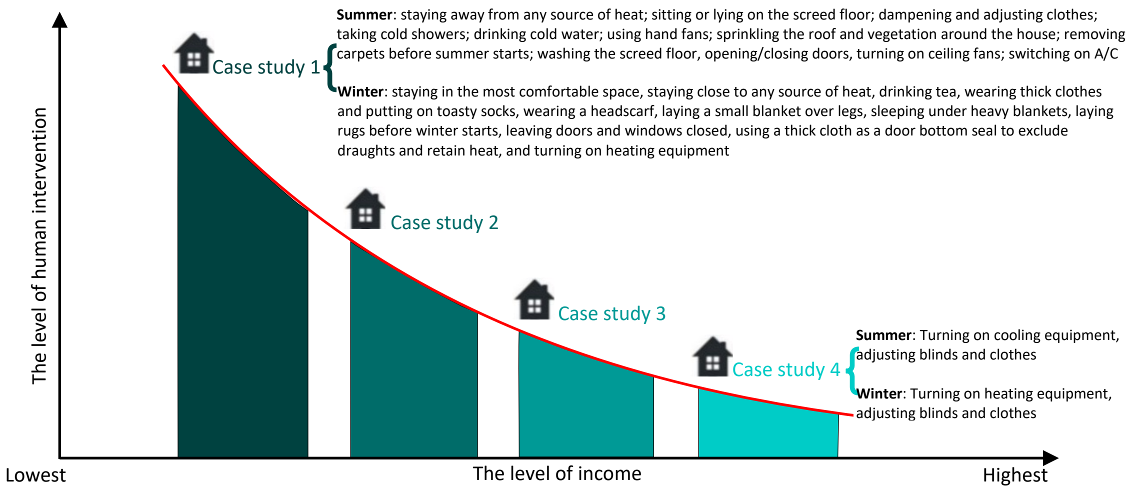


Figure 7.78 The relationship between the level of income and the level of human intervention in adjusting indoor thermal conditions (author)

What is surprising is that those who had no limitations of energy use and had the lowest level of human intervention in controlling the indoor environment had the lowest annual energy consumption per square meter of floor area (see Fig. 7.44). The amount that the upper-class household consumed was 155 kWh/m^2.y which was found to be 103 kWh/m^2.y lower than the amount consumed by the low-income household, i.e. the one with the highest level of human intervention. This was partly driven by their different value systems shaping their attitude towards energy use. In case study 4 (CS4) where the household (from an economic point of view) was able to consume in any way they please, for instance, the household felt that it is a religious and ethical obligation to reduce consumption of energy. This is why the conditioning of spaces was exclusively limited to spaces in use. Such a value system did not come onto the horizon with lower-income households, and this was noted very clearly in their attitude towards electricity use from the National Grid, i.e. the cheap energy. As there were no cost-related concerns due to its very low prices or because of having free access to it such as in the case of the working-class household, they were inattentively consuming it even at times when they were not in need to leave their equipment running. Among the cases emphasising this in CS2 is the habitual consumption of leaving air conditioner(s) on at the lowest possible temperature over night while covering themselves with a blanket or duvet due the low indoor temperatures caused by the A/C. Instead of resorting to the use of a blanket/duvet, the occupants could have simply increased the setpoint temperature and reduced energy consumption. Another case is in CS1 where the A/C of the main bedroom was being left on over the day although nobody was staying there. Such a periodic exposure to air-conditioning at the lowest possible temperature had likely led the occupants of those households to not tolerate higher indoor temperatures at times when they had no access to A/C, i.e. in the absence of electricity from the National Grid. This relationship between exposure to low temperature and the degree of tolerance was noted in different cases across the CS1, CS2, and CS3.

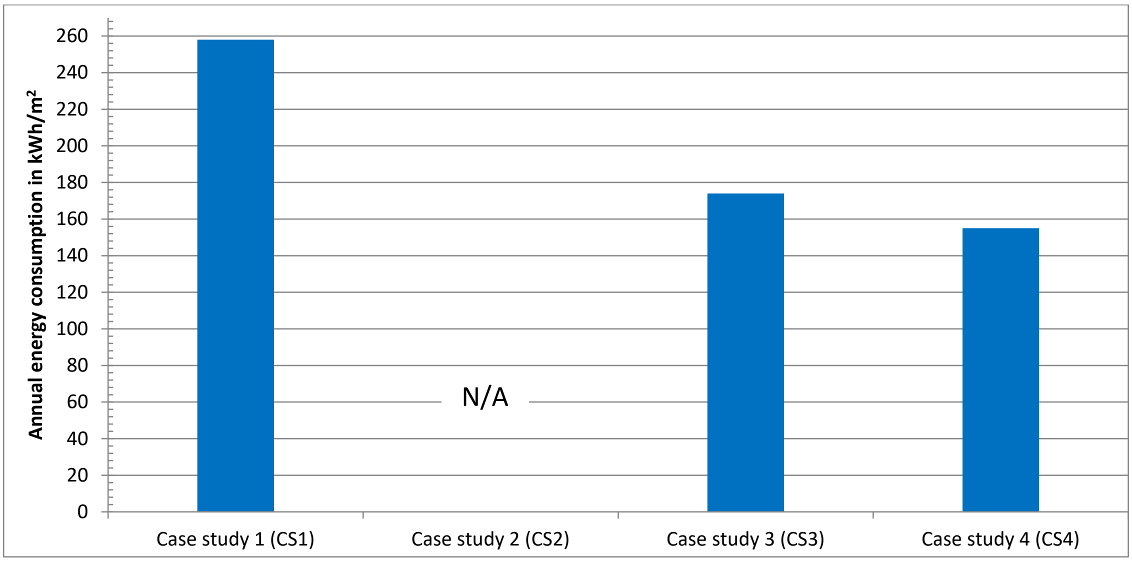


Figure 7.79 Annual energy consumption per square meter of floor area in the examined case study houses (author)

Despite such high figures, thermal discomfort as illustrated earlier had taken place in all four case studies (see Table 7.7), with the most uncomfortable conditions present in case study 1 (CS1) which reached a degree that poses threats to occupants' health. This was not only during the cooling season (as one may normally anticipate in hot climate regions) but also during the heating season. Such indoor thermal conditions were found to be predominantly driven by the physical attributes of the building, mainly weaknesses associated with the building fabric, e.g. the lack of thermal insulation, air infiltration, poor quality of the openings such as those of CS1, and the roof's prolonged sun exposure. These in turn were opening the road for a constant flow of heat from outside to inside or vice versa. Once the buildings were going into the free-running mode, the indoor climate was changing rapidly in accordance with the fall and rise in external temperature. This was particularly evident in CS1, CS2 and the top floor of CS3, thanks to the

Table 7.13 A summary of overheating assessment in regards to ASHARE adaptive comfort & CIBSE static standards

Case study	Room	Internal temperature Mean (°C)	Minimum (°C)	Maximum (°C)	Percentage of occupied hours above certain temperatures >26 °C	>28 °C	ASHRAE adaptive comfort standard: Occupied hours above T_{upper} (90% acceptability)	Occupied hours above T_{upper} (80% acceptability)
CS1	Living room	29.07	21.9	35.7	-	61%	236 (35%)	167 (24%)
CS2	Living room	28.4	24.2	32.2	-	56%	50 (14%)	13 (4%)
CS3	Living room	29.89	28.59	31.58	-	100%	60 (10%)	4 (0.6%)
CS4	Living room	30	26.4	32.1	-	94%	56 (19%)	6 (2%)
CS1	G.F. Bedroom	32.31	25.63	39.51	99%	-	133 (43%)	83 (27%)
CS2	G.F. Bedroom	27.5	22.4	33.6	54%	-	25 (9%)	7 (4%)
CS3	1st.F. Bedroom	31.47	27.36	37.66	100%	-	124 (40%)	63 (20%)
CS4	G.F. Bedroom	28.7	23.8	31	94%	-	4 (2%)	0

building fabric being unable to delay heat transfer. Indeed, U-values were found to be very high in all case studies (see Fig. 7.46), with the lowest ones present in case study 4. This was found to be strongly affecting the indoor conditions and influencing the way the occupants interacted with their immediate environment. In response to the excessive heat gains through the non-insulated exposed roof causing unbearable indoor conditions over the summer, for instance, the occupants of CS2 and CS3 were practicing internal migration which is a longstanding cultural practice in the region. The entire top floor was being left unoccupied throughout the daytime and all their activities were taking place on the ground floor. The occupants of CS4 dealt with the issue technologically by installing an evaporative air cooler in the attic to constantly supply cool air to the space and the corridor beneath during the daytime to mitigate such impact. And as the CS1 is a one-storey building, the household had no other option than running water on the roof, i.e. another longstanding cultural practice, to reduce the amount of heat transferred.

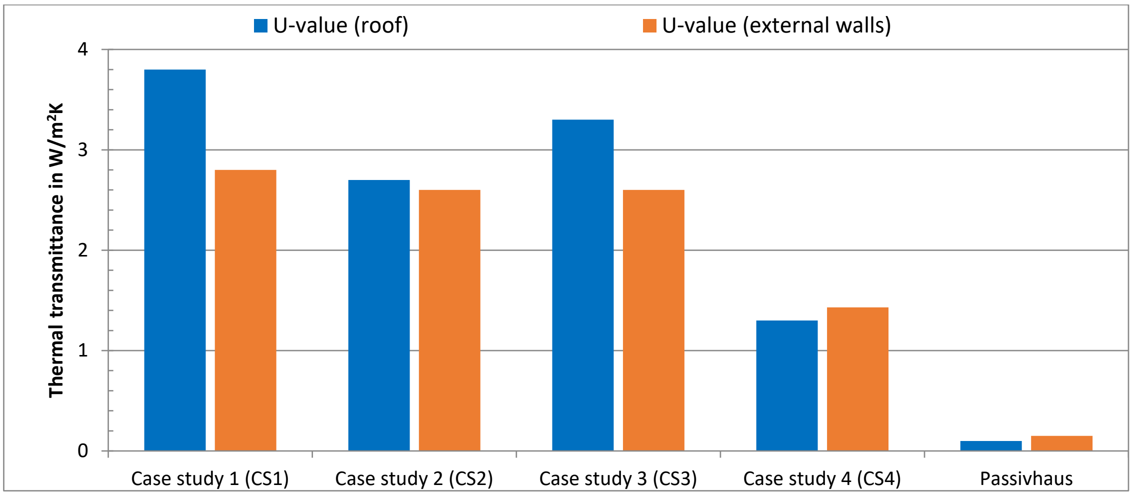


Figure 7.80 The U-values of roof and externals walls in the examined case study houses compared to the requirements of Passivhaus (author)

Other energy-use-related similarities were found amongst those socio-economically distinct households. Contrary to expectations that one would normally have about energy demand in hot climate regions, energy use in all case study houses was found to be notably higher in the winter period than in the summer period (see Fig. 7.47). The increased use of kerosene as the main heating fuel in which people do not normally consider when thinking about their energy consumption was causing such a difference. In fact, January recorded the highest monthly energy consumption in all case studies. This shows how important it is for design and construction professionals to consider the heating season as well when making decisions in such an environment, something that has not received enough attention yet.

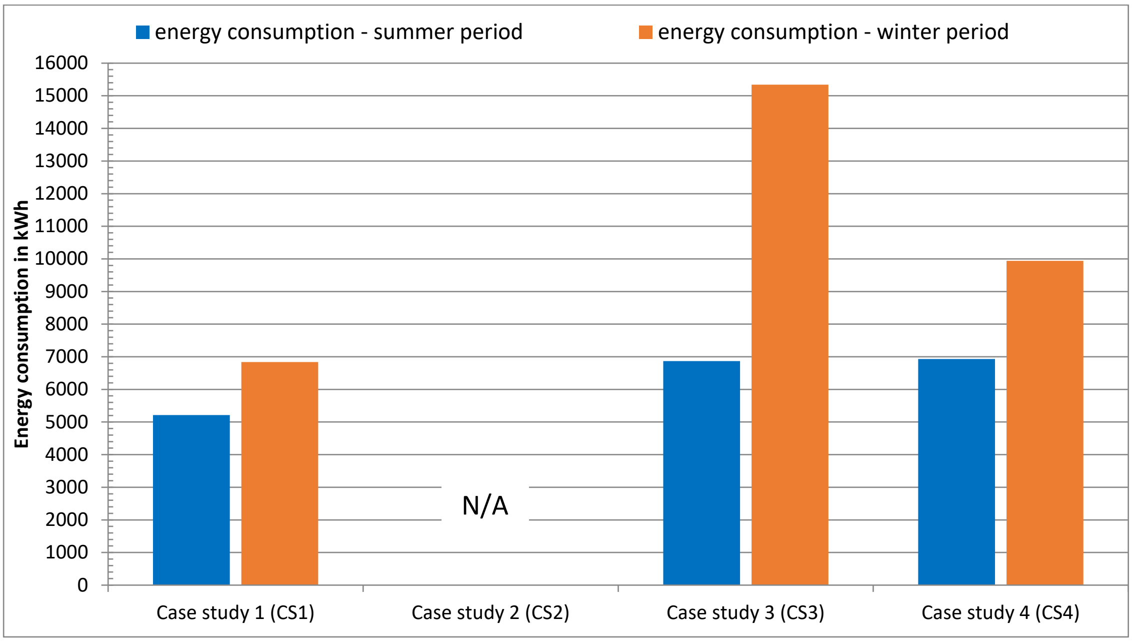


Figure 7.81 seasonal variation in energy use in the examined case study houses (author)

The households were also pretty much alike in their attitude towards kerosene use over winter nights. All of them were very keen to turn off such kerosene heaters before going to bed no matter how cold the indoor environment was. This was driven by the potential risks associated with the use of such heaters, e.g. fire hazard and carbon monoxide poisoning, which in turn have given rise to innumerable tragedies not only across the KRI but also throughout the world. Multiple studies (see e.g. Fisher, 1999; Abelsohn et al., 2002; Ritchie et al., 2003 and Prockop and Chichkova, 2007) have shown that health problems such as shortness of breath, difficulty in concentrating, nausea, weakness, dizziness and headache could arise from breathing kerosene fumes. With prolonged exposure, the symptoms could be more severe such as convulsions and loss of consciousness, especially within spaces that are poorly ventilated, and there is also a possibility of lung and heart failure which could lead to death. According to the World Health Organization (WHO), "*3.8 million people a year die prematurely from illness attributable to the household air pollution caused by the inefficient use of solid fuels and* *kerosene*." Those health concerns, in fact, frighten the majority of families across the region when using such a heating tool regardless of the income level.

However, one cannot deny that these findings cannot be extrapolated to the existing building stock due to the limitation of the sample size, but they generally offered intimate insights and raised some important questions: would adopting the fabric first approach to building design lead the buildings to achieve compliance with the western thermal comfort criteria, e.g. CIBSE criteria as recommended in the Building Control Regime (BCR) developed by UNDP-Iraq? If yes, what level of reduction in energy use would be achieved at the same time? Would its adoption provide a higher level of thermal comfort across the whole building not just the spaces in use? Is there the risk that the total energy use being higher than now? Experimentations are performed in the next chapter to see how far one can push that and what would be the outcome of improving the thermal performance of building fabric based.

Chapter 8

Dynamic thermal modelling

8.1 Overview

In the previous chapter, the emphasis was placed upon questions of performance and environmental control across a sample of dwellings of different technological standards and economic conditions. It was found that the four dwellings are not thermally efficient from fabric point of view, making the presence of thermal discomfort and associated increased consumption of energy inevitable in both summer and winter. Using a dynamic thermal simulation tool, this chapter provides a full assessment of the impact of upgrading the building fabric on the indoor thermal environment, energy use (primarily heating and cooling load), and reduction of CO2 emissions. Taking into account the socio-economic context which cannot be excluded from any in-depth analysis, out of the four dwellings, experimentations were performed on the two that represent opposite ends of the socioeconomic spectrum, i.e. case study 1 and 4. The reasoning behind this, as indicated in Chapter 3, is that the fabric upgrading intervention(s) that could fit a certain income group might not be suitable for another one.

The chapter starts with presenting the methodology in detail and then moves on to the development of the validated base models. The latter is predominantly based upon input parameters, e.g. construction and operational data, provided in the previous two chapters. Then the chapter presents a range of upgrading interventions and the potentiality they have in terms of reducing energy consumption and CO_2 emissions, and meeting thermal comfort criteria. The interventions are firmly guided by: the socio-economic considerations that impacted the people's lives in the case studies, the socio-technical constraints presented in chapter 5, and the principles of fabric first.

8.2 Building model and simulation settings

This part of the research was carried out employing an EnergyPlus-based energy modelling tool called DesignBuilder, one of the most widely utilised simulation tools in the industry for examining and predicting comfort, lighting, carbon, and energy performance of buildings [see e.g. Kulkarni et al. (2011), Cardinale et al. (2013), Wang et al. (2015), and Blanco et al. (2016)]. Offering a detailed dynamic thermal simulation and a user-friendly graphical interface, the tool enables energy consultants, engineers and designers to undertake thorough thermal and energy assessments. The software allows real and accurate data with respect to construction materials, building geometry, cooling and heating technologies, and occupancy profiles to be inputted. Therefore, professionals can easily visualise possible designs, predict the performance within probable real-life operating conditions and make changes in a way that improves the performance and lead to quicker, better, more affordable, more efficient and more sustainable outcomes.

In the very early stages and prior to modelling the case base dwellings, hourly measured weather data of the areas where the two case studies located were required. This is in the file format of EnergyPlus Weather (EPW), a weather file format that can be read by DesignBuilder. Normally, such a file includes measurements of certain weather parameters, e.g. cloud cover, wind direction, wind speed, solar radiation, relative humidity, air temperatures (wet bulb, dry bulb, and dew point ones), and etc. And since the built-in weather files of DesignBuilder and those of the EnergyPlus website do not include weather data sets for Kurdistan, the data had to be imported. The researcher first collected hourly data of ten consecutive years for both the city of Duhok and Erbil capital from their meteorological offices aiming to construct the required EPW files for simulations. Due to the fact that solar radiation measurements were missing, however, the researcher was not able to produce such a weather file. Following talks with a few experienced researchers in the field, the author was advised to attain the files in EPW format either through online sources, such as White Box Technologies and Climate.OneBuilding, or through weather generators, e.g. Meteonorm. In reliance upon hourly weather observations, these sources provide historical weather files for thousands of locations worldwide and in different formats, e.g. EPW and TMY. And this is something that even the EnergyPlus website recommends for locations that are not supplied by them (EnergyPlus, n.d.). The researcher then acquired the required EPW files from Climate.OneBuilding. However, the data sets of the city of Duhok where the first case study is located were not available; therefore, the researcher chose the data sets of the nearest available location which was the city of Zakho (56 km away) as an alternative. To ensure their accuracy, the researcher performed a comparison between the measured outdoor temperatures from summertime and wintertime fieldworks and those of the obtained EnergyPlus Weather files for both locations to see how close they are to each other. Variations were then noted to some extent as shown in Figure 8.1, something that one would normally expect given the fact that the two different sources of data do not represent the same period. The field data was recorded in the summer of 2018 and winter of 2019, whilst the EPW weather data files were built upon records of fourteen years in the past, i.e. 2004-

2018. However, such variations are not expected to give rise to misleading results since there is still reasonable proximity between the mean daily temperatures from the two different sources (see Table 8.1).

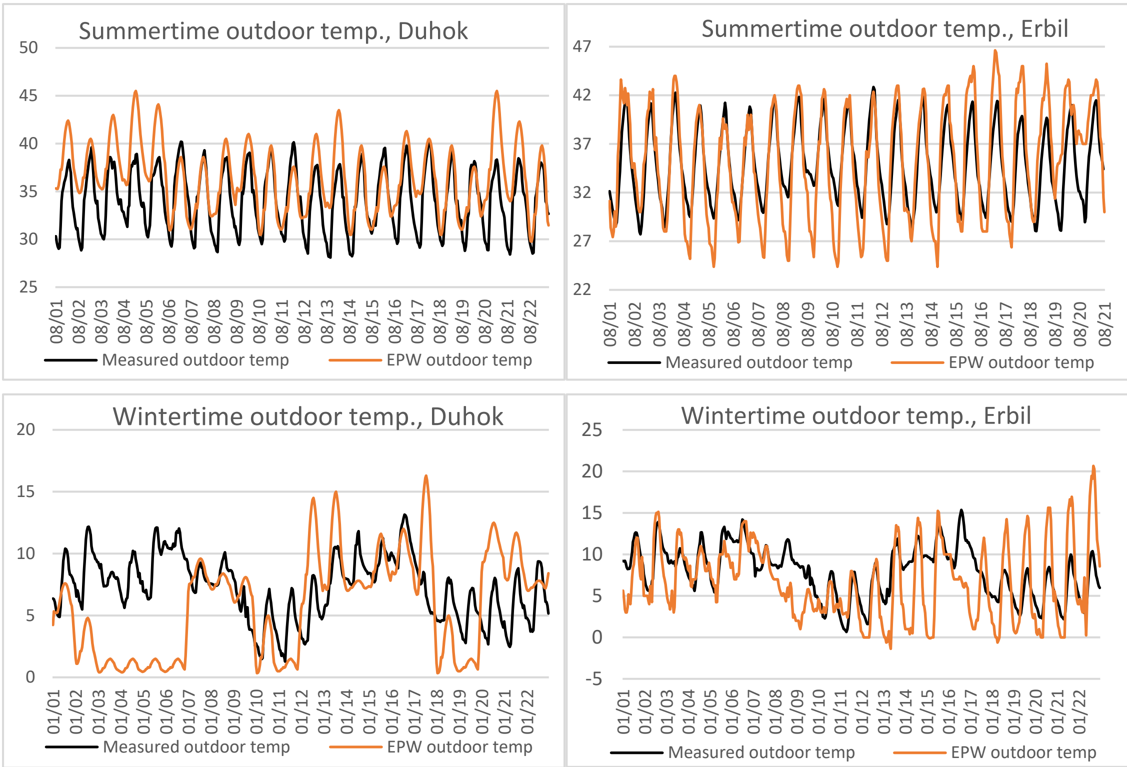


Figure 8.82 Comparison between outdoor temperatures from EneryPlus weather files and in-situ measurements for the city of Duhok (left) and Erbil capital (right)

Table 8.14 Comparison between the mean outdoor temperatures from EneryPlus weather files and in-situ measurements (author)

Location	Period	In-situ measurements	EnergyPlus Weather data
Duhok	Mean °C (August)	34.2 °C	36.5 °C
	Mean °C (January)	7.2 °C	5.8 °C
Erbil	Mean °C (August)	34.9 °C	35.2 °C
	Mean °C (January)	7.9 °C	6.7 °C

Having set the weather data in DesignBuilder, the case base houses were then modelled making use of the well-described inputs presented in Chapter 6 and 7. This was based on construction and operational data collected during site visits. These include, but are not limited to, working drawings, construction details, surveys of lighting equipment, heating and cooling systems, their capacity and operating schedules, set point temperatures, opening/closing curtains, and occupancy profiles and schedules. This input process was undertaken very precisely and far from using unrealistic input parameters. This is to bring the predicted performance close to the actual one so that the model becomes as realistic as possible prior to the application of physical and technological interventions described below. This is considered essential to avoid poor decisions and inappropriate use of resources, a key concern among researchers when undertaking such kind of building performance studies [see e.g. Norford et al. (1994), Williamson (2010), Menezes et al. (2012), Ryan and Sanquist (2012), De Wilde (2014), and Andersen et al. (2016)]. The adjacent buildings were also added to the site as component blocks for their potential role in casting shadows and reflecting sunrays (see Fig. 8.2).

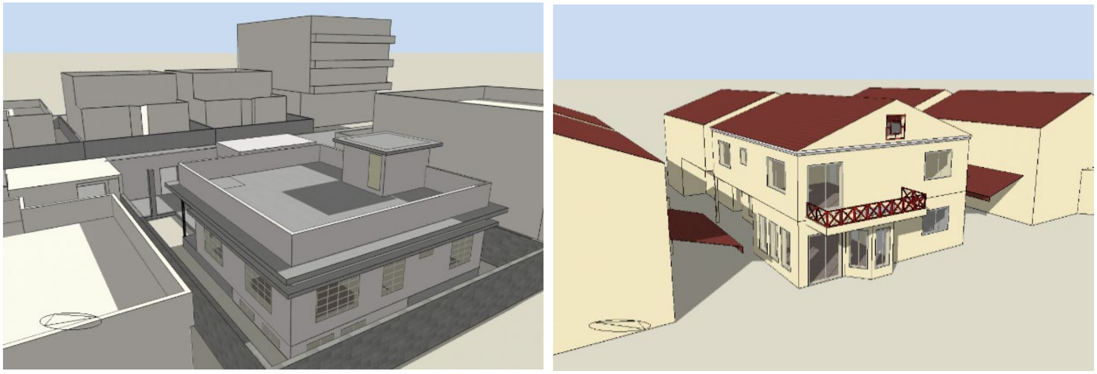


Figure 8.83 The base models of case study 1 (left) and case study 4 (right)

Despite the efforts to use the real-world input parameters, making reasonable assumptions was still inevitable to cope with the unknowns. Amongst the uncertain parameters that the author coped with during the input process was the operating schedules of cooling equipment, something that may have caused a slight difference between the actual and predicted performance. This is particularly in the first case study where the operation of cooling equipment is affected by the power cuts that are experienced with the national grid. And because of having no regular schedule for supplying electricity from that source, it was difficult to determine the exact operation schedule of air conditioning. Hence, the researcher used the approximate schedules that were provided by the oral reports from residents, four times spread out across the day where each time lasts for around three hours.

Another difficult task was related to the natural ventilation (NV) rates and settings. Generally, the software offers two different ways to set up natural ventilation simulation. The first method is Scheduled natural ventilation which is generally employed for early-stage modelling or when natural ventilation rates are likely to be small relative to other heat flows in the building. It is the least complex and quickest option, and thereby one can save a lot of time while running simulations using this method. However, approximate data with respect to natural ventilation and infiltration rates of each zone need to be known, a variable that was not measured during both summertime and wintertime fieldworks. The second method is Calculated natural ventilation, a more complex approach that takes longer to set up and simulate as a result of additional calculations needed in calculating the airflow rates at each time step. In the absence of ventilation data of the building, this method can be used as an alternative to the Scheduled one as it relies upon information about cracks across the fabric and their sizes. This is besides opening sizes and operation parameters as well as temperature data, internal gains, weather data to calculate the airflow rates through each zone. To speed up simulation and decrease the complexity of the models, however, the tool's user guide supports the use of the first method unless one is unable to estimate the NV rates reasonably. Since there was a lack of accurate data about the extent to which windows are opened and the magnitude of the existing cracks across the fabric elements, the researcher in line with what the software recommends adopted the first method and roughly estimated the maximum air change rates. This is based on what CIBSE guide A recommends, a factor which might arguably have created a little gap between the actual and modelled performance of the case base dwellings. However, it is worth noting that the operation schedules of Natural ventilation were likely realistic and based completely on data collected from the households. Accordingly, the schedules were set in a way that kept NV off during times when cooling equipment were running.

8.3 Modelling validation

Having set all the input parameters, the validation process had to take place to check the robustness of the models and degree of correspondence to reality and ensure that they are trusted to deliver an accurate prediction of performance. This is in fact considered an integral part of the modelling process. For this, different methods were found across the literature such as empirical validation, comparative testing, and analytical verification [see e.g. Jensen (1995), Witte et al. (2001) and Ryan and Sanquist (2012)]. Williamson (2010) defines these three approaches as follow:

> *Empirical validation, which compares simulated results with measured data in the real world, e.g. a building, a test cell or a laboratory. The ultimate validation test would be a comparison of simulation results with a perfectly performed empirical experiment with all simulation inputs perfectly known.*
>
> *Analytical verification, which compares simulation output from a program, subroutine, algorithm or software object with results from a known analytical solution or a set of quasi-analytical solutions.*
>
> *Intermodal comparison, which compares the output of one program with the results of other similar programs.*

And as in-situ measurements were a key part of this research (see chapter 6), accordingly, the researcher adopted the first approach which is generally considered as the most commonly used validation procedure. Simulations were run for the case base houses for a one year period, and the results (mainly indoor temperatures and energy use data) were then tested against their real-world counterparts, i.e. the monitored data, to see how close they are and address any possible error before applying the interventions, i.e. physical, technological and behavioural ones. The comparison showed reasonable proximity of both sets of results (see Tables 8.2, 8.3 and 8.4), something that provided much confidence to start upgrading their building envelope. And in agreement with the real-world situation, the poor quality of the building fabric emerged to be the key driver behind the poor energy and thermal performance of the houses.

Table 8.15 Comparison between the monitored and simulated indoor air temperatures in case study 1 and 4 (summertime)

Case study	Source of data	Space	Min °C	Max °C	Mean °C
1	Monitored results	Living room	21.9 °C	35.7 °C	29.07 °C
		Main bedroom	25.63 °C	39.51 °C	32.31 °C
	Simulated results	Living room	22.49 °C	36.6 °C	28.6 °C
		Main bedroom	25.7 °C	38.03 °C	30.6 °C
4	Monitored results	Living room	26.4 °C	32.1 °C	30 °C
		G.F. bedroom	23.8 °C	31 °C	28.7 °C
	Simulated results	Living room	25.6 °C	32.16 °C	27.5 °C
		G.F. bedroom	24.3 °C	28.8 °C	26.2 °C

Table 8.16 Comparison between the monitored and simulated indoor air temperatures in case study 1 and 4 (wintertime)

Case study	Source of data	Space	Min °C	Max °C	Mean °C
1	Monitored results	Living room	10.16 °C	26.16 °C	17.9 °C
		Main bedroom	4.71 °C	13.35 °C	9.4 °C
	Simulated results	Living room	9.94 °C	24.66 °C	19.2 °C
		Main bedroom	7.2 °C	15.1 °C	11.05 °C
4	Monitored results	Living room	16.4 °C	28.5 °C	22 °C
		G.F. bedroom	15 °C	28.2 °C	19.2 °C
	Simulated results	Living room	12.5 °C	29.2 °C	22.1 °C
		G.F. bedroom	15.1 °C	29.6 °C	21 °C

Table 8.17 Comparison between the monitored and simulated total energy use in case study 1 and 4 (author)

Case study	Source of data	Total Energy Use kWh
1	Monitored results	19601 kWh
	Simulated results	17056 kWh
4	Monitored results	26162 kWh
	Simulated results	24780 kWh

Following that, copies were made of the base models to introduce the upgrading scenarios where different measures ranging from simple to more complicated ones aiming to boost the fabric efficiency and reduce cooling and heating demand were applied. Then the energy saving potential and thermal efficiency of such interventions were predicted and compared to those of the case base models. The results are presented in a later section. It is worth mentioning that in the development of those interventions, the researcher based upon the parameters that emerged earlier in this thesis attempted to limit expensive and highly sophisticated solutions. Given the socio-economic and socio-technical conditions discussed previously and the cost implications of the proposed measures, however, all the measures considered by the author might still not be economically and/or technically applicable to the entire building stock. In the next sections, the building envelope upgrading scenarios alongside the simulated results of both case studies are presented individually.

8.4 Case study 1

8.4.1 Modelling scenarios

This unit, as indicated earlier, was modelled using the actual input parameters that are presented in section 6.2. Then four building fabric upgrading scenarios were proposed ranging from simple to more complicated ones as follow:

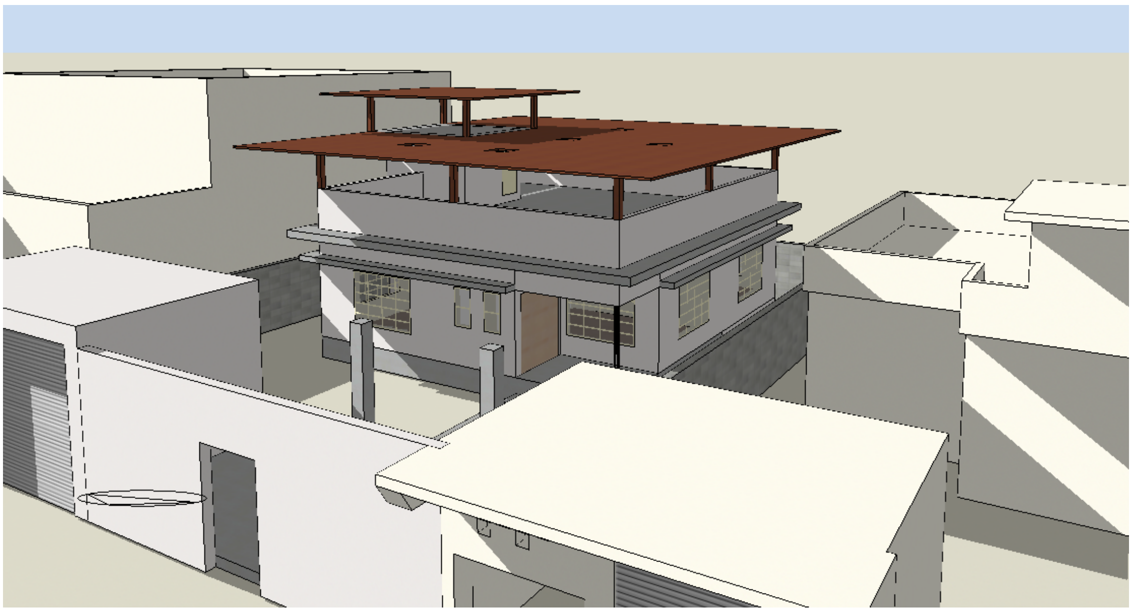


Figure 8.84 A wooden gazebo added to the rooftop (author)

In the first scenario, the researcher proposes a sun shade system to the rooftop using a simple wooden structure such as a pergola allowing deciduous plants to climb and grow all over the roof. This is an inexpensive and also an established cultural practice in the region in which people normally use to shade an outdoor sitting area and grow their own grapes. Such a roof covering aims to mitigate the excessive heat gains taking place through the non-insulated exposed flat roof causing high internal temperature as demonstrated earlier in this thesis. This would also reduce the burden of taking the garden hose to the housetop every morning and leaving the faucet on for few hours, which causes water wastage. And to assess the potential benefits of such an intervention in terms of energy saving and indoor comfort, a wooden gazebo was added to the original model in DesignBuilder (see Fig. 8.3). This is in such a way that extends well beyond the boundaries of the roof in order to block most of the direct sunlight from reaching the roof over the cooling season. However, it is noteworthy that such an intervention might have no influence on the building's energy and thermal performance over the heating season.

