Domestic Energy Use and Suppressed Energy Demand in Hot-Arid Climate

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DEDICATED TO

I dedicate this thesis to:

The only person in the world who believed in me and my ability to be who I am

and where I am now,

My late brother **Ghanim Alwan Shallal**,

I miss you and this one is just for you.

Domestic Energy Use and Suppressed Energy Demand in Hot-Arid Climate

ABSTRACT

The provision of energy services in many developing countries is insufficient to meet the growing demand for energy. The lack of access to energy infrastructure and poverty often result in unmet or suppressed energy demand, an appreciation of which is critical for the planning and development of energy infrastructures and services. Buildings account for 36% of global final energy consumption and 40% of carbon equivalent emissions. Therefore, understanding how suppressed demand is manifest in building energy consumption is essential to project future demand. However, many gaps exist in the literature on the nature and variability of suppressed energy demand in developing countries, especially in the hot-arid regions that rely on energy-intensive cooling to maintain indoor thermal comfort. Anthropogenic global warming and the resulting rise in surface temperatures will likely exacerbate this situation. This research aims to fill the gap in existing knowledge by developing an analytical method for the estimation of hourly suppressed energy demand in buildings and by investigating its temporal variability, and its influence on energy use and indoor thermal environment. Energy use was monitored at a resolution of 12-sec intervals, while the indoor and outdoor environmental conditions were monitored at a resolution of 5 minutes between January 2017 and August 2018 in seven case studies in Baghdad to identify baseline energy consumption against monitored ambient conditions. A questionnaire and semi-structured interviews were conducted among 210 households to investigate their energy use with the related dimensions including socio-economic influences and environmental systems.

The analysis of the energy use and environmental data resulted in the development of a method to estimate suppressed energy demand and its environmental implications. The findings revealed that the average annual suppressed demand for all case studies was 7,846 kWh, which was equal to ~77% of the total annual energy use average. Suppressed demand was highest during summer in all case studies with 3,860 kWh higher than the average of spring, autumn and winter with 1,553 kWh, 1,421 kWh and 1,348 kWh respectively. This seasonal variability reflected on both hourly and daily suppressed energy demand amount, where they were the highest in summer, with a maximum of 8.5 kWh and 135 kWh respectively. However, the projected demand among the households was 18,089 kWh including suppressed demand, against the average annual use of 10,243 kWh.

The share per person of the annual amount of energy use was 1,789 kWh/capita·year against the estimated demand per capita of 3,094kWh/capita·year.

Environmentally, 87% of the hourly measurements of the ambient conditions in the summer season were located within climatic zones where more air movement and humidity are required. The indoor thermal environment affected by both the suppressed energy demand and the severe outside weather conditions. More than 90% of captured hourly data in all monitored spaces in summer months needed more evaporative and mechanical cooling to maintain the environment within thermal comfort limits. This situation is expected to be worse with the trend of increasing the ambient temperature all over Iraq from 2 to 7 times faster than the global temperature rise. Moreover, covering the current housing shortage and the projected increase of housing units from 3.94 to around 8.4 million by 2030, more electricity supply will be needed, which could be hindered by suppressing the energy demand. The economic burdens of the suppressed energy demand resulted from the households' attempting to bridge the demand-supply gap, especially in summer. For example, the monthly expenses for electricity from community generators during summer was the highest compared to other expenses for electricity (national grid and community generators in winter), where it was between 251,000 and 300,000 IQD, which equal to £160 to £193 per month for some households. The lack of consideration of suppressed demand can result in an underestimation of future projections by more than three-fourths of the current estimations and adversely impacts the indoor thermal environment. The method that was developed to estimate suppressed energy demand has the potential for wider application in both energy and environmental studies in Iraq and other developing countries in similar circumstances.

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LIST OF ABBREVIATIONS

The following abbreviations have been used in this thesis:

NG	National Grid
CG	Community Generator
AT	Ambient Temperature
DBT	Dry-Bulb Temperature
RH	Relative Humidity
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
IEA	International Energy Agency
EIA	Energy Information Administration
IKN	Iraq - Knowledge Network Survey
OECD	Organization for Economic Cooperation and Development
HVAC	Heating, Ventilation, and Air-Conditioning
OPEC	Organization of the Petroleum Exporting Countries
UKERC	UK Energy Research Centre (UKERC)
GDP	Gross Domestic Product
ASEAN	Association of Southeast Asian Nations
MoWE	Ministry of Water and Electricity
INPC	Iraq National Population Commission
EASO	European Asylum Support Office
CSO	Central Statistical Organization
MoCHPM	Ministry of Construction and Housing and Public Municipalities
MoP	Ministry of Planning
PMV	Predicted Mean Vote
PPD	The Predicted Percentage of Dissatisfaction
CO_2	Carbon Dioxide
PG	Privet Generator
LGC	Liquid Gas Cylinder

Chapter 1: Introduction

The chapter presents the background and provides an introduction of the research. An overview of the research field, offering a statement of the problem in the case study location -Iraq- is presented in this chapter. It also explains how developed countries are dealing with the research issue. In addition, this chapter discusses the main aim, objectives and research questions, through which the significance of this research will emerge. This is followed by a discussion of the research flow within the main phases. This chapter ends by showing how the research is organised, including a brief outline of the following chapters.

1.1 Background

Electricity is an essential part of modern life and it is an essential source of energy for lighting, heating, cooling, and many more. An electricity shutdown would lead to a large economic loss due to the failure to sustain operations and other activities (Bhattacharyya & Timilsina, 2010). Consequently, electricity provision reflects a nation's economic and social development. Poor electricity supply can have a considerable impact in many areas, such as transportation, medical, employment, and education, which consume a tremendous amount of electricity every year (Kamaludin, 2013). In many developing countries, access to affordable energy in the form of electricity can be a major issue because the demand for electricity continues to exceed the supply. At present, about 1.3 billion people in developing countries still do not have access to a sufficient electricity supply (Bhattacharyya & Timilsina, 2010), which is due to a variety of challenges including inadequate infrastructure and low level of technology penetration (World Energy Council, 2016). For residential buildings, electricity is becoming an increasingly important energy source. For example, the electricity share of world residential electricity consumption was 39% in 2012 and predicted to grow up to 43% in 2040, and by 2025 it will surpass natural gas as the leading source of residential delivered energy (EIA, 2016). However, restricting and curtailing the total domestic electricity consumption in developing countries is the result of an insufficient electricity supply, where the household demand for daily basic services is suppressed and not met.

An inefficient supply and the resulted suppressed domestic energy demand can have two significant impacts. The first impact concerns the energy efficiency of dwellings, where energy use and actual energy demand are the common variables used for evaluating the energy efficiency of buildings (Calautit & Hughes, 2014). Therefore, the distortion of consumption behaviour due to the insufficient supply leads to the misrepresentation of the actual energy demand, and thereby wrong policy prescriptions are recommended for energy efficiency (Bhattacharyya & Timilsina, 2010). The second impact is the effect of suppressed energy demand on indoor thermal environment, particularly in very hot arid regions where very high energy demand for air-conditioned buildings to deliver the comfortable indoor environment is rapidly rising. The connection between energy efficiency and the indoor thermal environment is a major target to promote the occupants' comfort and wellbeing (Roaf, et al., 2009). Responding to these issues, there is a significant interest in many developing countries in adopting strategies to address both suppressed energy demand and its environmental implications. One of these adopted strategies is attempting to create climatically responsive buildings that can succeed in delivering adequate internal conditions while achieving energy efficiency, which is applied in many developed countries. Many studies have been published on both energy efficiency and optimal indoor thermal environment of dwellings in developing countries, for example, (Mahar, et al., 2018; Al-Aidroos & Krarti, 2015). Yet, there are still few studies of suppressed actual energy demand and its influence on both total energy use and the indoor thermal environment of buildings.

This chapter starts by briefly describing the significance of addressing domestic energy demand in the form of electricity in developing countries and how it is suppressed by many critical factors. This will be followed by an overview of the major challenges that are faced by the energy sector, including climate change and energy poverty. It will then move on to present a statement of the problems of suppressing the domestic energy demand in Iraq as a case study and its implications for the indoor thermal environment. The examination of the Iraq context in this thesis led to the formulation of the questions for the study, as well as the aim and objectives. The following sections will present an overview of these aspects of the research, along with its significance and a summary of the thesis structure.

1.1.1 Energy and climate

Climate change represents one of the major environmental problems faced by the world today (Wang, et al., 2015). The earth's temperature has increased by 0.74°C in the last hundred years (1906 to 2005), with a rate of increase of 0.15°C/decade. This increase was more significant after 1970 (IPCC, 2013). It is projected that the global mean temperature will continue to increase, and this will affect the daily, seasonal and annual energy demand for cooling and heating buildings (Wang, et al., 2016; Shahid, et al., 2016).

The bi-directional relationship between climate change and energy use showed that over the last few decades energy use has become an important issue and a great concern because of its environmental impacts, such as ozone layer depletion, global warming, and climate change, exhaustion of energy resources, energy supply difficulties, and rising energy costs. World energy consumption increased around 50% between 1990 and 2010, and energy demand is expected to increase at a rate of 1.8% per year according to the US Energy Information Administration (2014). In the same context, the electricity sector contributes to around 25% of global greenhouse (GHG) emissions (World Energy Resources, 2016). Therefore, the GHG emissions associated with the provision of energy services are a major cause of climate change and thereby an increase in the efficiency of electricity generation is essential in tackling climate change (William, et al., 2012).

Globally, buildings account for about 36% of the total energy use and they contribute to around 40% of the CO_2 emissions (Costa, et al., 2013). Although the energy utilisation by buildings represents a large portion of overall energy consumption, most of this energy is used for space heating and cooling purposes. For example, 51% of energy is used by heating, ventilating and air-conditioning (HVAC) systems in residential buildings according to the US Department of Energy's annual review (US Department of Energy, 2008). Nearly 40% of the total energy, in the EU building sector, is used in the provision of heating, cooling lighting and appliances (Spentzou, 2015). Meanwhile, in a hot climate, the energy required for cooling purposes has been predicted to be more than double the energy required for heating (Santamouris & Asimakopoulos, 1996). Therefore, over the last few decades, building performance has been seen to be a key contributor to the negative environmental impact of excessive energy generation and use (Hammad & Abu-Hijleh, 2010).

Since climate change affects building energy use through changes in heating and cooling demands, these changes are expected to change the mix of fuels used in buildings. For example, increasing the use of electricity for cooling while decreasing the use of natural gas and other fuels used for heating. Consequently, these changes will alter the amount of money that individuals spend to heat and cool their buildings, with the effect depending on whether the increase in cooling expenditures outweighs the decrease in heating expenditures, or vice versa (Clarke, et al., 2018). Because cooling and heating demand generally are going in opposite directions, net increases or decreases largely depend on a region's cooling or heating demand requirements.

1.1.2 Energy poverty

According to Reddy (2000), energy poverty can be defined as the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally-friendly energy services to support economic and human development. The definition touches on the two dimensions of energy poverty – the lack of choice of energy sources and the inadequacy of energy services to meet developmental needs. Acemoglu and Robinson (2012) posit that there should be sufficient choices of energy sources to foster development, which are often not available to most developing countries. On the other hand, energy as a service refers to the provision of energy services from various sources of energy, typically in the form of delivered energy such as electricity. The availability of primary energy such as oil and gas does not necessarily translate to the adequate provision of delivered energy in a country. For example, despite having vast primary energy reserves (e.g. fossil fuel) Iraq and Nigeria suffer from acute shortages of electricity. Energy poverty may arise not only from the lack of affordable supply but also from unsafe and unreliable infrastructure that do not meet the required quality of supply. Almost 1.6 billion people have no access to electricity, while 95% of those with no access to electricity live in sub-Saharan Africa, Asia and the Middle East (IEA, 2013). Hence, energy poverty is a critical issue in many developing countries.