In addition to the roof covering, in the second scenario, replacement of all window openings is applied, an energy-saving measure that is strongly recommended by the Building Control Regime (BCR) developed by UNDP-Iraq. All the old, steel-framed and single glazed windows in which their U-value according to DesignBuilder is around 6.1 $W/m^2.K$ are replaced with new low-E, double glazed and argon-filled ones in which their U-value is around 1.5 $W/m^2.K$ or even less and are commercially available in the city of Duhok where the case study is located. In fact, this was partly done in early December 2018 by a charity donor who in cooperation with the researcher already replaced the windows of the living room (see section 7.2.2 for further details). Such intervention aims to further improve the performance of the building envelope and reduce cooling and heating loads. These changes are again applied and assessed in DesignBuilder which are presented in a later section.

In the third scenario, emphasis is placed on the entire building envelope. An effective but low-cost building envelop aiming to minimise heating and cooling loads while providing a higher level of comfort is modelled. Besides the aforementioned interventions, i.e. roof covering and windows replacement, the researcher proposes the replacement of the old exterior doors and insulation upgrades across the exterior walls, floor, and roof. For that, the U-value of the external walls is reduced from 3.1 $W/m^2.K$ to 0.36 $W/m^2.K$, a figure that is even lower than what is recommended in the BRC (i.e. < 0.5 $W/m^2.K$). Such a figure is achieved by adding a 50 mm thick straw based insulation board and a layer of compressed earth-based bricks plastered with lime-based plaster. These layers are added to the original exterior walls, which are mainly made of concrete blocks, in such a way that avoids thermal bridging. All the proposed additional layers are made of cheap and locally available natural materials that provide great flexibility of use. They are widely applied by rural and marginalised communities across the region as indicated earlier in Chapter 5. Furthermore, the U-value of the roof is reduced from 3.8 $W/m^2.K$ to 0.28 $W/m^2.K$. This is again lower than what is recommended in the BCR (i.e. < 0.3 $W/m^2.K$). Such a low U-value is accomplished by using a certain roof construction type. It is composed of a suspended ceiling as an innermost layer, air gap, 50 mm thick straw based insulation board, the existing 200 mm thick concrete slab, vapour control layer, 50 mm thick straw based insulation board, 50 mm thick screed, and a waterproofing layer as an outermost layer. Improvements are also made to the floor in contact with the ground. Its U-value is reduced from 2.5 W/m^2.K to 0.45 W/m^2.K through adding a 50 mm thick straw based insulation board and a layer of screed to the existing concrete floor with bearing in mind door thresholds. All these interventions are applied in DesignBuilder where assessments are carried out. It is also worth mentioning that all these modelled interventions are locally within reach from a technical perspective and can be performed by local construction teams with the use of the available apparatus. And this is demonstrated in the pilot study, i.e. an attached two-storey house, which has been recently constructed by the author in the city of Duhok (see Appendix E).

To boost the fabric efficiency and reduce cooling and heating demand further, the researcher proposes an entirely hypothetical scenario aiming to explore the potential impact of full Passivhaus fabric requirements. In this last scenario, further improvements are applied to the entire building envelope through paying far more attention to the quality of windows, insulation, and airtightness. Since the window is required to have a U-value lower than 0.8 W/m^2.K to be certified by Passivhaus (Hines et al., 2015), all the window openings are replaced with triple glazed and argon filled ones in which their U-value according to DesignBuilder is around 0.78 W/m^2.K. However, such a window type is not quite common in the region and is only commercially available in the capital Erbil at the current time. This means that opting for such a type would involve transportation costs. Further insulation upgrades across the floor, roof, and external walls are also inevitable as in PH buildings, typically, the U-value of those components should not exceed 0.15 W/m^{2}K (Hines et al., 2015). Accordingly, the U-value of the external walls is reduced to 0.12 W/m^2.K through using the same wall layers applied in the third scenario with the exception of increasing the thickness of straw based insulation board to 250 mm. Meanwhile, the U-value of the roof is reduced to 0.125 W/m^2.K. This is again accomplished following the same roof layers applied in the previous scenario with the exception of increasing the thickness of both layers of straw based insulation board to 120 mm. And to further reduce the U-value of the floor in contact with the ground, a 250 mm thick straw based insulation board is added to the existing concrete floor instead of the 50 mm thick one applied in the previous scenario. By doing so, a U-value of 0.14 W/m^{2}K is achieved. Apart from increasing the level of insulation across the building envelope, emphasis is also placed on the level of airtightness. The model air infiltration rate at 50 Pa in DesignBuilder is set to 0.6 air changes per hour, a figure that needs to be achieved in PH buildings. Table 8.5 shows briefly the differences between the four upgrading scenarios.

Table 8.18 The differences between the upgrading scenarios (author)

Upgrading scenarios	Roof covering	Ext. windows U-value	Ext. walls U-value	Roof U-value
Base model	N	6.1 $W/m^2.K$	3.1 $W/m^2.K$	3.8 $W/m^2.K$
Scenario 1	Y	6.1 $W/m^2.K$	3.1 $W/m^2.K$	3.8 $W/m^2.K$
Scenario 2	Y	1.5 $W/m^2.K$	3.1 $W/m^2.K$	3.8 $W/m^2.K$
Scenario 3	Y	1.5 $W/m^2.K$	0.36 $W/m^2.K$	0.28 $W/m^2.K$
Scenario 4	Y	0.78 $W/m^2.K$	0.12 $W/m^2.K$	0.125 $W/m^2.K$

These four modified models alongside the base case were first simulated in DesignBuilder predicting their effectiveness with adding no technological and behavioural interventions. No changes were therefore made to the way the household runs the house, environmental controls that modify the indoor conditions, and their operation hours. This means, as presented in Chapter 6 and 7, that the rear bedroom remains unoccupied. Besides, cooling is only supplied in the living room and the main bedroom through split-type air conditioners and is restricted to the availability of power from the national grid. Meanwhile, heating is only provided in the living room. Both cooling and heating schedules alongside their setpoint temperatures are set based on real data collected from the field works. Following the simulation process, indoor thermal conditions and cooling and heating consumption are assessed in each scenario.

In the second attempt, the third and fourth scenario alongside the base case are simulated. This time, some behavioural and technological interventions are taking place aiming to provide ideal indoor conditions by keeping the home at the right temperature during both cooling and heating seasons. First, the rear unoccupied bedroom, which is used as a storage area as a result of concerns over the cost of power bills, is turned into an occupied one for the housewife to sleep there overnight instead of sleeping in the living room. Second, cooling/ heating is supplied in all the habitable rooms, i.e. the living room and both bedrooms, during the occupied hours (i.e. 8 am to 11 pm and 11 pm to 8 am for the living room and bedrooms respectively). This is without being affected by the power cuts that are experienced with the national grid. Moreover, cooling and heating setpoint temperatures are set to meet CIBSE static criteria, the criteria that align with what the BCR generally recommends. The former is set at 24 °C for both the living room and bedrooms, while the latter is set at 22 °C and 19 °C for the living room and bedrooms respectively. In realistic terms, such cooling setpoint temperatures might be considered low and energy-intensive. But for the purpose of this hypothetical investigation, they are used to simulate the implications of aiming for such comfort criteria and complying with the BCR recommendations. This is despite the fact that aiming for a higher temperature, e.g. 26 °C, would lead to achieving more savings. The kitchen and corridor are also provided with some sort of cooling and heating through setting setback temperatures allowing them to avoid temperatures above 28 °C and below 15 °C during the occupied hours. It is worth mentioning that such changes will understandably lead to an increase in annual heating and cooling consumption while also improving indoor thermal conditions.

8.4.2 Simulation results – the model under physical interventions

The findings demonstrate clearly how significant the physical interventions can be in reducing cooling and heating demand and improving indoor thermal conditions, particularly when the entire building fabric is upgraded. The next sub-sections present the simulated results of each scenario.

8.4.2.1 Scenario 1

In the first scenario, for instance, shading the rooftop with a wooden gazebo led to a 1.3 and 2 K reduction in the mean indoor temperature of the partly conditioned spaces, i.e. the living room and main bedroom, and the unconditioned areas, e.g. the kitchen and corridor, respectively over the cooling season (see Fig. 8.4). This is besides a 1433 kWh reduction in the annual cooling energy use, which is equivalent to a 17 kWh/m^2.yr reduction in the total energy consumption (see Fig. 8.5).

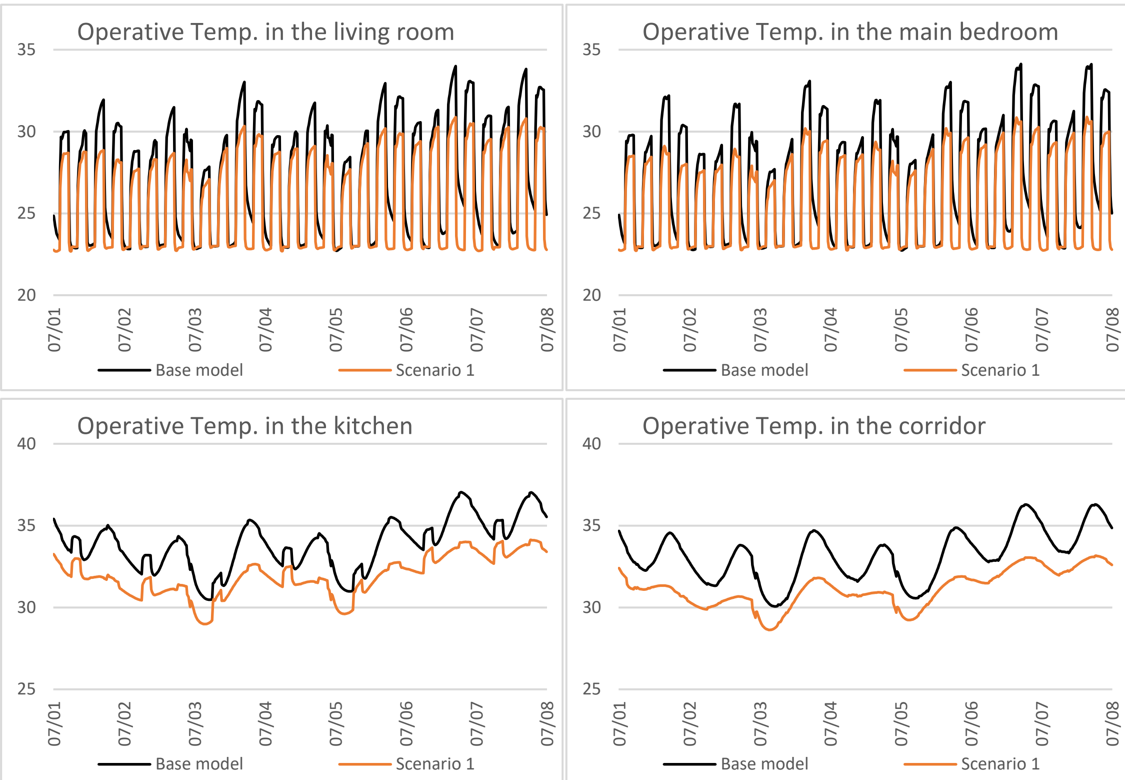


Figure 8.85 The impact of roof covering on indoor operative temperature across different spaces (author)

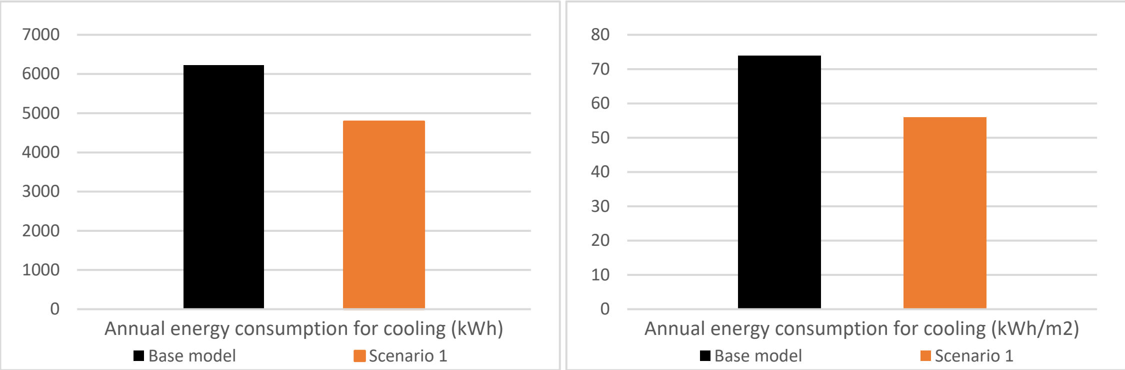


Figure 8.86 The impact of roof covering on the annual cooling energy use (author)

8.4.2.2 Scenario 2

In the second scenario, meanwhile, the drop in the mean operative temperature during summertime reached 1.5 K and 2.2 K across the partly conditioned and unconditioned spaces respectively (see Fig. 8.6), whilst annual cooling energy use fell by 2015 kWh. This is equivalent to a 24 kWh/m^2.yr reduction in the total energy consumption (see Fig. 8.7). By comparing such figures with those of the first scenario, one could argue that the replacement of window openings did not significantly contribute in improving the house performance during summertime since the differences are quite humble. However, what makes this scenario superior to the previous one was also its relative contribution in improving the performance over wintertime where a 284 kWh reduction in annual heating energy use was accomplished with an insignificant impact on indoor temperatures.

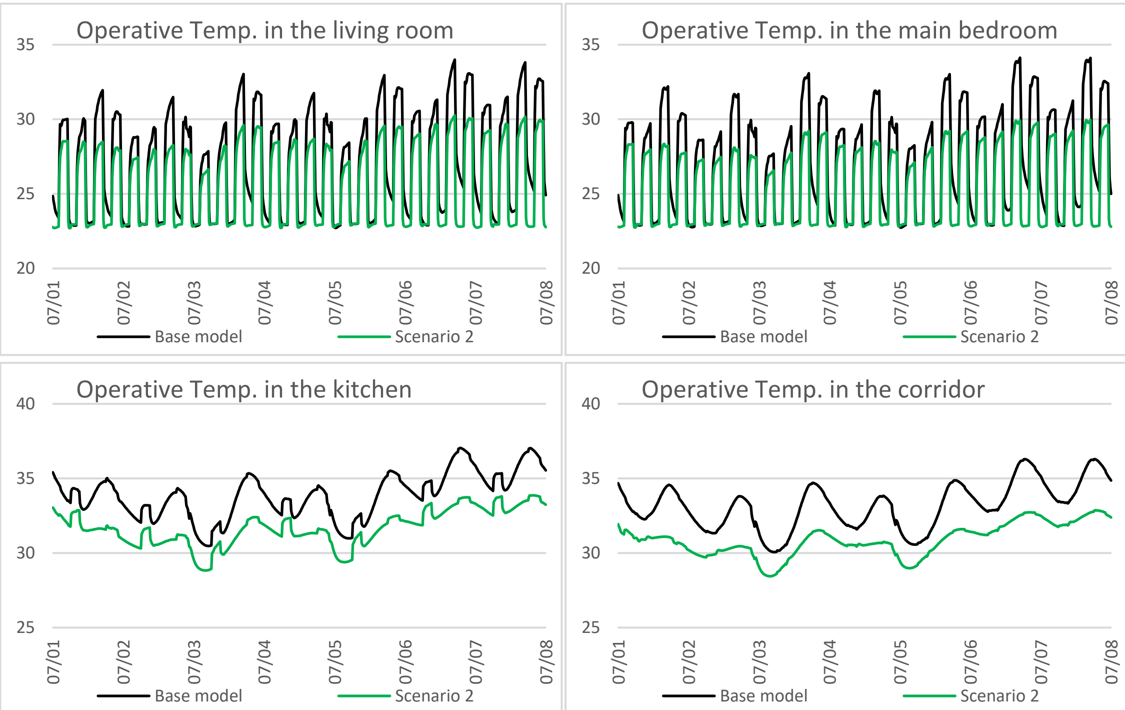


Figure 8.87 The impact of windows replacement alongside roof covering on indoor operative temperature across different spaces during summertime (author)

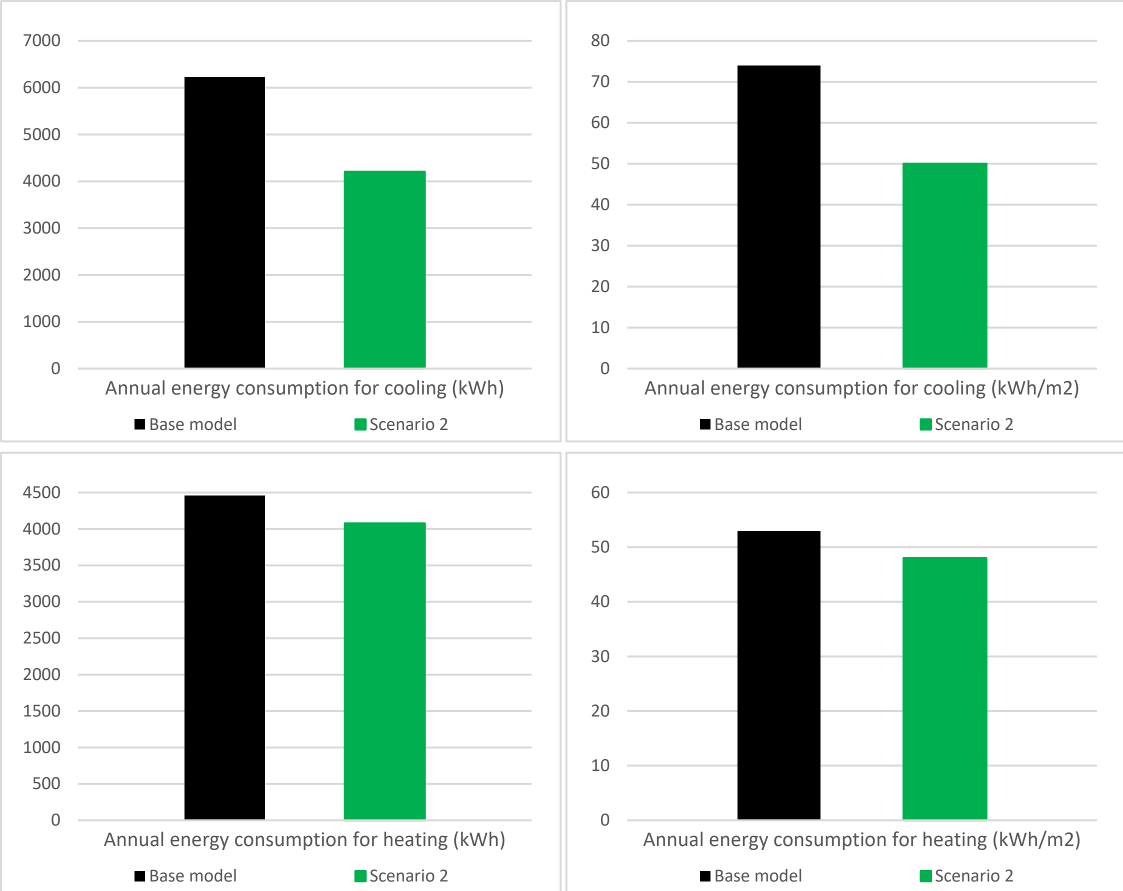


Figure 8.88 The impact of physical interventions proposed in Scenario 2 on annual cooling and heating energy use (author)

8.4.2.3 Scenario 3

Moving to the simulated data of the third scenario, upgrading the entire building fabric based upon the physical interventions described earlier was found to be far more effective. It gave rise to remarkable improvements in the overall energy and thermal performance of the house. During the cooling season, for example, cooler indoor thermal conditions throughout both the free-running and partly conditioned spaces are evident (see Fig. 8.8). The results show a 5 to 6 K reduction in the average maximum temperature compared to the one of the base model. Despite being partially air-conditioned for the reasons mentioned earlier, both habitable rooms (i.e. the living room and main bedroom) appeared to meet both 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria, with no indoor operative temperatures in excess of 28 °C. On average, the temperature swing in both rooms remained within the range of 3.0-3.5 K, something that clearly emphasises the impact of the proposed building fabric upgrade in delaying the heat transfer. Despite all such better indoor conditions, the annual cooling energy consumption dropped significantly by approximately 64% (from 6221 kWh to 2294 kWh) as shown in figure 8.9. This is equivalent to a 45 kWh/m^2.yr reduction in the total energy consumption. However, the contribution made does not stop there.

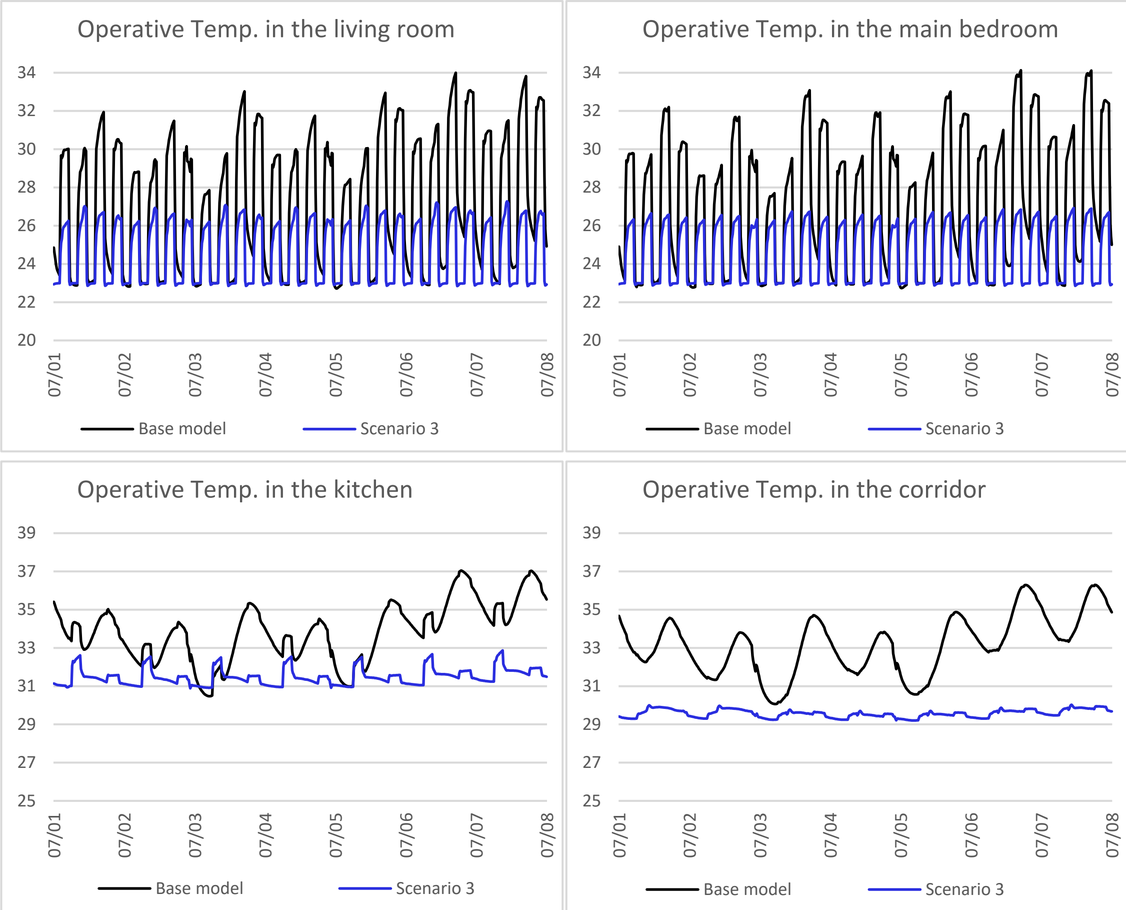


Figure 8.89 The impact of physical interventions proposed in Scenario 3 on indoor operative temperature across different spaces during summertime (author)

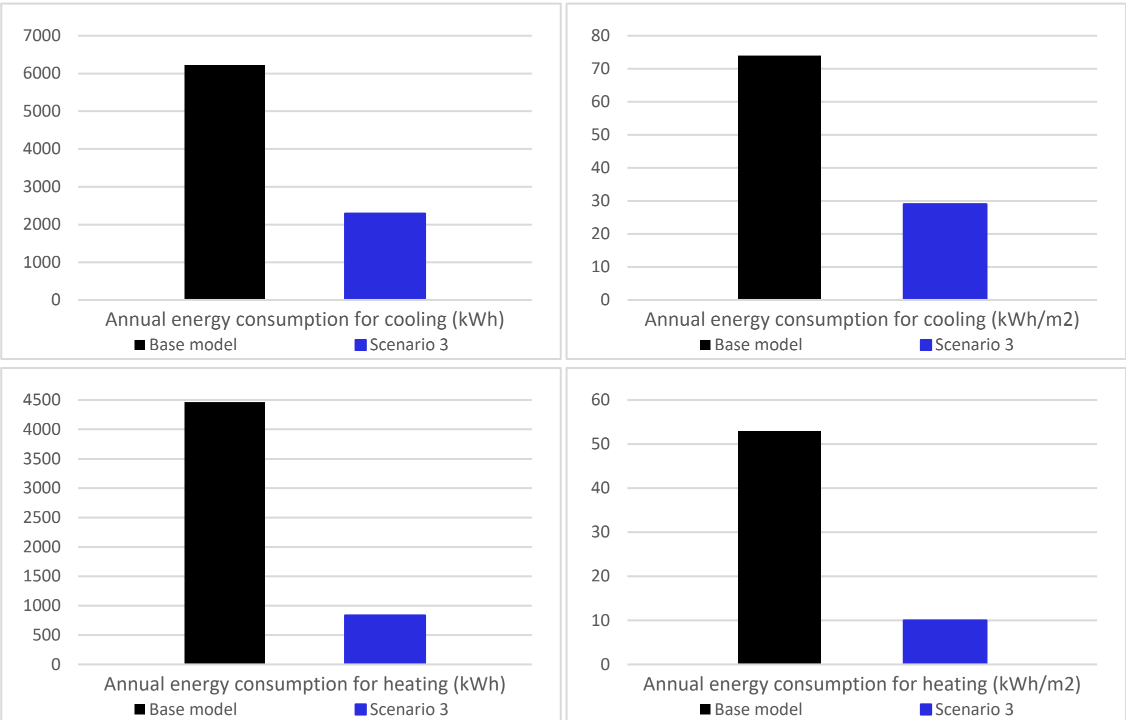


Figure 8.90 The impact of the entire building envelop upgrade proposed in Scenario 3 on annual cooling and heating energy use (author)

During the heating season, warmer indoor conditions were found across the house with the average minimum temperature being 6 to 7 K higher than the one of the base model. This is not only in the living room, which is the only space that is heated, but also in areas with no heating supply, e.g. the main bedroom and corridor, where the mean operative temperature remained above 16 °C (see Fig. 8.10). The temperature swing remained within the range of 3-3.5 K and 0.5-1.0 K in the heated and unheated areas respectively. And on top of that, the amount of energy required for heating dropped by 82% (from 4462 kWh to 833 kWh), a figure that is equivalent to a 43 kWh/m^2.yr reduction in the total energy consumption. In total, with the physical interventions introduced in this scenario, the potential energy saving in this residential unit is predicted to reach up to 7556 kWh per year, which is equivalent to a reduction of 4.9 tonnes of CO2 emissions if one considers kerosene as the main heating fuel.

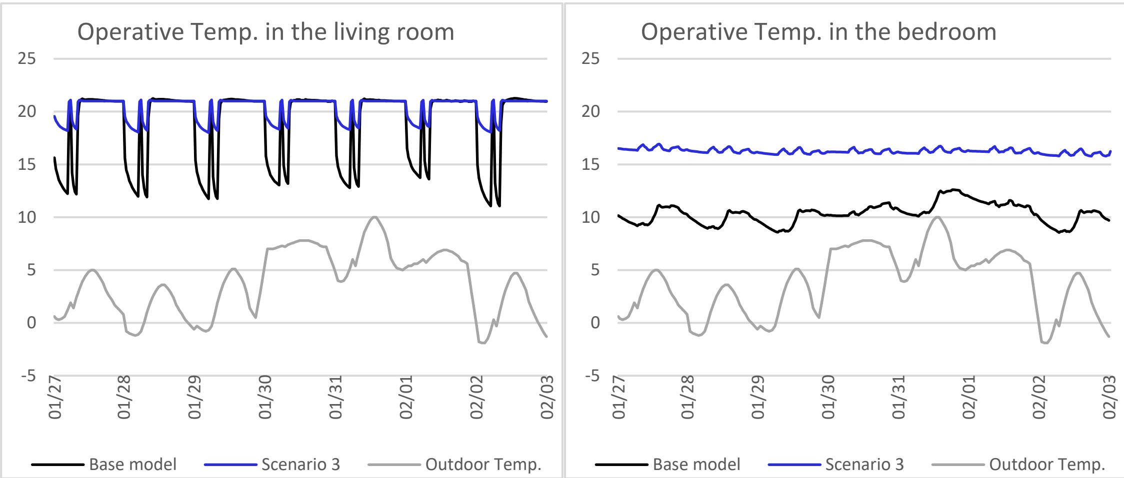


Figure 8.91 The impact of physical interventions proposed in Scenario 3 on indoor operative temperature across different spaces during wintertime (author)

8.4.2.4 Scenario 4

In the fourth scenario where the selected fabric interventions are based on Passivhaus fabric requirements, the overall performance was predicted to be even better. Although the indoor thermal conditions over the cooling season appeared to be very close to those of the previous scenario where almost a 5.0-6.0 K reduction in the average maximum temperature was recorded, the annual energy consumption for cooling continued to fall. With the same operation schedules of AC units, interestingly, the model needed only 1685 kWh, a figure that is equivalent to 27% of the amount required in the case base model (see Fig. 8.12). In addition, the temperature swings that occur due to the AC units being run intermittently in the living room and main bedroom were found to be slightly smaller than those of the previous scenario, being within the range of 2.5-3.0 K (see Fig. 8.11). Similar to the previous scenario, indoor thermal comfort across both the intermittently air-conditioned rooms was evident. Both spaces met the 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria, with no indoor operative temperatures in excess of 28 °C.