1.1.3 Energy use in developing countries

In many countries, energy demands are increasing over time, depending on their economic growth and their changing socio-economic structures. Although access to electricity is a fundamental social right, the demand continues to exceed many countries' ability to supply electricity because of a lack of fuels, transmission, or infrastructure (World Energy Council, 2016). The failure of these countries to increase energy generation despite their increasing energy consumption results in an important problem, known as an energy deficit (Esen & Bayrak, 2017). Statistically, the World Bank (2016) indicates that 84.6% of the world had access to electricity in 2012. However, electricity access in developing countries was just 34.3%. This large variation of electricity access is first considered a key disparity between developed and developing countries, although developing countries are expected to use more energy than developed countries by the year 2020 (Lombard, et al., 2008). Second, it reflects the fact that despite access to electricity is required in developing countries to raise the living standard for millions of people, the actual demand of electricity still continues to exceed the supply in many countries. This deficit is due to a variety of challenges, such as energy poverty, low income, inadequate infrastructure and low level of technology penetration (World Energy Council, 2016).

Another disparity between developed and developing countries with respect to the electricity sector is that the electricity generation processes are much sophisticated in developed countries as compared to the developing countries. Developed countries outnumber the developing states in using alternative sources of electricity generation and are even generating electricity from biomass and solar energy, while most developing countries are still unable to efficiently utilise their prime inputs of electricity generation such as fossil fuels, coal, and natural gas (Atif & Siddiqi, 2010). The unsustainable resources used by developing countries are imposing pressures on achieving development and sustainability. Ignoring these characteristics is inappropriate given their critical role in providing access to an affordable, clean and reliable supply of energy for sustainable development (Ailawadi & Bhattacharyya, 2006) but at the same time, incorporating them is not easy (Bhattacharyya & Timilsina, 2010).

A closer assessment of the energy system in most of developing countries reveals that although there is a wide diversity among developing countries in terms of socio-economic conditions (size, economic structure, human resources and energy endowments, and level of urbanisation), some common energy system characteristics can be found (OTA, 1991). For example, they share almost the same infrastructure barriers, the predominant use of traditional energy and supply network, reliance on back-up generation besides social and economic barriers, which hinder technology penetration. These characteristics have been added to the significant differences between energy systems in developing and developed countries (Urban, et al., 2007; Bhattacharyya, 1995; 1997; Shukla, 1995). In view of these impediments, many developing countries are plagued by supply energy shortages, in general, and electricity, in particular (LDC Environment Centre, 2013). This insufficient supply of energy in return restricts and curtails energy consumption, especially of households, where the supply has yet to meet the demand for basic services. This unmet demand is commonly termed suppressed demand, which occurs when the minimum required services are unavailable or only available to an inadequate level (Gavaldão, et al., 2012).

1.1.4 Energy supply and use in Iraq

Iraq is richly endowed with energy resources; for example, it ranks as the second-largest crude oil producer in the Organization of the Petroleum Exporting Countries (OPEC) after the Kingdom of Saudi Arabia. In addition, Iraq holds the fifth-largest proven crude oil reserves in the world, which is estimated at 140 billion barrels (EIA, 2017). It also possesses 8.1% of the worldwide fixed reserve of natural gas, and thus Iraq is ranked tenth in the world among countries rich in natural gas (Kazem & Chaichan, 2012). However, Iraq's energy sector suffers from a series of critical challenges, including severe and chronic shortages of electricity supply, which has made it difficult for Iraq to keep up with its growing demand (World Bank Group, 2015).

One of the most significant challenges facing Iraq nowadays is the electricity crisis that has arisen after decades of war and economic sanctions. For example, according to the Ministry of Electricity (2017), the deficit ratio of electricity generation was about 59% in 2016. This is reflected in daily supply hours, especially in extreme summer periods when the demand reaches its peak. According to Mohamed et al. (2015), in 2015 Iraq only generated 8 of the 13 to 15 GWh of power required to meet its needs; thus, electricity was only available for a few hours a day. The World Bank's report shows that Iraqi households and consumers receive an average of 14.6 hours of electricity per day, of which only 7.6 hours per day is provided by the national grid (NG)—as a primary electricity source with uninhibited supply capacity for all sectors including the residential sector—, leaving Iraqis to rely on expensive and polluting diesel generators for power (World Bank, 2017). This insufficient supply has resulted in restricting the total energy consumption, especially for domestic buildings where household demand for daily basic services has not been met, although the domestic buildings is the largest consumer of energy with around 48% of the total energy used in Iraq, while the share of electricity in total energy consumed in the buildings sector was 58% (Najim, 2014). Iraq's buildings sector, including the residential sector, projected to see demand increase from around 7 Million Tonnes of Oil Equivalent (Mtoe) in 2010 to over 19 Mtoe in 2035, where the residential sector retains the largest share of consumption over the period and is predicted to accounts for more than 45% of final consumption in 2035 (IEA, 2012).

Both growing demand and projected increase in consumption are underpinned by many factors, such as population and economic growth, urbanisation, new housing supply and burgeoning appliance ownership. Although several large-scale housing projects are either planned or under construction, Iraq is currently short of between 1.6 million and 3 million housing units (MoP, 2010). This significant level of expected construction creates an important opportunity to incorporate high energy efficiency standards for buildings (MoP, 2010; IEA, 2012). In the near term, in Iraq the challenge is to provide an adequate supply of grid electricity to households and businesses, eliminating the considerable shortfall in generation relative to demand that has resulted from war damage limiting supply, while economic and population growth has boosted demand (Rashid, et al., 2018). Another factor that has boosted energy demand is the improved reliability of cheaper grid-based electricity, with households buying a greater range of appliances and using them more often. Air conditioning remains as a key component of consumption, along with other consumer goods (IKN, 2012). As with building standards, the introduction of energy performance standards for household appliances, especially air conditioning, is an obvious priority.

According to the World Bank, Iraq has made significant progress in restoring its power generation from a peak supply of about 5GW in 2005 to 14GW in 2016. However, it continues to face many challenges, including high demand growth of over 10% per annum (World Bank Group, 2018), and this achieved progress is still patchy and the state of Iraq's energy transport, storage and infrastructure, while improving, continues to be a serious constraint (IEA, 2012). Covering such unmet or suppressed demand by closing the generation-demand gap with reliable and continuous supply represents the main and immediate concern for Iraq's households. Therefore, they have tried to fill this growing gap by using replacement sources with limited supply capacity and operation periods. Around 90 % of Iraqi households supplement the national grid (NG) with the use of back-up diesel generators, which are known among Iraqi households as local community generators (CGs) operating at the neighbourhood level (IKN, 2012). This issue will be discussed further in the following section.

An additional challenge for Iraq is that the electricity demand is seasonal, with the highest peak occurring in summer months as a result of very high temperatures in much of the country. During the summer, peak hourly electricity demand could be expected to reach levels around 50% above the average demand level, which increases the gap between grid-based electricity supply and demand (IEA, 2012). A total of 42% of the electric energy consumption in Baghdad, for example in 2006 was used for space cooling and 27% was used for heating (Hasan, 2012). These numbers show the need to consider the comfortable indoor thermal environment and energy efficiency criteria at the relevant future policies development (Rashid, et al., 2018).

Another important issue related to energy sector in Iraq is that a review of the available studies which conducted in this regard (e.g. (MoP, 2010; IEA, 2012; Istepanian, 2014; Al-Badri & Abu Hijleh, 2014; Mohamed, et al., 2015) revealed a conflicting estimation of energy generation, supply, consumption and demand, which could be attributed to unreliable and poorly documented data, which is made worse by the lack of precise information and statistics, with figures varying by source. The scope of the Iraq model has been narrowed in some areas where data is more limited, such as energy use in households and industry (IEA, 2012). While the existing electricity supply and use in Iraqi domestic buildings remain complicated, it is further worsened by the lack of accurate historical data since the 1990s (Istepanian & Al-Khatteeb, 2015). These issues explain why providing a reliable and accurate estimation of actual demand for Iraqi domestic building is considered as a difficult task and needs further investigation.

1.1.5 Community generators

Although the development of the Iraqi electricity system to ensure sufficient generation and supply capacity is an immediate priority and central importance to the outlook for Iraq in general (IEA, 2012), at present, one of the key obstacles to Iraq's development is the lack of reliable electricity supply. Iraq's electricity stations now produce more electricity than ever before, but the supply is still insufficient to meet demand and electricity cuts are a daily occurrence. Therefore, the use of local CGs is widespread.

The current complicated situation of electricity supply could be explained by receiving electricity from NG—main supply source—ranging between 12 and 16 non-continuous hours/day in most of the Iraqi cities including Baghdad (Mohamed, et al., 2015). Given that the households in Iraq represented the largest consumers of electricity, they have been the most affected by supply shortages. This restricted supply to consumers has led to suppressed demand to consume electricity until the power from the NG becomes available. When that happens, the consumers reconnect again to the NG and their desire to consume the electricity will be met (LDC Environment Centre, 2013). The households attempt to fill some of the electricity supply gaps has caused high dependence on alternative sources of electricity such as CG or a Private Household Generator (PHG). It is important to mention here that there is not a single governorate where all people rely on NG, even though 98% of the households are connected to the NG (CSO, 2011). Around 90% of Iraqi households supplement NG with private generators, either CGs operating at neighbourhood level (with 87% within capacities of 9 to 45 kWh), where these CGs sell a few amperes per line for houses in one or two streets for a certain time schedule, or PHG (25.6% within capacities of 0.8 to 9 kWh) (IKN, 2012). Rashid (2012) estimated that in 2011 CGs accounted for 8.1% of the total energy consumption. The inability of power supply from NG to keep pace with rising demand resulted in an increase in continuous blackouts, especially in the hot summer season.

Although the local CGs currently play an important role in reducing Iraq's shortfall in electricity supply and the number of blackouts (Parsons Brinckerhoff, 2009), using them is fraught with many serious challenges, including:

- The amount of energy available for supply from the CGs as alternative sources is limited and insufficient to cover the actual demand of each house. This could be explained by the given low amperage from CGs, which only allows very small electrical appliances to be run at a minimum services level (Gvenetadze & Hegazy, 2015).
- Many families cannot use electricity from these generators - which considered costly- because of their lower income. National grid-based electricity is subsidised by the local government and is relatively cheap compared with electricity sourced from private and CGs. Although CGs are owned by local investors in the private sector they receive subsidised fuel from the Government. However, consumers pay between 10 and 15 times more than what they pay for grid electricity (Zahawi, et al., 2016). Consumers tend to concentrate their consumption, as far as possible, at times when the national grid-based electricity is available, which exacerbates problems with the reliability of the electricity supply system (IEA, 2012).
- It is important to note that the power provided from CGs is difficult to quantify and measure because they are outside of the metering and billing systems (World Bank Group, 2015; Istepanian, 2014).

- Almost every house has to apply a converter to switch from NG electricity to the CGs, and vice versa, many times during the day. This device is often damaged through continuous use and then has to be replaced, which costs money and effort (Al-Badri & Abu Hijleh, 2014).
- The use of these generators with diesel engines and fossil fuel for operation creates critical environmental problems such as increased carbon dioxide (CO_2), carbon monoxide (CO), unburnt hydrocarbons, and oxides of nitrogen (NOx), especially the higher power generators that are normally operated by unprofessional labourers (Al-Waeely, et al., 2014).
- Many of these generators throw their dirt into health deflation pipes, causing additional environmental problems (Al-Waeely, et al., 2014).
- Noise pollution can be a further problem, where most of these generators were run simultaneously in residential areas, thus the noise interference peak can often exceed the acceptable level of ambient noise pollution in cities (Kazem & Chaichan, 2012).
- Excessive heat losses from these unit generators can add to the already unbearable heat of summer in Iraq (Kazem & Chaichan, 2012).
- The randomness of electricity connection cables that have been added without any level of safety adherence. The locations for these generators in the neighbourhoods are not designed for this purpose. At the same time, the areas that they occupy are not subjected to standards or regulations (Al-Waeely, et al., 2014).

The key concern for Iraq's households is to try to fill the growing generation-demand gap with a reliable and continuous supply by using replacement sources with limited supply capacity and operation periods. However, this situation has raised three questions. First, have Iraqi households succeeded in meeting their actual electricity demand by using these alternative limited sources? Second, is it possible to provide a precise estimate of the actual domestic energy demand, including the difference in the supply capacity of supply sources and the outages periods? The third question asks about the economic burdens and environmental impacts of the current energy use in Iraqi domestic buildings, especially in the summertime, due to the potential for increased discomfort and higher energy costs resulting from more extreme outdoor weather conditions, thus more reliance on CGs. These issues have helped to shape the development of the research questions and method that will be used in this research.