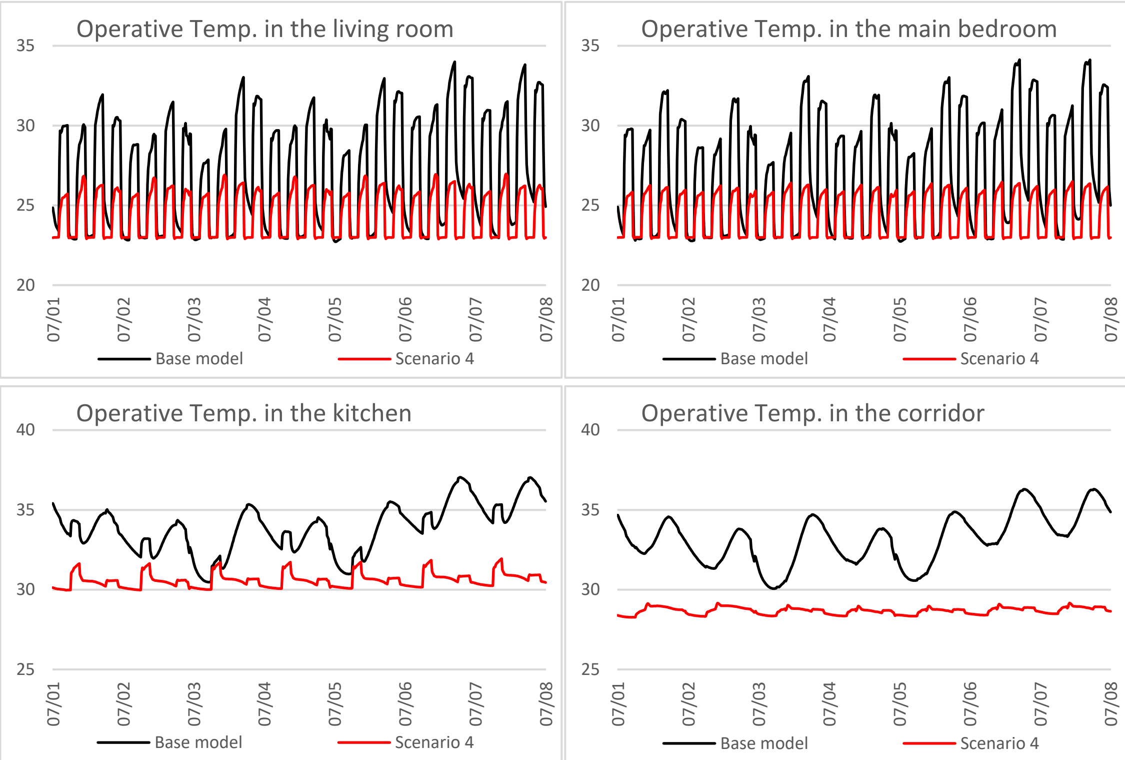


Figure 8.92 The impact of physical interventions proposed in Scenario 4 on indoor operative temperature across different spaces during summertime (author)

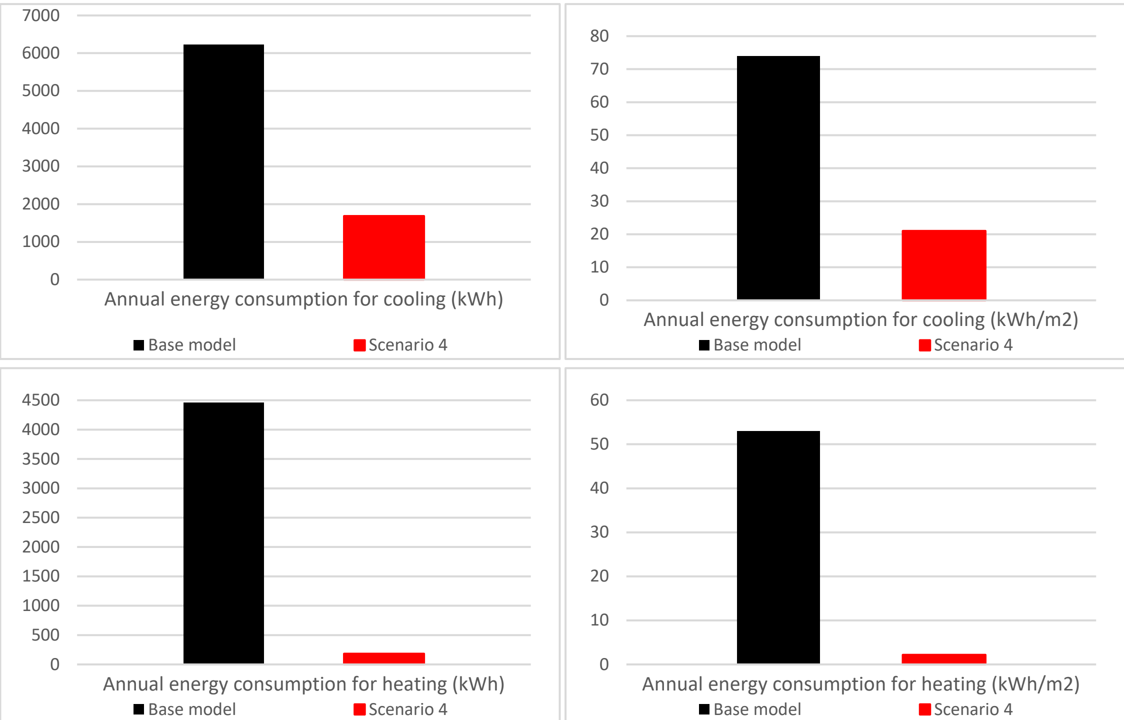


Figure 8.93 The impact of the entire building envelop upgrade proposed in Scenario 4 on annual cooling and heating energy use (author)

The measures applied in this scenario continued in enhancing the performance even during the heating season. Their contribution in providing comfortable thermal conditions can be clearly noted especially in areas that had no access to heating, e.g. the main bedroom and corridor, where the mean daily temperature remained within the range of 18 to 19 °C and 21 to 22 °C respectively. Also in the living room when heating was turned off during sleeping hours, indoor operative temperatures remained around 20 °C, which is just one degree lower than what was normally there when heating was supplied (see Fig. 8.13). And despite all these extraordinary outcomes, an enormous drop in the annual heating energy use was found where the house needed just 182 kWh for the entire heating season to provide such comfortable indoor conditions (see Fig. 8.12). And this is equivalent to 4% of the consumption shown by the case base model, i.e. 4462 kWh. Overall, with the fabric interventions introduced in this scenario, based on these simulated data, the house would require 23 kWh/m^2.yr for both cooling and heating, achieving savings of 8816 kWh per year. This is equivalent to a 5.9 tonnes reduction in CO_2 emissions if one considers that the household would entirely rely on kerosene for heating rather than electricity. If not, the reduction would be even greater.

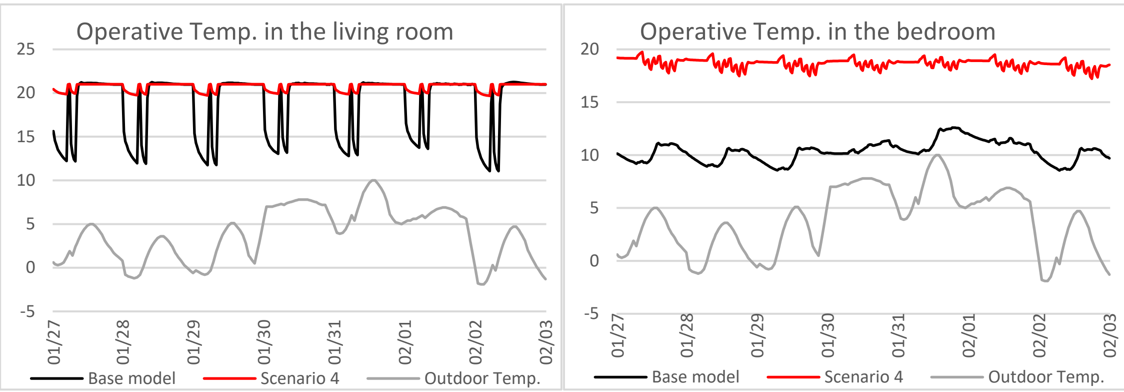


Figure 8.94 The impact of physical interventions proposed in Scenario 4 on indoor operative temperature across different spaces during wintertime (author)

Figure 8.14 and 8.15 alongside table 8.6 bring the outcome of all the scenarios together and illustrate the potential influence that each one of them can have on the energy and thermal performance of this residential unit. It is clear that the fourth scenario followed by the third one resulted in the highest improvement in thermal comfort levels and the highest reduction in energy consumption, carbon dioxide (CO2) emissions, and of course energy bills. This is thanks to the strictly controlled airflow and solar gains, high level of insulation throughout the fabric, and quality windows. In terms of space heating and cooling demand, the former scenario as indicated earlier needed almost 23 kWh/m^2.yr, a figure that completely complies with Passivhaus standard that allows consuming up to 30 kWh/m^2.yr for cooling and heating together. Meanwhile, the latter scenario exceeded the allowed limit by almost nine kWh/m^2.yr, yet it still met the EnerPHit standard, which allows retrofitted buildings to perform at a slightly lower level of energy efficiency due to the more complicated nature of such buildings compared to the new build ones.

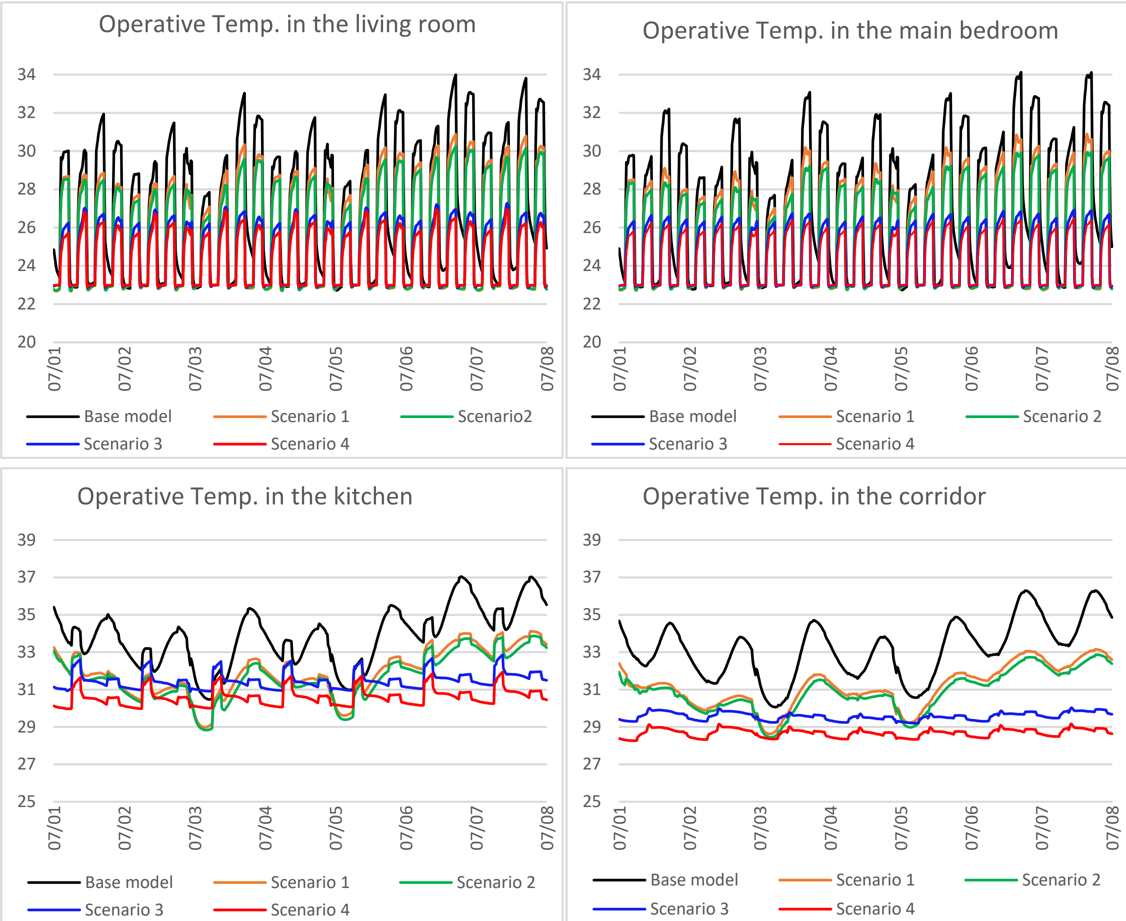


Figure 8.95 The impact of physical interventions proposed in all modelling scenarios on indoor operative temperature across different spaces during summertime (author)

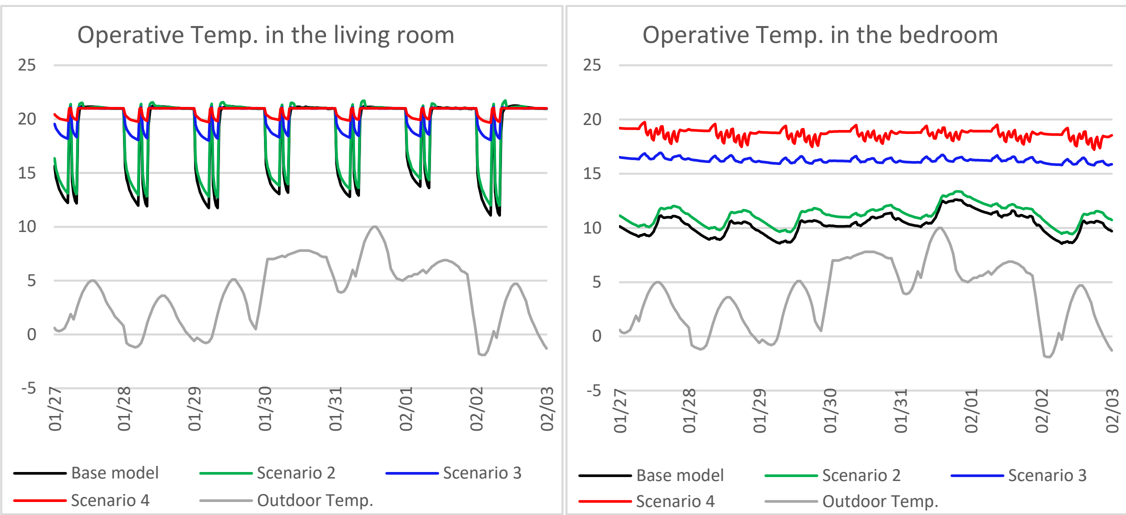


Figure 8.96 The impact of physical interventions proposed in all modelling scenarios on indoor operative temperature across different spaces during wintertime (author)

Table 8.19 The simulated heating and cooling energy use of all the scenarios compared to the case base model (Note: kerosene is considered as the main heating fuel in the calculations of heating costs and the related carbon footprint)

	Heating Consumption (END USE)			Heating Consumption (per m2)			Cooling Consumption (END USE)			Cooling Consumption (per m2)			Total heating/cooling Consumption (END USE)			Total heating/cooling Consumption (per m2)		
	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO2	USD	kWh	kg CO2	USD
Base model	4462	1160	260	53	13.8	3.1	6221	5105	1555	74	60.7	18.5	10683	6265	1815	127	74.5	21.6
Scenario 1	4462	1160	260	53	13.8	3.1	4788	3929	1197	56	46	14	9250	5089	1457	109	59.8	17.1
Scenario 2	4078	1060	238	48	12.5	2.8	4206	3451	1052	50	41	12.5	8284	4511	1290	98	53.5	15.3
Scenario 3	833	217	48	10	2.6	0.6	2294	1882	573	29.3	24	7.3	3127	2099	621	39.3	26.6	7.9
Scenario 4	182	47.32	10.5	2.2	0.6	0.13	1685	1383	345	22	18	5.5	1867	1430	355.5	24.4	18.6	5.6

Despite meeting those standards in terms of energy use, it is worth noting that in both scenarios, i.e. 3 and 4, the entire house was not fully granted comfortable indoor temperatures. There were some indications of thermal discomfort mostly during the cooling season, especially in the free-running areas such as the kitchen and rear bedroom that was left unoccupied all the time. Introducing some behavioural and technological interventions that aim to provide ideal indoor thermal conditions was therefore necessary. This is to find out how far the heating and cooling energy use could exceed the allowed limits in the case base model as well as the best two scenarios if thermal discomfort is to be avoided across the entire home during the occupied hours. The changes as indicated earlier included providing all the habitable rooms (including the rear bedroom) with heating/cooling during occupied hours at a level that meets CIBSE static criteria. This is besides avoiding temperatures above 28 °C and below 15 °C in the kitchen and corridor. This is something that one should bear in mind as such building efficiency upgrades would likely raise the household's comfort expectations. The results are presented in the next section.

8.4.3 Simulation results – the model under physical, behavioural and technological interventions

Maintaining comfortable temperatures across the house during both cooling and heating seasons led to a dramatic increase in the energy consumption in the case base model, recording an increase of 8900 kWh in the total energy consumption (see Table 8.7). This is equivalent to an increase of 4.5 tonnes of CO_2 emissions. The annual heating energy use increased by approximately 110% (from 53 kWh/m^2.yr to 111 kWh/m^2.yr), and the expected increase in the annual cooling energy use was found to be around 64% (from 74 kWh/m^2.yr to 121 kWh/m^2.yr).

Such increases in space heating and cooling energy use would very likely require the family to spend around $3100 on energy to stay thermally comfortable throughout the year. And this is something that is beyond their means as this amount of money represents almost 74% of their annual income (regardless of the donations they occasionally receive).

Table 8.20 The predicted heating and cooling energy use of the third and fourth scenario and the case base model when comfortable temperatures are maintained all year round across the house (author)

	Heating Consumption (END USE)			Heating Consumption (per m2)			Cooling Consumption (END USE)			Cooling Consumption (per m2)			Total heating/cooling Consumption (END USE)			Total heating/cooling Consumption (per m2)		
	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO2	USD	kWh	kg CO2	USD
Base model	9369	2436	543	111	28.9	6.4	10210	8378	2553	121	99	30.3	19579	10814	3096	232	128	36.7
Scenario 3	1317	342	76	16.8	4.4	1	2651	2175	662	33.8	27.7	8.5	3968	2517	738	50.6	32.1	9.5
Scenario 4	266	69	15	3.5	0.9	0.2	2050	1682	512	27	22.2	6.8	2316	1751	527	30.5	23.1	7

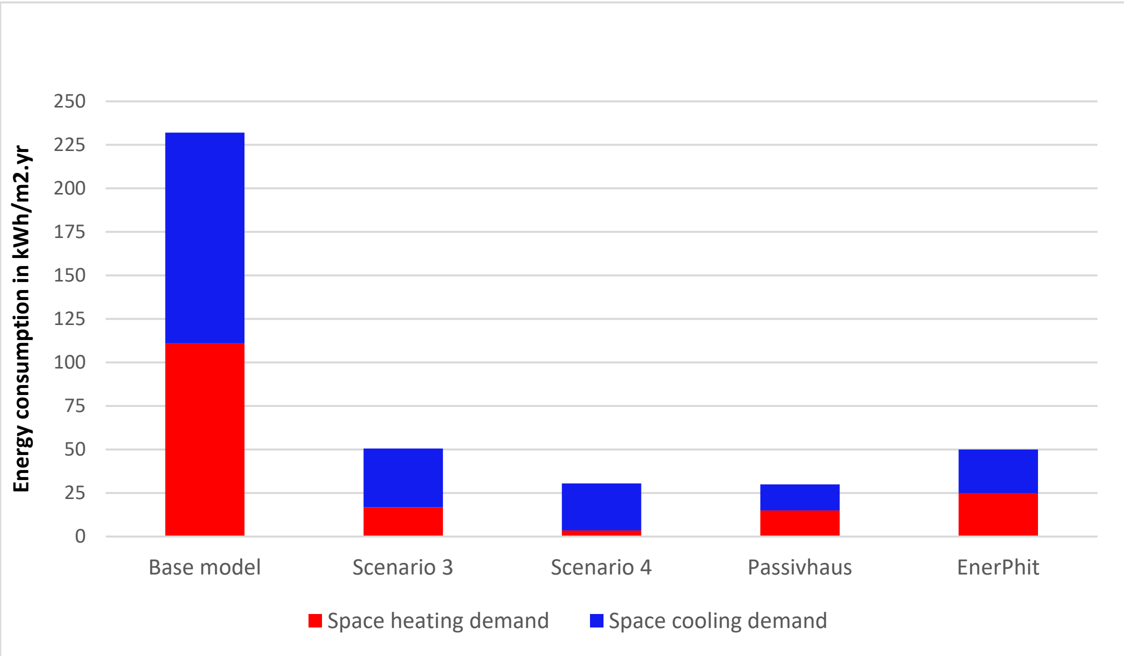


Figure 8.97 The predicted heating and cooling energy use of the third and fourth scenario and the case base model compared to Passivhaus and EnerPHit standards (note: comfortable temperatures are maintained all year round within the predictions)

On the other hand, the results that emerged from the fourth and third scenario were significantly lower, underlining the increased efficiency and effectiveness of their proposed building envelopes. Interestingly, the former scenario showed the lowest increase in the total energy, requiring just an extra 449 kWh (i.e. 6 kWh/m^2.yr). This means that in total the house with Passivhaus-based fabric interventions will just need 2316 kWh (i.e. 30.5 kWh/m^2.yr) to maintain comfortable temperatures all year round. This is equivalent to 12% of the expected amount required for the case base model (i.e. 232 kWh/m^2.yr), and it is just 0.5 kWh/m^2.yr above the allowed limit by Passivhaus standard (see Fig. 8.16). Among those 2316 kilowatt-hours, only 266 kWh (i.e. 3.5 kWh/m^2.yr) were used for heating throughout a year, an amount that will annually cost the family somewhere around $15 if kerosene is to be used as the heating fuel. This means that with this Passivhaus-based scenario the household would no longer need to go through all the difficulties that they experience over the winter period to cope with the harsh indoor thermal conditions. With no doubt, such a highly efficient performance is mainly attributed to the high levels of insulation and airtightness applied across the building envelop as well as the use of highly efficient window openings.

With the third scenario, meanwhile, the increase in the total energy consumption was relatively higher reaching up to 841 kWh (i.e. 11 kWh/m^2.yr). And this is understandable given the efficiency differences of the physical interventions of both scenarios. The stringent Passivhaus standard could not be achieved with this scenario, but still the resulting consumption was significant. It was indeed very close to meeting the EnerPHit standard, a slightly relaxed standard allowing consumption of up to 50 kWh/m^2.yr for cooling and heating together. In total, the house needed 3968 kWh (i.e. 50.6 kWh/m^2.yr) to maintain comfortable temperatures all year round, an amount that accounts for one-fifth of the expected amount required for the case base model. From this amount, one third which is 1317 kWh (i.e. 17 kWh/m^2.yr) was used for heating throughout a year, costing the family somewhere around $76 if they rely on kerosene. Similar to the Passivhaus fabric-based scenario, one could argue that with this scenario the family would no longer need to go through all the difficulties that they experience over the winter period to cope with the harsh indoor thermal conditions.

8.5 Case study 4

8.5.1 Modelling scenarios

Following the validation process, as with the previous case study, three upgrading scenarios were examined for case study 4 which took into account the different socio-economic context the case study has. In the first scenario, the researcher replaces the pitched corrugated steel roof. This is an element that receives sunrays during the day, leads the attic to be a heat trap, and increases the heat gains which in turn cause an unfortunate impact on indoor thermal conditions, mainly in the first-floor rooms. Inspired by western architecture, in fact, this imported building element has been increasingly adopted in recent years as an aesthetic element all over the region, especially in the newly built housing estates. It is placed right above the flat roof almost like a hat to give a house a sort of western identity. This is without considering the potential contribution that such an element makes in raising the indoor temperatures and increasing the cooling loads that in turn lead to high electricity bills and CO2 emissions. Bearing in mind the aesthetic reasons for using such an element in the English village where the case study is located, instead, the researcher proposes a pitched roof pergola. This is to shade the concrete flat roof, allow better airflow and avoid heat being trapped above it while giving the building a similar visual appeal to that of the corrugated gable roof (see Fig. 8.17). With such a physical intervention, most likely, the household will no longer need to run evaporative air cooler the whole day to mitigate the impact of heat trapping. Despite the family's wealth enabling them to afford more complicated and advanced energy efficiency improvements, this upgrading scenario is mainly developed to evaluate how far the corrugated roof influences the building's thermal and energy performance during the cooling season. For this, changes are made to the case base model in DesignBuilder for simulation and assessment. As with the previous case study, the author is not expecting this scenario to have a notable impact during the heating season.

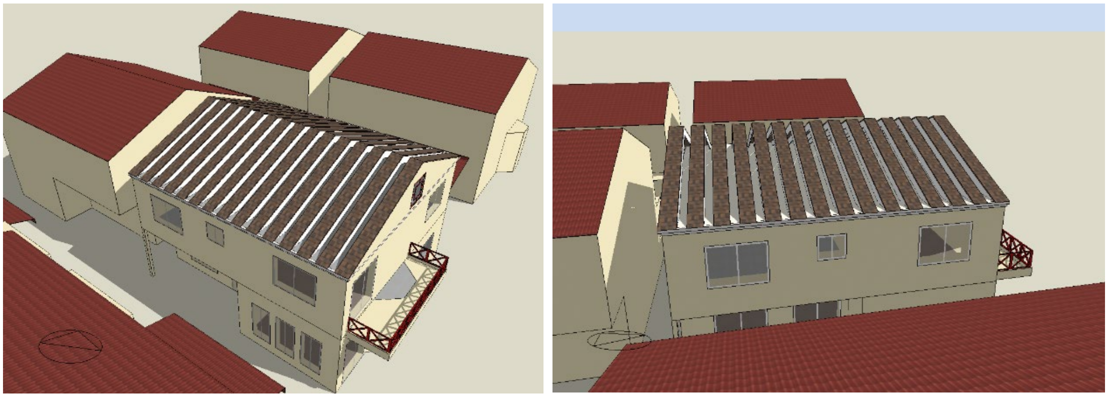


Figure 8.98 Showing the proposed gabled roof (author)

Moving to the second scenario, as with the third scenario of the previous case study, emphasis is placed on the entire building envelope using locally available construction materials, components and techniques. Besides the replacement of the pitched corrugated steel roof, notable reductions in the U-value of the window openings, exterior doors and walls, floor, and roof are applied. The existing double-pane window openings are replaced with low-E argon-filled ones resulting in a 1.1 $W/m^2.K$ reduction in their U-value (i.e. from 2.6 $W/m^2.K$ to 1.5 $W/m^2.K$). Bearing in mind thermal bridging, moreover, a 50 mm thick straw-based insulation board and a layer of compressed earth-based bricks are added to the external brick walls leading to a 1.15 $W/m^2.K$ reduction in their U-value (i.e. from 1.5 $W/m^2.K$ to 0.35 $W/m^2.K$). Due to the village's rules with regard to changes affecting the external appearance of the houses, the limestone cladding should stay in place, something that would technically cause some difficulties in reality while upgrading the walls. Furthermore, the U-value of the flat roof is reduced from 2 $W/m^2.K$ to 0.28 $W/m^2.K$ through using a certain roof construction type. It is composed of: a suspended ceiling as an innermost layer, air gap, 50 mm thick straw-based insulation board, the existing 200 mm thick concrete slab, vapour control layer, 50 mm thick straw-based insulation board, 50 mm thick screed, and a waterproofing layer as an outermost layer. On top of that, the pitched roof pergola comes to shade the flat roof. Insulation upgrades are also applied to the floor in contact with the ground causing a 1.9 W/m^2.K reduction in its U-value (i.e. from 2.4 W/m^2.K to 0.5 W/m^2.K). It is noteworthy that all these targeted figures are in line with what is recommended by the Building Control Regime developed by UNDP-Iraq. These changes are applied to the case base model in DesignBuilder where assessments are carried out.

Aiming to meet the Passivhaus requirements in the third scenario, as with the fourth scenario of the previous case study, the building fabric is upgraded further. Attention is given to the quality of windows, insulation, and airtightness along with keeping the pitched roof pergola in place. The U-value of all the fabric elements including exterior doors, windows, walls, roof and floor are significantly reduced to a level lower than what is allowed by the PH standard. Starting with the window openings, triple glazed and argon filled ones that normally come with a U-value lower than 0.8 W/m^2.K are used. As these windows are commercially available in the capital Erbil where the English village is located, transportation fees will not be an issue for this case. Moreover, the U-value of the external walls, roof, and floor in contact with the ground is reduced to 0.12, 0.13, 0.13 W/m^2.K respectively. These values are achieved using the same construction layers applied in the previous scenario with only one change concerning the thickness of straw-based insulation layer. Instead of the 50 mm thick insulation layer applied in the previous scenario, a 250 mm thick one is used for the walls and floor and two 120 mm thick layers are used for the roof. Apart from increasing the level of insulation across the building envelope, emphasis is also placed on the level of airtightness. The model's air infiltration rate at 50 Pa in DesignBuilder is set to 0.6 air changes per hour, a figure that needs to be achieved in PH buildings. Table 8.8 shows briefly the differences between the three upgrading scenarios.

Table 8.21 The differences between the upgrading scenarios (author)

Upgrading scenarios	Roof covering	Ext windows U-value	Ext. walls U-value	Roof U-value
Base model	Y (pitched metal roof)	2.6 W/m^2.K	1.5 W/m^2.K	2 W/m^2.K
Scenario 1	Y (wooden roof pergola)	2.6 W/m^2.K	1.5 W/m^2.K	2 W/m^2.K
Scenario 2	Y (wooden roof pergola)	1.5 W/m^2.K	0.35 W/m^2.K	0.28 W/m^2.K
Scenario 3	Y (wooden roof pergola)	0.78 W/m^2.K	0.12 W/m^2.K	0.13 W/m^2.K

All these scenarios are simulated individually along with the case base model to see how effective they are in reducing heating/cooling loads and providing indoor thermal comfort. In this case study, unlike the previous one, no heating and/or cooling equipment are added to the habitable rooms as they are all originally fitted with air-conditioning units. And as the family's economic status enables them to operate the units and keep the home at the right temperature, only one set of simulations is undertaken considering all the scenarios as well as the case base model to be providing ideal indoor conditions during the occupied hours. These are Saturday to Thursday (9 am to 3 pm, 5 pm to 11 pm) and (3 pm to 5 pm, 11 pm to 8 am) for the living room and bedrooms respectively. During these hours, accordingly, the same cooling and heating setpoint temperatures are used in all different scenarios in a way that meets CIBSE static criteria. The former is set at 24 °C for both the living room and bedrooms, while the latter is set at 22 °C and 20 °C for the living room and bedrooms respectively. The kitchen and corridor are also provided with cooling and heating through setting setback temperatures allowing them to avoid temperatures above 28 °C and below 15 °C during the occupied hours. It is worth mentioning that three out of four bedrooms on the first floor are unoccupied and thereby are not included in the calculations and total floor area.

8.5.2 Simulation results

The next sub-sections show the predicted impact of each upgrading scenario on the performance of the house.

8.5.2.1 Scenario 1

Starting from the outcome of the first one, the contribution that replacing the pitched corrugated steel roof with the pergola one does to the optimisation of the building's performance appeared to be quite humble. As figure 8.18 illustrates, only a 0.5 to 0.7 K reduction in the summertime average maximum temperature of the upper floor's rooms was predicted. Although the annual cooling energy use dropped by 547 kWh, which is equivalent to 2.7 kWh/m^2.yr reduction in the total energy consumption, the amount of energy required for heating increased from 7305 kWh to 8250 kWh (see Fig. 8.19). Perhaps this indicates the role the corrugated steel roof and the air gap beneath play in lowering heat losses through the flat roof.

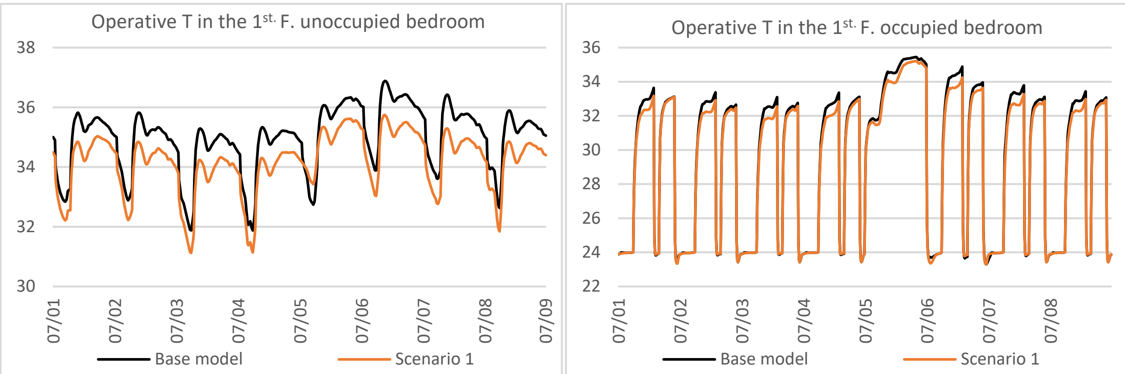
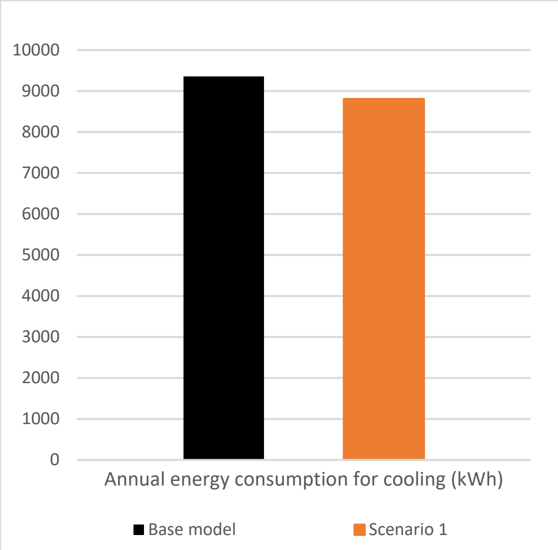


Figure 8.99 The impact of the intervention proposed in the first scenario on indoor operative temperature across upper floor's spaces during summertime (author)



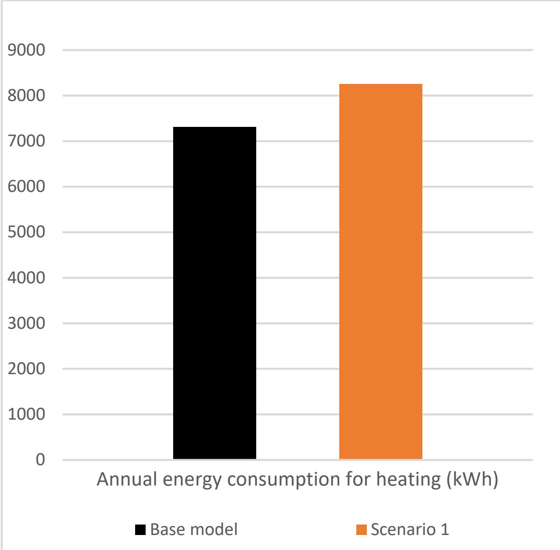


Figure 8.100 The impact of the intervention proposed in the first scenario on the annual cooling and heating energy use (author)

8.5.2.2 Scenario 2

The building efficiency in the second scenario where the entire building envelope was upgraded was found to have significantly improved using the same cooling and heating setpoint temperatures. This is evident from both energy-saving and thermal comfort perspectives. During the heating season as figure 8.20 illustrates, for example, the average minimum temperature was found to be 3 to 5 K higher than the one of the base model. The temperature swing remained within the range of 3 to 3.5 K in the habitable rooms where heating is available and 0.5 to 1.0 K in the kitchen and corridor where heating is only supplied when the operative temperature falls below 15 °C. And despite all of that, as figure 8.22 shows, the annual heating energy consumption fell considerably by approximately 78% (from 7305 kWh to 1615 kWh). This is equivalent to a 28 kWh/m^2.yr reduction in the total energy consumption.

Over the cooling season, a 4 to 5 K reduction in the average maximum temperature was noted in the upper floor spaces (see Fig. 8.21). In fact, the role of the proposed building fabric upgrade in delaying the heat transfer is unquestionable as on average the temperature swing remained within the range of 3-4 K. And despite that, the amount of energy required for cooling dropped by 47% (from 9354 kWh to 4982 kWh), a figure that is equivalent to a 20 kWh/m^2.yr reduction in the total energy consumption. In total, with the physical interventions introduced in this scenario, the potential energy saving in this house is predicted to reach up to 10062 kWh per year. This is equivalent to a reduction of approximately 5.1 tonnes of CO_2 emissions if one considers kerosene as the main heating fuel.

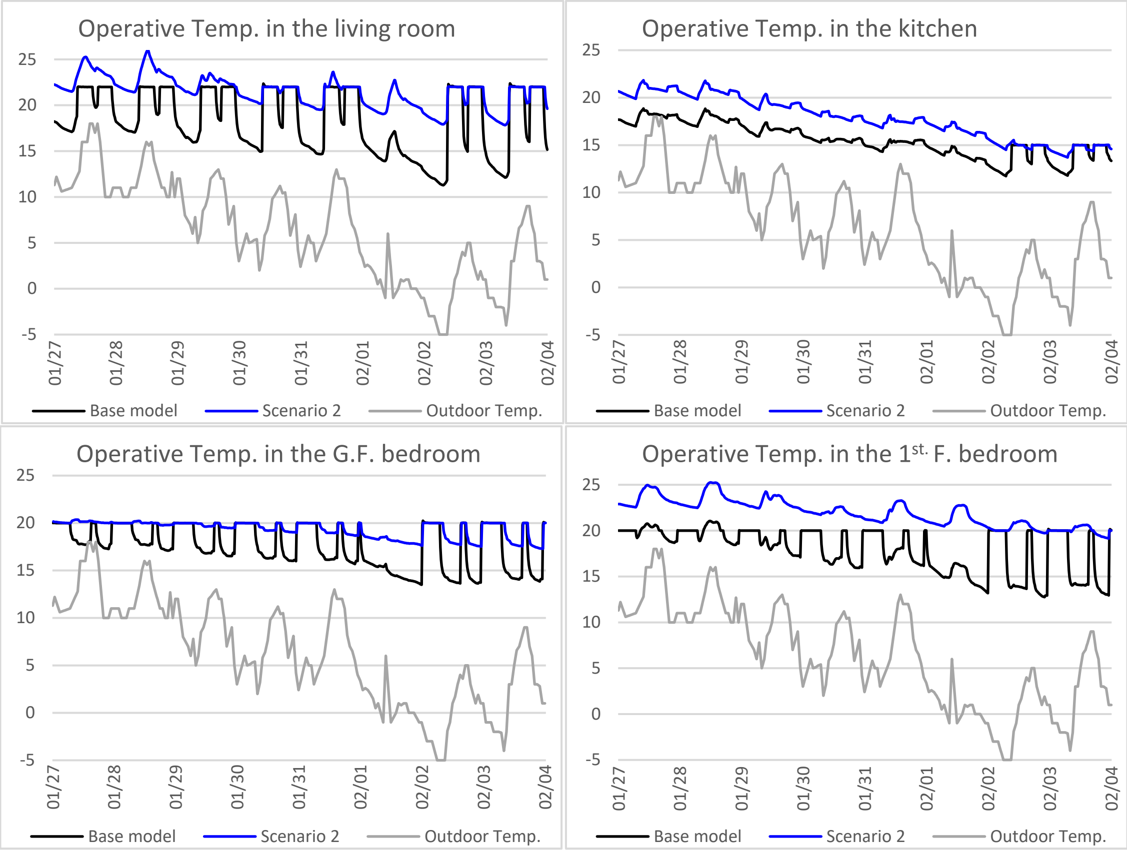


Figure 8.101 The impact of the physical interventions proposed in Scenario 2 on indoor operative temperature across different spaces during wintertime (author)

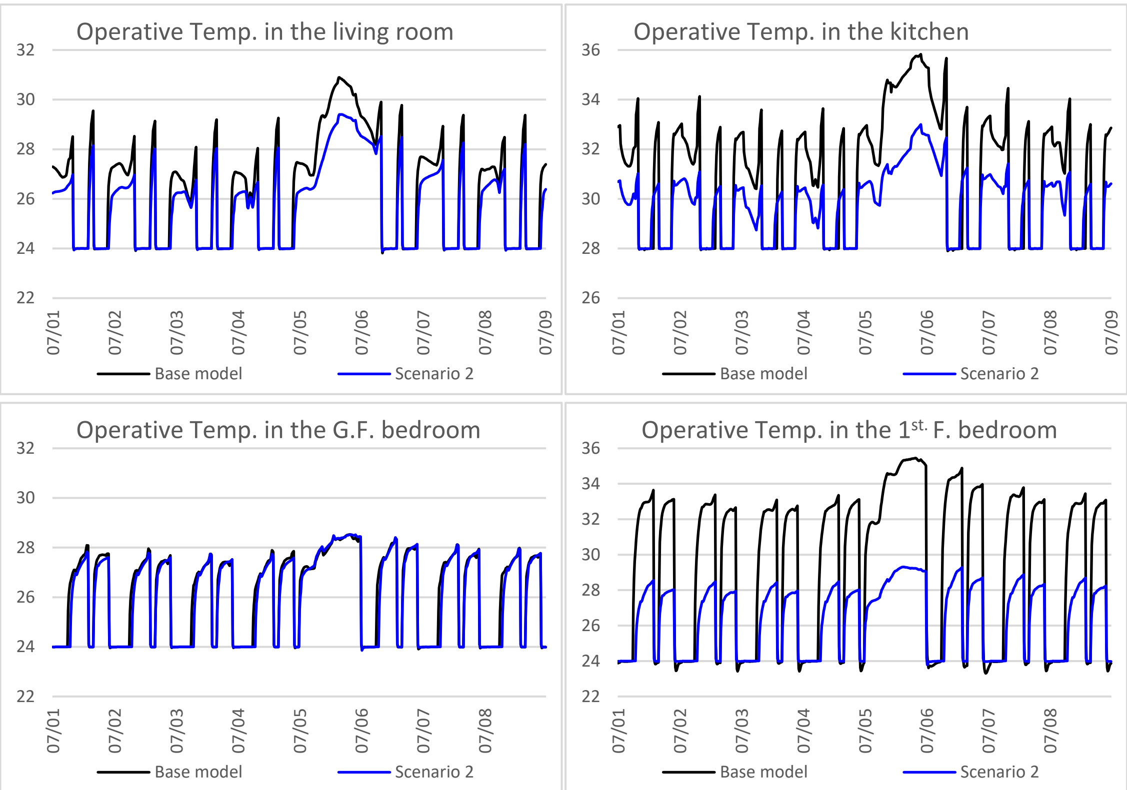


Figure 8.102 The impact of the physical interventions proposed in Scenario 2 on indoor operative temperature across different spaces during summertime (author)

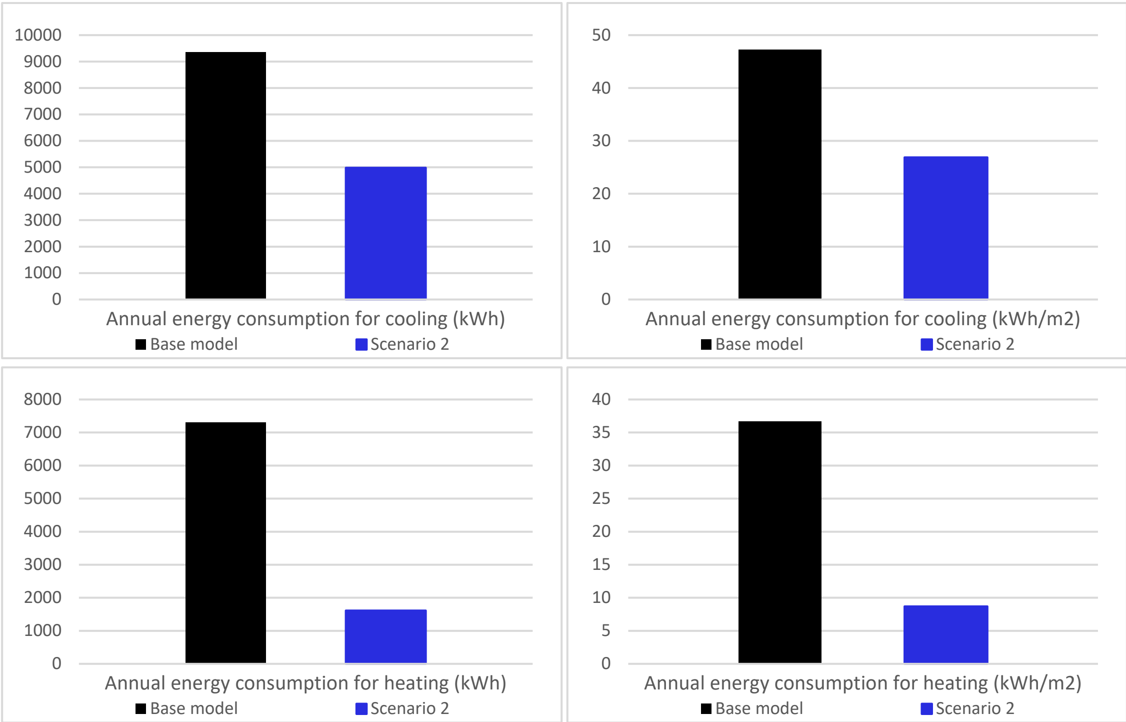


Figure 8.103 The impact of the physical interventions proposed in Scenario 2 on the annual cooling and heating energy use (author)

8.5.2.3 Scenario 3

Moving to the third and last scenario where the selected fabric interventions are based on Passivhaus requirements, the building efficiency was predicted to be even further increased. Starting with the cooling season, even though the simulated indoor operative temperatures appeared to be very close to those of the previous scenario with slightly smaller temperature swings (see Fig. 8.23), further reductions in annual cooling demand were expected. As figure 8.25 demonstrates, the amount required was found to be around 4322 kWh, which is about 46% of the cooling demand in the case base model. This is despite using the same cooling setpoint temperatures and operation schedules for the air conditioning. In addition, the measures applied in this scenario offered further improvements to the building performance. As shown in figure 8.25, the simulations predicted a significant drop in the heating demand showing that the dwelling would just need around 2.1 kWh/m^2.yr, and this equals 19% of the base model consumption. During the wintertime occupied hours, however, the results show a possibility for both the living room and upper floor bedroom to experience temperatures in excess of 25 °C (see Fig. 8.24), a fixed threshold that indoor operative temperatures of a Passivhaus building should not exceed for more than 10% of the occupied hours per year. These indoor thermal conditions are most likely driven by the high levels of airtightness and insulation that the building fabric provides. If such higher temperatures are to be avoided, the occupant would need to open the windows from time to time to let fresh air in and slightly cool down the indoor environment. If this were the case, then overall, the house would presumably need

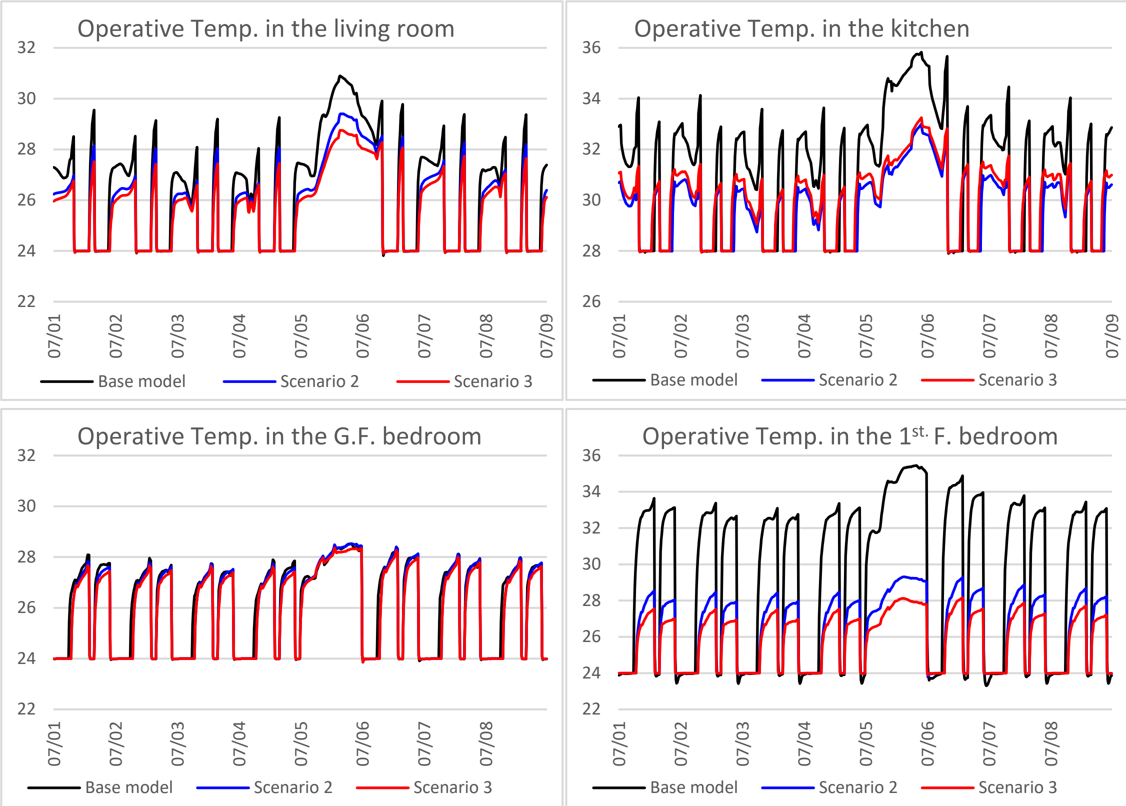


Figure 8.104 The impact of the physical interventions proposed in Scenario 3 on indoor operative temperature across different spaces during summertime (author)

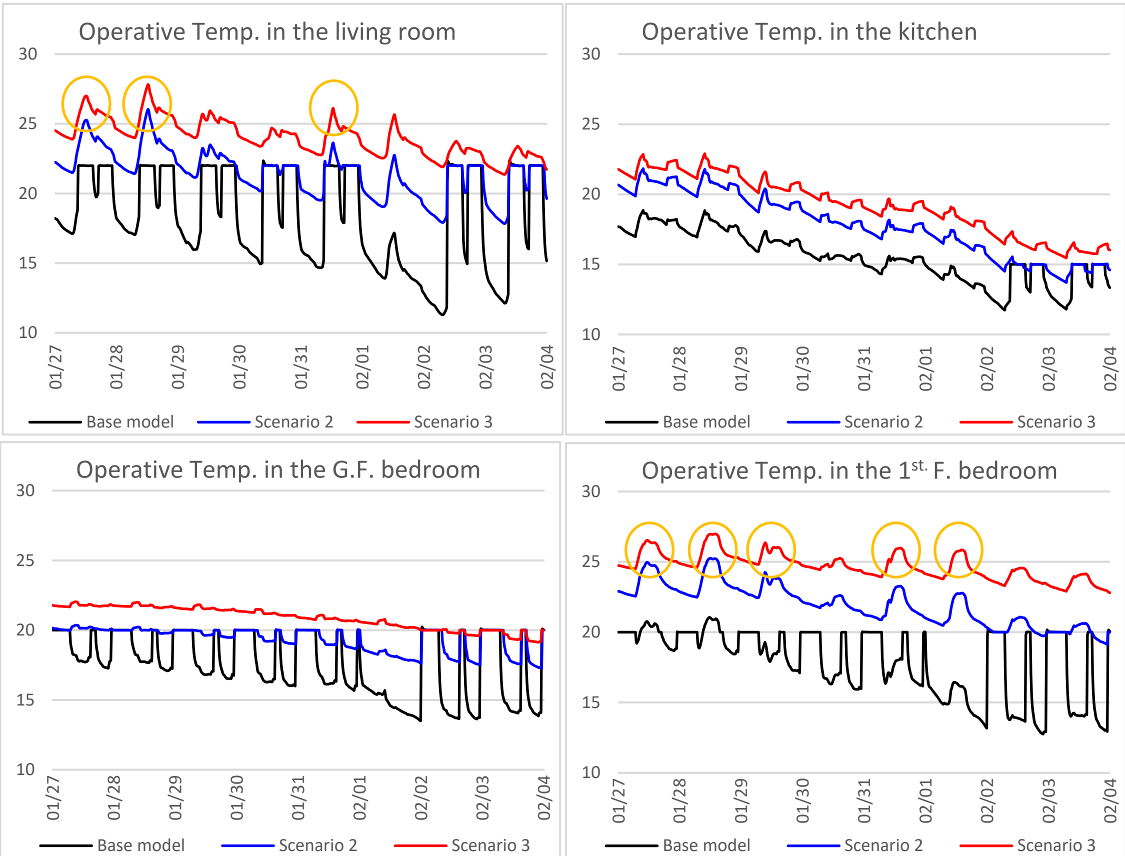


Figure 8.105 The impact of the physical interventions proposed in Scenario 3 on indoor operative temperature across different spaces during wintertime (author)

around 27 kWh/m^2.yr for both cooling and heating. However, if that was not the case and the occupants relied on air conditioning instead of opening windows to avoid temperatures in excess of 25 °C during wintertime occupied hours, the annual cooling energy use would likely increase from 4322 kWh to 5170 kWh (i.e. from 24.6 to 28.8 kWh/m^2.yr). Accordingly, the total annual energy use for both cooling and heating would jump to around 31 kWh/m^2.yr. In any case, however, the house with Passivhaus-based fabric interventions would save around 11-12 MWh. This in turn will reduce CO_2 emissions by 5.2 to 6 tonnes if one considers that the household would entirely rely on kerosene for heating rather than electricity.

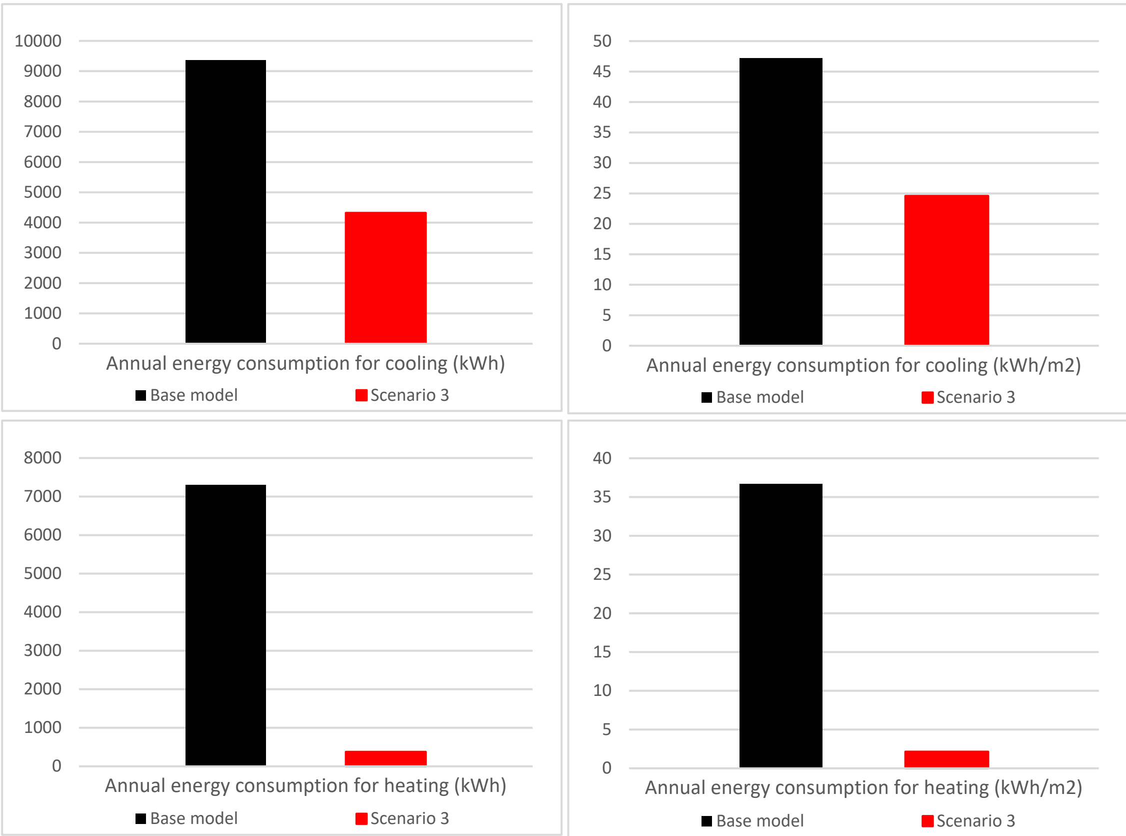


Figure 8.106 The impact of the physical interventions proposed in Scenario 3 on the annual cooling and heating energy use (author)

Table 8.9 presents the outcome of all those three upgrading scenarios together and shows the expected reductions that the house can achieve in space heating and cooling demand, carbon dioxide (CO2) emissions, and energy bills with the measures applied in each scenario. From the table, as with the previous case study, it is clear that the building fabric developed in the third scenario is the one leading the house to be most efficient where the Passivhaus standard with respect to annual cooling and heating demand is met. As can be noted from the table and figure 8.26, the second scenario is also close to that level with only 5.6 kWh/m^2.yr in excess of what the standard allows, i.e. ≤ 30 kWh/m^2.yr.

Table 8.22 The simulated heating and cooling energy use of all the scenarios compared to the case base model (Note: kerosene is considered as the main heating fuel in the calculations of heating costs and the related carbon footprint)

	Heating Consumption (END USE)			Heating Consumption (per m2)			Cooling Consumption (END USE)			Cooling Consumption (per m2)			Total heating/cooling Consumption (END USE)			Total heating/cooling Consumption (per m2)		
	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO_2	USD	kWh	kg CO2	USD	kWh	kg CO2	USD
Base model	7305	1900	425	36.7	9.5	2.13	9354	7676	2339	47.2	38.7	11.8	16659	9576	2764	83.9	48.2	14
Scenario 1	8250	2146	480	41.7	10.8	2.4	8807	7227	2202	44.5	36.5	11.1	17057	9373	2682	86.2	47.3	13.5
Scenario 2	1615	420	94	8.7	2.3	0.5	4982	4088	1245	26.9	22	6.7	6597	4508	1339	35.6	24.3	7.2
Scenario 3	378	98	22	2.15	0.5	0.13	4322	3546	1080	24.6	20.2	6.1	4700	3644	1102	26.8	20.7	6.2

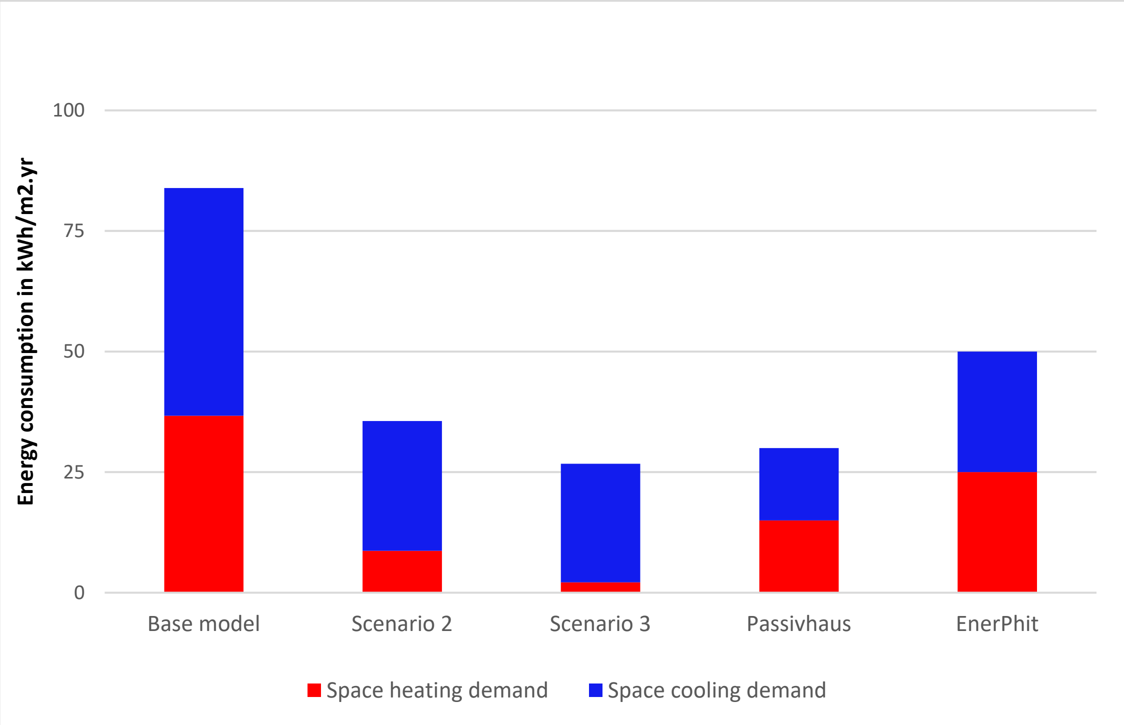


Figure 8.107 The predicted heating and cooling energy use of the second and third scenario and the case base model compared to Passivhaus and EnerPHit standards (author)

8.6 Conclusion

Using dynamic building simulation, parametric analysis has been performed on energy saving potential and thermal comfort provision in two residential units marked by different architectural styles and building characteristics and occupied by two socioeconomically distinct households. A number of energy-saving measures ranging from simple to ones that are more complicated has been tested under the climate conditions of Iraqi Kurdistan with a primary focus on the efficiency of building fabric.

What emerged from the analysis is that when a single physical intervention, such as roof shading or windows replacement, is applied individually, the degree of improvement in the building performance remains insignificant. Whereas when the entire building envelope, whether through applying the Passivhaus-based approach or the slightly relaxed proposal, is upgraded, the outcome appears to be very encouraging and presents exceptional potential in boosting the building efficiency. It alone does not guarantee to keep indoor spaces at comfortable temperatures all year round in such a climate region, but indeed, it leads to a massive reduction in annual space cooling and heating demand while keeping the diurnal temperature variations very low.

With applying the PH-based scenario, for instance, the demand (heating and cooling together) can be kept around 30 kWh/m2.yr while ideal indoor thermal comfort conditions are provided during the occupied hours. This amount represents somewhere between 12 to 28% of what would normally be consumed by the case base dwellings when similar indoor conditions are provided. This percentage varies to some extent from a house to another depending on the size and quality of the existing building, and of course comfort expectations of its occupants. Despite such an exceptional achievement, the findings suggest that the likelihood of annual cooling demand exceeding 15 kWh/m2.yr under such hot climate conditions is inevitable. This is consistent with what Schnieders et al. (2015) and Abu-Hijleh and Jaheen (2019) found when conducted assessments on the effectiveness of applying the PH approach in Abu Dhabi and Dubai. Also given the high levels of airtightness and insulation that this fabric first approach provides, as previous researches indicated (see chapter 2), the findings reveal a possibility for indoor temperatures to exceed 25 °C during the heating season when cooling is no longer provided. Opening windows is therefore important from time to time to promote natural ventilation and avoid such a phenomenon and any potential increase in cooling loads.

While with the slightly relaxed scenario of building envelope upgrade, the demand represents somewhere between 20 to 38% of what would normally be consumed by the case base dwellings when similar indoor conditions are provided. Again, the variation in this percentage is likely contingent on the size and quality of the existing building as well as the comfort expectations of its occupants.

The findings also suggest that both upgrading scenarios are most effective during the heating season where 2 to 3.5 kWh/m2.yr are found to be enough to keep the homes at the right temperatures despite the cold weather conditions that the region faces during the wintertime. This indicates that households, especially those classed as fuel poor, would no longer need to go through all the difficulties that they experience over the winter period to cope with the harsh indoor thermal conditions if one of those upgrading scenarios is to be applied. Given the more challenging nature of the PH-based scenario in terms of technical complexity and cost-implications involved, however, one may prefer the slightly relaxed proposal to the PH-based approach, especially when it comes to retrofit projects or projects with limited budgets. This is because the differences in their energy efficiency and thermal comfort outcomes are not so significant.

Chapter 9

Conclusions and final remarks

8.1 Overview

In this chapter, the author concludes the research and provides a summary of the main findings followed by suggestions for future work.

The research aimed to investigate the application of the fabric first approach to design and construction within the residential context of Iraqi Kurdistan (KRI) and explore how important it could be in freeing people from the increased reliance on energy to maintain a reasonable standard of thermal comfort. The study attempted to revisit the Passivhaus principles to develop a realistic model to upgrade buildings in a way that is appropriate and feasible for that part of the world across the socio-economic spectrum.

As outlined in Chapter 2, the core concept of this construction line of creating environmentally optimised buildings lies in prioritising the performance of the building envelope over the use of mechanical means of heating and cooling. It gives the components and materials that make up the envelope careful consideration, maximises the level of insulation and airtightness across the building fabric, and avoids thermal bridges to minimise the amount of energy required to maintain thermal comfort. One of the very advanced and ambitious versions of fabric first approach is the Passivhaus standard developed by Wolfgang Feist in the early 1990s in Germany. In reliance on such a set of principles, the standard aims to keep the primary energy demand considerably low, i.e. ≤ 120 kWh/m^2.yr, while providing comfortable thermal conditions all year round. The interest in this standard grows as concerns about climate change increase. Across European countries and beyond, in fact, building in accordance to Feist's approach is on the rise. As of June 2021, there were over 65000 certified PH buildings all around the world. The vast majority are located in Scandinavia and German-speaking states experiencing lower temperatures most of the year, countries that are highly advanced in terms of building technology.

In this thesis, however, the researcher attempted to understand the general principles and apply them to a sample of existing buildings in Iraqi Kurdistan to explore how far one can push the performance in a less intrusive way. This is in a completely different climate context where there is a high demand for both cooling and heating. The author also explored their applicability in the light of limited economic resources, locally available skills, construction methods and materials across the region.

In the first part of this thesis, a questionnaire survey followed up by in-depth interviews with key stakeholders engaged in the building industry were conducted. This was to understand the context and get an in-depth insight into the mainstream construction culture in the KRI and the possible problems that are faced there. This helped defining the underlying factors that would determine the nature of the fabric first approach in the region in terms of the materials used, skills and technical solutions needed, etc. Then summertime and wintertime investigations were carried out on a sample of dwellings occupied by socio-economically distinct households. This aimed to get an in-depth insight into their energy and thermal performance, the nature of the architectural fabric, the role of technology and behavioural factors for the development of computer-based models and building fabric upgrading scenarios that are culturally embedded.

Following that, the author developed a range of hypothetical scenarios firmly guided by the principles of fabric first and the understanding of the cultural context and the socio-economic considerations that had impacted the people's lives in the case studies. Then modelling through DesignBuilder was undertaken to test the propositions, i.e. upgrading scenarios, and explore the potentiality they have in terms of increasing thermal comfort, reducing energy consumption and CO_2 emissions, and meeting Passivhaus criteria.

8.2 Key findings

From the findings of this thesis, some fundamental conclusions and observations can be drawn as follow:

- Contrary to expectations that one would normally have about energy demand in hot climate regions, in the KRI, both space cooling and space heating contribute almost equally to the rising demand for energy. This is evident across the case study houses presented in Chapter 7. The region, in fact, experiences both hot summers and cold winters although the latter do not normally receive enough attention when addressing questions of energy and thermal comfort. Designing in such an environment must therefore give careful consideration to both seasons and maximising heat retention must be at the top of designers' agenda when dealing with the high demand of keeping the buildings warm.

- Envelope-wise, as demonstrated in Chapters 6 and 7, poor thermal efficiency seems to be a common feature that residential buildings are generally characterised by in the region. Thermal bridges, air infiltration, and lack of thermal insulation are amongst the common weaknesses associated with the building fabric. No matter how wealthy or poor the households are or how new or old the dwellings are, normally, U-values of building envelope elements are very high in comparison to what is required by modern-day energy-efficient standards. Those of opaque elements, for instance, often exceed 3 $W/m^2.K$. This affects the indoor thermal conditions and the way building occupants interact with their immediate environment and opens the road for excessive use of heating and cooling technologies to make the buildings inhabitable. Getting anywhere near meeting a reasonable standard of thermal comfort all year round across the entire house, in fact, becomes an energy-intensive task. It leads to an increased rise in energy demand and puts an extreme strain on the capacities of the energy sector in northern Iraq. This is where load-shedding is a common daily practice, especially at peak periods when demand is high. When access to cooling and heating becomes limited, experiencing poor indoor thermal conditions becomes inevitable. In dwellings with more than one floor, in particular, migration pattern becomes an integral part of occupants' adaptive behaviour. As a result of roof's prolonged exposure to high solar radiation and temperatures during summertime and its failure in delaying heat transfer, the top floor is often left unoccupied throughout the daytime, especially when occupants cannot afford the constant use of mechanical controls. In such cases when affordability becomes an issue, the element of human behaviour becomes much more engaged in controlling the indoor environment, something that is clearly observed with low-income households.