1.1.6 Suppressed energy demand

Suppressed energy demand in this study refers to a situation where the energy services provided to meet the end user's basic needs such as lighting, heating, and cooling are unmet because of one or a host of the barriers (UNDP, 2013). These barriers have been explained in 1.1.3, 1.1.4 and 1.1.5 subsections. The existence of suppressed demand in developing countries has many negative impacts, including misestimation of both the current energy supply and demand as well as the future trend. In particular, the future trend is unlikely to follow the same path as in the past due to the expected economic and social changes in many of these countries. Identifying the energy baselines, like in any projection, depending on assumptions and forecasting about the future. Therefore, the key assumptions cannot be implemented without including the actual level of both energy supply and demand (Mohammed, 2018; Winkler & Thorne, 2002).

While the complexity of characterising and estimating the actual energy supply and demand in energy systems remains a challenge in developing countries, it is quite clear that suppressed demand represents the most prominent challenge. Consequently, suppressed demand must be considered at the policy development level if the goal of achieving sustainable development in these countries is to be attained. The resulting energy policy framework should fully integrate and align suppressed demand with sustainable development objectives. However, suppressed demand is still not included in the clean development mechanism for sustainable projects in developing countries, despite its close connection with sustainable development objectives (LDC Environment Centre, 2013).

Although the process of estimating the reliable suppressed demand and identifying its implications on energy use and actual demand are considered to be critical issues in developing countries, this area of research still lacks comprehensive research. While it is easy to construct the actual consumption curve, it is more difficult to construct the suppressed demand curve accurately, which may require further study. It can be argued that over time as the household income increases, more resources will be allocated to meet the desired energy needs. Therefore, eliminating the suppressed demand occurs when the suppressed demand curve and the actual consumption curve merge into one curve (LDC Environment Centre, 2013). However, given all of the challenges that confront the energy systems in developing countries, how can a reliable curve of energy suppressed demand and actual demand be constructed for these countries?

Environmentally, most of the studies that have addressed the suppressed demand of electricity have focused on the environmental implications of this suppressed energy demand through its impact on the greenhouse gas (GHG) emissions reductions (Cao & Pawłowski, 2013; Chen, 2009). However, part of the emission reduction could be achieved by the utilisation of lower GHG energy sources, such as renewable energy sources, and technical efficiency, which in return could help to change the consumer's behaviour. Roy (2000) describes the effect of applying the technical efficiency in a way in which "the benefits from savings in energy demand arising out of the technical efficiency improvement, and hence reduction in GHG emissions are greater than the actual savings". Meanwhile, (Nawaz & Alvi, 2018) pointed to the increasing reliance on imported sources for the production of electricity in Pakistan, where the major reliance on depleting fossil fuels and natural gas results in a huge demand-supply gap, which is evident in suppressed demand for electricity and which has social, economic and environmental consequences. Most countries have shifted their focus from imported to indigenous resources, which are often cheap and environmentally friendly. However, the literature is deficient in providing evidence on the impact of suppressed energy demand on the indoor thermal environment of buildings, especially the residential buildings where people spend most of their time.

From an economic point of view, households may face economic constraints due to suppressed energy demand. If they allocate their total budget between two basic services, then they can only consume more of one service at the expense of the other (Nicholson, 1995). Therefore, households cannot move to higher levels of service, due to the income constraint. This situation can be found where the budget constraint lies below any service level considered to meet the basic needs of the household. Application of strategies that can assist to minimize the suppressed demand and maximize the energy savings at the same time means that the household income increases, allowing the household to satisfy levels of service (Winkler & Thorne, 2002). However, this raises the following question: "What level of energy service might be considered 'satisfied' and whether this might be an international, regional or local standard?"**.** In addition, for some scholars, more reliance on modern energy, such as renewable use, may enable people with low income in developing countries to participate in productive use rather consumptive use, which leads to improved living conditions (Nawaz & Alvi, 2018; Brew-Hammond & Kemausuor, 2009). However, it is necessary to address the economic implications of suppressed energy demand on households by conducting an empirical study to obtain more reliable results.

1.1.7 Actual energy demand with suppressed energy demand

Although energy supply and demand estimation and/or projection are one of the prominent challenges confronted by those interested in developing sustainable energy systems in developing countries, this important aspect is still under-researched (Tembo, 2018). In some developing countries, the estimation and/or projection of energy demand would even be more challenging due to suppressed demand, which distorts the consumption behaviour because of the insufficiency of supply, thereby leading to the misestimation and/or misrepresentation of the actual energy demand. Bhattacharyya and Timilsina (2009) reported that the available statistics of energy consumption do not imply that the actual demand has been measured because there would be considerable unmet demand, due to the supply shortages that these countries are experiencing. Therefore, any study that seeks to estimate energy intensity based on these statistics and data would have significant errors or uncertainty, which could hinder the provision of precise estimations of energy demand, production of accurate results and thereby the wrong policy prescriptions would be recommended (Bhattacharyya & Timilsina, 2010).

In the context of developing countries, data limitations arise as an additional limitation to the research of the energy sector. Actual energy demand and end-use approaches require sets of information, and often such detailed data is either unavailable or where it is available the quality may not be of a high standard. The data gap poses significant problems for energy research, including energy scenarios, evaluating technologies and analysing policy impacts (Worrell, et al., 2004). The lack of data means that it is difficult to predict future energy demand, while precise estimates of supply often suffer from unreliable and poorly documented data (Ruijven, et al., 2008). Moreover, the lack of accurate data and the lack of adequate statistical analysis are major constraints on the implementation of energy demand models, which then adversely affect energy demand projections (Akinbami & Lawal, 2009; Elharidi, et al., 2013).

1.2 Research questions

The research questions are as follows:

1. How is energy, especially electricity used in Iraqi dwellings? and how does it vary temporally and compare regionally?
2. Does the existing supply meet the occupants' demand for electricity and if not, how can the unmet demand be estimated?
3. How do the socio-economic and physical characteristics of dwellings influence energy use?
4. How do occupants interact with the building and its environmental systems to maintain a comfortable indoor environment?
5. How do ambient conditions and suppressed energy demand affect the indoor thermal environment?

1.3 Aims and objectives

The aim of this research is to investigate existing energy use and suppressed energy demand in dwellings in a hot-arid climate, and their implications on indoor environment conditions. The objectives of this research are to:

1. Review the state-of-the-art in energy use in dwellings and suppressed demand and their impact on indoor environment conditions;
2. Investigate the energy use and its temporal variability in existing dwellings and determine if the supply meets the needs of the occupants;
3. Develop a method to estimate the suppressed and the actual electricity demand and investigate their diurnal, seasonal and annual variability;
4. Investigate the influence of socio-economic and physical characteristics on energy use in dwellings and the behavior of the occupants in response to suppressed energy demand; and
5. Evaluate the effects of ambient conditions and suppressed energy demand on the indoor thermal environment.

1.4 Contribution to the knowledge

The major knowledge contributions made by the research include:

- **A new method to estimate hourly suppressed and actual energy demand**

The method for estimating suppressed energy demand developed in this research offers the most comprehensive approach to quantify hourly suppressed demand, show its diurnal, seasonal variability over the year. Estimating the suppressed demand in turn used to estimate the desired energy demand in different scales, such as (kWh per capita, and kWh per square meter) for domestic buildings, which firstly could support the development of future energy demand models, and secondly, used for comparative studies. Applying this method answered the research question "Does the existing supply meet the occupants' demand for electricity and if not, how can the unmet demand be estimated?". The possibility of calculating the hourly energy suppressed demand was confirmed. In addition, providing such estimation contributes towards determining the energy demand required to meet the needs of existing domestic buildings, and future demand capacity of housing.

- **Hourly and daily energy use including the contribution made by local community generator**

This research contributes to the body of knowledge by determining the energy use (in kWh, kWh per capita, and kWh per square meter) for different seasons in dwellings, to be used to identify whether these levels of energy use are satisfied or not by using international or regional benchmarks and/or standards. In addition, the daily scenarios of energy supply based on the dependence of different supply sources were investigated in order to identify the share of supply source in the total electricity supply for domestic buildings. This contribution answered the research question "How is energy, especially electricity used in Iraqi dwellings? and how does it vary temporally and compare regionally?". In addition, the results of this study regarding the energy use provided an accurate and timely data of energy use; identified energy supply systems' inefficiencies and failures to meet the occupants' needs and obtained benchmark to manage the residential energy use in Iraq.

- **Coupling monitoring tools to investigate suppressed energy demand and indoor thermal environment of dwellings**

The coupling of in-field instrumental monitoring energy use and indoor environment conditions were found to be a useful and quick prediction tool for the purpose of detailed evaluation of the houses' energy use and indoor thermal environment, as well as studying the suppressed energy demand and its influence on the indoor environment conditions in this study. In addition, previous studies highly recommended monitoring approach in energy use and thermal environment studies due to its accuracy and effectiveness. Based on real data of energy use from long-term monitoring, this approach produces detailed results and informs the accurate and efficient analysis of energy use and thermal environment, which could be used to improving housing indoor thermal environment, thus, to achieve efficient energy performance.

- **The indoor thermal environment of domestic buildings over the year**

One principal objective of the study was to investigate the indoor thermal environment over the different seasons, taking into account the extreme diurnal, seasonal variability of the local weather conditions throughout the year. This aspect can help to provide insights for how important adopting housing climate responsive design, which could improve the energy efficiency in future housing design. This contribution answered the research question "How do occupants interact with the building and its environmental systems to maintain a comfortable indoor environment?

- **The effects of both suppressed energy demand and outdoor weather conditions on the indoor thermal environment**

It was obvious that the suppressed energy demand in tandem with hot arid climate conditions have a significant effect on the indoor thermal environment. The insufficient supply of electricity coupled with the severe local outdoor weather conditions over the different seasons of the year negatively influence the indoor thermal environment of dwellings. This contribution answered the research question " How do ambient conditions and suppressed energy demand affect the indoor thermal environment?

- **An overview of energy use from the occupants' perspective**

This research contributes to the body of knowledge by providing a comprehensive understanding of the occupancy peculiarity in domestic building and the ways in which the occupants operate their dwellings with respect to energy use. In addition, the study provided insights of the residents' behavior in response to suppressed energy demand in order to maintain the indoor thermal environment within acceptable level over the year, with taking into consideration the impacts of the social, economic, and physical characteristics of dwellings. This contribution answered the research question " How do the socio-economic and physical characteristics of dwellings influence energy use?

1.5 Research approaches and flow

This research sets out to investigate the energy use and suppressed energy demand in actual domestic environments of the selected case study homes by conducting the following approaches: -

1. Literature review to provide a comprehensive background regarding the research area of this study as a result of the research's first stage.
2. Sociological approach using a transverse questionnaire to enhance the monitoring approach by understanding the occupancy diaries with the assistance of formal and structured interviews;
3. Monitoring approach using long-term field measurements to acquire physical measurements by applying the properly configured monitoring scheme in the selected case study homes;
4. Analytical approach with effective data pre-processing, presentation, and analysis.
5. Collection of findings with discussion, and ending with conclusions and recommendations.

   Figure 1-1 summaries the research flow and phases.