- The rise in energy consumption associated with the use of heating and cooling technologies can be addressed by shifting the focus towards the efficiency of the fabric, something which has been forgotten. With upgrading the efficiency of the entire building envelope following the principles of fabric first, one can create a situation where the level of indoor thermal comfort is necessarily improved with a significant reduction in cooling and heating demand and CO_2 emissions. People would still need to use heating and cooling technologies to maintain thermal comfort but in a much more efficient way. This is evident in Chapter 8 where the upgrading propositions were tested using dynamic building simulation.

- In a full assessment of two upgrading scenarios, improving the level of airtightness across the building fabric and reducing the U-values of its elements demonstrated some great potential. Despite being a highly ambitious target, the investigations showed the possibility of meeting even western standards of thermal comfort, e.g. ASHRAE and CIBSE standards, in the climate context of Iraqi Kurdistan. This is while achieving somewhere between 60 to 86% reduction in annual space cooling and heating demand. Such a range depends mainly on the level of upgrade and the size and quality of the existing building. As outlined in Chapter 8, the physical interventions of one scenario were fully guided by Passivhaus requirements where the U-value of opaque building components (i.e. external walls, floor, and roof) and the one of windows should not be greater than 0.15 and 0.8 $W/m^2.K$ respectively. The other proposition was simply a slightly relaxed version of the PH-based one allowing slightly higher U-values. With the PH-based scenario, the simulation results showed the possibility of keeping space annual cooling and heating demand around 30 $kWh/m^2.yr$, while with the slightly relaxed one there is a possibility to keep the demand around 50 $kWh/m^2.yr$ or even slightly lower. With such upgrading propositions, interestingly, the space heating demand drops dramatically where the former scenario requires no more than 3.5 $kWh/m^2.yr$ to keep the homes at the right temperatures during the heating season while the latter scenario requires no more than 17 $kWh/m^2.yr$. Such resulting figures are significant when compared to the amount of energy consumed by the real buildings for the same purpose.

- Moving to a much larger scale, if the proposed fabric first-based upgrading scenarios were to be applied across the KRI's existing housing stock, which is the largest contributor to energy consumption (responsible for 41% of the KRI's energy use), the benefits are expected to be remarkable. As of 2015, the total number of dwellings in northern Iraq was 1,140,309. Around 319,286 units of them were estimated to have similar conditions to those of case study 1, i.e. the one occupied by the low-income household. Applying the slightly relaxed building fabric upgrading proposition across this group of dwellings could lead to substantial energy savings, somewhere around 5 million megawatt-hours (i.e. 27% of the amount consumed by the KRI's residential buildings in 2015). This is while improving the thermal environment and perhaps minimising the level of adaptive behaviour. Such a substantial energy saving will surely help the region to tackle the growing energy shortage and reduce fuel poverty. This is besides lowering the use of private generators which according to government data (see Kassamani, 2018) cause too much damage to the KRI's environment and people's health as a result of the amount of pollution they produce.

- If the abovementioned level of reduction in space heating demand could be achieved, furthermore, such an application across the housing stock will significantly limit the increased use of kerosene, the main heating fuel in northern Iraq. Taking the low-income group as an example, again, applying the slightly relaxed upgrading proposition across their dwellings could result in a substantial saving in kerosene use (up to 248 million litres). This will help the region to limit the potential risks attributable to the inefficient use of kerosene and their associated costs. These include fire hazards and carbon monoxide poisoning which give rise to serious health problems (e.g. shortness of breath and loss of consciousness) that cost the KRI's health service a lot and lead to innumerable tragedies.

- In terms of climate change mitigation, promoting the building fabric following the abovementioned propositions can contribute in a substantial reduction in CO_2 emissions. This is something that Iraq, a country that is responsible for almost 0.6 percent of global GHG emissions, agreed to fulfil in the Paris Agreement. Back then, the country set a target to accomplish a 15% reduction in greenhouse gas emissions by 2035. This could arguably be considered as a humble target when compared to what the European Union set to achieve. KRI, meanwhile, set a more ambitious target and promised to achieve through implementing sustainable energy action plans at least 40% reduction in GHG emissions by 2030 (Kassamani, 2018). Nevertheless, such initiatives and promises have remained on paper and have not received the necessary political support as a result of the harsh political landscape in the country. No legislation whatsoever has been in place to regard climate change consistent with the agreed target, one of the key reasons why the country's annual CO_2 emissions are still rising. In fact, Iraq is identified as one of the countries that are severely impacted by climate change. Sand and dust storms, deficiency of precipitation, and rising temperatures are among the challenges facing the country. In the KRI, according to government data, the residential sector is the largest contributor to carbon emissions (Kassamani, 2018). It is responsible for almost 54% of the region's annual CO_2 emissions. Accordingly, upgrading the building envelope across the existing housing stock in Iraqi Kurdistan could strongly help the region to achieve the climate targets that the government is committed to and reduce their carbon footprint. Taking the low-income group as an example, again, applying the slightly relaxed upgrading proposition across their dwellings could result in a remarkable reduction in CO_2 emissions (somewhere around 2.65 million tonnes of CO_2 emissions). This is equivalent to 24% of CO_2 emissions produced by the KRI's residential buildings in 2015.

- Given the socio-economic and socio-technical conditions in northern Iraq, as thoroughly discussed in Chapter 5, one should accept that this fabric transition across the existing building stock is a challenging task despite all the aforementioned encouraging benefits. The process will likely be hamstrung by a set of political, economic, and technical barriers in which their impact on the degree of success and speed of transition is unquestionable. Starting from the political landscape, the research found that the existing legislative environment shows generally a very modest interest in energy saving. There is still no Energy Conservation Building Code and regulation in which homebuilders, design professionals and real estate developers comply with. This generally leaves design and construction practices across the region not to be subjected to any obligatory requirements that concern sustainability and energy efficiency. With the absence of such regulatory support, in fact, triggering the public to invest in this fabric transition will not be a five-finger exercise, especially in a region that is increasingly susceptible to political instability.

- Economic-wise, upgrading the building envelope following the principles of fabric first requires special construction techniques, components and materials (such as energy efficient windows and appliances, super thermal insulation, etc.), and more time. These tend to add extra direct costs to the total construction cost. In an environment marked by an economic downturn and increased levels of poverty and inequality, those associated costs become an issue, especially for those with limited investment capacity.

- Moving to the technical side of this transition, applying fabric first interventions requires a different knowledge base from what the majority of the workforce possess. It requires greater attention to be paid to things like solar gain, insulation, air leakages, thermal bridges, etc. This in turn presents another challenge which can slow down the transition process given the skills shortage and the fact that the region is still at quite an early stage of introducing the concept of energy efficiency to the construction sector.

- Considering those challenges, introducing the full Passivhaus fabric requirements as a model to upgrade the housing stock might not be realistic and realisable within the context of KRI at the current time, mainly for low-income people. However, the principles could still be applied but they need to be slightly relaxed in order to be economically and technically viable for all socio-economic groups. However, the question would still remain as whether such relaxation would make it a leading trend across the industry. In this regard, introducing financial aid mechanisims and support programmes in the form of subsidies or loans by the KRG would be central especially for those with limited investment capacity.

- In the early stages, it is important to introduce the principles in a form of voluntary standard to build up the capacity and skills over time in a way that becomes a learning process for the whole industry. At this stage, establishing the necessary training programs by educational institutions and changing the curriculum in a way that introduces and focuses on energy-efficient techniques would be necessary.

8.3 Future work

Further investigations need to be carried out within the KRI's context to estimate the additional costs associated with the application of fabric first principles. This is to explore how significant they are in comparison to the long-term economic and environmental benefits those interventions generate over the building's life cycle e.g. the savings that result from the reduction in energy consumption and lower maintenance, and improved indoor comfort level and quality of life. As the predicted benefits are based on simulations, it is also of paramount importance to evaluate the performance of the real building(s) built based on fabric first principles to see how they perfrorm in reality under the harsh climate conditions of the KRI. For this, as a follow-up for the findings of this research, the author is aiming to carry out summertime and wintertime investigations on the performance of the two-storey house he designed based on fabric first principles in the City of Duhok (see Appendix E). This is to provide a full assessment of its energy and thermal performance in comparison with the predictions made through simulations.

References

A

Abdallah, L., Abdel Aziz, T., Ali, N., Ali, S., Alkhoja, G., Bahnson, C., Dahdah, S., Dajani, I., Denizer, C., Minatelli, J., Esen, F., Fotovat, S., Hart, T., Jaffrin, G., Jennings, R., Jokanovic, I., Kamphuis, B., Krishnan, N., Kulaksiz, S. & Mattoo, A., 2015. *The Kurdistan region of Iraq : assessing the economic and social impact of the Syrian conflict and ISIS,* Washington, D.C.: The World Bank.

Abdulkareem, H., 2016. Thermal comfort through the microclimates of the courtyard. A critical review of the middle-eastern courtyard house as a climatic response. *Procedia-Social and Behavioral Sciences,* Volume 216, pp. 662-674.

Abdulkareem, H., Schoenefeldt, H. and Nikolopoulou, M., 2020. *Managing Thermal Comfort within the Residential Context of a Developing Region. A Field Investigation Based on Two Socioeconomically Distinct Households.* London, The Windsor Conference.

Abelsohn, A., Sanborn, M. D., Jessiman, B. J., & Weir, E., 2002. Identifying and managing adverse environmental health effects: 6. Carbon monoxide poisoning. *CMAJ : Canadian Medical Association journal,* 166(13), pp. 1685-1690.

Abidin, N., 2010. Investigating the awareness and application of sustainable construction concept by Malaysian developers. *Habitat international,* 34(4), pp. 421-426.

Abu-Hijleh, B. and Jaheen, N., 2019. Energy and economic impact of the new Dubai municipality green building regulations and potential upgrades of the regulations. *Energy Strategy Reviews,* Volume 24, pp. 51-67.

Achtnicht, M., 2011. Do environmental benefits matter? Evidence from a choice experiment among house owners in Germany. *Ecological Economics,* 70(11), pp. 2191-2200.

Ali, H.H. and Al Nsairat, S.F., 2009. Developing a green building assessment tool for developing countries–Case of Jordan. *Building and Environment,* 44(5), pp. 1053-1064.

Al-Khatib, I.A., Ju'ba, A., Kamal, N., Hamed, N., Hmeidan, N. and Massad, S., 2003. Impact of housing conditions on the health of the people at al-Ama'ri refugee camp in the West Bank of Palestine. *International Journal of Environmental Health Research,* 13(4), pp. 315-326.

Alkilani, S. and Jupp, J., 2012. Paving the road for sustainable construction in developing countries: a study of the Jordanian construction industry. *Australasian Journal of Construction Economics and Building, Conference Series,* 12(1), pp. 84-93.

Andersen, R.K., Fabi, V. and Corgnati, S.P., 2016. Predicted and actual indoor environmental quality: Verification of occupants' behaviour models in residential buildings. *Energy and Buildings,* Volume 127, pp. 105-115.

Andriessen, J.W., Brunekreef, B. and Roemer, W., 1998. Home dampness and respiratory health status in European children. *Clinical and Experimental Allergy,* 28(10), pp. 1191-1200.

Anisimova, N., 2011. The capability to reduce primary energy demand in EU housing. *Energy and Buildings,* 43(10), pp. 2747-2751.

ANSI/ASHRAE Standard 55, 2010. Thermal environmental conditions for human occupancy. *American Society of Heating, Refrigerating and Air-Conditioning Engineers,* Volume 55, pp. 1-37.

ANSI/ASHRAE Standard 55, 2013. *Thermal environmental conditions for human occupancy,* Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Azeem, S., Naeem, M.A., Waheed, A. and Thaheem, M.J., 2017. Examining barriers and measures to promote the adoption of green building practices in Pakistan. *Smart and Sustainable Built Environment,* 6(3), pp. 86-100.

B

BADESCU, V., LAASER, N. and CRUTESCU, R. , 2010. Warm season cooling requirements for passive buildings in Southeastern Europe (Romania). *Energy,* 35(8), pp. 3284-3300.

Badescu, V., Rotar, N. and Udrea, I., 2015. Considerations concerning the feasibility of the German Passivhaus concept in Southern Hemisphere. *Energy Efficiency,* 8(5), pp. 919-949.

Baker, N. and Standeven, M., 1996. Thermal comfort for free-running buildings. *Energy and Buildings,* 23(3), pp. 175-182.

Balachandra, R. and Friar, J.H., 1997. Factors for Success in R&D Projects and New Product Innovation: A Contextual Framework. *IEEE Transactions on Engineering management,* 44(3), pp. 276-287.

Banfi, S., Farsi, M., Filippini, M. and Jakob, M., 2008. Willingness to pay for energy-saving measures in residential buildings. *Energy economics,* 30(2), pp. 503-516.

Bekleyen, A., Gönül, I.A., Gönül, H., Sarigül, H., Ilter, T., Dalkiliç, N. and Yildirim, M., 1998. Vernacular domed houses of Harran, Turkey. *Habitat international,* 22(4), pp. 477-485.

Bell, M., Wingfield, J., Miles-Shenton, D. and Seavers, J., 2010. *Low carbon housing: lessons from Elm Tree Mews,* York: Joseph Rowntree Foundation.

Bernard, H. R., 2006. *RESEARCH METHODS IN ANTHROPOLOGY: Qualitative and Quantitative Approaches..* 4th ed. Lanham: ROWMAN & LITTLEFIELD PUBLISHERS.

Bhattacharya, S. and Cropper, M., 2010. Options for energy efficiency in India and barriers to their adoption: a scoping study. *Resources for the Future.*

Bhattacherjee, A., 2012. *Social science research: Principles, methods, and practices.* 2nd ed. Tampa, Florida: Global Text Project.

Blanco, J.M., Buruaga, A., Rojí, E., Cuadrado, J. and Pelaz, B., 2016. Energy assessment and optimization of perforated metal sheet double skin façades through Design Builder; A case study in Spain. *Energy and Buildings,* Volume 111, pp. 326-336.

Bouden, C. and Ghrab, N., 2005. An adaptive thermal comfort model for the Tunisian context: a field study results. *Energy and Buildings,* 37(9), pp. 952-963.

Bozonnet, E., Doya, M. and Allard, F., 2011. Cool roofs impact on building thermal response: A French case study. *Energy and Buildings,* 43(11), pp. 3006-3012.

BP, 2020. *Statistical Review of World Energy 2020,* LONDON: BP.

Brager, G.S. and De Dear, R.J., 1998. Thermal adaptation in the built environment: a literature review. *Energy and buildings,* 27(1), pp. 83-96.

Brown, H.S. and Vergragt, P.J., 2008. Bounded socio-technical experiments as agents of systemic change: The case of a zero-energy residential building. *Technological Forecasting and Social Change,* 75(1), pp. 107-130.

Brunsgaard, C., Heiselberg, P., Knudstrup, M.A. and Larsen, T.S., 2012. Evaluation of the indoor environment of comfort houses: Qualitative and quantitative approaches. *Indoor and Built Environment,* 21(3), pp. 432-451.

Bryman, A., 2016. *Social research methods.* 4th ed. Oxford: Oxford university press.

C

Cantin, R., Burgholzer, J., Guarracino, G., Moujalled, B., Tamelikecht, S. and Royet, B.G., 2010. Field assessment of thermal behaviour of historical dwellings in France. *Building and Environment,* 45(2), pp. 473-484.

Cardinale, N., Rospi, G. and Stefanizzi, P., 2013. Energy and microclimatic performance of Mediterranean vernacular buildings: The Sassi district of Matera and the Trulli district of Alberobello. *Building and Environment,* Volume 59, pp. 590-598.

CEN Standard EN15251, 2007. *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics,* Brussels: Comite'Europe'en de Normalisation.

Chappells, H. and Shove, E., 2005. Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment. *Building Research & Information,* 33(1), pp. 32-40.

Charmaz, K., 2006. *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis.* London: Sage Publications.

CIBSE, 2006. *Environmental design, Guide A.* 7th ed. London: The Chartered Institution of Building Services Engineers.

Clarke, J., 2007. *Energy simulation in building design.* 2nd ed. New York: Routledge.

Cole, R. J., Robinson, J., Brown, Z., & O’Shea, M., 2008. Re-contextualizing the notion of comfort. *Building Research & Information,* 36(4), p. 323–336.

Collins, H., 2010. *Creative research: the theory and practice of research for the creative industries.* Lausanne: AVA Publishing.

Cooper, R., 1999. From experience: the invisible success factors in product innovation. *Journal of product innovation management,* 16(2), pp. 115-133.

Costanzo, V., Fabbri, K. and Piraccini, S., 2018. Stressing the passive behavior of a Passivhaus: An evidence-based scenario analysis for a Mediterranean case study. *Building and Environment,* Volume 142, pp. 265-277.

Cotterell, J. and Dadeby, A., 2012. *Passivhaus handbook: a practical guide to constructing and refurbishing buildings for ultra-low-energy performance.* Totnes: Green Books.

Crawley, D.B., Hand, J.W., Kummert, M. and Griffith, B.T., 2008. Contrasting the capabilities of building energy performance simulation programs. *Building and environment,* 43(4), pp. 661-673.

Creswell, J., 2009. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches.* 3rd ed. London: Sage Publications.

D

De Dear, R. and Brager, G.S., 1998. Developing an adaptive model of thermal comfort and preference. *In: ASHRAE Transactions,* Volume 104, pp. 1-18.

De Medeiros, J.F., Ribeiro, J.L.D. and Cortimiglia, M.N., 2014. Success factors for environmentally sustainable product innovation: a systematic literature review. *Journal of Cleaner Production,* Volume 65, pp. 76-86.

De Vecchi, R., Sorgato, M.J., Pacheco, M., Cândido, C. and Lamberts, R., 2015. ASHRAE 55 adaptive model application in hot and humid climates: the Brazilian case. *Architectural Science Review,* 58(1), pp. 93-101.

De Wilde, P., 2014. The gap between predicted and measured energy performance of buildings: A framework for investigation. *Automation in Construction,* Volume 41, pp. 40-49.

Djokoto, S.D., Dadzie, J. and Ohemeng-Ababio, E., 2014. Barriers to sustainable construction in the Ghanaian construction industry: consultants perspectives. *Journal of Sustainable Development*, *7*(1), p.134.

Dodoo, A., Gustavsson, L. and Sathre, R., 2010. Life cycle primary energy implication of retrofitting a wood-framed apartment building to passive house standard. *Resources, Conservation and Recycling,* 54(12), pp. 1152-1160.

Du Plessis, C., 2002. *Agenda 21 for sustainable construction in developing countries,* Pretoria: CSIR Building and Construction Technology.

Du Plessis, C., 2007. A strategic framework for sustainable construction in developing countries. *Construction Management and Economics,* 25(1), pp. 67-76.

Dudley, E., 1993. *The Critical Villager: Beyond Community Participation.* London: Routledge.

Dwaikat, L.N. and Ali, K.N., 2016. Green buildings cost premium: A review of empirical evidence. *Energy and Buildings,* Volume 110, pp. 396-403.

E

EnergyPlus, n.d. *Weather Data for Simulation.* [Online] Available at: https://energyplus.net/weather/simulation [Accessed 24 May 2021].

F

Fang, Z., Li, N., Li, B., Luo, G. and Huang, Y., 2014. The effect of building envelope insulation on cooling energy consumption in summer. *Energy and Buildings,* Volume 77, pp. 197-205.

Fathy, H., 2010. *Architecture for the poor: an experiment in rural Egypt,* Chicago: University of Chicago press.

Feist, W., 2005. *First Steps: What can be a Passive House in your region with your climate.* [Online] Available at: http://www.solaripedia.com/files/170.pdf [Accessed 05 11 2017].

FEIST, W., SCHNIEDERS, J., DORER, V. and HAAS, A., 2005. Re-inventing air heating: Convenient and comfortable within the frame of the Passive House concept. *Energy and Buildings,* 37(11), pp. 1186-1203.

Figueiredo, A., Kämpf, J. and Vicente, R., 2016. Passive house optimization for Portugal: Overheating evaluation and energy performance. *Energy and Buildings,* Volume 118, pp. 181-196.

Finegan, E., Kelly, G. and O'Sullivan, G., 2020. Comparative analysis of Passivhaus simulated and measured overheating frequency in a typical dwelling in Ireland. *Building Research & Information,* 48(6), pp. 681-699.

Fisher, J., 1999. Carbon monoxide poisoning: a disease of a thousand faces. *Chest,* 115(2), pp. 322-323.

Fokaides, P.A., Christoforou, E., Ilic, M. and Papadopoulos, A., 2016. Performance of a Passive House under subtropical climatic conditions. *Energy and Buildings,* Volume 133, pp. 14-31.

Ford, B., Schiano-Phan, R. and Zhongcheng, D., 2007. *The Passivhaus Standard in European warm climates: Design guidelines for comfortable low energy homes. Part 1. A review of comfortable low energy homes.* [Online] Available at: http://www.eerg.it/passive-on.org/CD/1.%20Technical%20Guidelines/Part%201/Part%201%20-%20English.pdf [Accessed 3 November 2017].

Frost, P.J. and Egri, C.P., 1990. Influence of political action on innovation: Part II. *Leadership & Organization Development Journal,* 11(2), pp. 4-12.

G

Galvin, R., 2010. Thermal upgrades of existing homes in Germany: The building code, subsidies, and economic efficiency. *Energy and Buildings,* 42(6), pp. 834-844.

Galvin, R., 2014. Are passive houses economically viable? A reality-based, subjectivist approach to cost-benefit analyses. *Energy and Buildings ,* Volume 80, pp. 149-157.

Garrett, M.H., Rayment, P.R., Hooper, M.A., Abramson, M.J. and Hooper, B.M., 1998. Indoor airborne fungal spores, house dampness and associations with environmental factors and respiratory health in children. *Clinical and Experimental Allergy,* 28(4), pp. 459-467.

Gatóo, A., 2015. *Building from the ground up: participatory design in Kenya's oldest slum.* [Online] Available at: http://www.cam.ac.uk/research/features/building-from-the-ground-up-participatory-design-in-kenyas-oldest-slum
[Accessed 08 01 2018].

General Directorate of Duhok Electricity, 2018. *Total Summary loads region 2018,* Duhok: General Directorate of Duhok Electricity.

Gibberd, J., 2005. *Assessing sustainable buildings in developing countries–the sustainable building assessment tool (SBAT) and the sustainable building lifecycle (SBL).* Tokyo, Proceedings of the world sustainable building conference, pp. 1605-1612.

Glaser, B.G. and Strauss, A.L., 1967. *The discovery of grounded theory: strategies for qualitative theory.* New Brunswick: Aldine Transaction.

Gomaa, M., Carfrae, J., Goodhew, S., Jabi, W. and Veliz Reyes, A., 2019. Thermal performance exploration of 3D printed cob. *Architectural Science Review,* 62(3), pp. 230-237.

Gram-Hanssen, K., 2010. Residential heat comfort practices: understanding users. *Building Research & Information,* 38(2), pp. 175-186.

Grün, G. and Urlaub, S., 2016. *Towards an identification of European indoor environments' impact on health and performance: Mould and Dampness,* Stuttgart: Fraunhofer IBP.

Guba, E.G. and Lincoln, Y.S., 1994. Competing paradigms in qualitative research. In: N. a. L. Y. Denzin, ed. *Handbook of qualitative research.* Thousand Oaks, CA: SAGE Publications, pp. 105-117.

Guerra Santin, O.L.I.V.I.A. and Tweed, A.C., 2013. *Summer post occupancy evaluation of a Passivhaus care home in the UK.* Munich, PLEA Sustainable Architecture for a Renewable Future.

Guillén-Lambea, S., Rodríguez-Soria, B. and Marín, J.M., 2017. Comfort settings and energy demand for residential nZEB in warm climates. *Applied Energy,* Volume 202, pp. 471-486.

Gupta, R. and Chandiwala, S., 2010. Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments. *Building Research & Information,* 38(5), pp. 530-548.

Gupta, R. and Dantsiou, D., 2013. *Understanding the gap between 'as designed'and 'as built'performance of a new low carbon housing development in UK.* Berlin, Heidelberg, Springer, pp. 567-580.

Gupta, R. and Kotopouleas, A., 2018. Magnitude and extent of building fabric thermal performance gap in UK low energy housing. *Applied Energy,* Volume 222, pp. 673-686.

Guy, S. and Shove, E., 2000. *The sociology of energy, buildings and the environment: Constructing knowledge, designing practice.* London: Routledge.

H

Hards, S., 2013. Status, stigma and energy practices in the home. *Local Environment,* 18(4), pp. 438-454.

Hirst, E. and Brown, M., 1990. Closing the efficiency gap: barriers to the efficient use of energy. *Resources, Conservation and Recycling,* 3(4), pp. 267-281.

Hitchings, R., Waitt, G., Roggeveen, K. and Chisholm, C. , 2015. Winter cold in a summer place: Perceived norms of seasonal adaptation and cultures of home heating in Australia. *Energy Research & Social Science,* Volume 8, pp. 162-172.

Hoes, P., Hensen, J. L.M., Loomans, M. G.L.C., De Vries, B. and Bourgeois, D., 2009. User behaviour in whole building simulation. *Energy in Buildings,* Volume 41, p. 295–302.

Hong, S.H., Gilbertson, J., Oreszczyn, T., Green, G., Ridley, I. and Warm Front Study Group, 2009. A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment. *Building and Environment,* 44(6), pp. 1228-1236.

Humphreys, M., 1997. An adaptive approach to thermal comfort criteria. In: D. Clements-Croome, ed. *Naturally Ventilated Buildings: Buildings for the senses, the economy and society.* London: E & FN Spon, pp. 129-139.

Hwang, B.G. and Tan, J.S., 2012. Green building project management: obstacles and solutions for sustainable development. *Sustainable development,* 20(5), pp. 335-349.

I

Ibrahim, R.K., Zebari, H.N. and Abdulkareem, H.A., 2016. Potential of Energy Conservation in Residential Building Regulations–Kurdistan, Iraq. *Procedia Environmental Sciences*, *34*, pp.506-513.

IEA, 2012. *Iraq Energy Outlook,* Paris: International Energy Agency.

Indraganti, M., 2010. Adaptive use of natural ventilation for thermal comfort in Indian apartments. *Building and environment,* 45(6), pp. 1490-1507.

Indraganti, M., 2010. Behavioural adaptation and the use of environmental controls in summer for thermal comfort in apartments in India. *Energy and buildings,* 42(7), pp. 1019-1025.

Iwaro, J. and Mwasha, A., 2010. A review of building energy regulation and policy for energy conservation in developing countries. *Energy Policy*, *38*(12), pp.7744-7755.

J

Jakob, M., 2006. Marginal costs and co-benefits of energy efficiency investments: The case of the Swiss residential sector. *Energy policy,* 34(2), pp. 172-187.

James, J., 1993. New technologies, employment and labour markets in developing countries. *Development and change,* 24(3), pp. 405-437.

Jensen, S., 1995. Validation of building energy simulation programs: a methodology. *Energy and buildings,* 22(2), pp. 133-144.

Johnson, B. and Christensen, L., 2008. *Educational research: Quantitative, qualitative, and mixed approaches.* London: Sage Publications.

K

Kassamani, O., 2018. *Sustainable Energy Action Plan (SEAP): Kurdistan Region of Iraq,* s.l.: Clima-Med.

Kats, G., Alevantis, L., Berman, A., Mills, E. and Perlman, J., 2003. *The costs and financial benefits of green buildings: A report to California's sustainable building task force,* California: s.n.

Kavgic, M., Summerfield, A., Mumovic, D., Stevanovic, Z.M., Turanjanin, V. and Stevanovic, Z.Z., 2012. Characteristics of indoor temperatures over winter for Belgrade urban dwellings: indications of thermal comfort and space heating energy demand. *Energy and Buildings,* Volume 47, pp. 506-514.

Kempton, W. and Lutzenhiser, L., 1992. Introduction. *Energy and Buildings,* Volume 18, p. 171–176.

Kennedy, M. and Basu, B., 2013. Overcoming barriers to low carbon technology transfer and deployment: An exploration of the impact of projects in developing and emerging economies. *Renewable and Sustainable Energy Reviews,* Volume 26, pp. 685-693.

Khalfan, M. and Sharples, S., 2016. The Present and Future Energy Performance of the First Passivhaus Project in the Gulf Region. *Sustainability,* 8(2), p. 139.

KRG Ministry of Planning, 2012. *Building the Kurdistan Region of Iraq: The Socio-Economic Infrastructure,* Erbil: A Joint Report by the KRG Ministry of Planning and UNDP.

KRG Ministry of Planning, 2013. *Kurdistan Region of Iraq 2020: A Vision for the Future,* Erbil: Ministry of Planning.

KRSO and IOM, 2018. *Demographic Survey: Kurdistan Region of Iraq,* Baghdad: International Organization for Migration (IOM).

Kulkarni, K., Sahoo, P.K. and Mishra, M., 2011. Optimization of cooling load for a lecture theatre in a composite climate in India. *Energy and Buildings,* 43(7), pp. 1573-1579.

L

Langevin, J., Gurian, P.L. and Wen, J., 2013. Reducing energy consumption in low income public housing: Interviewing residents about energy behaviors. *Applied Energy,* Volume 102, pp. 1358-1370.

Larsen, T.S. and Jensen, R.L., 2011. *Comparison of measured and calculated values for the indoor environment in one of the first Danish passive houses.* Sydney, Proceedings of Building Simulation, pp. 1414-1421.

Leaman, A., Stevenson, F. and Bordass, B., 2010. Building evaluation: practice and principles. *Building Research & Information,* 38(5), pp. 564-577.

Lewis, F., 2013. Design Issues. In: J. a. L. J. Ritchie, ed. *Qualitative research practice: A guide for social science students and researchers.* London: SAGE Publications, pp. 47-76.

Libovich, A. 2., 2005. *Assessing green building for sustainable cities.* Tokyo, Proceedings of the world sustainable building conference, pp. 1968-1971.

Liddell, C. and Guiney, C., 2015. Living in a cold and damp home: frameworks for understanding impacts on mental well-being. *Public Health,* 129(3), pp. 191-199.

Liu, F., Meyer, A.S. and Hogan, J.F., 2010. *Mainstreaming building energy efficiency codes in developing countries: global experiences and lessons from early adopters (Vol. 204).* Washington, DC: The World Bank.

Liu, J.Y., Low, S.P. and He, X., 2012. Green practices in the Chinese building industry: drivers and impediments. *Journal of Technology Management in China,* 7(1), pp. 50-63.

Liu, Y., Liu, T., Ye, S. and Liu, Y., 2018. Cost-benefit analysis for Energy Efficiency Retrofit of existing buildings: A case study in China. *Journal of Cleaner Production,* Volume 177, pp. 493-506.

M

Mahdavi, A. and Doppelbauer, E.M., 2010. A performance comparison of passive and low-energy buildings. *Energy and buildings,* 42(8), pp. 1314-1319.

Mara, D.D. and Alabaster, G.P. , 1995. An environmental classification of housing-related diseases in developing countries. *Journal of tropical medicine and hygiene,* Volume 98, pp. 41-51.

Mata, É., Kalagasidis, A.S. and Johnsson, F., 2013. Energy usage and technical potential for energy saving measures in the Swedish residential building stock. *Energy Policy,* Volume 55, pp. 404-414.

Matsumoto, H., Tsuzuki, K. and Susanti, L., 2017. Bioclimatic Analysis in Pre-Design Stage of Passive House in Indonesia. *Buildings,* 7(1), pp. 1-25.

McLeod, R.S. and Hopfe, C.J., 2015. Introduction: Climate change and the built environment. In: C. a. M. R. Hopfe, ed. *The Passivhaus Designer's Manual: a technical guide to low and zero energy buildings.* Oxfordshire: Routledge, pp. 1-31.

McLeod, R.S., Hopfe, C.J. and Kwan, A., 2013. An investigation into future performance and overheating risks in Passivhaus dwellings. *Building and Environment,* Volume 70, pp. 189-209.

Menezes, A.C., Cripps, A., Bouchlaghem, D. and Buswell, R., 2012. Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied energy,* Volume 97, pp. 355-364.

Mills, B. and Schleich, J., 2014. Household transitions to energy efficient lighting. *Energy Economics,* Volume 46, pp. 151-160.

Minke, G., 2012. *Building with Earth: Design and Technology of a Sustainable Architecture.* 3rd ed. Basel: Walter de Gruyter.

Mirza, U.K., Ahmad, N., Harijan, K. and Majeed, T., 2009. Identifying and addressing barriers to renewable energy development in Pakistan. *Renewable and Sustainable Energy Reviews,* 13(4), pp. 927-931.

Mitchel, R., 2017. *The performance of Passivhaus in new construction: Post occupancy evaluation of certified Passivhaus dwellings in the UK: Early Results,* London: Passivhaus Trust.

MLAKAR, J. and ŠTRANCAR, J., 2011. Overheating in residential passive house: Solution strategies revealed and confirmed through data analysis and simulations. *Energy and Buildings,* 43(6), pp. 1443-1451.

Mlecnik, E., 2013. *Innovation development for highly energy-efficient housing: Opportunities and challenges related to the adoption of passive houses (Vol. 45).* Amsterdam: IOS Press.

Mondal, M.A.H., Kamp, L.M. and Pachova, N.I., 2010. Drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh—An innovation system analysis. *Energy Policy,* 38(8), pp. 4626-4634.

Montalvo, C., 2008. General wisdom concerning the factors affecting the adoption of cleaner technologies: a survey 1990–2007. *Journal of Cleaner Production,* 16(1), pp. S7-S13.