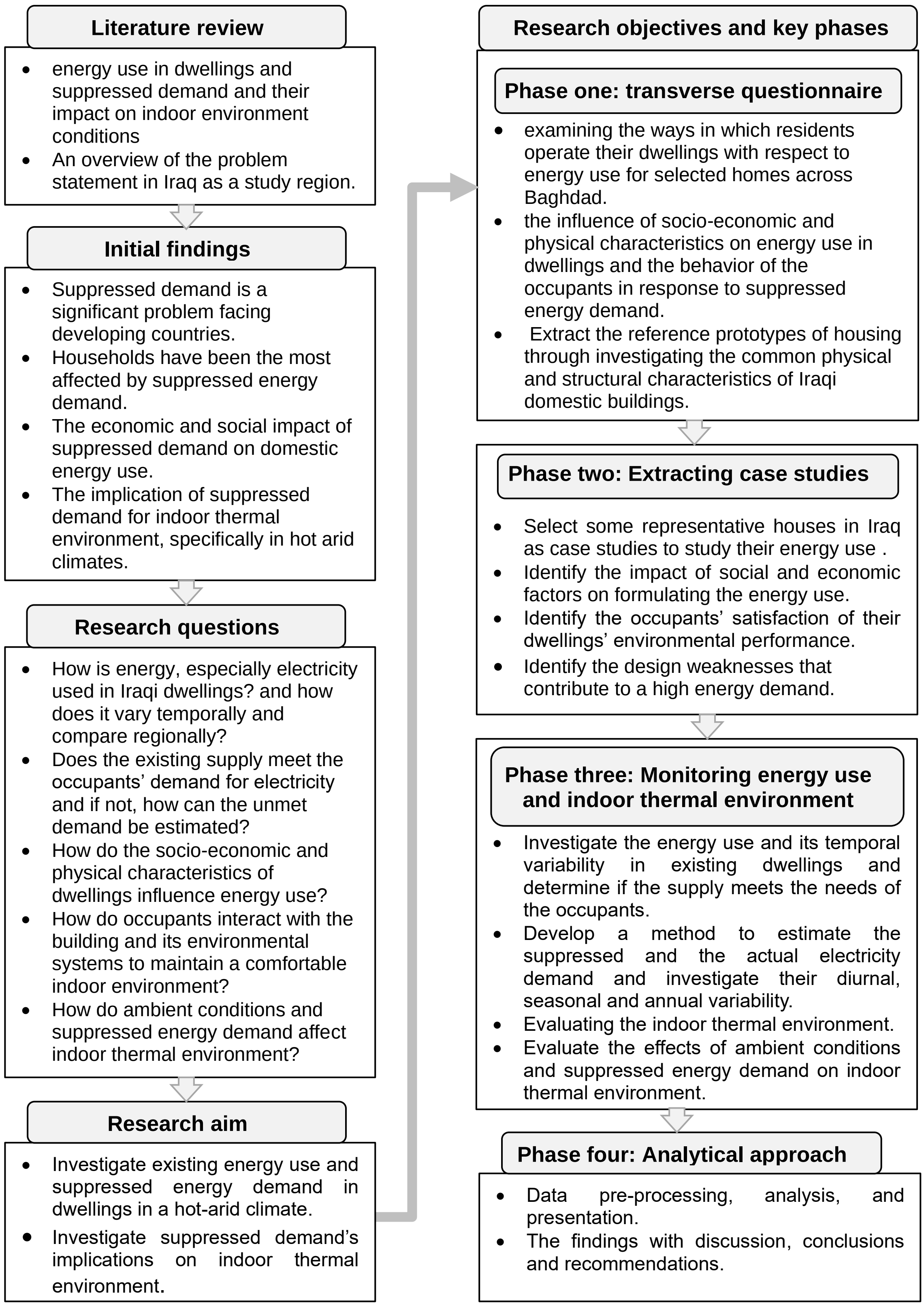

Figure 1-1. Research framework and flow.

1.6 Structure of the thesis

A brief description of the structure of this thesis follows.

Chapter 1: Introduction. This chapter highlights the background of the study topic, both as a global issue and as a national challenge. It details the proposed aim, objectives, and the research plan and approach used to achieve them. In addition, it outlines the research questions and the contribution to knowledge that this study offers, and it explains how this thesis is organised.

Chapter 2: Literature review. This chapter conducts a comprehensive literature review, which ranges from a research background and relevant concepts to commonly applied approaches in associated research fields. This chapter seeks to cover the important issues and aspects investigated in the research, starting with energy use and suppressed energy demand to the main issues that influence the topic of the study. It then presents a background and overview of Iraq. Another aspect that reviewed in this chapter is a comfortable indoor thermal environment and how it is affected by the suppressing of energy demand in domestic buildings within hot arid regions.

Chapter 3: Research method. This chapter presents a detailed account of the method that was designed for this study to ensure that its aims have been adequately addressed. A number of approaches are presented to provide a clear indication of the chosen method. This chapter describes the three main approaches that were employed by the researcher to arrive at the results and objectives, including measurements of individual parameters, interviews and questionnaires. This chapter also illustrates the steps of extracting case studies and then the monitoring process. Moreover, this chapter will justify the research design in general and each approach in particular.

Chapter 4: Dwellings characteristics, energy use and socio-economic influences. This chapter aims to achieve the objectives in studying the factors that influence both energy use and indoor thermal environment of domestic buildings in the research case study Iraq/ Baghdad. This chapter is concerned with the data that were collected from the occupants in their homes during the subjective field survey by means of questionnaires. It defines the results to understand the social, economic, physical dimensions of the energy use in Iraqi domestic buildings. Finally, it provides a brief summary of the questionnaire results and the research problem.

Chapter 5: Case studies: site visit-interviews. This chapter presents the main prototypes of dwellings, which are used as representative houses in the research context. It presents the demographic information regarding the dwellers and the available data on their daily behaviour in terms of energy use. It then describes the dwelling samples and the factors that characterise them, including their locations, orientations, built year, area, construction and finishing material, insulation and the type of mechanical ventilation, together with some comments drawn from the informal interviews. Finally, it presents a summary of the site visits and the interview results.

Chapter 6: Energy use and suppressed demand. This chapter is concerned with the first part of the data collected during field monitoring. It analyses and evaluates all of the measured data of energy use, by which the energy suppressed demand and then the actual energy demand were estimated. The first section highlights the energy use's details in terms of the monitoring horizon, the supplied energy based on the source with outages, the different supply scenarios, the hourly and daily energy use for different seasons, and the detailed energy use per square meter and per capita for different seasons. The second part discusses the hourly and daily estimated suppressed energy for different seasons and the suppressed energy demand per square meter and per capita for different seasons. The last part of this chapter focuses on the estimated energy use after adding suppressed demand to the consumed.

Chapter 7: Suppressed energy demand vs indoor thermal environment. This chapter analyses and evaluates all of the available data of the second part of field monitoring- outdoor weather and indoor environment conditions collected in the form of objective data, which are described in detail. The relationship between energy use, outdoor weather conditions and indoor thermal environment were investigated to evaluate the impact of energy suppressed demand on the indoor thermal environment.

Chapter 8: Conclusion: This chapter summarises the research findings and presents a summary of how the established research questions have been answered through the research stages. This chapter presents an account of how the main aims of the research have been met, as well as the limitations and challenges. Finally, it describes the future work that may be carried out by the researcher and provides recommendations for future researchers, as well as decision-makers, architects, developers and homeowners. Appendices provide additional information. The research structure and chapters are presented in Figure 1-2.

Part 1: Approach

- **Chapter 1 Introduction**
  - Domestic energy use and suppressed energy demand
  - Identification of the problem
  - Formulation of the research aim, objectives, and questions
  - Definition of the study scope and structure

Part 2: Theoretical and conceptual background

- **Chapter 2 Literature review**
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- **Chapter 3 Research method**
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Part 5: Conclusion

- **Chapter 8 Conclusion**

Figure 1-2. The structure of the thesis.

Chapter 2: Literature Review

This chapter provides the theoretical background of the research, which is necessary to formulate the study questions and achieve its objectives. This literature review will support research in the domestic energy field. This chapter has four sections. The first section presents the background and gives an overview of the main issue of this research (domestic energy use). The second section reviews recent studies and research related to the factors that could impact domestic energy use. The third section will give the context of the research, including a brief overview of Iraq. It gives the background to the factors that have influenced the existing housing energy use in Iraq. The final section reviews the main methods that are used to carry out the research, which will define a suitable method for the present study. Brief summaries of the key contributions and gaps that shape the study questions are given in each section. This chapter ends by giving some concluding remarks from the overall literature.

2.1 Background

Suppressed energy demand is increasingly being included in energy studies, especially in developing countries. The previous chapter showed how the existence of suppressed demand can misestimate the current energy supply and demand, which in turn affects the future trend of energy. In addition, suppressing the energy demand has the potential to adversely influence the environment conditions, especially in domestic buildings where people spend most their time. This part of the research aims to develop an understanding of energy use in domestic buildings and the factors that affect this use. In addition, an overview is provided of the case study used in this research. Then, the methods to investigate energy use, suppressed demand, and the indoor environment conditions are reviewed. Finally, gaps in the current literature regarding energy use in domestic buildings are identified.

2.2 Domestic energy use

Residential energy use is of special interest because it may be considered to be an adequate indicator of welfare or development. In addition, it is closely related to lifestyle choices and living standards (Joyeux & Ripple, 2007). Energy use in the home accounts for significant proportions of total energy use, both in industrialised and developing countries (Wood & Newborough, 2003). Globally, about a quarter of total final energy demand can be attributed to the residential sector, with a generally increasing trend since 1970 (Johansson, et al., 2012). Domestic energy use constitutes one-third of the total energy consumed in the world and in developed countries alike (Nilsson, et al., 2017; Vassileva, et al., 2012), this implies that the energy use characteristics in the residential sector should be of particular concern. Policymakers have realised that without significant reductions in the energy demand, and significant increases in the energy efficiency of the domestic sector, it will be impossible to lower carbon dioxide (CO_2) emissions and mitigate the risks of global climate change (Lomas, 2012). To support informed decisions about how to reduce energy use and CO_2 emissions from the housing sector, it is essential to know which factors influence domestic energy use. That will be explained in the next section.

Academic studies on domestic energy use can be broadly classified into four categories: (i) energy use as an issue of technology and buildings, (ii) the economics of energy use, (iii) individual behaviour and energy use, and (iv) social constructions of energy use (Shwom & Lorenzen, 2012; Wilson & Dowlatabadi, 2007). Meanwhile, empirical studies on energy use in domestic buildings can be categorised into two groups. The first group of the studies are explanatory and seek to account for variation in energy use patterns between households. These studies collect data on energy behaviours or use of a sample of individuals or households, and they include the various characteristics of the person or household and their energy use patterns or behaviours. In addition, these studies can either be qualitative and provide detailed insight on the household's lifestyle practices (Lorenzen, 2012; Schelly, 2014), or they can be quantitative and correlate various demographic, attitudinal, or technological characteristics, behavioural and use outcomes (Poortinga & Vlek, 2004). Quantitative studies that seek to understand the human factors of energy use are often survey-based. These surveys usually have sample sizes of under one thousand individuals or households and often collect self-reported energy behaviours rather than measured behaviours or actual use. More recently, large datasets on home energy use have become available as utilities modernise and implement smart meters. However, these "big datasets" are rarely available in conjunction with detailed information about the household occupants. The second group of studies are those that are intervention-based and have produced researchable change strategies. These studies look at an individual or household energy use over time and they evaluate the impacts of relative parameters, such as a social, economic, or environmental. In these studies, researchers have collected data on self-reported behaviours or energy use over time. These studies are natural experiments where conditions change in the real world. Generally, these studies could be used to investigate effective approaches to increase energy conservation or renewable technology adoption (Abrahamse & Shwom, 2018).

2.3 Parameters that influence domestic energy use

Internationally, there is an extensive literature devoted to understanding the main drivers of energy use in households. Domestic energy use, together with other influenced parameters, such as peoples' everyday habits, behaviour and energy awareness, and different energy-saving strategies have been investigated and discussed by many researchers. How these different parameters affect the households' energy use has also been analysed. This section attempts to review the key parameters that have a significant effect on residential energy use through a comprehensive literature review of research. These parameters will be discussed as follows:

2.3.1 Social parameters

Energy research has traditionally focused on the technical aspects of the energy challenge but more recently attention has turned to the role individual behaviour can play in enabling the transition to a low and efficient energy future. It has become clear that rather than relying solely on new energy supply technologies, attention needs to be paid to the ways in which people consume and relate to energy (Hole, 2014). To reduce energy use in buildings, it has become clear that in addition to technical solutions, the behaviour of individuals needs to change (Stern & Aronson, 1984). This has assisted in conducting more detailed investigations of how lifestyles shape energy use and have forced engineering-orientated studies, fixated upon a techno-economic paradigm, to include a social science perspective in research into energy demand (Janda, 2011). The acknowledgement of household members as active energy users has paved the way for a different approach to demand reduction in the domestic sector. Alongside tackling energy efficiency and increasing low carbon energy generation, it has become clear that reducing energy demand through behaviour change will play a crucial part in the transition to a low carbon future (Hole, 2014). With appropriate policy action, the UK Energy Research Centre (UKERC) has estimated that social and lifestyle change has the potential to reduce carbon emissions and national energy use by 30% and 35% below 1990 and 2000 levels, respectively (UKERC, 2009). More recently, it has become clear that reducing energy use in buildings is a critical component of meeting carbon reduction commitments (Janda, 2011). The benefits of a social science perspective—considering how people use energy, how they think about efficiency, how their lifestyles are shaped by cultural practices, social norms and different values—have been substantiated and demonstrated in environmental and energy studies (Hole, 2014). However, the effect of occupant behaviour is more difficult to identify and correct, especially when given the large variety of occupant typologies, comfort preferences and the importance of the interaction of the user with the energy efficiency and low carbon technologies. Evidence suggests that there is potential for households to reduce direct and indirect domestic energy use. A recent survey of U.S. households indicates that greenhouse gas emissions (GHG) from household direct energy use could be reduced by up to 20% through the adoption of efficiency and curtailment behaviors (Dietz, et al., 2009).