Moore, T., Ridley, I., Strengers, Y., Maller, C. and Horne, R., 2017. Dwelling performance and adaptive summer comfort in low-income Australian households. *Building Research & Information,* 45(4), pp. 443-456.

Mudarri, D. and Fisk, W.J., 2007. Public health and economic impact of dampness and mold. *Indoor air,* 17(3), pp. 226-235.

Müller, L. and Berker, T., 2013. Passive House at the crossroads: The past and the present of a voluntary standard that managed to bridge the energy efficiency gap. *Energy policy,* Volume 60, pp. 586-593.

N

Nadarajan, M. and Kirubakaran, V., 2016. Simulation tools for residential buildings—A review on concepts and technologies. *ARPN Journal of Engineering and Applied Sciences,* 11(5), pp. 2998-3007.

Nader, P., 2010. Appropriate Development, Architecture and Planning Technologies (ADAPT). *Case Study prepared for Growing Inclusive Markets. UNDP.*

Newell, R.G., Jaffe, A.B. and Stavins, R.N., 1999. The induced innovation hypothesis and energy-saving technological change. *The Quarterly Journal of Economics,* 114(3), pp. 941-975.

Nicol, F. and Roaf, S., 2017. Rethinking Thermal Comfort. *Building Research & Information,* 45(7), p. 711–716.

Nicol, F., Humphreys, M. and Roaf, S., 2012. *Adaptive thermal comfort: principles and practice.* London: Routledge.

Nicol, J.F. and Humphreys, M., 1998. Understanding the adaptive approach to thermal comfort. *ASHRAE transactions,* Volume 104, pp. 991-1004.

Nicol, J.F., Raja, I.A., Allaudin, A. and Jamy, G.N. , 1999. Climatic variations in comfortable temperatures: the Pakistan projects. *Energy and buildings,* 30(3), pp. 261-279.

Norford, L.K., Socolow, R.H., Hsieh, E.S. and Spadaro, G.V., 1994. Two-to-one discrepancy between measured and predicted performance of a 'low-energy'office building: insights from a reconciliation based on the DOE-2 model. *Energy and buildings,* 21(2), pp. 121-131.

O

Oreszczyn, T., Hong, S.H., Ridley, I., Wilkinson, P. and Warm Front Study Group, 2006. Determinants of winter indoor temperatures in low income households in England. *Energy and Buildings,* 38(3), pp. 245-252.

P

Passipedia, 2017. *The Passive House Resource » Examples.* [Online] Available at: https://passipedia.org/examples [Accessed 14 November 2017].

Patton, M. Q., 1990. *Qualitative evaluation and research methods.* 2nd ed. Thousand Oaks, CA, US: Sage Publications.

Pearson, D., 1998. *The new natural house book: Creating a healthy, harmonious, and ecologically sound home.* New York: Simon and Schuster.

Pitt, M., Tucker, M., Riley, M. and Longden, J., 2009. Towards sustainable construction: promotion and best practices. *Construction innovation,* 9(2), pp. 201-224.

Pitts, A., 2017. Passive House and Low Energy Buildings: Barriers and Opportunities for Future Development within UK Practice. *Sustainability,* 9(2), p. 272.

Preciado-Pérez, O.A. and Fotios, S., 2017. Comprehensive cost-benefit analysis of energy efficiency in social housing. Case study: Northwest Mexico. *Energy and Buildings,* Volume 152, pp. 279-289.

Presser, S., Couper, M.P., Lessler, J.T., Martin, E., Martin, J., Rothgeb, J.M. and Singer, E. , 2004. Methods for testing and evaluating survey questions. *Public opinion quarterly,* 68(1), pp. 109-130.

Prockop, L.D. and Chichkova, R.I., 2007. Carbon monoxide intoxication: an updated review. *Journal of the neurological sciences,* 262(1-2), pp. 122-130.

R

Rael, R. .., 2009. *Earth Architecture.* New York: Princeton archìtectural press.

Rakhshan, K. and Friess, W.A., 2017. Effectiveness and viability of residential building energy retrofits in Dubai. *Journal of Building Engineering,* Volume 13, pp. 116-126.

Ramage, M.H., Ochsendorf, J., Rich, P., Bellamy, J.K. and Block, P., 2010. Design and construction of the Mapungubwe National Park interpretive centre, South Africa. *ATDF JOURNAL,* 7(1/2), pp. 14-23.

RCREEE, 2015. *Arab future energy index,* Cairo: Report by the Regional Center for Renewable Energy and Energy Efficiency (RCREEE).

Ridley, I., Bere, J., Clarke, A., Schwartz, Y. and Farr, A., 2014. The side by side in use monitored performance of two passive and low carbon Welsh houses. *Energy and buildings,* Volume 82, pp. 13-26.

Ridley, I., Clarke, A., Bere, J., Altamirano, H., Lewis, S., Durdev, M. and Farr, A., 2013. The monitored performance of the first new London dwelling certified to the Passive House standard. *Energy and Buildings,* Volume 63, pp. 67-78.

Rijal, H., Tuohy, P., Humphreys, M. A., Nicol, J. F., Samuel, A. and Clarke, J., 2007. Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings. *Energy and Buildings,* 37(7), p. 823–836.

Ritchie, G., Still, K., Rossi Iii, J., Bekkedal, M., Bobb, A. and Arfsten, D., 2003. Biological and health effects of exposure to kerosene-based jet fuels and performance additives. *Journal of Toxicology and Environmental Health, Part B,* 6(4), pp. 357-451.

Ritchie, J., 2013. The Applications of Qualitative. In: J. a. L. J. Ritchie, ed. *Qualitative research practice: A guide for social science students and researchers.* London: SAGE Publications, pp. 24-46.

Rogers, E., 2003. *Diffusion of innovations.* 5th ed. New York: FREE PRESS.

Rohdin, P., Molin, A. and Moshfegh, B., 2014. Experiences from nine passive houses in Sweden–Indoor thermal environment and energy use. *Building and Environment,* Volume 71, pp. 176-185.

Rojas, G., Wagner, W., Suschek-Berger, J., Pfluger, R. and Feist, W., 2016. Applying the passive house concept to a social housing project in Austria–evaluation of the indoor environment based on long-term measurements and user surveys. *Advances in Building Energy Research,* 10(1), pp. 125-148.

Rosenow, J. and Galvin, R., 2013. Evaluating the evaluations: Evidence from energy efficiency programmes in Germany and the UK. *Energy and Buildings,* Volume 62, pp. 450-458.

Ryan, E.M. and Sanquist, T.F., 2012. Validation of building energy modeling tools under idealized and realistic conditions. *Energy and buildings,* Volume 47, pp. 375-382.

S

Sağlam, N.G., Yılmaz, A.Z., Becchio, C. and Corgnati, S.P., 2017. A comprehensive cost-optimal approach for energy retrofit of existing multi-family buildings: Application to apartment blocks in Turkey. *Energy and Buildings,* Volume 150, pp. 224-238.

Saleh, M.S. and Alalouch, C., 2015. *Towards sustainable construction in Oman: Challenges & opportunities.* s.l., Procedia Engineering, pp. 177-184.

Saman, W., Boland, J., Pullen, S., de Dear, R., Soebarto, V., Miller, W., Pocock, B., Belusko, M., Bruno, F., Whaley, D. and Pockett, J., 2013. *A framework for adaptation Australian households to heat waves,* Gold Coast: National Climate Change Adaptation Research Facility.

Sameh, S., 2014. Promoting earth architecture as a sustainable construction technique in Egypt. *Journal of cleaner production,* Volume 65, pp. 362-373.

Sameni, S.M.T., Gaterell, M., Montazami, A. and Ahmed, A. , 2015. Overheating investigation in UK social housing flats built to the Passivhaus standard. *Building and Environment,* Volume 92, pp. 222-235.

Santín, O., 2010. *Actual energy consumption in dwellings: The effect of energy performance regulations and occupant behaviour.* Amsterdam: IOS Press.

Saunders, M., Lewis, Ph. and Thornhill, A., 2011. *Research methods for business students.* 5th ed. Essex: Pearson Education.

Schleich, J., Gassmann, X., Faure, C. and Meissner, T., 2016. Making the implicit explicit: A look inside the implicit discount rate. *Energy Policy,* Volume 97, pp. 321-331.

Schnieders, J. and Hermelink, A., 2006. CEPHEUS results: measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building. *Energy Policy,* 34(2), pp. 151-171.

Schnieders, J., 2003. *CEPHEUS–measurement results from more than 100 dwelling units in passive houses.* s.l., European Council for an Energy Efficient Economy: Summer Study.

Schnieders, J., 2005. *A first guess passive home in southern France. Passive-On Project report.* [Online] Available at: www. maison-passive-nice. fr/documents/FirstGuess Marseille. pdf [Accessed 3 November 2017].

Schnieders, J., Feist, W. and Rongen, L., 2015. Passive Houses for different climate zones. *Energy and Buildings,* Volume 105, pp. 71-87.

Serpell, A., Kort, J. and Vera, S., 2013. Awareness, actions, drivers and barriers of sustainable construction in Chile. *Technological and Economic Development of Economy*, *19*(2), pp.272-288.

Seyfang, G., 2010. Community action for sustainable housing: Building a low-carbon future. *Energy Policy,* 38(12), pp. 7624-7633.

Shah, S.A.A., Solangi, Y.A. and Ikram, M., 2019. Analysis of barriers to the adoption of cleaner energy technologies in Pakistan using Modified Delphi and Fuzzy Analytical Hierarchy Process. *Journal of Cleaner Production,* Volume 235, pp. 1037-1050.

Sharpe, T. and Morgan, C., 2014. *Towards low carbon homes–measured performance of four Passivhaus projects in Scotland.* Aix-les-Bains, The International Solar Enery Society.

Shen, L., He, B., Jiao, L., Song, X. and Zhang, X., 2016. Research on the development of main policy instruments for improving building energy-efficiency. *Journal of Cleaner Production,* Volume 112, pp. 1789-1803.

Shi, Q., Zuo, J., Huang, R., Huang, J. and Pullen, S., 2013. Identifying the critical factors for green construction–an empirical study in China. *Habitat international*, *40*, pp.1-8.

Shim, J., Song, D. and Kim, J., 2018. The economic feasibility of passive houses in Korea. *Sustainability,* 10(10), pp. 1-16.

Shove, E., Chappells, H., Lutzenhiser, L. and Hackett, B., 2008. Comfort in a lower carbon society. *Building Research & Information,* 36(4), p. 307–311.

Smith, P., 1990. Architectural innovation and experimentation at Ganj Dareh, Iran. *World archaeology,* 21(3), pp. 323-335.

Snape, D. and Spencer, L., 2013. The Foundations of Qualitative Research. In: J. a. L. J. Ritchie, ed. *Qualitative research practice: A guide for social science students and researchers.* London: SAGE Publications, pp. 1-23.

Soebarto, V. and Bennetts, H., 2014. Thermal comfort and occupant responses during summer in a low to middle income housing development in South Australia. *Building and environment,* Volume 75, pp. 19-29.

Spitler, J., 2006. Building Performance Simulation: The Now and the Not Yet. *HVAC&R Research,* 12(3a), pp. 711-713.

Steen, A.S., Steen, B. and Bainbridge, D., 1994. *The straw bale house.* Vermont: Chelsea Green Publishing.

Stevenson, F. and Rijal, H.B., 2010. Developing occupancy feedback from a prototype to improve housing production. *Building Research & Information,* Volume 385, pp. 549-563.

T

Tan, Y., Shen, L. and Yao, H., 2011. Sustainable construction practice and contractors' competitiveness: A preliminary study. *Habitat international,* 35(2), pp. 225-230.

The World Bank, 2008. *Global Economic Prospects 2008: Technology Diffusion in the Developing World.* Washington, DC: The World Bank.

Toledo, L., Cropper, P. and Wright, A.J., 2016. *Unintended consequences of sustainable architecture: Evaluating overheating risks in new dwellings.* Los Angeles, PLEA (Passive and Low Energy Architecture).

Tommerup, H. and Svendsen, S., 2006. Energy savings in Danish residential building stock. *Energy and buildings,* 38(6), pp. 618-626.

Tubelo, R., Rodrigues, L.T. and Gillott, M., 2014. A Comparative Study of the Brazilian Energy Labelling System and the Passivhaus Standard for Housing. *Buildings,* 4(2), pp. 207-221.

Tuohy, P.G., Murphy, G.B., Cowie, A., Devici, G. and Theoboldt, I. , 2011. *POE+ Monitoring including the 1st Scottish Passive House.* s.l., UK Passivhaus Conference.

U

UNCED, 1992. *Agenda 21,* Rio de Janerio: United Nations Division for Sustainable Development.

UNEP, 2003. *Environmentally Sound Technologies for Sustainable Development,* s.l.: UNEP International Environmental Technology Centre.

W

Wang, X., Altan, H. and Kang, J., 2015. Parametric study on the performance of green residential buildings in China. *Frontiers of Architectural Research,* 4(1), pp. 56-67.

Wejnert, B., 2002. Integrating models of diffusion of innovations: A conceptual framework. *Annual review of sociology,* 28(1), pp. 297-326.

Wilhite, H., Nakagami, H., Masuda, T., Yamaga, Y. and Haneda, H., 1996. A cross-cultural analysis of household energy use behaviour in Japan and Norway. *Energy policy,* 24(9), pp. 795-803.

Williamson, T.J., 2010. Predicting building performance: the ethics of computer simulation. *Building Research & Information,* 38(4), pp. 401-410.

Winkler, H., Spalding-Fecher, R., Tyani, L. and Matibe, K., 2002. Cost-benefit analysis of energy efficiency in urban low-cost housing. *Development Southern Africa,* 19(5), pp. 593-614.

Wisdom, J.P., Chor, K.H.B., Hoagwood, K.E. and Horwitz, S.M. , 2014. Innovation adoption: a review of theories and constructs. *Administration and Policy in Mental Health and Mental Health Services Research,* 41(4), pp. 480-502.

Witte, M.J., Henninger, R.H., Glazer, J. and Crawley, D.B., 2001. *Testing and validation of a new building energy simulation program.* Rio de Janeiro, Brazil, International Building Performance Simulation Association (IBSPA)

Wong, N.H., Feriadi, H., Lim, P.Y., Tham, K.W., Sekhar, C. and Cheong, K.W., 2002. Thermal comfort evaluation of naturally ventilated public housing in Singapore. *Building and Environment,* 37(12), pp. 1267-1277

Wotzak, R., 2009. *First US Passive House shows energy efficiency can be affordabl.* [Online] Available at: http://www.greenbuildingadvisor.com/homes/first-us-passive-house-shows-energy-efficiency-can-be-affordable
[Accessed 05 11 2017].

Y

Yudelson, J., 2010. *The green building revolution.* Washington: Island Press.

Appendices

Appendix A. Energy efficiency and the built environment: A Survey Questionnaire

A.1. English version

Survey Questionnaire
Towards low-energy buildings

Dear Participants,

You are asked to take part in a survey questionnaire distributed to professionals engaged in the construction sector in the region to collect data about the current status of energy efficiency in buildings. The results of the survey will be used to develop a framework for applying building energy efficiency standards, which help improving building's indoor comfort and reducing its energy consumption for cooling, lighting, heating and etc.

The survey is conducted by a PhD student at University of Kent. The details about the researcher are available at https://www.kent.ac.uk/architecture/people/profiles/abdulkareem-haval.html

Your time and effort that you will make in completing this survey questionnaire is highly appreciated. Please take some time to read through the following information before you start filling the form. If at any point you have any questions, please do not hesitate to ask the researcher, Haval Abdulkareem, or contact him at any time at: ha387@kent.ac.uk

Overview

During the last decade, Kurdistan has experienced a construction boom leading to a rapid expansion in the size of cities owing to factors like growing population, economic growth, refugee crises and urbanization. Data shows that most of the projects being undertaken are residential buildings in order to meet a rapid growth in housing demand. However, buildings in the region are characterized with severe excess of electrical usage due to their quality deficiency, and air-conditioning is the key component of such consumption to ensure the thermal comfort of the indoor environment. This has put an extreme strain on the capacities of energy sector. Electricity supply from all sources was reported to be 12-16 hours per day, and many existing dwellings experience both overheating and overcooling throughout the year. Accordingly, the level of indoor thermal discomfort and high rates of energy consumption will continue unless the way that buildings are constructed is changed.

The aim of this study

This study aims to develop a framework for applying building energy efficiency standards to housing sector in Kurdistan. Practitioners engaged in the construction are invited to take part in the study to explore a broad set of factors concerning the adoption of low-energy buildings.

Please move to the next page to start answering the questions.

Page 1 of 5

Please answer the questions by putting an "**x**" in the box for the answer or answers that come closest to your opinion, or by writing your answer in your own words.

1- **Please indicate your degree level and the country in which you obtained it** (tick all that apply)

☐ Bachelor, please specify the country____________

☐ Diploma, please specify the country____________

☐ Masters, please specify the country____________

☒ Doctorate/ PhD, please specify the country____ UK ____

☐ Other, please specify ____________

2- **How long is your experience in the construction sector?**

☐ Less than 5 years ☐ 5-10 years ☒10-15 years ☐15-20 years ☐ More than 20 years

3- **Please specify the type of firm you are representing:**

☐ Architecture ☒ Civil Engineering ☐ Project Management ☐ Contractor

☐ Other, please specify ____________

4- **Are you aware of the environment-friendly construction practices strategy set by Kurdistan regional government in 2012?**

☐ Yes. Please specify which one briefly,

☒ No. Please explain the reason briefly,

This is due to the lack of advertising and even the local government was not serious of applying that strategy in the ground. Furthermore, the penalty of not applying that strategy by the contractors is nothing.

5- **How do you rate the level of desire amongst your clients for energy-efficient buildings?**

[Energy-efficient buildings: buildings that use relatively little energy to provide comfortable indoor conditions]

☐ Very high ☐ High ☒ Medium ☐ Low ☐ Very low

Please explain the reason briefly,

This is belonging to the cost of the materials used for building because the energy-efficient construction needs more cost compare to conventional. Furthermore, there is no support or even rules from the government to implement or use the energy efficient techniques

6- **Does your firm use energy efficiency methods and techniques?**

[For instance, insulating a building which allows its users to consume less energy for cooling or heating]

☒ No ☐ Plan to use ☐ Yes ☐ Other, please specify ____________________

7- **If yes. For which building type does your firm use energy efficiency methods and techniques?** (tick all that apply)

☐Residential ☐Commercial ☐Educational ☐Offices ☐other, please specify__________

8- **If your answer is yes for question 6, what kind of methods and techniques does your firm use?**

Please specify briefly,

9- **Which factor do you consider most important when choosing building materials for a project?**

☐ Recycled materials ☒ Initial cost ☒ Durability ☐ Aesthetic ☐ locally manufactured

☐ Thermal properties of the material ☐ Workforce capacity (the labourers' skills)

☐ Other, please specify ____________________

Please explain the reason briefly,

This attributed to the mentality here or the culture because the people or even the government seek to achieve the selected factors or these are the benchmark for comparison between any two constructions in Kurdistan

10- **Please indicate the importance of the following factors when you choose building materials**

Factor	Least important	Somewhat important	Neutral	Important	Very Important
Thermal properties			☒		
Initial cost					☒
Durability					☒
Aesthetic		☒			
Recycled materials		☒			
Locally manufactured		☒			

11- Do you use computer-based modeling to estimate building's energy and thermal performance at the design stage?

[Computer-based model is a computer program that is designed to help engineers and designers to predict the energy and thermal performance of any project in addition to other measurements such as CO2 emissions]

☐ Yes ☒ No. Please explain the reason briefly,

Because that simulation needs extra cost and the customer or even the government (in the contractions) are not ready to pay that fees to the designer or to the engineer. On the other hand, there is a lack of scientific research illustrating important of that simulation and how this step will save money to people and to the government

12- If yes. What modelling programme do you use? Please specify____________________________

13- Do you think it is time for the housing sector in the region to apply energy efficiency standards?

☒ Yes ☐ No

Please explain the reason briefly,

Due to the increasing of population and also the lack of electricity in Kurdistan

14- **Please identify the main drivers for applying building energy efficiency standards** (tick all that apply)

☒Reduce energy consumption ☐ Improve indoor comfort ☐ Improve health and safety

☒ Satisfy inhabitants' needs ☒ Reduce operating cost/ lower energy bill (cost benefits)

☐ No benefits ☒ Reduce carbon footprint (protect environment)

☐ Other, please specify

15- **Please identify the main barriers in adopting energy-efficient buildings in Kurdistan** (tick all that apply)

☒ Lack of public awareness (lack of client demand) ☒ Lack of government initiatives

☒ Lack of technical knowledge and skills ☒ Initial cost investment

☐ Too complex to implement ☐ Available construction materials

☐ Other, please specify

There is no Bank (private or public) supports energy efficient building. However, the government gives the people the money as a debit but without any privilege of one who is implementing the energy-efficient construction and the one who is not considering the aforementioned feature

Page 4 of 5

16- **Introducing energy efficiency standards might require new skills which might be a challenge for the current construction laborers who haven't learned those skills. Do you think that this could be an issue in adopting energy-efficient buildings in the region?**

☐ Yes ☒ No

Please explain the reason briefly,

The people here are keen to learn new things if there is an agency or body deliver the training course regarding the skills related to energy efficiency and an example of supporting my point view is the diversity of material and designs of buildings in Kurdistan in which different design here differ from the material used in building to the different kinds of techniques used in construction.

17- **What are the key actions that have to be done to increase the adoption of energy-efficient buildings?** (tick all that apply)

☐ Establishing standards
☐ Introducing new or improved materials and components
☒ raising public awareness
☒ Providing financial support
☐ Increasing cost effectiveness
☐ Education and training
☒ providing demonstration projects [Projects built to prove the viability of energy-efficient buildings]
☐ Other, please specify

Thank you very much for taking the time to complete this questionnaire. **If you are prepared to take part in an interview with the researcher, please leave your contact details below**

Email: [illegible]

Mobile: [illegible]

A.2. Arabic version

استبيان حول كفاءة الطاقة في المباني

الأخوة والأخوات المهندسين والمهندسات والمقاولين والمقاولات العاملين في قطاع البناء الذين تفضلوا مشكورين بإبداء الرغبة في التعاون لملء الاستبيان أدناه.. في البداية نود أن نشكركم على الوقت والجهد الذي سوف تبذلونه في ملء هذا الاستبيان. ثم نرغب أن نوضح لكم أن اهتمامكم وحرصكم على ملء هذا الاستبيان بجدية تامة هو محل شكرنا وتقديرنا، فهذه الدراسة تتطلب من المشارك أن يكون واقعياً قدر الإمكان.

يتم توزيع هذا الاستبيان على المهنيين العاملين في قطاع البناء في الإقليم لجمع البيانات حول الوضع الحالي لكفاءة الطاقة في المباني. سيتم استخدام نتائج الاستبيان لتطوير إطار لتطبيق معايير كفاءة الطاقة في المباني السكنية في الأقليم، مما يساعد على تحسين الراحة الداخلية للمبنى وتقليل استهلاكه للطاقة المستخدمة للتبريد والإضاءة والتدفئة وغيرها.

يتم إجراء هذه الدراسة من قبل طالب دكتوراه في جامعة (Kent)، ولمعرفة المزيد حول الباحث يرجى زيارة الموقع التالي: https://www.kent.ac.uk/architecture/people/profiles/abdulkareem-haval.html

ارجو من سعادتكم التفضل بقراءة المعلومات التالية قبل البدء بالإجابة على الأسئلة التي تبدأ في الصفحة التالية. وإذا كان لديك أي سؤال، في أي وقت، فلا تتردد في سؤال الباحث (**هفال عبدالله عبدالكريم**) أو الإتصال به في أي وقت على البريد الإلكتروني:

ha387@kent.ac.uk

نظرة عامة

خلال العقد الماضي شهد أقليم كردستان طفرة في البناء أدت إلى التوسع السريع في حجم المدن بسبب عوامل مثل النمو السكاني والنمو الاقتصادي وأزمات اللاجئين والتحضر. وتشير البيانات إلى أن معظم المشاريع التي تم تنفيذها هي المشاريع السكنية من أجل تلبية النمو السريع في الطلب على المساكن. وتتميز المباني في الأقليم بالإفراط الحاد في إستهلاك الطاقة وذلك بسبب نقص في جودة وكفاءة المباني مثل عدم الإهتمام بالعزل الحراري وتسرب الهواء من والى داخل المباني وعدم وجود التهوئة المناسبة وغير ذلك. وتعتبر مكيفات الهواء (أجهزة التبريد والتكييف) العامل الرئيسي في هذا الاستهلاك لغرض توفير الراحة الحرارية للبيئة الداخلية للمباني مما يؤدي الى وضع ضغط شديد على قطاع الطاقة. وتشير البيانات على أن إمدادات الكهرباء من جميع المصادر تتراوح بين ١٢ إلى ١٦ ساعة في اليوم ، لذلك فأن العديد من المساكن القائمة تعاني من الحر والبرد على مدار السنة. تبعا لذلك ، فإن مستوى الانزعاج الحراري داخل المباني والمعدلات العالية لاستهلاك الطاقة سوف تستمر ما لم تتغير الأساليب التي يتم بها تشييد المباني.

الهدف من الدراسة

تهدف هذه الدراسة إلى تطوير إطار لتطبيق معايير كفاءة الطاقة في قطاع الإسكان في أقليم كردستان. يتم دعوة المهنيين العاملين في قطاع البناء للمشاركة في هذه الدراسة لمناقشة مجموعة واسعة من العوامل المتعلقة باعتماد مباني منخفضة الطاقة.

التعريفات

المباني الموفرة للطاقة: المباني المصممة بشكل متوافق مع المناخ المحلي والتي تستخدم طاقة قليلة نسبيًا لتوفير بيئة داخلية مريحة بالإعتماد على أساليب وتقنيات بناء معينة على سبيل المثال: إستغلال غلاف المبنى في خلق حدود حرارية جيدة بين البيئة الداخلية و الخارجية، و ذلك من خلال منع تسرب الهواء و عزل الحرارة.

الراحة الحرارية: هو شعور الإنسان بالراحة الجسدية والنفسية التامة بفعل البيئة الحرارية المحيطة (داخل الفراغات المعمارية)، وتختلف حدوده طبقًا للجنس والعمر والمكان والفصول المناخية. ويرتبط الارتياح الحراري بدرجة حرارة الهواء المحيط والرطوبة النسبية وحركة الهواء ومتوسط الحرارة الإشعاعية ونوع الألبسة وطبيعة النشاط البشري وغير ذلك.

برامج المحاكاة (Computer-based modelling and simulation tools): برامج كمبيوتر مصممة لمساعدة المهندسين والمصممين لتقييم الأداء الحراري داخل فراغات المباني بالإضافة إلى قياسات أخرى مثل تقييم استهلاك الطاقة و تقييم انبعاثات ثاني أكسيد الكربون و غير ذلك.

الرجاء الإجابة عن الأسئلة بوضع علامة "×" في المربع للإجابة أو الإجابات الأقرب إلى رأيك ، أو بكتابة إجابتك بكلماتك الخاصة.

١- **يرجى الإشارة إلى الشهادة أو الشهادات التي حصلت عليها مع ذكر البلد الذي حصلت عليها فيه** (ضع علامة على كل ما ينطبق)

☒ البكالوريوس، يرجى تحديد البلد العراق

☐ الدبلوم العالي، يرجى تحديد البلد

☒ الماجستير، يرجى تحديد البلد العراق

☒ الدكتوراه، يرجى تحديد البلد ماليزيا

☐ أخرى، يرجى التحديد

٢- **كم هي مدة خبرتك في قطاع البناء؟**

☐ أقل من خمس سنوات ☐ ٥-١٠ سنوات ☐ ١٠-١٥ سنة ☒ ١٥-٢٠ سنة ☐ أكثر من ٢٠ سنة

٣- **يرجى تحديد نوع المكتب أو الشركة التي تمثلها:**

☐ معمارية ☐ هندسة مدنية ☐ إدارة مشاريع ☒ مقاولات ☐ أخرى، يرجى التحديد

٤- **هل أنت على علم باستراتيجية ممارسات البناء الصديقة للبيئة التي وضعتها حكومة إقليم كردستان في عام ٢٠١٢؟**

☐ نعم. يرجى ذكرها بشكل مختصر

☒ لا. يرجى توضيح السبب بشكل مختصر

...لم يتم تعميمها على شركات المقاولات...

٥- **كيف تقيم مستوى الرغبة والطلب على المباني الموفرة للطاقة من قبل زبائنك؟**

☐ عالي جداً ☐ عالي ☒ وسط ☐ قليل ☐ قليل جداً

يرجى توضيح السبب بشكل مختصر

....عوامل عديدة اهمها : الوعي المجتمعي لهذا الموضوع ،الكلفة ، اليد العاملة...الخ .

٦- هل تستخدم شركتك أساليب وتقنيات في البناء للحد من استهلاك الطاقة؟

☐ لا ☒ ننوي إستخدامها في المستقبل ☐ نعم ☐ أخرى، يرجى التحديد ____________________

٧- اذا جاوبت ب (نعم). لأي نوع من المباني تستخدم شركتك تلك الأساليب والتقنيات؟ (ضع علامة "**×**" على كل ما ينطبق)

☐ سكنية ☐ تجارية ☐ تعليمية ☐ إدارية ☐ أخرى، يرجى التحديد____________________

٨- إذا كانت إجابتك نعم للسؤال (٦)، ما هي الأساليب والتقنيات التي تستخدمها شركتك؟

يرجى ذكرها بشكل مختصر

٩- ما هو العامل الذي تعتبره أكثر أهمية عند اختيارك لمواد البناء؟

☐ المواد المعاد تدويرها ☒ الكلفة الأولية ☐ المتانة ☐ الناحية الجمالية ☐ الصناعة المحلية

☐ الخصائص الحرارية للمادة ☒ قدرات القوى العاملة (مهارات العمال) ☐ أخرى، يرجى التحديد ________________

يرجى توضيح السبب بشكل مختصر

يوجد العديد من المواد والتقنيات الا ان عدم وجود الكفاءة البشرية المتخصصة للتعامل معها يدفع باتجاه تجنبها في معظم الاحيان..بالاضافة الى الكلفة ، مع الاخذ بنظر الاعتبار ان شركات المقاولات هي شركات تقوم بتنفيذ المشروع كما مصمم ومصادق عليه من قبل الجهة المستفيدة، اعتقد ان الشركات المصممة للمشاريع لابد من تاخذ هذه العوامل بنظر الاعتبار...

١٠- يرجى الإشارة إلى أهمية العوامل التالية عند اختيارك لمواد البناء (ضع علامة "**×**" على درجة أهمية كل عامل بالنسبة لك)

العوامل	أقل أهمية	مهم الى حد ما	حيادي	مهم	مهم جداً
الخصائص الحرارية للمادة				×	
الكلفة الأولية					×
المتانة				×	
الناحية الجمالية				×	
المواد المعاد تدويرها	×				
الصناعة المحلية	×				

١١- هل تستخدم برامج المحاكاة لتقييم الأداء الحراري للمبنى في مرحلة التصميم؟

ملاحظة: راجع قسم التعريفات في الصفحة الأولى للمزيد من التوضيح حول هذه البرامج

☐ نعم ☒ لا. يرجى ذكر سبب عدم استخدامك لهذه البرامج بشكل مختصر

عدم وجود اهتمام كبير من قبل الجهة المستفيدة من المشروع بالاداء الحراري كمعيار اساسي ، يجعل استخدام هذه البرامج اضافة غير مجدية ، مع الاخذ بنظر الاعتبار ان شركات المقاولات هي شركات تقوم بتنفيذ المشروع كما مصمم ومصادق عليه من قبل الجهة المستفيدة، اعتقد ان الشركات المصممة للمشاريع لابد من تاخذ هذه البرامج بنظر الاعتبار...

١٢- إذا أجبت ب نعم، يرجى ذكر اسم البرنامج أو البرامج التي تستخدمها ______________________

١٣- هل تعتقد أن الوقت قد حان لتطبيق معايير كفاءة الطاقة في قطاع الإسكان في الإقليم ؟

☒ نعم ☐ لا

يرجى توضيح السبب بشكل مختصر

...ببساطة كلفة المشروع شيء وكلفة استدامة المشروع ضمن السياق الحضري شيء اخر... كشركة نتمنى ان تنتبه الجهات المستفيدة لهذه النقطة... فمشروع بكلفة واطئة بحد ذاته يصبح مكلف جدا مع الوقت والاستخدام المفرط والخاطئ للطاقة.

١٤- يرجى تحديد الدوافع الرئيسية لتطبيق معايير كفاءة الطاقة (ضع علامة "×" على كل ما ينطبق)

☒ الحد من إستهلاك الطاقة ☐ تحسين مستوى الراحة داخل المباني ☐ تحسين الصحة والسلامة

☐ تلبية إحتياجات الساكنين ☒ فوائد من حيث التكاليف المالية: تقليل تكاليف التشغيل/ تقليل فاتورة الكهرباء

☐ لا يوجد هناك أي فائدة ☒ تقليل والحد من الآثار البيئية للمباني (حماية البيئة)

☐ أخرى، يرجى ذكرها

الدوافع التي تم اختياره تؤثر على الاخرى وهكذا...