The related studies detailed the social parameters that affect the energy use of domestic buildings, such as the number of occupants and family composition. One of these studies was conducted by (Yohanis, et al., 2008), where the authors' examined the average daily annual energy use (kWh) per unit floor area for dwellings occupied by one, two, three or four or more occupants in Northern Ireland and established that households with four or more occupants consumed the largest amount of electricity and there was a small difference between the use in households with two or three occupants. In addition, Tiwari (2000) recognised that a five-member family in India would have 23% more electricity expenditure compared to a two-member family. This study also quantified the effect of an additional household member on energy use and concluded that its increased use by 7.7%. Similarly, Zhou and Teng (2013) in their study in China found an increase of 8% for every additional family member. In comparison, Brounen et al. (2012) established that an additional occupant in Dutch households increased electricity use by about 21%.

In terms of family composition, a significant effect of family composition (i.e. presence of children, teenagers, adults and elderly people) on energy use in residential buildings has been widely acknowledged in the literature (McLoughlin, et al., 2012; Brounen, et al., 2012; Nielsen, 1993; Wiesmann, et al., 2011). The presence of children and their influence on energy use was shown to be significant by McLoughlin et al. (2012), who determined that adults living with children in Ireland consumed considerably more electricity than those living alone or with other adults. Brounen et al. (2012) revealed that households in the Netherlands with children consumed almost 20% more electricity than families without children, and this effect was stronger when the age of the children increased. Similar results were published in Wiesmann et al. (2011) (Portugal) and Nielsen (1993) (Denmark). Some studies related the age of households' members to electricity demand and usage patterns (Thøgersen & Grønhøj, 2010; Matsumoto, 2016).

2.3.2 Economic parameters

The relationship between energy use and income has been a popular issue of debate in economic development and the environment. However, there is still no consensus regarding the bi-directional relationship between energy use and income. At the national level, many studies find that the causality may run in both directions. For example, if there exists causality running from income to energy use, then this denotes a less energy-dependent economy, such that energy conservation policies may be implemented with little adverse or no effects on income (Jumbe, 2004). Meanwhile, (Lee, 2005) investigated the co-movement (in both directions) and the causality relationship between energy use and gross domestic product (GDP) in 18 developing countries, using data for the period 1975 to 2001. Their results showed that both long-run and short-run causalities run from energy use to GDP, but not vice versa. This indicates that energy reduction may harm economic growth in developing countries, regardless of being transitory or permanent. These results matched with the findings of (Belke, et al., 2011; Shaari, et al., 2013). Both Ighodaro (2010), Lise and Montfort (2007), stated that a decrease in energy use can affect economic growth. Whereas, Ighodaro (2010) used various types of energy use (e.g. coal, electric, oil and gas use) as determinants of economic growth. Their results reported that energy use can influence economic growth. Narayan and Prasad (2008) also studied in Organization for Economic Cooperation and Development (OECD) countries by examining the causality between energy use and economic growth. Their findings show that energy use has an effect on economic growth in case of Australia, Iceland, Italy, the Slovak Republic, the Czech Republic, Korea, Portugal, and the UK, while the economic growth does influence energy use in Finland and Hungry (Shaari, et al., 2013).

Statistically, there is a significant positive association between economic growth, energy use and carbon emissions in the ASEAN countries (Lean & Smyth, 2010), China (Chang, 2010; Govindaraju & Tang, 2013) and among a total of 69 countries involving high, middle- and low-income groups (Sharma, 2011). It has been estimated that by 2020, energy use in emerging economies in Southeast Asia, Middle East, South America and Africa will exceed that in the developed countries in North America, Western Europe, Japan, Australia and New Zealand (Pérez-Lombard, et al., 2008). As countries progress, their energy use increases. For example, the trends in energy use from 1970 to 2010 in China rose from150 kWh per capita in 1970 to 3000 in 2010 (i.e. 20 times more). However, in some African countries where there has been little or no economic progress, energy use has hardly increased at al. For instance, in Ethiopia consumption increased from 18 kWh per person in 1970 to 58 in 2010. Per capita, electricity consumption in

Ethiopia (58 kWh per capita) in 2010 was 250 times lower than in the United States (13.394 kWh per capita). Some policies have been suggested by previous studies (e.g. (Shahiduzzaman & Alam, 2012) that a policy on energy consumption should be established because of bi-directional causality between GDP and energy use in Australia (Shaari, et al., 2013).

Regarding the causality relationship between energy use and income at the household level (i.e. at the individual household scale), Summerfield et al. (2007) reported a follow-up study of 15 low energy houses in Milton Keynes, UK. After the monitoring period of 1989 to 1991, the measurement was resumed in 2005 and 2006 to produce comparable results for the indoor temperatures and energy use of three groups of households that were classified as low level, middle level, and high-level energy users. Summerfield et al. (2007) found that the high-level energy users remained the highest-level energy users and consumed an amount of energy equating to the sum of energy used by the other two groups, although the building size and income level of the high-level energy users were not the highest. Meanwhile, Weismann et al. (2011) Jones et al. (2015) also stated that an increase in income results in higher per capita electricity consumption in Portuguese households.

2.3.3 Physical parameters

As mentioned in subsection 1.1.1 that building sector accounts for about 36% of global final energy consumption and it contributes to around 40% of the CO_2 emissions. This concern has led to a number of studies to improve building energy efficiency based on the design and construction of building envelopes (e.g. thermal insulation and glazing layers) (Dongmei, et al., 2012; Joudi, et al., 2013). Several dwelling parameters have been studied in the literature, including: (i) dwelling type; (ii) dwelling age; (iii) number of rooms; (iv) number of bedrooms; (v) number of floors; (vi) total floor area; and (vii) shape of the building. The relationship between dwelling type and electrical energy use in residential buildings has been the subject of extensive research. A large number of studies have concluded that electrical energy consumption increases with the degree of detachment of the dwelling, which suggests that families residing in detached houses consume more electricity than semi-detached houses, and these consume more than terrace houses and apartments (McLoughlin, et al., 2012; Kavousian, et al., 2013; Bedir, et al., 2013). In terms of the age of the dwelling, previous studies have observed higher domestic electricity consumption in newer houses, which has commonly been attributed to the penetration of air conditioning and other high consumption appliances (Baker & Rylatt, 2008; Chong, 2012). In contrast, other studies have reported a decrease in household electric energy consumption for newer houses, which has been attributed to improved insulation and use of more efficient appliances, lighting and air conditioning (Wyatt, 2013; Bartusch, et al., 2012; Brounen, et al., 2012). Other studies have reported a non-significant effect for dwelling age on electrical energy consumption (Kavousian, et al., 2013; Hamilton, et al., 2013).

The impact of the number of rooms on electricity consumption in domestic buildings has also been investigated, where a significant positive relationship with electricity consumption in domestic buildings has been found. As the number of rooms increases, more electricity is used (Bedir, et al., 2013). Carter et al (2012) reported that there is a significant and positive relationship between the number of bedrooms and domestic electricity consumption. Whereby an increase in the number of bedrooms results in an increase in household electrical energy demand. Bartusch et al. (2012) determined that the number of floors in Swedish dwellings did not represent any statistically significant variance in annual electricity consumption per m^2 of living space. Meanwhile, Bartiaux and Gram-Hanssen (2005) and Gram-Hanssen et al. (2004) observed that the total floor area was the parameter with the third-largest explanatory power for electricity consumption in residential buildings in Denmark. Similar results were found by Baker and Rylatt (2008) in a UK-based study.

Moreover, many researchers have confirmed that the shape of the building is a major factor in its energy consumption (Ourghi, et al., 2007; Al-Anzi, et al., 2009). The shape of a building determines the total area of exposed surfaces and therefore affects the thermal performance of the whole building (Pacheco, et al., 2012). Bektas and Aksoy (2011) noted that it is important to recognise design parameters when designing a building, especially those directly related to the processes of heat transfer. In addition to the building’s shape, they identify design parameters, such as orientation, thermal properties of building materials, and distance between buildings that influence energy demand (Bektas & Aksoy, 2011). Moreover, research has shown the differences between the expected and the actual performance of buildings, both in terms of energy use and indoor thermal environment, which are caused by faults in the building envelope and systems, and by the influence of occupants’ behaviour in the operation of the building. Faults in the building envelope or systems usually occur during the construction process (Doran, 2005; Hens, et al., 2007). Faults in the building envelope have a prominent effect on the performance of the buildings. There is, however, a wide selection of methods to find and correct these faults, although they are not yet used on a large scale in standard practice (Guerra-Santin, et al., 2013).

2.3.4 Thermal environment parameters

Since the end of the nineteenth century, researchers have been interested in comfortable indoor thermal environment. Emphasis has been given to understanding what circumstances will create a comfortable indoor thermal environment and an acceptable thermal atmosphere (Parsons, 1993). Nicol (1993) has specified three motivations in understanding the significance of comfortable indoor thermal environment: first, to deliver an adequate condition for occupants; second, to monitor energy use; and finally, to set and propose criteria for these thermal circumstances. In addition, (Huntington, et al., 1951) cited in (Auliciems & Szokolay, 2007) claimed that each building element should be designed to react with the climate and provide comfortable indoor conditions for the occupants because when the occupant is in their most comfortable state, their mood will generally be good, while their mood will worsen when they are uncomfortable.

In the context of the current research, it is necessary to first clarify what is meant by thermal comfort. Olgyay (1963) cited in (Auliciems & Szokolay, 2007) was the first to simplify the notion of thermal comfort with the idea of the “comfort zone”. He clarified the term as what a human being achieved in decreasing the amount of desired energy use to adapt to the surrounding atmosphere. While Givoni (1998) presented an operational definition of thermal comfort, where who states that it is the range of climatic conditions considered comfortable and acceptable inside buildings. Based on ASHRAE standard 55 (2010) the conceptual definition of thermal comfort is that condition of mind that expresses the satisfaction with the thermal environment. Although these definitions seem reasonably precise, the range of comfort varies between individuals (Alshaikh, 2016).

The second issue for the comfortable indoor thermal environment is understanding the correlation between thermal environment and energy use. For modern buildings, the indoor thermal environment is artificially maintained at acceptable levels of comfort, resulting in excess energy consumption, particularly during the severe climate periods of winter and summer (Auliciems & Szokolay, 2007). However, the energy that is consumed by mechanical systems is specified by the difference of the outdoor environment and the desired indoor thermal conditions (Alders & Kurvers, 2010). A significant proportion of the increase in energy use could be attributed to the spread of the HVAC installations in response to the growing demand for the better indoor thermal environment within the built environment (Chung, 2011). In general, in developed countries, HVAC is the largest energy end-use, accounting for about half of the total energy consumption in buildings (Chua, et al., 2013). A recent literature survey of indoor environment conditions found that thermal environment is ranked by building occupants to be of greater importance compared with visual and acoustic comfort and indoor air quality (Frontczak & Wargocki, 2011). In the UK, Given that air conditioning accounts for 70% of the electric energy demand from residential buildings, the electricity generation capacity has doubled in the last decade to around 50,000 MW (MoWE, 2012) but still attempts to keep up with the cooling demand in summer, which can rise by as much as 50% at peak periods. Air conditioning is the crucial factor in this peak, which can even lead some regions to suffer systematic power outages, with serious health consequences as temperatures reach 40–50ºC and higher (Alshaikh, 2016).