١٥- يرجى تحديد العوائق الرئيسية في تبني المباني الموفرة للطاقة في أقليم كردستان (ضع علامة "×" على كل ما ينطبق)

☒ نقص الوعي العام تجاه هذه المباني (نقص الطلب من قبل العملاء) ☒ عدم وجود مبادرات حكومية تجاه هذه المباني

☒ نقص المعرفة والمهارات التقنية (القدرة المحدودة للقوى العاملة) ☒ التكلفة الأولية لهذا النمط من المباني عالية

☐ هذه المباني معقدة للغاية للتنفيذ ☐ مواد البناء المتاحة

☐ أخرى، يرجى ذكرها

١٦- قد يتطلب إدخال معايير كفاءة الطاقة مهارات جديدة قد تشكل تحدياً لعمال البناء الحاليين الذين لم يتعلموا هذه المهارات. هل تعتقد أن هذا يمكن أن يكون مشكلة في تبني المباني الموفرة للطاقة في الإقليم؟

☒ نعم ☐ لا

يرجى توضيح السبب بشكل مختصر

...ولكنها ليست مستحيلة حيث يمكن تدريب العمال من قبل معاهد تفتح لهذا الغرض في المستقبل.

١٧-ما هي الإجراءات الرئيسية التي يتعين القيام بها لزيادة اعتماد المباني الموفرة للطاقة؟ (ضع علامة "×" على كل ما ينطبق)

☒ توفير مواد ومكونات بناء جديدة أو محسنة في السوق المحلي ☒ وضع المعايير

☒ رفع الوعي العام تجاه هذه المباني ☒ توفير الدعم المالي

☒ تعليم و تدريب المهنيين والقوى العاملة كيفية تنفيذ هذه المباني ☒ زيادة الفعالية من حيث التكلفة

☒ تقديم مشاريع إيضاحية أو إرشادية [مشاريع صغيرة تبنى لإثبات جدوى المباني الموفرة للطاقة]

☐ أخرى، يرجى ذكرها

...اجد كل ماسبق يؤثر في زيادة اعتماد المباني الموفرة للطاقة ...الا ان رفع الوعي العام تجاه هذه المباني اهمها من وجهة نظري...فمثلا وضع المعايير مطلوب ولكن اذا لم يتم تقبل هذه المعايير بشكل ايجابي تبقى مجرد معايير يمكن الالتفاف عليها.

شكرا جزيلا على الوقت والجهد الذي بذلتموه لإستكمال هذا الاستبيان. إذا كنت مستعدًا للمشاركة في مقابلة مع الباحث لمناقشة تفاصيل أخرى متعلقة بهذه الدراسة، فالرجاء من سعادتكم التفضل بترك تفاصيل الإتصال الخاصة بك أدناه... و شكراً

رقم الموبايل : ××××××××××××

البريد الألكتروني: ××××××××××××c

الصفحة ٥ من ٥

Appendix B. Mainstreaming energy-efficient building practices in Iraqi Kurdistan: The underlying issues – In-depth Interviews

B.1. Participant information sheet – English version

PARTICIPANT INFORMATION SHEET
Student No: 17903976

University of Kent

Challenges and opportunities in applying Fabric First principles in regions of the developing world: A case study based in the Kurdistan Region

Investigator: Haval A. Abdulkareem
Kent School of Architecture, University of Kent

Dear Participant,

You are invited to take part in a PhD research study exploring the challenges and opportunities concerning the adoption of energy-efficient buildings in Kurdistan. Please take some time to read through the following information before you decide if you wish to participate. If at any point you have any questions, please do not hesitate to ask the researcher, Haval, or contact him at a later date at: ha387@kent.ac.uk.

Overview

During the last decade, Kurdistan has experienced a construction boom leading to a rapid expansion in the size of cities owing to factors like growing population, economic growth, refugee crises and urbanization. Data shows that most of the projects being undertaken are residential buildings in order to meet a rapid growth in housing demand. However, buildings in the region are characterized with severe excess of electrical usage due to their quality deficiency, and air-conditioning is the key component of such consumption to ensure the thermal comfort of the indoor environment. This has put an extreme strain on the capacities of energy sector. Electricity supply from all sources was reported to be 12-16 hours per day, and many existing dwellings experience both overheating and overcooling throughout the year. Accordingly, the level of indoor thermal discomfort and high rates of energy consumption will continue if the way that buildings are constructed is not changed.

This study aims to develop a framework for applying building energy efficiency standards to housing sector in Kurdistan. Practitioners engaged in the construction sector as well as representatives from government and education are invited to take part in the study to explore a broad set of political, cultural, social and economic factors concerning the adoption of low-energy buildings to provide input for such framework. Questions concerning your experiences in the field, the progress made to date relating the implementation of energy efficiency interventions, the weaknesses and strengths of the current building trades, the application of new building design, components and materials, factors that might impede or facilitate the adoption of low-energy design including policy, societal and technological factors and possible solutions to overcome socio-technical barriers will be asked

What you have been asked to do

You are asked to participate in a confidential and anonymous interview, lasting around 60 minutes. This will be arranged for a time, date and location of your convenience, prior to the end of August 2018. You are not obliged to, but you might find it useful to have a think about issues related to the study prior to the interview.

Your data

For the purposes of enhancing the accuracy of the qualitative analysis of the data from our interview session, with your consent I will record the audio of the session. Also with your permission, I may include selective quotes from the transcription to illustrate points in my thesis and any resulting publications. These will be anonymised and great care taken to ensure that any quotes cannot be attributed to you. Your interview responses will be confidential. Notes and recordings will be anonymised and stored within an encrypted folder, accessible only to the researcher, Haval Abdulkareem. Your identity will not be discussed with either of the researcher's PhD supervisors, Professor Marialena Nikolopoulou (Kent School of Architecture) and Dr Henrik Schoenefeldt (Kent School of Architecture).

Your participation in this study is completely voluntary. You may choose not to answer any of the pre-planned questions asked of you. You may withdraw your participation at any time during or after the interview session up until any potential publication of the findings.

As a reminder, if you have questions, please do not hesitate to contact the researcher, Haval Abdulkareem, on the contact details provided below.

Thank you for reading this information sheet and we hope to speak with you soon!

Haval A. Abdulkareem
Kent School of Architecture
University of Kent

Email: ha387@kent.ac.uk
h.a.a.abdulkareem@kent.ac.uk

B.2. Participant information sheet – Arabic version

إستمارة المعلومات للمشاركين
رقم هوية الطالب: ١٧٩٠٣٩٧٦

التحديات والفرص في تطبيق مبادئ المباني الموفرة للطاقة في أقاليم العالم النامي: دراسة حالة في إقليم كردستان

الباحث: هه فال عبدالله عبدالكريم
Kent School of Architecture, University of Kent

عزيزي المشارك،

أنت مدعو للمشاركة في دراسة بحثية تستكشف التحديات والفرص المتعلقة بتبني المباني الموفرة للطاقة في أقليم كردستان. الرجاء أن تأخذ(ي) الوقت الكافي لقراءة المعلومات التالية بتأن قبل أن تقرر(ي) إذا كنت تريد(ين) المشاركة أم لا. بإمكانك طلب إيضاحات أو معلومات إضافية عن أي شيء مذكور في هذه الإستمارة أو عن هذه الدراسة ككل من الباحث الرئيسي (هه فال) عبر البريد الإلكتروني: ha387@kent.ac.uk.

نظرة عامة

خلال العقد الماضي شهد أقليم كردستان طفرة في البناء أدت إلى التوسع السريع في حجم المدن بسبب عوامل مثل النمو السكاني والنمو الاقتصادي وأزمات اللاجئين والتحضر. وتشير البيانات إلى أن معظم المشاريع التي يتم تنفيذها هي المباني السكنية من أجل تلبية النمو السريع في الطلب على المساكن. وتتميز المباني في الأقليم بالإفراط الحاد في إستهلاك الطاقة وذلك بسبب نقص في جودة المباني ، وتعتبر مكيفات الهواء (أجهزة التبريد والتكييف) العامل الرئيسي في هذا الاستهلاك لغرض توفير الراحة الحرارية للبيئة الداخلية للمباني مما يؤدي الى وضع ضغط شديد على قطاع الطاقة. وتشير البيانات أن إمدادات الكهرباء من جميع المصادر تتراوح بين ١٢ إلى ١٦ ساعة في اليوم ، لذلك فأن العديد من المساكن القائمة تعاني من الحر والبرد على مدار السنة. تبعا لذلك ، فإن مستوى الانزعاج الحراري داخل المباني والمعدلات العالية لاستهلاك الطاقة سوف تستمر إلا إذا تغيرت الطريقة التي يتم بها تشييد المباني.

تهدف هذه الدراسة إلى تطوير إطار لتطبيق معايير كفاءة الطاقة في قطاع الإسكان في إقليم كردستان. يتم دعوة المهنيين العاملين في قطاع البناء وممثلين عن الحكومة والتعليم للمشاركة في هذه الدراسة لمناقشة مجموعة واسعة من العوامل السياسية والثقافية والاجتماعية والاقتصادية المتعلقة باعتماد مباني منخفضة الطاقة بهدف الحصول على مدخلات لهذا الإطار.

ما يطلب منك القيام به

يطلب منك المشاركة في مقابلة تستمر حوالي ٦٠ دقيقة. سيتم ترتيب ذلك حسب الوقت والمكان المفضل لديك قبل نهاية أغسطس ٢٠١٨. لست ملزماً ولكن قد تجد أنه من المفيد أن تفكر مسبقا في القضايا المتعلقة بالدراسة قبل المقابلة.

سوف نناقش أسئلة تتعلق بخبراتك في هذا المجال، والتقدم المحرز حتى الآن فيما يتعلق بتنفيذ التقنيات والمعالجات الموفرة للطاقة، ونقاط الضعف والقوة في المهن الراهنة المعنية بإنشاء وتشطيب المباني، تطبيق التصاميم والمكونات والمواد الجديدة، والعوامل التي قد تعيق أو تسهل اعتماد تصميم منخفض الطاقة، بما في ذلك العوامل السياسية والاجتماعية والتكنولوجية والحلول الممكنة للتغلب على تلك الحواجز.

البيانات الخاصة بك

لغرض تعزيز دقة التحليل النوعي للبيانات الصادرة من جلسة المقابلة وبموافقتك، سأقوم بتسجيل صوتي للجلسة. أيضًا بعد الحصول على إذن منك ، قد أضمِّن اقتباسات مباشرة في الأطروحة وأي منشورات ناتجة. سوف نقوم بعناية بحماية المعلومات التي تطلعنا عليها. ولحماية خصوصيتك، سوف يتم تسجيل النتائج مع رمز سري. سيتم تخزين الملاحظات المكتوبة والتسجيل الصوتي في مجلد مشفر. والوصول اليها يتم فقط من قبل الباحث الرئيسي للدراسة. أية بيانات يمكن ان تنتج عن هذه الدراسة لن تذكر أسماء المشاركين في الدراسة.

إن المشاركة طوعية تماما ولك الحق في عدم الإجابة على أي سؤال من الأسئلة. ويمكنك أيضًا سحب مشاركتك من هذا البحث في أي وقت.

إذا كان لديك أي أسئلة ، مخاوف أو شكاوى، يرجى الاتصال بالباحث الرئيسي للدراسة على تفاصيل الاتصال الواردة أدناه.

نشكرك على قراءة استمارة المعلومات هذه ونأمل أن نتحدث معك قريبًا!

Haval A. Abdulkareem
Kent School of Architecture
20.03.2018

Email: ha387@kent.ac.uk
h.a.a.abdulkareem@kent.ac.uk

B.3. A sample of Interview transcripts

Transcript 1: An interview with 2 architects working in the industry (coded as R.I. and S. Th.)

An overview about the participants

R. I. is known as the architect of low-income people as he mostly designs and constructs residential buildings in low-income areas. He has a Bachelor degree in Architectural Engineering and MSc in Healthy Buildings. In his early years of practicing architecture, he worked for the municipality and was involved in designing and planning some of the new districts of the city.

S. Th. has a Bachelor degree in Architecture and MSc in Sustainable Environmental Design. He has worked as an architect for a few well-recognised construction companies in the region and has been involved in designing and constructing many residential, commercial, recreational projects across the region.

Researcher: What are the key guidelines that you follow in designing and constructing projects? And what are the factors affecting your design and construction decisions?

R. I.: well, as far as I know there are no regulations to follow. Architects are free to use whatever materials, construction techniques, and rendering colours they desire. When you apply for a Building Permit actually, it's not required at all to show the use of certain materials or techniques or to achieve a certain U-value. So we heavily rely on our experience.

S. Th.: Yeah he is right; it is highly dependent on our experience. But additionally to that, the clients and their desires and ways of thinking I would say have a considerable impact on our decisions. You tell the client what you think is right but sometimes they may not accept your idea. For example, when a client comes with a north-facing plot, you know the problems with such plots with respect to winter sun, so I tell them that instead of having a front garden or front yard, we will do a backyard which will help to have south-facing windows so that you get the desirable sunlight. But many reject the idea saying that the neighbouring houses haven't done that so why would we do or saying that we can use an extra barrel of kerosene for heating or an extra air-conditioning unit instead of that. You know it is really hard; people awareness of energy-efficiency and environmental issues is way low, and you alone cannot change their beliefs and ways of thinking. You try to convince them; they may agree and they may not.

But if let's say municipality or the competent authorities imposed regulations, for instance, saying that for the north-facing plots you should have a backyard instead of front-yard, then everybody would obey the laws. This is why I think that the government needs to establish the building regulations first and then impose them. This doesn't mean that designers should not listen to their clients and consider their requirements because at the end of the day they will occupy that house or building so they need to meet their requirements. But designers can still consider their requirements in accordance with the established regulations.

So I believe if there were regulations and enforcement then people will have no choice except complying with these regulations because in this case if the design doesn't comply with the established standards when you apply for the Building Permit then the application will be rejected by the municipality and they will not allow you to build. But when the municipality don't have such requirements and don't pay attention to energy-efficiency of the design, then you as a designer cannot force your clients to spend more money on energy-efficiency measures.

What I noticed recently after the increase in energy prices, clients have started asking about the possible ways that would increase the energy efficiency of their buildings. They started to use double or triple glazed windows instead of single glazed ones. Even the window frames, people are looking for the types that have a thermal barrier to improve airtightness around windows. All this been driven by the increase in energy prices.

R. I.: I agree the clients have a great influence on our decisions. We can't really neglect their views and desires even if they are wrong, because generally speaking if you just do and impose what you think is right and neglect their thoughts then maybe as an architect you are not going to have clients anymore. So for instance they may tell you we want a design similar to someone's house and even if you think that the house they referred to has lots of shortcomings yet they may push you to do so. In such situations, what we do is trying our best to convince them with the right decisions.

Especially in my case, as you know the vast majority of my clients are people on a limited income, so the cost does matter a lot; I mean affordability is a key determinant. So it's something that I can't neglect when designing. That is why you can notice from my buildings that I always tried to avoid oversized spaces, and paid attention to low-cost construction techniques.

Regarding Mr Saad's point about enforcing energy efficiency standards, I think if we consider the socio-economic context, you can't force people living in poverty and slums to insulate their shelters. It is something that is not within their priorities at all. So I would say that there must be some exceptions.

Researcher: In your opinions, what might be the driver behind the lack of desire towards energy-efficient designs among clients?

R. I.: Well, I think cost plays a key role. For instance, they know that a significant amount of heat comes in through the roof and they know that something like a green roof or insulating the roof is important to avoid that heat. But they think of the initial cost of these measures without taking the life cycle costing into account, so they just don't go for it. They think that if they wanted to sell the house after some years nobody will appreciate these energy-efficiency measures in their house and nobody will be ready to pay more money for such things.

Meanwhile, there are clients particularly those who have lived abroad in western countries focusing a lot on the thermal efficiency of the building and comfort-related issues and even sometimes they provide us with examples of techniques that they have seen in western countries to be applied in the design of their house. So you have both groups.

S. Th.: Well, I was thinking that way too but having worked for wealthy people for years I realised that it's more about cultural awareness among people than cost barriers. I've had many clients with no financial barriers at all, yet they were not giving importance to energy efficiency and the demand for such measures was low.

I think having more concrete examples on the ground (e.g. energy-efficient projects which could be built by whether stakeholders or maybe investors) demonstrating the significant benefits of energy-efficiency measures in terms of increasing energy saving and lowering bills while providing healthy and comfortable indoor thermal conditions will be one way of raising public awareness and encouraging people to adopt these measures. However, this will not be effective in a small scale I mean a scale of one or a few buildings. This should be done in a much larger scale, a scale of housing developments for instance. And we have noticed this after the emergence of some of the apartments that used insulation layers within their fabric with high quality windows, e.g. Avro City. People started hearing from the residents of these apartments that they use much less energy whether in winter or in summer than households living in conventional residential units. And this was the main reason actually that attracted many people to move to these apartments.

Also, the lack of know-how among practitioners and labourers in applying energy-efficiency measures might also be a barrier. One way to overcome this is that by importing foreign expertise and investing in local staff training. Also, it is crucial when making contracts with international companies and contractors that the government force them to recruit and train more local labourers and professionals when taking part in construction projects.

R.I.: With respect to public awareness about energy efficiency, I think energy costs, being very low in this country, were not supportive to drive people to think of energy-saving and cultivate that awareness. I remember when I was studying in the UK I stayed for some days at a friend's house and one day my wife forgot to switch off the bathroom light and then immediately my friend's daughter started shouting saying "turn off the light; turn off the light; it costs money." So you see how her reaction was driven by energy cost, why? Simply because it is expensive. But when you know it is very cheap then why would you think of saving. For instance, when you know the difference in energy bill between consuming energy in an extravagant way and consuming it in a thrifty way is a matter of let's say 10 or 15 USD, then you would not be keen to save. I think this is an important factor that drives people's behaviour towards energy use, and you can see its impact clearly across the region where you see how people placed exterior lights extensively all over their dwellings. They are left ON for hours without being needed showing how unconscious people are about energy use. You will be amazed by such attitudes. You see restaurants with hundreds of exterior lights. It is unbelievable.

By increasing energy cost I think, people will be obliged to think of energy-saving, they will be obliged to look for measures that reduce their consumption of energy. It will be important for them to introduce sufficient daylight to avoid turning on artificial lights; it will be important for them to insulate the fabric to reduce heating/cooling loads. They will not be behaving unconsciously and leave the doors and windows open while Air conditioners are running. I think this will cultivate their awareness towards energy efficiency.

S. Th.: I think the level of education also plays a role in promoting environmental awareness. I mean as I said I have designed and built houses for many clients from upper-income class, and I noticed with those who have not received much education that they don't really care about thermal efficiency. What they most care about is oversized spaces, High-End Finishes and Exquisite Decorations. But with educated people even if they have no idea about energy-efficiency measures and their importance, but they are more open to understand and accept such ideas.

R.I.: Well, there are people with a university degree, but still, they don't give importance to these environmental aspects of design, and there are others who might not be well educated but because they travelled abroad and may be stayed there for some time so they know about these aspects and put emphasis on things like ventilation, daylighting and insulation. So I think the level of education is not always a driver. But I could say that the majority of my clients have no idea about energy efficiency, they know nothing about thermal insulation, air tightness and etc. They often tend to mimic what they have seen in other buildings.

S. Th.: Their past experiences also play a role. They often shed light on the design weaknesses of their old places so that we avoid. You often hear things like "please reduce west-facing windows, the space gets really hot," "avoid double-volume spaces, they are hard to be heated or cooled," or "please keep the airshafts big so that we get sufficient ventilation and daylight."

R.I.: Yeah he is right. The demand for double-volume spaces has reduced over the last five years. Some years ago, even people with limited income were pushing us to include the central double-volume space in the design but now after knowing the consequences of such design in terms of heating and cooling loads they don’t ask for it.

Researcher: Could you please talk about one of your buildings that you aimed to increase its energy efficiency, and give little details about the techniques that you have used to achieve that?

S. Th.: Yes, I will talk about one of my recent buildings. It is 1400 m^2 luxury house located at the mountain side facing Duhok Lake. The place gets really cold in winter and like everywhere in this region it becomes hot in summer. There were no financial restraints, so I was able to spend money on energy efficiency measures. The client did not actually ask for and he was not aware of these aspects. But to be honest I played a significant role in pushing him to do that. I remember in my early discussions with him I asked him how he is going to feel when he moves to the house and find that after spending lots and lots of money on the house, those luxury and oversized spaces are hardly habitable because of extreme indoor thermal conditions. I told him are you going to use three to four A/C units for every single space. Instead, why don't we increase the efficiency of the building and lower your reliance on technology? So I started explaining the significance of these measures, specifically with respect to the building fabric, and indeed he was quite open to my ideas not because of energy bills but he thought that it is a right thing to do. So I received the green light from him to increase the thermal efficiency of the house where possible, so we focused a lot on the fabric.

The external walls are well insulated. They are built with hollow concrete blocks. From inside there is a 50mm thick layer of Rockwool and a layer of gypsum board, and from outside there is a 80mm thick Styrofoam panel plastered with cement. All windows were made by a well-known Turkish company. They are double glazed with a configuration of 6-12-6mm. All are aluminium framed and made with thermal breaks. Some are provided with external shading devices and some with shutters to avoid undesirable sunlight to come in. The concrete roof is also insulated with Styrofoam panels from outside and then covered with a layer of lean concrete and Tiles. For heating, the house relies entirely on radiant heating system (water based). And for cooling, the client preferred to use A/C units. We also considered the landscape design; deciduous trees were placed in a way that shades the outdoor sitting areas.

A combination of local and foreign staffs is involved in the construction process. Most of the work is done by local staffs, but things like high-quality windows and the cladding work are done by Turkish companies. The good thing about the cladding work is that the company provided an interesting workshop for us about the application of such technique.

I can say that like any project, we faced some technical challenges during the construction process. Some labourers were not familiar with the design of the fabric and they were complaining a lot. So I had to stay there most of the time to guide them. Not just for the labourers to be honest, even for me there were some challenging moments. But we all have learned a lot during the process. One of the problems that I remember was that after the installation of Rockwool insulation and gypsum board, those were installing the radiant heating system were unable to hang the radiators on plasterboard. So we had to remove the plasterboard and Rock wool from the wall and then connect wall brackets with the blockwork to support the radiator and then reinstall the insulation layer and plasterboard again. And this took some of the time from us.

The project has not finished yet, but I believe the overall thermal efficiency will be quite good.

R.I.: My turn haha. My case I think will be different because most of the time my clients come with a very limited budget, so you don't have much space to go for things that Mr S.Th. talked about. Generally, the techniques that I try to apply in construction are quite simple, for instance using brickwork for external walls instead of concrete blocks or hollow concrete blocks instead of solid ones. But shading is something that I highly focus on, whether through simple shading devices or vegetation, like the grapevine trellis. Also, avoiding oversized spaces is one of my design strategies.

Researcher: Considering these socio-economic challenges, in your opinion, what might be the possible techniques that we can apply nowadays to increase the energy and thermal efficiency of buildings while ensuring affordability?

S. Th.: I think this is an important question that architects and practitioners must start thinking about. Thermal comfort is becoming an issue for low-income households; they are the people who struggle to pay their energy bills; they need to have a proper environment to occupy with paying less. So we need to develop affordable solutions that minimise energy consumption and at the same time provide better indoor conditions. And this is not something impossible. We generally have in the Middle East a rich history of affordable and environmental design techniques. You can see the architecture of Hassan Fathy as an example which I think if you compare it with some of our modern-day buildings, his buildings perform much better from an environmental perspective. What so-called Earth architecture where you rely on raw-earth materials like clay bricks has been a widely practised technique throughout history. Regardless of its effective role in providing thermal comfort, living in a mud house even helps to remove negative energy from your mind; the texture of its surfaces looks really nice. It is doable nowadays; materials are there you just need to incentify people and practitioners to restore these traditional techniques. And it doesn't have to be done in an old fashion just like village houses; I know people give importance to the appearance of their shelters. So it can be rendered with modern-day materials.

R.I.: It is a good idea and you can involve the community as well. However, building more than one storey might be a bit challenging with rammed earth walls. Also given the modern lifestyle, I think not many people would accept to live in mud houses.

S. Th.: Well, I don't think that building more than a floor will be a problem. I've seen mud buildings up to four storeys. And regarding your point about the modern lifestyle, I agree with you. But as I said before, you don't have to restore these techniques in an old fashion; you can simply render the rammed earth walls with whatever materials they would like to have.

Researcher: But do we have the required technical skills nowadays for such traditional construction techniques?

S.Th.: Well, when something becomes a trend then everybody will adapt to. You just need to provide a couple of workshops and maybe building a couple of pilots where practitioners and workers develop their skills and gain experience with the application of these techniques. This even happens with us when a company introduces a new technique. This is why I think technical skills will not be an issue.

R.I.: Well, traditional construction methods are still practised in Erbil; something like brickwork is quite common there. So I believe they can provide good lessons to other areas if needed.

S. Th.: What Mr R.I. just said reminded me of something happened with us some years ago. I had a design where I used brick walls, and we were struggling for some time to find a bricklayer here in Duhok so we had to bring bricklayers from Erbil. But it was not a big deal.

Researcher: In your opinions, is the building industry ready to adopt energy efficiency standards? And how quickly would the workforce respond to such standards?

S. Th.: Look, quick solutions are not always the best. This process will take some time depending on how keen and committed the stakeholders are in adopting the standards. And obviously we will face some challenges, especially at the beginning. But it is said that "A journey of a thousand miles begins with a single step." So we need to start from somewhere and start addressing all the challenges.

I think the workforce will adapt to the new construction practices as long as they find them relevant to their interest. You can see how advanced they become in the capital after the construction boom that swept the region and the entry of foreign companies, contractors and expertise. Of course the skill gap is bigger here in the city of Duhok than in the capital because you know in the capital the level of development is significantly higher and most of the international companies are based in there, so the local staffs there have more contact with the imported expertise. But generally I believe the workforce can adapt. Maybe the first few projects will be a bit challenging, but I am sure that day by day the skill gap will be minimised, especially if we promoted training opportunities and invested in things like opening training centres and setting up workshops that cover all the required skills. Maybe polytechnic schools can provide all that.

R. I.: Yeah he is right. Not just polytechnic schools but even Universities can take a role in that.

S. Th.: Yeah. So you promote the education-industry collaboration.

Mr. R.I.: Given the contextual factors just to be more realistic, it might be difficult to train for example all practitioners, builders, carpenters and etc. we can start with small groups, let's say 30 to 40 people for each profession. And then for a long-term plan, the polytechnic schools can update their curriculum in a way that covers buildings' energy-efficiency related knowledge and skills so that when people graduate they become ready for these construction practices. You will need these people with such knowledge not only for construction but also for building control bodies.

S. Th.: Yeah. And I think that will even provide many job opportunities for nationals across the country because you will no longer need to import skilled labourers from other countries. So you can say that shifting towards energy-efficient buildings will have many benefits for the region.

Researcher: You talked about the idea of education-industry collaboration, so I would like to discuss that further. Based on the questionnaire survey I carried out, the results indicate that a large proportion of engineers are not that much aware of energy-efficiency measures, so I wonder what might be the reason. Is it because Universities don't provide that knowledge?

R. I.: Yes, our architects and engineers are not up to the required standard from a technical and environmental angle. And I think there are a few factors here. It is first and foremost the architecture and engineering curriculum. As far as I know that architecture and engineering programs in our universities don't really give importance to environmental issues. In architecture departments, for instance, they focus more on aesthetics, theories of architecture, history of architecture. They put little emphasis on the technical knowledge. So when you don't cultivate energy efficiency awareness in universities, and when there is no demand for environmental design and energy-efficient buildings in the real world, don't expect that practitioners would go and acquire that knowledge and develop their skills. Even if they acquired some of that knowledge during the university years, after some years of not practising what they learned, that knowledge would just vanish. Just like when you learn a new language, after some time if you don't practice and use that language, you will forget it.

S. Th.: Look, students are not stupid. They look at the building industry and see what are the things that are applied in the real world and what are the skills and knowledge that they gonna need when they graduate, and so place the highest emphasis on that knowledge during their study. When they find for instance that what generally matters for clients is aesthetics and decorations, they go and focus on that. Even within design studios, when they find that design tutors are not giving importance to environmental issues and within the assessment criteria there is nothing to do with environmental considerations, then they are not going to pay attention to environment-related subjects and incorporate that knowledge in their designs. But if the student knew that his/her design will be downgraded if the design is not developed environmentally no matter how architecturally good the design is, then he/she will definitely take environmental aspects into account. Similarly, if students knew that energy-efficiency, thermal comfort, functionality of building and these aspects are key requirements among clients and construction companies, then they will surely give importance to it and develop their energy-efficient design-related skills to be ready for the real world.

So back to your question, the role of education is quite significant. I could be an example; I had worked for several years with a big construction company designing and constructing many projects, some of them were huge projects like Family Mall [It is a well-known shopping centre in the region]. And sadly all this had been without paying attention to their thermal and energy-efficiency, why? It is because I and my team were not aware of these issues. But since I went abroad and took some courses in sustainable architecture and environmental design, my design approach has significantly changed. Now, I find myself guilty of not thinking of energy performance of all those projects, especially the Family Mall one because energy consumption there is considerably high. If we were aware of energy-efficiency measures and their importance at that time, we would have surely developed a much better design.

Mr R.I.: Yeah, there are environment-related subjects taught in architecture schools but I think the available tutors are not environmentally up to scratch to inspire students to incorporate knowledge from those subjects.

Researcher: Alright! My last question just to conclude, in your opinions what are the best course of actions that would lead to an energy-efficient built environment in the Kurdistan region?

R.I.:

1- We need to increase social equality and social justice. You might think that this is irrelevant. But believe me without this, we are not going to have a remarkable outcome. The established laws should be the same for everyone and everybody must be seen as equal in the eyes of law, not forcing a certain group of people to comply with the regulations while letting people in power to build in whatever way they want.
2- We need to raise public awareness with respect to energy efficiency through education. This should start from primary schools teaching our kids the importance of sustainable resource use and reducing unnecessary consumption.
3- You know conservation and avoiding consumption is at the core teachings of our religion, so I believe it could make a significant influence on peoples' attitudes towards energy consumption. So I think places of worship must take leadership in this matter and push people towards an energy-efficient built environment.
4- Also, we need to develop architecture and construction education in our universities and well prepare graduates. We need a real collaboration between universities and industry.
5- Once you prepared the society and practitioners, you can start establishing regulations that fit our context and that lead to an energy-efficient built environment.

S. Th.: I agree with all the points that he has made, and I would add a couple more. I think stakeholders whether the government, developers or construction companies need to do more in this matter. For instance, it is not going to work if the government enforce some certain construction practices that are hardly applicable in the region. They first need to prepare the market, prepare the workforce and practitioners and provide the required skills, products and etc. and then start imposing energy-efficiency standards.

Transcript 2: An interview with an architect (coded as Z.Y.)

Researcher: What are the key guidelines that your firm follows in designing and constructing projects?

Z. Y.: Unfortunately, we've been working for years in a complete absence of any sort of building regulations. There have been only some zoning restrictions in terms of the height of buildings, the number of storeys, and setbacks. And in recent years, they added a few more restrictions for building within the area around Erbil Citadel which is inscribed on the World Heritage List. They imposed some certain materials, e.g. bricks, to be used for external rendering in that zone.

Other than that, there have been no building regulations to follow in designing and constructing projects. This is why within a neighbourhood you see dwellings with different designs, different materials, and different colours led to kind of visual pollution indeed. Another important thing that we're missing here in Kurdistan is Building Rating System which is widespread in developed countries.

The region could have taken advantage from developed countries and adopt their regulations with adjustments of course in a way that fits our context. But unfortunately we did not.

Researcher: Okay then in the absence of building regulations, what are the factors affecting your design and construction decisions?

Z. Y.: The decisions are heavily influenced by our experience in the industry and the requirements of clients and their desires. When designing a dwelling, for example, we always try to have a detailed conversation with the household to understand what would be the things that they like to have and what would be the things that they don't like to have. Also, we try to know the shortcomings of their previous house and consider all that in the design. However, their desires often tend to mimic others. Sometimes you have a client (a family of two), their requirements are just like a family of ten. Even when you explain and try to convince them for some environmental design ideas in terms of natural ventilation and using local building materials for instance, they would still prefer something that they have seen on the ground and a house that is similar to what others have built. So you could say that the issue is to some extent related to their mentality and their awareness. Also, the local authority should have enforced all those design considerations in fact and directed the construction practice towards the right direction.

If you look at those old neighbourhoods around the citadel, there are some important environmental strategies in the houses such as courtyards, shading elements, local materials, the orientation of openings, the thickness of the external walls and others. But nowadays, instead of recovering such environmental strategies, we simply neglected them. Even in the General hospitals that were built by the Japanese in the 1980s all over Iraq, they have reused most of these traditional environmental design elements. Whilst in nowadays hospitals you don't find them.

The buildings nowadays are simply like radiators in the summer and freezers in winter thereby demanding a lot of energy. This I would say is driven by two main factors:

- Practitioners on the ground who have not paid much attention to those environmental issues
- The absence of building regulations and enforcement

Researcher: In your opinion, what might be the driver behind the lack of desire towards energy-efficient designs among clients?

Z. Y.: Well, they often follow the conventional route and pay more attention to aesthetics which I would say has become more like a trend among people. This is beside the cost implications of energy efficiency measures and uncertainty of the potential savings. In many cases, I had clients who wanted to well insulate their houses but after knowing the cost implications of that they change their mind either because they don't have enough budget or they think it is not worth it despite the fact that many of them spend too much money on decorations and expensive finishing materials such as marble. This is why I think much more effort needs to be spent on raising public awareness, introducing the benefits of energy-efficient buildings and the idea of long-term investment to the community. And I think the Media could be quite effective in that.