For more details, it is necessary to review the findings from the studies of the energy scene in some countries. For the European Union, for example, 36% of energy is consumed by the building sector, of which 22% is consumed by residential buildings. By rough estimation, space conditioning accounts for more than 11% of electric energy consumption in the EU (estimation based purely on the residential sector) (Georgiou, 2015). However, due to high/low humidity and extremely hot days in summer, the Gulf countries consume large amounts of energy to cool buildings to maintain the thermal environment (Al-Saeed & Ahmed, 2018). The local climate in the Gulf countries makes air conditioning necessary to ensure a comfortable thermal environment inside buildings (Al-dossary, 2015). In the United Arab Emirates (UAE), for example, the cooling of residential buildings requires an electricity load of 47% of the total electricity demand, which can increase to above 60% during the peak summer period (IRENA, 2015; Al-Awadhi, et al., 2013). Considering the reported 47% average cooling energy fraction of the total residential electric energy consumption, residential buildings in the UAE consume 18.3 TWh electric energy for cooling (Rakhshan & Friess, 2017). In Abu Dhabi, up to 80% of the electricity is used to meet the demand for air cooling (Giusti & Almoosawi, 2017). In Saudi Arabia, the biggest responsible for domestic energy consumption is air conditioning, which uses up to 69% of the total energy consumed (Al-dossary, 2015).

2.4 Iraq: an overview

Iraq is located in southwest Asia (Lat: 29°15′N-38°15′N and Long: 38°45–48°45′E) and it covers an area of 434,128 km^2, forming 3.2% of the total area of Arab countries. However, the deserts located in Al-Anbar, Al-Muthana, Thee Qar and Al-Basra account for more than a one-third of this area, and around a quarter of the area is mountainous areas located in the north region (INPC, 2012), will be explored in detail in the next section. Iraq's population was estimated at 39,339.753 million in 2018[1] (World Bank Group, 2017), with 50.2% of male and 49.8% female. Iraq has a very high proportion of young people, where about 39% of the population aged between 0 and 14 years old, and the median age is 19.5 (JAU, 2013; MoE, 2013; EASO, 2019). Moreover, the estimated density of the population in Iraq is about 88 people per km^2, while the density of the population in the world is about 59 people per km^2 (World Bank, 2017). According to demographic and socio-economic indicators reported by the Iraqi Ministry of Planning (MoP) the population density in Iraq for 2013 was (80.7) people per km^2 (CSO, 2013). However, this figure does not reflect the actual population density because the cities are concentrated in Mesopotamia with high population density—excluding deserts—where the population density goes up to 119 people per km^2 (INPC, 2012). Administratively, Iraq is composed of 18 governorates that vary in terms of area and population size. The governorate of Al-Anbar is Iraq's largest governorate in the area but is the least densely populated, while Baghdad is the smallest governorate in the area (Figure 2-1) but has the largest population (INPC, 2012; COS, 2016). The urban area in Iraq constitutes 69.4% of Iraq total area and 30.6% for the rural area (CSO, 2013), while the total number of dwellings is 4,810,555, which account for 76.1% of total buildings in Iraq and of which single-family houses constitutes 80% (MoP, 2007). The dwelling percentage in urban areas is 70.2% and in rural areas is 29.8%, and the total number of households in Iraq is 4,696,265 and urban areas constitute 73.3% of total households. The average household size in Iraq in 2009 amounted 6.7 individual per household, with an average of 6.3 individual per household in urban areas and 7.8 individual per household in rural areas (CSO, 2011).

[1] No census has been undertaken in Iraq in recent years; the latest full census was in 1987. The Central Organization for Statistics (COS) has developed models to produce population estimates and projections (World Bank Group, 2017).

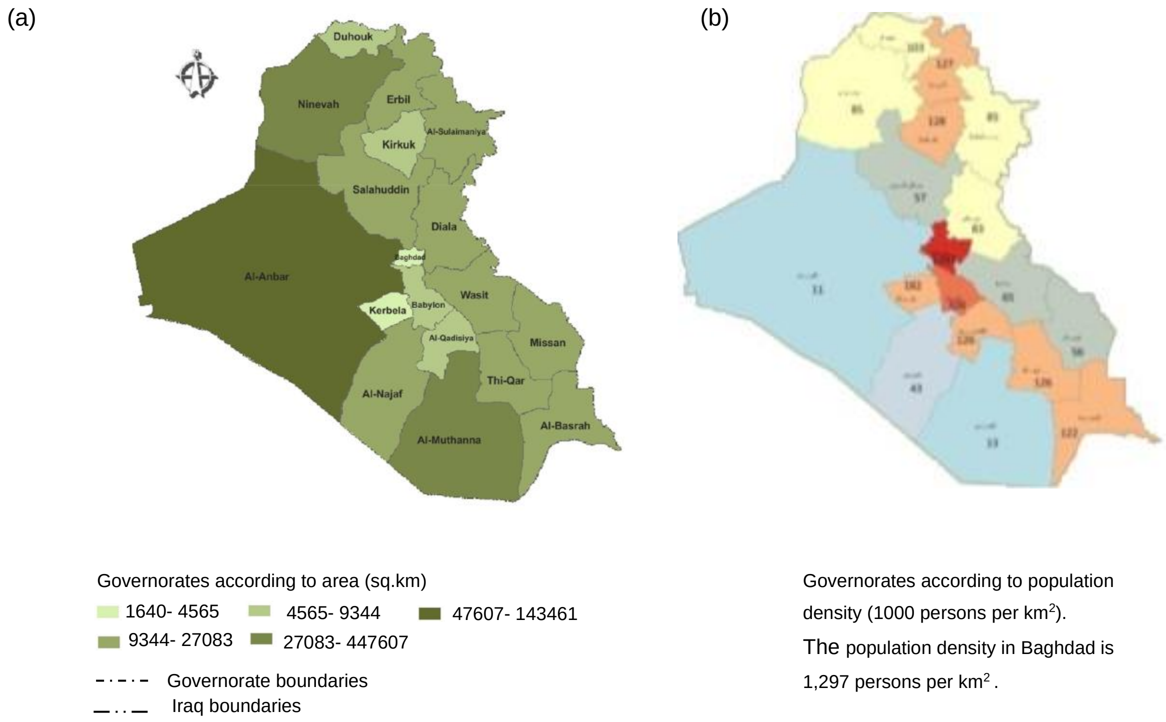


Figure 2-1. Iraq map, by governorate. (a) Governorates according to the area, (b) Governorates according to population density. Baghdad is the smallest governorate in the area but has the largest population (Source: (CSO, 2011; MoE, 2013)).

2.4.1 Climate and weather

Iraq can be broadly classified into four zones (FAO, 2003): zone 1 is a mountainous region in the northern and northeast covers 21% of the country; zone 2 is an undulating land in the south and the west of the mountainous region covers 9.6% area; zone 3 is the great Mesopotamian plain in the central region and the south covers 30.2% area; and zone 4 is the western Plateau in the west, which is an extension of the Syrian and Arabian deserts and covers about 39.2% area (Salman, et al., 2017). Climatically, Iraq is dominated by the continental subtropical climate characterised by moderately cold winters and hot dry summers. In the north, the Mediterranean climate prevails with its mild winters and moderate summers (INPC, 2012). The climate of Iraq must be characterised with some care. Although it is simplistically predictable—the summers are almost guaranteed to be very hot and extremely dry while winters are typically characterised by mild to cool temperatures with precipitation commonplace—, the potential for a variety of climatic or weather hazards such as drought and sandstorms make the reliance on short and long-term forecasts problematic.

Generally, Iraq has two major climatic seasons, a hot and dry summer that lasts from June to September, and a cool and wet winter that extends from December to March. About 90% of the annual rainfall occurs between November and April, while the rest of the year is extremely dry (Fisher, 2013).

Based on the Köppen climate classification scheme, Iraq's climate is classified into four distinct climate regions (Goode's World Atlas, 2000). The southern half of Iraq from the coastal areas near Al-Basrah to the Syrian Desert is closest to the subtropical high-pressure zone and is consequently classified as a Subtropical Desert (BWh), which forms around 63% of the total area above (273500 km^2). The upland region north of Baghdad is significantly wetter, particularly in winter, and can be classified as a Subtropical Steppe (BSh), this area constitutes 22% of the area of Iraq (95508 km^2). In the northern mountain regions, where conditions are much cooler and rainfall more abundant, the climate is Cold semi-arid (Csa), with 13% of the area of Iraq (56436 km^2). Finally, the fourth area with 2% of the area of Iraq is located far in the northern and north-eastern part and spans the border with Turkey and Iran (Wendell, et al., 2002). The climate map (Figure 2-2) outlines these four regions.

From Köppen-Geiger climate classification, it is recognised that most of the Iraqi territory lies within the hot- arid climate zone, while the mountain area on the north-eastern borders is classified as having a warm temperate climate with hot summer (Kottek, et al., 2006). Based on the above climate classification, it can be seen that in most of the regions in Iraq, the climate is characterised by extremely hot and dry summer with maximum daily temperatures between 46–50°C in July and August with large diurnal temperature variation. In winter, the weather is moderate, and the temperature only reaches freezing in some nights. The northern moderate climate region has a more moderate summer and snowfall in winter with more precipitation (MoCHPM, 2015). With these extreme climate conditions, high energy use is required for cooling or heating buildings to reach comfortable indoor conditions (Rashid, et al., 2018), as will be clarified in the following subsections.

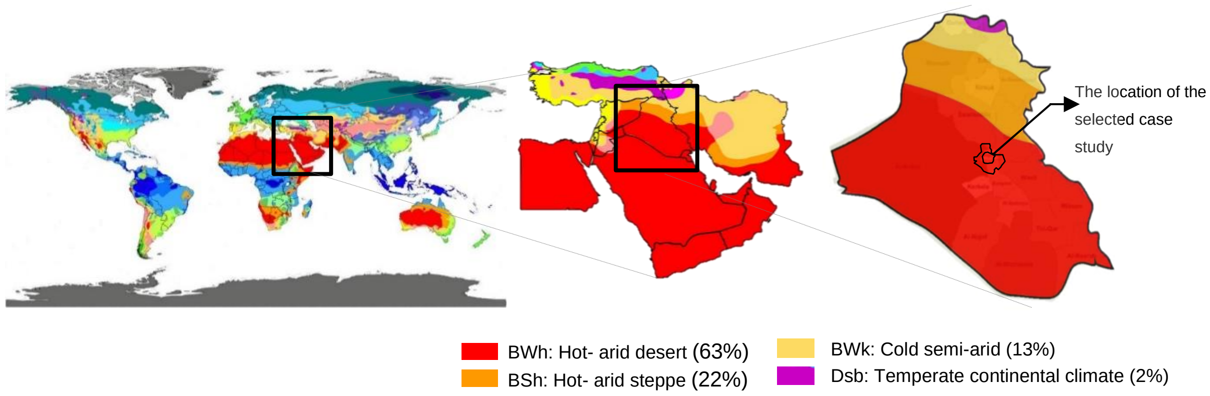


Figure 2-2. Regional Köppen climate classification of Iraq and the location of the selected case study. Around 63% of Iraq's total area (including Baghdad, the case study) lies within the hot-arid climate zone (Kottek, et al., 2006).

2.4.2 Baghdad as the study region

Baghdad is the political and economic capital of Iraq, and it is the nation's centre of commercial and administration activities. Baghdad governorate is located in central Iraq and it is surrounded by the governorates of Diyala, Wassit, Babil, Al-Anbar, and Salah Al-Din. It is the smallest governorate in the area but the most populous, with an area of around 4,555 km^2 (1.5% of Iraq) and population 7,837,963 (24.1% of the total population in Iraq) (INPC, 2012; COS, 2016). With this population, Baghdad is the second most populous Arab city after Cairo in Egypt. It has over 70 neighbourhoods, which are divided into 10 districts (Al-bayati, 2016). Baghdad city (administratively is known "mayoralty", which represents the current study region, consists of 14 municipalities, namely: Al-Rasheed, Al-Dora, Al-Mansur, Al-Karkh, Al-Shualla, Al-Kadhimiya, Al-Shaab, Al-Adhamiya, Al-Rusafa, Al-Sader/1, Al-Sader/2, Al-Gadir, Baghdad Al-jedidah, Al-Karrada (Baghdad Mayoralty, 2014).

Dwellings and population in Baghdad governorate account for the highest percentage among governorate (Figure 2-3 and Figure 2-4). Moreover, Baghdad has witnessed a considerable increase in the number of houses over the second half of the twentieth century, or more than 10 times, as can be seen in (Figure 2-5). This growth has made Baghdad the largest city in Iraq in terms of the number of houses. The impact of the pattern of population distribution on population density can be seen in increased population pressure on available natural resources, particularly water and energy (INPC, 2012). One of the main reasons for giving priority to Baghdad as the case study region is its importance at the national level and besides that the continuous pressure on it as a result of increasing the population in this city, and its negative reflection services and infrastructure (EASO, 2019). Another reason why priority was given to Baghdad as the case study is the number of households.

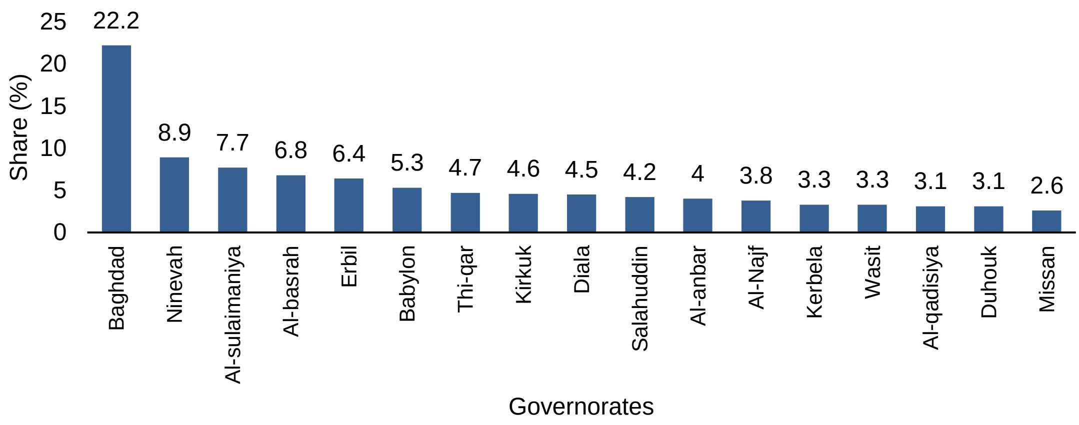


Figure 2-3. Percentage distribution of dwellings in Iraq by governorate. Dwellings in Baghdad account for the biggest share (22.2%) of conventional houses in Iraq. Data source: (Ministry of Planning, 2013).

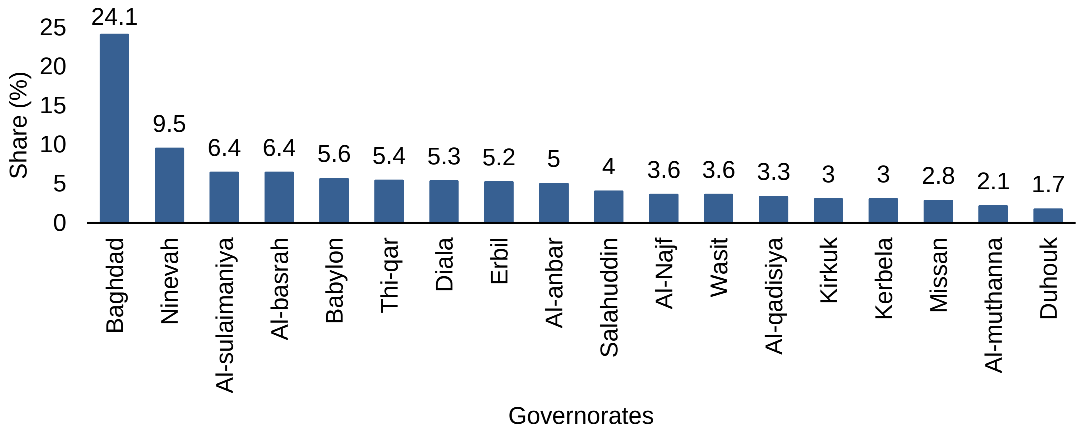


Figure 2-4. Percentage distribution of the population in Iraq by governorate. Population in Baghdad account for the biggest share (24.1%) of the population in Iraq. Data source: (MoE, 2013)

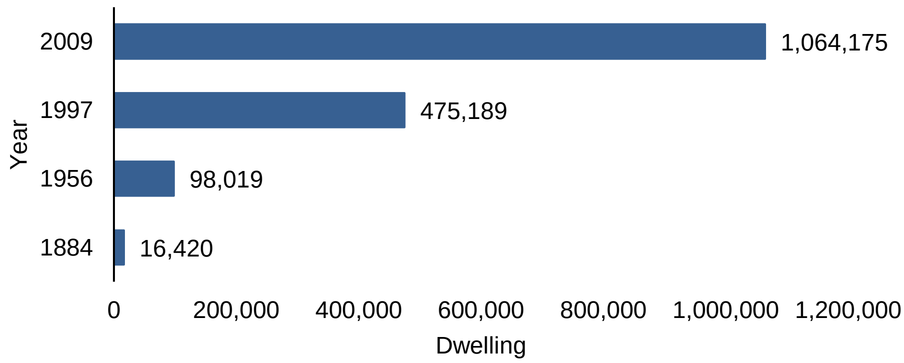


Figure 2-5. Number of dwellings in Baghdad. A considerable increase in the number of houses, more than 10 times, over the second half of the twentieth century. Data source: (Al-Alashab, 1974; Ministry of Planning, 2013).

Baghdad governorate accounts for the highest percentage of households, or 22.2% of total households in Iraq, with an average household size of 6.5 individuals per household (CSO, 2011). The third priority is the environment, Baghdad's location means that it suffers from hot arid harsh weather conditions, where the temperatures in summer rise above 40ºC and sometimes pass 50ºC. Fortunately, cheap fossil fuel heating is widely available during the winter period. However, in summer the situation is much more difficult because it requires heavy cooling using air conditioners. This results in a huge increase in electricity loads (Kharrufa, 2008). This explains why the housing sector was selected in this study because it has a major role in ensuring efficient energy use and reducing environmental impacts. Moreover, Baghdad city was selected to be the study region in this research under the assumption that houses built in Baghdad are representative of Iraqi housing prototypes in general, where Baghdad is not only one of the oldest cities in Iraq and has maintained its supremacy as the most important urban centre there but also because it has observed phenomenal urban growth during the last hundred years or so as (Alobaydi & Rashid, 2017), as will be explained next subsection.

2.4.2.1 Evolution of architectural design in Baghdad

The courtyard house (CH) was the original design of housing in Iraq and is still a constant feature of Iraqi domestic architecture. The CH can be traced back to the Mesopotamian civilization, which was in existence more than 5000 years ago. This residential prototype has distinct architectural characteristics which are a reflection of the Iraqi lifestyle. The CH is characterised by an organic, intensive and inward-looking design (to the courtyard) with habitable spaces gathering around the courtyard (Ratti, et al., 2003; Warren & Fethi, 1982; Reuther, 1910). The courtyard space is usually the spatial, social and environmental heart of the dwelling. Through this vital space, the house is provided with daylight and ventilation, visual and physical communication is achieved between habitable rooms at different levels. This housing prototype remained popular in Iraq until the early-twentieth-century, they were then neglected due to the influence of new urban design forms and regional impacts, which have affected the overall pattern of architecture in Iraq (Soflaee & Shokouhian, 2005; Dili, et al., 2010).

After World War I, urbanisation in most Iraqi cities, particularly Baghdad, was influenced by the British mandate and its architectural policy. The results of applying these foreign policies were clear—geometric house layouts with checkerboard streets patterns accompanied by outward-looking houses. These changes impacted many traditional social ideals. This transformation was the end of the traditional house model and the beginning of a transitional typological phase between traditional and Western-style housing, or “the modified traditional type” (Al-Biruti, 1992; Al-Hasani, 2012). This hybrid pattern of housing design continued until 1940 when the first generation of Iraqi architects graduated from European universities, who returned to Iraq and established the Higher Council for Reconstruction in 1950. This council set modern planning concepts for cities with an emphasis on Western housing style with detached houses and walled gardens following new plot sizes and shapes (Pieri, 2005).

The economic boom of the 1960s cast a shadow over housing design by increasing the plot area and reducing the coverage ratio to a minimum of 50–55%. This period also led to the need for an external space for a car, which was a new facet in housing design. This new space (garage) played a significant role in re-formulating functional relationships and thus the spatial network of houses as a whole (Al-Hadethy, 2006). Economic prosperity continued with oil nationalization in the 1970s, but the Iran–Iraq war between 1980 and 1988 adversely impacted the residential sectors, like other vital sectors. The plot areas were exploited economically, thus seeing an increase in coverage ratio and a reduction in open areas (Al-Sanjary, 2008).

The influence of political and economic factors on housing layout design continued from 1990 up to 2003. During this period, Iraq was under international economic sanctions, which reduced the role of public and governmental sectors in housing construction. In contrast, the private sector was activated, resulting in the emergence of new housing patterns involving new and non-typical concepts, such as open spaces and double volume spaces in imitation of foreign design (Al-Fadilla, 2005). Mohammed (2011) pointed out that a linear pattern, zoning overlap and increase in the built-up ratio within limited plot areas were the main architectural alterations seen in the first decade of the twenty-first century in Iraqi housing layout design, which was a remedy to the housing shortage. A combination of housing deficits, an unstable economic situation, residential re-subdivision and random partitioning of residences without prior planning, have subsequently become dominant features of housing layout design post-2010. These illegal phenomena have produced new spatial configurations, which have had negative impacts on residential units by emerging plots in different areas and dimensions, thus raising the population, accommodation density and floor area ratio (Shamsulddin, 2011).

2.4.3 Iraq's domestic energy use

Having highlighted the parameters that could affect households' energy use in general, and presented an overview of Iraq and the study region context of Baghdad city, it is important to next explore the main parameters impacting on energy use in Iraq's domestic buildings, and thus assisting in diagnosing the energy use problems in this vital sector.

2.4.3.1 Population

The growth in population is one of the key factors that have contributed to the increased demand for electricity. The world's population has experienced a large increase since 1950 and global energy use shows a similar trend, especially in emerging countries (BP Statistical Review, 2011). Iraq has a significantly larger and rapidly growing population. Its population was around 20 million in 1994 and it increased to 33.3 million in 2011 and is expected to reach 55.85 million by 2030. This growth is expected to exert tremendous pressure on the energy resources of the country, and in particular electricity power (United Nations, 2010; Al-Khatteeb & Istepanian, 2015). The outlook for future electricity demand projects a continuous increase in consumption, especially for urban areas, where more houses will be required over the coming years to address the ever-increasing housing shortages. As mentioned in subsection 1.1.4 that between 1.6 and 3 million housing units would be required to mitigate the housing backlog created as a result of a combination of two wars, economic sanctions and the over-centralization of public administration (MoCHPM, 2006; MoP, 2010). It is worth noting that with a projected increase of housing units from 3.94 million to around 8.4 million by 2030, 97% of houses will be connected to the national electricity grid compared with 79 % in 2012, which suggests the need for more electricity supply (Istepanian, 2014). Another important point of note is that the changes in energy demand of residential sector are also related to demand per capita changes (Bhattacharyya & Timilsina, 2010). In Iraq, as a result of lower and insufficient availability of electricity, the electricity consumption per capita (under suppressing) has remained almost at the same level at 1,068 kWh/capita in 2011 since the 1980s, even though electricity consumption has grown from 10,815 GWh in 1980 to 41,115 GWh in 2011 (World Bank, 2011). In comparison to neighbouring countries, Iraq has the lowest electricity consumption per capita, where it was 1,100 kWh/capita·year, compared to consumption in neighbouring countries that reached 4,000 kWh/capita·year in recent years, driven largely by the demand for energy for cooling (World Bank, 2016).