Another problem is that they are highly influenced by the advice of non-professionals like normal people, their friends and so on more than us. We have made designs for people with different levels of education, and what I noticed with our clients that sometimes the level of education influences their desires and requirements but I could say that those who were interested in energy efficiency were generally limited. The majority follow the conventional route of construction. Over the last decade, however, the desire for energy-efficiency measures has increased among clients particularly after the construction of some relatively low-energy buildings which were conducted by foreign companies in Erbil, but you could say that there is a lack of trust in the sense that our construction labourers are not skilled enough to implement such measures and again you have cost barriers associated with foreign and imported workforce.

Researcher: In your opinion, what might be done to overcome those cost barriers?

Z. Y.: Learning from the past and recovering the traditional typologies with respect to the design elements, construction techniques and etc. One of the examples that were used widely is the grapevine trellis. With all the benefits that it has in terms of shading, aesthetic, growing grapes, growing grape leaves for Dolma [It is a famous dish in the region where the leaves are stuffed with rice], and etc. people no longer have them in their homes nowadays mainly due to the fallen leaves and cleaning. This is weird. It doesn't cost anything and has many benefits.

Also, people can avoid going over the budget while increasing energy efficiency by avoiding additional costs that spent on expensive materials for rendering and avoiding building far more floor area than they need. Then these savings can be sufficient to add energy efficiency measures to the building. But this again could be done when you raise their awareness and introduce the benefits of energy efficiency measures to them. We try to convince our clients to avoid having more floor area than their need and instead increase the green space within the house for instance.

Researcher: What are the current construction techniques that are used in Erbil that have potential for energy saving?

Z. Y.: Well in terms of building materials, people are starting to use bricks instead of concrete blocks, Styrofoam insulation sheets are used for external walls and roof, double glazed windows, suspended ceilings with air gap, and a few other techniques.

But I could say that not all the products available in the market are up to standard; you have to be careful about the quality of materials and products that you use. Also, not everything that you wish to apply in the construction is available in our market. Sometimes, you find some good quality construction materials/products online that could be very effective in making the building more efficient but unfortunately you don't find them in the market. So either you have to change or import them from a country like Turkey which again take us to the cost-related issues as you know you have transportation costs and etc. And sometimes you cannot buy and import a small quantity of a certain material for just one building because this will cost you a lot. And given the political circumstances, we both know that importing something is not an easy task in this country that everyone could do. So the government, mainly the competent bodies, and entrepreneurs should take the leadership role in that.

Another point I would like to make is that temperatures here reach up to 50C sometimes, so thermal insulation alone cannot protect the occupants from the extreme heat and provide comfortable conditions. There are other environmental considerations that we, architects, have to take them into account in the design.

And remember it is not just the construction techniques and design that make a building use less energy, but the way occupants operate their buildings is also critical. Twenty years ago, you know the majority of us used to sleep at the rooftop during summers without using air conditioners or air coolers, but now you see that this has been changed. Most people rely on cooling technologies causing much higher rates of energy consumption. But given this paradigm shift in people's behaviour, we designers and builders must change the way we think of designing and building. What we can do is to optimize the quality of building envelope to reduce cooling and heating loads. I think the concrete roof slabs that we are using are one of the main construction weaknesses that we must address.

Researcher: When a company introduces a new construction product or technique into the market, how do they usually make practitioners and labourers aware of its specifications, benefits and applications?

Z. Y.: Of course, they want to increase sales. So despite advertisements, they provide all the necessary instructions through catalogues and other forms, e.g. websites, where you can find all the relevant information, video tutorials and so on online. But with the labourers who are uneducated, these forms of providing instructions are not effective, which is why providing workshops on the ground is important. This is not a problem I think because as I said they do whatever is needed to increase sales.

Researcher: You also mentioned that temperatures in Erbil reach up to 50C, is there any alternative to air-conditioners so that people can cool their houses down with less use of energy?

Z. Y.: Well, evaporative air coolers are used widely as an alternative, but I can say that they are not always used correctly. They are either installed not in a shaded area or they are connected to spaces with no air outlets which make them less effective.

For heating, you have various types of portable heaters, e.g. LPG gas, kerosene and electric heaters. And in recent years, some people started to use radiant heating system (water-based) being installed by some Iranian professional at the beginning but now there are local ones who do the same job but all the necessary tools and components are imported from neighbouring countries, mainly Turkey and Iran, they are not produced here.

Researcher: In your opinion, is building industry ready to adopt energy efficiency standards?

Z. Y.: Well, by adopting energy efficiency standards, we will surely face some challenges at the beginning especially technical ones, e.g. skills gap. And I think the level will vary from a city to another as in the capital for example you have much more advanced construction skills than other areas.

The problem with skills gap is that we don't have vocational training centres or something like Skills Certificate Scheme to make sure that those engaged in construction whether labourers or professional cadres have the required skills. This is something that policymakers really need to address because we architects and engineers struggle a lot with this issue. Many of them, for example, are not educated and find it hard to read and understand the building drawings and diagrams. When we pick and employ someone, e.g. a bricklayer, in a project, there is no such certificate so that we know how experienced they are. So we rely on their reputation and the works that they have done before.

But anyway back to your question, we will face some practical challenges, but I think this is normal when you introduce a new idea/technique into an area. Again, the workforce and professional cadres might not be able to respond immediately and perform correctly. But they can adapt through a gradual process with of course having training programs. I can say based on my experience, our professional cadres and labourers have that desire to learn new techniques so it will be just a matter of time to adapt. Especially if the related authorities imposed the standards, then the workforce, construction companies, contractors and etc. will have no choice other than learning the required skills and adapting to the introduced construction methods.

Also, there are foreign staffs available who can take an important role in such an initiative. For instance, you know because of the political instability in Syria there are many Syrian practitioners and labourers working here in the construction sector. This is additionally to Iranian and Turkish ones. They are very good and well experienced indeed, especially those who have been involved in constructing mega projects. And I would say they are even more patient than the local ones [This was stated in a funny way] and sometimes even cheaper. So you can have a combination of local and foreign people.

And you can see how successful this combination has been in those housing developments and mega projects that been built in recent years across the region.

Researcher: Talking about those housing developments, in your opinion, how successful they have been in providing comfortable indoor conditions to users?

Z. Y.: Well, when you look at those housing estates from outside, I mean aesthetically, they look good. But when you go inside and look at some of the details, there are shortcomings. In terms of open spaces and ventilation, I can say that some of the projects are well designed. But in terms of the building envelope and construction materials, they have similar issues to conventional residential units. The external walls and roof, for instance, are made of concrete with no insulation. So you can say that heat gains or heat loses issues are there.

I believe that they could have been designed in a more efficient way. But the problem is that in the early stages when the design is reviewed by the related authorities and municipality for approval, they don't pay attention to energy and thermal comfort-related matters. One reason is that there are no regulations in that regard to be enforced. Also, those who review and approve designs often lack such knowledge, and this happens when the government employ ill-prepared people, e.g. new graduates with no or little experience, in such critical posts. It is nonsense. Just a few simple questions: does it make sense having the exterior of many of those buildings coated with dark coloured materials, e.g. black marble, which absorb heat in the light of the strong sunlight that we have? Does it make sense having north-facing windows with shading devices and south or east-facing windows without shading devices? These indicate the lack of awareness among designers and those reviewing and approving designs. So I think the government needs to restructure these bodies and resolve this issue or at least train these people through workshops and so on, and also involve those who are specialised in energy-efficient buildings in the review and approval process.

Transcript 3: An interview with a regional planner (coded as H.J.)

Researcher: In your opinion, what are the key challenges in shifting towards energy-efficient buildings?

H.J: Shifting towards energy-efficient buildings is quite doable. But let me make it simple for you, the transforming process needs a political will and campaigns that seek to raise public awareness. KRG should take the leadership role in that and start with the necessary steps to promote this shifting within the building sector. The government needs to invest in energy efficiency, incentify people, and introduce subsidies to remove financial barriers. For instance, they could financially support people to insulate their houses to scale up energy efficiency and short up energy demand or to go for renewable energy sources like what some of the European countries are doing. For example, my brother lives in Sweden, the government there introduced subsidies to encourage households to install heat pumps in their dwellings which, in a long-term run, is something quite useful for both parties. So similarly to that, in the light of the strong sunlight that we have here in Kurdistan, the government could invest in solar energy as part of a national energy strategy. You know here normally the demand for energy is at its highest in summer due to increased air temperatures, so the government could incentify households to install PV panels on the top of their houses through subsidies programs to produce some of the electricity they need for cooling purposes. This will substantially reduce the burden on the energy sector and reduce all the pollution that is caused by private generators and thereby reducing their harmful effects on human health (e.g. respiratory diseases that people widely suffer from) and the environment that we live in. In this way, you also raise the level of satisfaction among people who have been struggling with the constant power shortages for decades and improve their living conditions and their trust in government. The required tools and materials are available in the market but there is no encouragement to install such a system. And most people are not aware of its benefits over the lifecycle of the building to invest in.

There are two key challenges that I would like to shed light on:

The first one is related to the way people think and plan. People generally are not long term thinkers and this is mainly attributed to the political instability and uncertainty that we've been going through throughout history [….. here the interviewee is mentioning some of the wars that took place in the region]. No one would build a house to be efficient for, let's say, the next 20 years because they think that the region is vulnerable to external threats from their neighbours at any moment. So you could say that psychologically and also culturally people are not prepared for long-term thinking and I believe shifting to energy-efficient buildings surely needs long-term thinkers.

The second one is political immaturity, especially at the government level. This is in terms of the relative absence of state institutions and political will for long-term planning. We don't have this. If you look at some of the western countries, there are certain boards which are responsible for setting up the detailed strategic plans for things like economic development, infrastructure, social planning, and so on. Whilst in our country, people in power could change the direction the way they wish with no robust and long-term plan in hand leading to sort of chaos (having thousands of newly built housing units unoccupied across the capital is one of the outcomes). The one that we have is the KRG's Regional Strategic Development Vision for 2020 which was set by the Ministry of Planning in association with UN organisations and I can say that people have no idea about such plan at all.

So I would say if there is political will, then they could do a long-term strategic plan and provide the appropriate tools to apply it. One area that really needs to be developed in the first place is the quality of education in our universities and institutes as it has progressively deteriorated. Most of the graduates I would say are not well-prepared for the real-world workplace. Another thing that we really need to work on is the rules of professional practice and the union of engineers (the syndicate).

Researcher: Can you talk about the nature of the project that you've been working on with the government regarding establishing Building Regulations? At which stage are you at the moment and what are the key contents?

H.J: Yes sure. For three years with UN-Habitat, We (a team of local and international experts in association with an Italian university) been working on a project aimed to establish building control regime in Kurdistan region which covers everything related to building. The work was being observed by a board of 17 members who were representing different ministries and related bodies. We first started with analysing the current nature of construction in the region addressing eight different building-related aspects including the building permit procedures, government oversight of the construction process, the way engineering firms and construction companies work, health and safety in construction practice, and other aspects which you can find in the draft [The interviewee provided all the necessary documents regarding this project]. We studied and assessed the current situation of each aspect and then provided recommendations.

One of the early points that we realised was the absence of the Building Act which is the main legislation under which the building codes are made. So we reviewed some of the European building regulations, but you know you can't just adopt them as they are because they might not be appropriate to our context. We also reviewed those been developed by the Iraqi government recently, I think they are around 13 to 14 building codes which were inspired by the national building codes of Jordan. But based on the evaluations that we carried out to the Iraqi ones, we found some sort of immaturity and lack of appropriateness to the context of Kurdistan region especially from technical aspects. So we decided to develop our own Codes; we suggested 25 Building Codes to be established. Out of these, as an initial stage we developed six of them including regulations related to energy efficiency, fire safety, and so on [all are available within the given documents]. Of course, it was an early draft which needed to be developed further. So we conducted focus groups where there were some key stakeholders such as the ministers of Planning, Housing, municipalities and public services and the governors for possible feedback to develop the draft further. So you could say that there have been persistent interventions from the involved bodies and that the draft has been under progress for almost 2 to 3 years. But still if you compare our codes with the international standards, I would say they are not as developed as they should be.

Alongside that, upon the request of the minister of Planning, we (in association with a Dutch expert) even developed a detailed plan for the enforcement of the codes. However, the government has not reviewed the final draft yet. And the approval process could take some time because one should not forget that Kurdistan is not an independent country and it is still part of Iraq, so it is not that easy to put in place such legislations the way we wish which could lead to conflicts with the federal government.

Researcher: You mentioned that the draft is not developed as it should be, can you elaborate on that please?

H.J: You know it is still a proposal or you may call it an initial effort and I can say that they [the proposed codes] are not mature enough and surely need further development. But you have to remember that we are in an environment where we lack the enforcement of some of the basic building regulations. Therefore, all bodies involved agreed at the beginning that for this stage the codes must be developed to a degree that remain applicable in our context taking into account all the constraints, all the socio-economic and socio-technical challenges that we have in order to achieve successful enforcement. And this could be a crucial starting point but I think periodical updates will be necessary to allow adjustments to take place and ramp up the policies.

I said that and I am sure you will also realise that when you compare the proposed codes with the European ones for example. I am personally not that much aware of all the international standards, but I have good background knowledge about the building regulations in the

Netherlands as I worked there for almost two decades. In the Netherlands and I think across Europe, when you apply for building permit there are certain requirements in relation to the energy efficiency of the building. It says, for instance, energy use per square meter of floor area should not exceed a certain number of kWh. So design professionals take all the requirements into account when they design, and within the team there are technical experts who are experienced in building physics. They do all the necessary evaluations for the design, and if the predicted energy consumption is higher than the standard then they improve the design and minimize it. But we cannot have the same procedure here at this stage; we lack technical experts indeed who can do assessments for things like thermal performance of the building and so on. Our professionals, the majority of them, lack this knowledge. They are not always aware of the energy measure. So given these technical constraints besides other political and financial challenges that we discussed, you can't be too ambitious and adopt those developed regulations as they are. They should be at a level that fits our context and then through a gradual process, they could be updated and developed further and further within a timeframe.

In our proposal, in relation to energy efficiency regulations, we focused mainly on the building fabric, e.g. the insulation of the roof and walls, glazing type and some other basic things that you can find in the draft. This is a bit anecdotal, but one of the things that we were advised by one of the involved bodies regarding the U-value is that not too many understand the U-value, so instead, they suggested to specify certain insulation types with certain thicknesses to be installed. And this is frustrating when you see how design professionals nowadays in this country are lacking some basic technical knowledge which architecture students were being taught in universities in the 1970s and 1980s. I remember when I was at the undergraduate level in the 1980s, we had courses regarding 'professional practice' where we studied things like building regulations, British Standard Codes of Practice and so on. But it seems to me that technical knowledge is paid no attention to at our universities nowadays. So this takes us again to the point I mentioned earlier which is the quality of architecture and construction education and its crucial role in preparing graduates for successful adoption of energy efficiency standards. This is why at some point we tried to engage the architecture schools and as far as I remember we carried out workshops at five universities across the region to get them involved and encourage them to pay more attention to these issues in their curriculum

So back to your question, yes I would say the proposed codes are not as developed as they should be, but I believe this is a good starting.

Appendix C. A sample of semi-structured interviews for post-occupancy evaluation in case studies

SECTION A: **Background Information**

1. **Gender:** Female
2. **Age:** 62 years
3. **Marital status:** Widow
4. **Employment status:** Unemployed (housewife)
5. **Socio-economic status:** Low-income (the average monthly income is around 300-350 USD)
6. **Highest level of education:** Literacy school (level-6)
7. **Tenure category:** Owner occupier
8. **How many people live here?** Just me and my son, who goes to work every day from early morning till late afternoon. **(2 people)**
9. **How long have you been living in this house?** We moved to this house in 1985, and I have been living here since that time. But the house was built in 1970s, but I am not sure in which year exactly was built.

SECTION B: **Building attributes/ energy consumption**

10. **House type:** Single-family dwelling
11. **Number of bedrooms:** There are two bedrooms, but we no longer use one of them as a bedroom because it is thermally inappropriate. I mean it gets very cold in winter and very hot in summer, so we use it like a storage area storing our clothes and some other stuff, and that is why its door is always closed. In fact, nothing differentiates the other spaces from that room [*she means here the unusable bedroom*], I mean in terms of their construction details, except that that room is more exposed to direct sunlight in summer.

    Where do you sleep then?

    I sleep in the living room, and my son sleeps in the other bed room.

12. **The best building attribute:** There is nothing really to highlight but I can say that the best thing is that it is close to city centre. **(Its location)**
13. **The worst building attribute:** There are many which I am sure that you [*she means the researcher*] have already observed, but the worst one is air infiltration especially through windows. Sometimes, you can clearly hear the sounds of air infiltration from

outside especially during windy conditions. And as you [she means the researcher] see, I used sealing tape (adhesive tape) to prevent that, but it is not very effective.

14. **Your average monthly electricity bill from the national grid (public network):** Around 10 to 15 USD
15. **Your alternative source of electricity supply:** It is a shared generator operating at neighbourhood level which provides us with **3 amps**.
16. **Your average monthly electricity bill from your alternative source of electricity supply:** 30 USD.

SECTION C: **Indoor thermal conditions**

17. **What are you using to keep yourself comfortable?**

Space/ Control	Open Windows	Open Doors	Ceiling fan	Split A/C	Air cooler	Roof-top water sprinkling	Floor water sprinkling	Wearing wet clothes
Living room		✓	✓	✓		✓	✓	✓
Bedroom		✓	✓	✓		✓		
Kitchen	✓	✓				✓	✓	✓

18. **How often do you use them?**

Well, let me explain it in two different cases: **a.** when electricity is supplied from the national grid and **b.** in the absence of electricity from the national grid. **In the first case**, I often leave both air-conditioners On, and close the doors of the living room and use some thick fabric sheets as a door bottom seal to keep cool air in. Sometimes, I leave bedroom's door open to cool the hallway, but the size of the unit that runs in the bed room is small, so it does not make a significant change in the hallway. In fact, nobody is using the bedroom over the day, but the reason why I leave it On is that I store some food there, and the power supply from the national grid has been cheap by far, so I prefer to leave it On. Especially, the electricity supply from the national grid during this summer is better than last years, I mean in terms of electricity shortage. And this is apparently because of the general elections that will be held on September 30. [*Then she said in a funny way that* the ruling party is trying to make some reputation].

In the second case and as soon as the air-conditioner stops running, the indoor environment changes rapidly, I mean it becomes warm causing discomfort. So I open the doors, including the entrance door, and turn on the ceiling fan, and sometimes especially in hot days I wear wet clothes and sometimes I dampen my clothes couple times a day. And because I used sealing tape to prevent air infiltration through windows, I can't open them especially in the living room.

Me: Why don't you just leave air-conditioners on if the indoor environment gets warm as you say?

We cannot switch on A/C to adjust the thermal environment while we have electricity from the neighbourhood generator because it costs a lot and we cannot spend most of our income on that even though we want it.

Me: I see a platter full of plastic cups of frozen water here in the living room, may I know why?

Since I drink cold water a lot during hot periods [when A/C goes off], *I bring several cups of ice water together from time to time to avoid going to the warm kitchen where the refrigerator is located for as long as possible."*

Me: What about water sprinkling that you mentioned earlier? Well, that depends on the water supply, I can't say that I do wash the floor and sprinkle water on the roof-top daily, but if not daily I can say few times a week. I'm used to take the water hose to the roof-top before midday or in the morning sometimes and leave it for few hours to remove heat from the roof. If you can visit us tomorrow, you will probably see that and you can take pictures if you want to. My mom used to do the same at the time [....] when I don't do that, we feel excessive heat coming down through the roof.

Me: I see two air coolers also around the house, but you did not mention them. Do you use them? Actually, we no longer use them.

May I know the reason please? To be honest, we had used air coolers for years and they were good enough, but most of the people around us, I mean our relatives, shifted from using air coolers to using air-conditioners over the last years, and I don't know how to explain this for you, but we were really hoping to follow them and have AC. So you can say it was kind of social influence. And fortunately, a medical doctor donated two new Split Air Conditioners for us which are the ones that we are using now. But the problem is that we cannot run them while we have electricity from the neighbourhood generator because it costs a lot and we cannot afford that.

Anything else you would like to add about thermal control? Yes, as you see I remove the carpets at the beginning of hot season and leave the concrete floor exposed till the beginning of winter.

[*In the next questions she had difficulties to differentiate between some of the given scales*]

19. **Thermal Sensation in the rooms:**

When electricity is supplied from the national grid	**Cold**	**Cool**	**Slightly cool**	**Neutral**	**Slightly warm**	**Warm**	**Hot**
Summer daytime?				✓			
Summer night?			✓				

In the absence of electricity from the national grid	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
Summer daytime?						✓	
Summer night?						✓	

[*Her choices for the summer night are based on the living room indoor environment as she sleeps there*].

20. **Humidity in the rooms:**

	Very dry	Dry	Slightly dry	Neutral	Slightly humid	Humid	Very humid
Summer daytime?			✓				
Summer night?			✓				

[Again here she highlighted that she is used to dampen her dress in hot days]

21. **Air movement in the rooms**:

	Very little	Little	Slightly little	Neutral	Slightly much	Much	Very much
Summer daytime?				✓			
Summer night?				✓			

[Here, she highlighted the role of ceiling fans]

22. **Overall Indoor environment**:

	Very uncomforta ble	Uncomforta ble	Slightly uncomforta ble	Neutral	Slightly comfort-table	Comfort-table	Very comfort-table
Summer daytime?		✓					
Summer night?		✓					

[In this question she said that: if the electricity prices will be going up as we hear from news, then we will probably be unable to run A/C, so the indoor environment will be very uncomfortable]

23. **Thermal preference**:

	Much cooler	Slightly cooler	No change	Slightly warmer	Much warmer
Summer daytime?		✓			
Summer night?		✓			

24. **Your typical clothing at home**: Kurdish dress [*It is a long dress*]

Appendix D. Monthly Energy Consumption Readings

K37

	A	B	C	D	E	F	G	H	I
1	English Village, Villa No. 98, power usage status								
2	Date	Reading Time	Generator Blance	Smart meter readings for the Generator	Smart meter readings for National Grid	Summation of both readings	Electricity consumption kWh *through* Generator	Electricity consumption kWh through the National Grid	Total Consumption
3	01-Aug-18		172	9782	36532	46314			
4	02-Aug-18		161	9793	36574	46367	11	42	53
5	03-Aug-18		143	9811	36611	46422	18	37	55
6	04-Aug-18		129	9825	36636	46462	14	25	39
7	05-Aug-18	7:15 AM	106	9848	36688	46537	23	52	75
8	06-Aug-18		87	9867	36776	46644	19	88	107
9	07-Aug-18	6:00 PM	66	9888	36840	46729	21	64	85
10	08-Aug-18		444	9910	36922	46832	22	82	104
11	09-Aug-18								0
12	10-Aug-18		415	9939	37080	47020	29	158	187
13	11-Aug-18	5:00 PM	401	9953	37154	47107	14	74	88
14	12-Aug-18								
15	13-Aug-18	7:30 AM	373	9981	37238	47220	28	84	112
16	14-Aug-18	7:15 AM	353	10001	37297	47298	20	59	79
17	15-Aug-18								
18	16-Aug-18	7:10 AM	320	10034	37403	47437	33	106	139
19	17-Aug-18	10:30 AM	310	10044	37482	47527	10	79	89
20	18-Aug-18	7:10 AM	290	10064	37546	47610	20	64	84
21	19-Aug-18	9:15 AM	231	10123	37597	47720	59	51	110
22	20-Aug-18	9:15 AM	209	10145	37642	47788	22	45	67
23	21-Aug-18								
24	22-Aug-18		195	10159	37742	47902	14	100	114
25	23-Aug-18		185	10169	37773	47942	10	31	41
26	24-Aug-18		167	10188	37814	48002	19	41	60
27	25-Aug-18	10:00 PM	111	10243	37837	48081	55	23	78
28	26-Aug-18								
29	27-Aug-18	7:00 AM	83	10271	37920	48192	28	83	111
30	28-Aug-18	7:00 AM	68	10286	37967	48253	15	47	62
31	29-Aug-18	7:00 AM	49	10306	38006	48312	20	39	59
32	30-Aug-18	1:00 PM	33	10321	38079	48401	15	73	88
33	31-Aug-18	10:15 AM	23	10331	38131	48462	10	52	62
34									
35		***Total Consumed electricity during August 2018 for Generator & National Power***					**549**	**1599**	**2148**

	A	B	C	D	E	F	G	H	I
1	English Village, Villa No. 98, power usage status								
2	Date	Reading Time	Generator Blance	Smart meter readings for the Generator	Smart meter readings for National Grid	Summation of both readings	Electricity consumption kWh through Generator	Electricity consumption kWh through the National Grid	Total Consumed
4	01-Sep-18	10:00 AM	412.37	10343.00	38212.00	48555.00	12.00	81.00	93.00
5	02-Sep-18	7:00 AM	391.00	10363.00	38256.00	48619.00	20.00	44.00	64.00
6	03-Sep-18	7:10 AM	376.00	10378.00	38273.00	48651.00	15.00	17.00	32.00
7	04-Sep-18	7:15 AM	362.87	10392.00	38340.00	48732.00	14.00	67.00	81.00
8	05-Sep-18	7:10 AM	345.24	10409.76	38394.00	48803.76	17.76	54.00	71.76
9	06-Sep-18	7:10 AM	322.45	10432.55	38421.77	48854.32	22.79	27.77	50.56
10	07-Sep-18	9:20 AM	309.45	10445.00	38443.00	48888.00	12.45	21.23	33.68
11	08-Sep-18	9:35 AM	299.80	10455.21	38501.38	48956.59	10.21	58.38	68.59
12	09-Sep-18	8:00 AM	281.27	10473.00	38528.73	49001.73	17.79	27.35	45.14
13	10-Sep-18	7:10 AM	263.76	10491.24	38563.53	49054.77	18.24	34.80	53.04
14	11-Sep-18	7:30 AM	254.31	10500.69	38608.25	49108.94	9.45	44.72	54.17
15	12-Sep-18	7:05 AM	238.14	10516.85	38639.39	49156.24	16.16	31.14	47.30
16	13-Sep-18	7:10 AM	213.25	10541.75	38656.37	49198.12	24.90	16.98	41.88
17	14-Sep-18	9:15 AM	200.25	10554.79	38691.27	49246.06	13.04	34.90	47.94
18	15-Sep-18	9:30 AM	173.92	10581.08	38719.09	49300.17	26.29	27.82	54.11
19	16-Sep-18	7:10 AM	156.17	10598.83	38751.39	49350.22	17.75	32.30	50.05
20	17-Sep-18	7:00 AM	145.93	10609.07	38792.26	49401.33	10.24	40.87	51.11
21	18-Sep-18	7:05 AM	125.77	10629.23	38815.89	49445.12	20.16	23.63	43.79
22	19-Sep-18	7:10 AM	111.14	10643.86	38840.76	49484.62	14.63	24.87	39.50
23	20-Sep-18	9:05 AM	90.53	10664.47	38881.38	49545.85	20.61	40.62	61.23
24	21-Sep-18	9:30 AM	77.87	10677.13	38891.63	49568.76	12.66	10.25	22.91
25	22-Sep-18	9:35 AM	65.57	10689.42	38934.52	49623.94	12.29	42.89	55.18
26	23-Sep-18	7:15 AM	58.78	10696.22	38976.06	49672.28	6.80	41.54	48.34
27	24-Sep-18	7:20 AM	47.25	10707.75	39004.35	49712.10	11.53	28.29	39.82
28	25-Sep-18	7:15 AM	34.14	10720.86	39019.94	49740.80	13.11	15.59	28.70
29	26-Sep-18	7:10 AM	18.96	10736.04	39032.32	49768.36	15.18	12.38	27.56
30	27-Sep-18	7:20 AM	7.79	10747.21	39056.15	49803.36	11.17	23.83	35.00
31	28-Sep-18	7:15 AM	1.51	10753.59	39084.05	49837.64	6.38	27.90	34.28
32	29-Sep-18	7:10 AM	390.79	10764.20	39105.02	49869.22	10.61	20.97	31.58
33	30-Sep-18	10:30 AM	374.36	10780.64	39120.42	49901.06	16.44	15.40	31.84
34	01-Oct-18	8:30 AM	371.70	10783.30	39147.94	49931.24			
35						0.00			
36		***Total Consumed Power during August 2018 for Generator & National Power***					**437.64**	**908.42**	**1439.06**

A sample of the way electricity readings were recorded in Case study 4

Appendix E. A two-storey House designed based on fabric first principles by the author

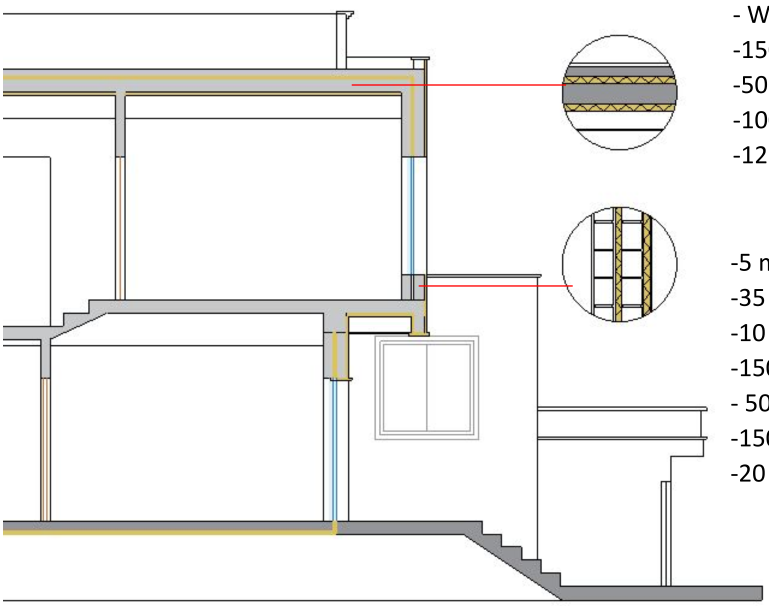
The initial design

E.1. General Information

	General Information
Architect	Haval Abdulkareem
Location	Duhok, Iraq
Starting date	May 2020
Completion	June 2021
House Type	Two-storey, attached
Floor area	244 m^2
Roof's U-value	0.3 W/m^2K
External walls' U-value	0.26 W/m^2K
Windows' U-value	1.5 W/m^2K
Window type	Low-E sliding windows, aluminium framed, double glazed, and argon filled

E.2. Plans and Section

Ground floor plan (left) and 1st floor plan (right)



<u>Roof construction layers</u>

-50 mm thick protective screed
-50 mm thick XPS insulation
- Waterproofing layer
-150 mm thick structural slab
-50 mm thick XPS insulation
-100 mm cavity
-12 mm thick plasterboard ceiling

<u>Wall construction layers</u>

-5 mm thick plaster rendering (external)
-35 mm thick EPS Insulation
-10 mm thick Cement plaster
-150 mm thick concrete block
- 50 mm thick XPS insulation
-150 mm thick thermal block
-20 mm thick gypsum plaster (internal)

Section showing some construction details

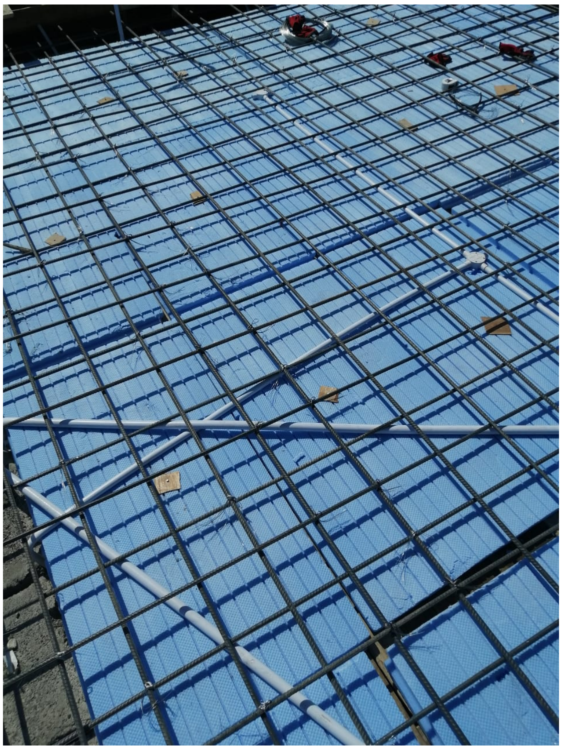
E.3. Construction phases

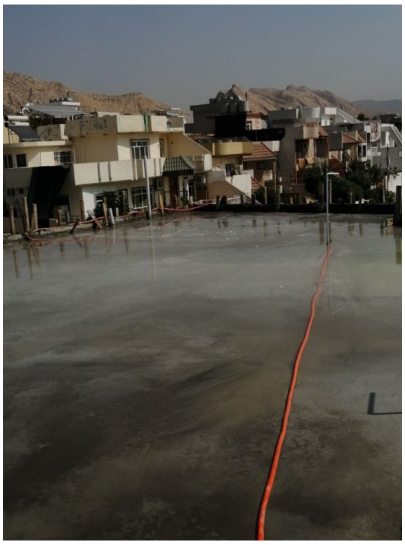
- The Building Plot

- Foundation work

- Walls construction, Insulation and Waterproofing

- Roof construction




- Finishes and closures