2.4.3.2 Thermally inadequate houses

Some recent studies have stated that Iraqi domestic buildings have very poor energy performance thanks primarily to poorly insulated walling. A single-skin system and single glazing are still dominant, and the dynamic thermal properties of these construction materials respond to the temperature variation during the day. These poorly thermal characteristics can explain the high energy use by the residential sector in Iraq, where more than 60% of the total consumed electricity is used for air conditioning during the summer season. They can also explain the continuous increase in electricity demand, which rises by about 5% annually (Rashid, 2012; Najim, 2014). Demand for energy, especially in summer, is likely to increase as the temperature rises through global warming, as will be illustrated in 2.4.3.3 subsection. Furthermore, the significant variation between the outdoor and indoor temperature in houses during both winter and summer seasons could be attributed to the lack of electricity supply and frequent blackout hours, which results in poor control of indoor environment conditions in Iraq's domestic buildings, thus the thermal environment difficult to clearly define (Rashid, et al., 2018).

2.4.3.3 Increased ambient air temperature

Temperature is one of the most influential elements of meteorological and climatological components, which in turn directly affects peoples' lives. According to Intergovernmental Panel on Climate Change (IPCC), which is one of the most important associations providing data on the global warming changes, the global average surface air temperature has increased by 0.13°C–0.03°C per decade over the last 50 years (Solomon, et al., 2007), and it is expected to rise by 1.8–4.0°C in the twenty-first century (Brohan, et al., 2006). The environmental implications of these changes are particularly significant for areas already under stress, such as arid regions where temperature extremes are a common phenomenon. Arid regions are often predicted to be the most vulnerable regions to environmental changes (Salguero-Gómez, et al., 2012; Dutta & Chaudhuri, 2015). According to the IPCC (2013), the increased temperature in the arid region of Asia could cause an increase in potential evapotranspiration, which may lead to severe water-stress conditions, deterioration of food security and more people at risk of hunger (Salman, et al., 2017). High pressure usually persists over the Middle East during summer months, resulting in an extreme heatwave (Nasrallah, et al., 2004). Therefore, the region is generally considered to be particularly vulnerable to climate change.

Iraq predominantly has an arid climate and thus has frequently experienced temperature extremes. Consequently, the country has been ranked as one of the most vulnerable counties in the Arab region to climate change (UNDP, 2010). Iraq has been experiencing more summer heatwaves in recent years. For example, on 22 July 2016, the temperature in the southern city of Al-Basrah reached 54°C, which is one of the hottest ever recorded in the Eastern Hemisphere (Salman, et al., 2017).

In Iraq, the temperature is increasing 2 to 7 times faster than global temperature rise. The minimum temperature is increasing more (0.48–1.17°C/decade) than the maximum temperature (0.25–1.01 °C/decade). Air temperature rise is higher in summer than in other seasons. The hot extremes, particularly warm nights, are increasing all over Iraq at a rate of 2.92–10.69 days/decade. Meanwhile, the numbers of cold days are decreasing at a rate of −2.65 to −8.40 days/decade (Salman, et al., 2017). Al-Timimi & Al-Khudhairy (2018) analysed the monthly mean surface air temperature at 23 stations in Iraq for temporal trends and spatial variation during 1980–2015. The results revealed that the trend of increasing mean air temperature was about 2.1°C/year. In the winter season, the increasing trend of mean air temperature was 1.75°C/year in north Iraq and the same in the middle and southern region in Iraq. The increasing trend of autumn means air temperature was the same value in the northern and middle parts of Iraq (1.4°C/year) and increased in the south to 2.45°C/year. In spring the rising trend of mean air temperature was 2.1°C/year in the northern and the middle region of the country and reached 2.45°C/year in the southern region. The highest value of increasing trend of mean air temperature was in the southern part of Iraq during the summer, with a value of 3.5°C/year.

Although the climatic changes slightly vary from one region to another, the variation of the average air temperature has an additional challenge related to the energy use and demand in Iraq, which is seasonal. The highest peak occurring in the summer months as a result of very high temperatures in much of the country, where the use of mechanical cooling systems in buildings is necessary to ensure a suitable indoor environment for the occupants. The residential air conditioning use increase in summer accounts for nearly 50–60% of the total energy usage, which in turn has led to an overall increase in building energy consumption, especially in domestic buildings, which are the highest consumer-as mentioned in subsection 1.1.4. Consequently, demand pressure on the poor electrical power infrastructure results in more electricity outages during summer (Mohamed, et al., 2015). In other words, peak hourly energy demand during summer can be expected to reach levels around 50% above the average demand level (World Bank, 2012), which means increasing the gap between national grid-based electricity supply and demand

and causing power shortages (UN, 2012). With the non-reliable energy supply in tandem with very hot summer temperatures exceeding 40°C, many Iraqi households are forced to rely on CGs to rectify the shortfall, which are estimated to provide an additional 1 GW of capacity in Baghdad alone (Latta, 2012).

Another important issue needs to be taken into consideration regarding the ambient air temperature in Iraq is that the temperature continuously fluctuates over the day/night time. Therefore, the dynamic analysis for both indoor environment conditions and energy consumption should be applied when the temperature is considerably varied; that is, daytime temperature variations (Stazi, et al., 2013; Istepanian, 2014; Najim, 2014).

2.4.3.4 Affordability

Understanding the bi-directional and causal between energy consumption and income is the key to successful socio-economic development and growth policy for post-war countries, such as Iraq. However, the correlation between energy consumption and economic dimension in Iraq needs to be conducted in many different directions and at many levels. The first is the national level, where the link between energy consumption and (GDP) needs to be investigated. In Iraq, the rising GDP, and the increase in population and high demand for housing have been defined as key contributing factors to the increase in energy demand since 2003. The average growth in energy demand was around 4.76% prior to the war in 2002, and thereafter fluctuated between 40.3% and 34.6% in 2005 and 2009, respectively. The sharp growth in demand after 2003 can be attributed to the increase in the public sector's salary, which increased the purchasing power of Iraqi households. At the same time, electric appliances became more affordable, especially air-conditioning units (Istepanian, 2014; Sachs, et al., 2011). Energy use is expected to increase thanks to the expected increase in population and GDP, in tandem with an increase in temperature. Therefore, any attempt to estimate the actual demand should take these factors into consideration.

Another direction that needs to be explored regarding the correlation between energy consumption and economic dimension in Iraq is the economic characteristics of the energy system. The tariff structure in Iraq suffers from a low cost to end-users. The cost of electricity from the NG, which is presented as a primary source of electricity supply, are heavily subsidised, reflecting historical pricing patterns and the impossibility of raising prices while the energy supply is insufficient. Iraq's tariff structure charges US$.01 per kilowatt-hour (kWh) consumed, with higher prices being charged when more than 20,000 kWh are consumed (Zahawi, et al., 2016).

Electricity provided from the NG to household consumers is charged on a sliding scale, starting from $0.017 per kWh for consumption up to 1000 kWh per month, with higher prices for consumption above this threshold. In 2010, the average per household consumption in Iraq's residential sector was only 800 kWh per year. Therefore, most households consume all or most of their electricity at the lowest price band. This price is almost ten times lower than the OECD countries average household electricity price in 2010 of $0.16 per kWh. Iraq's tariff rates are about one-tenth of the rates in other the Middle East and North Africa (MENA) countries. Because national grid-based electricity is relatively cheap compared with electricity sourced from private and community generators, end-users have an incentive to concentrate their consumption, far as possible, at times when national grid-based electricity is available, which further hamper the NG and exacerbates the problems with the reliability and ability of the energy supply system. The tariff for industrial users is a flat rate of $0.10 per kWh, which is much higher than for the residential sector. This heavy subsidy of electricity from the national grid has led to the minimal incentive to the consumer to use electricity efficiently. However, for the Ministry of Electricity, it will be difficult to increase tariff rates until the quality and duration of electricity is improved (Zahawi, et al., 2016).

The billing system in Iraq's energy system also requires further research. In particular, the lack of metering and payment collection for electricity use is another challenge that must be taken into consideration. In Iraq, payment discipline for electricity is relatively weak and it is estimated that tariff revenue is collected only on around one-third of the electricity that enters the distribution network. There are also many illegal network connections (World Bank Group, 2014). Furthermore, the tariffs only cover about 10% of the cost to the Ministry of Electricity (Al-Khatteeb & Istepanian, 2015). The high proportion of residential consumers who use national grid electricity without paying at all means that the effective rate of subsidy is even higher than is implied by the low tariff level (IEA, 2012). In addition to the lack of payment collection, it is difficult for investors to properly cover their operating expenses and recover their cost of capital due to the illegal networks provided by the private generators (Zahawi, et al., 2016).

This review has highlighted the main parameters affecting the energy consumption in Iraq's housing stock, thus the indoor thermal environment, including (i) the projected growth of population and the current housing deficit, (ii) the increasing trend of ambient air temperature in Iraq, and (iii) the economic dimension of energy use. All these parameters should be taken into consideration in any future energy policy.

2.5 The approaches used in previous studies

The crucial factor when selecting the method is the nature and quality of the research; for example, whether the research is observational, experimental, or correlational (Alshaikh, 2016). The fundamental principle with which to judge the success of any approach for these types of studies is the degree of appropriateness and trustworthiness of the data collected and analysed through the particular approach. This data will probably form the basis of a whole set of explanations, interpretations and predictions for the research problem. In addition, fundamental decisions could be made on this foundation, hence the right method is vital for effective results. Generally, an investigation of energy issues that considers the indoor thermal environment and its conditions requires a combination of both qualitative and quantitative responses (Groat & Wang, 2013; Creswell & Clark, 2017; Gray, 2009). These responses can be obtained by several research approaches, each of which has different types of designs and methods, such as surveys, experiments, case studies, and monitoring. Each method is designed to answer one or more specific research questions. However, while it responds to part of the research objectives, it may not be enough to cover all of the major dimensions. Therefore, the integration of different methods would be more fruitful.

Patton (1987) pointed out that each data collection strategy has strengths and weaknesses. The researcher can overcome this problem by using more than one approach because combining strategies can avoid some of the weaknesses and also enhance the results. The notion of employing more than one method for accurate data collection appears for many researchers to be more reliable. These methods have been employed to determine a rational and logical technique to explore the problems under investigation (Kitchenham, 2010; Yin, 2014). Kitchenham (2010) found that using multiple methods, through a mixed-method approach will provide opportunities for the research questions to be measured, analysed, and interpreted, which enables the researcher to obtain meaningful answers. Employing a mixed-method approach results in a more robust outcome, especially in case study research that involves rich empirical data gathered through varied data collection techniques.

The term of mixed-method approach is commonly used to denote a fusion of both qualitative and quantitative techniques for data collection and analysis (Saunders, et al., 2009). This combined approach enables the use of multiple techniques, either simultaneously or sequentially, as required by the needs of the research in question (Saunders, et al., 2009). In summary, the power of mixed-method research comes from allowing the ‘gaps’ in qualitative research methodologies to be filled or overlapped by quantitative methods and techniques, and vice versa (Alshaikh, 2016). Typically, qualitative and quantitative world views are included in the research approaches stage, with quantitative data being analysed by quantitative techniques and qualitative data analysed by qualitative techniques (Saunders, et al., 2009). However, from an analytical point of view, the mixed-method approach combines the strengths of quantitative and qualitative methods, which can be applied in the process of data acquisition and analysis to combine analysis with a clear statistical image of the current situation (Cui, 2014). The combination of these two approaches has proven to be fruitful in many areas (Al-dossary, 2015).

Generally, the qualitative and quantitative approaches enable research in which both numerical and non-numerical data are taken into consideration. Essentially, the quantitative method is typically employed for data collection techniques, such as surveys using questionnaire distribution techniques, or data analysis processes that use or generate numerical data, such as statistics or graphs (Saunders, et al., 2009). In contrast, qualitative approaches are generally used for data collection techniques, such as interviews, which use or generate visual and/or non-numerical data (Al-dossary, 2015). Nevertheless, Bryman (2012) pointed out that mixed-method research should not be considered as a universally applicable method. Briefly, to produce integrated and interpretable results, the selected approaches that suit the research subject and area should be competently designed and professionally conducted (Bryman, 2012). The following subsections will present the approaches that have been used in associated studies, giving particular focus to the design and implementation of mixed-method for data acquisition and analysis. It will begin with a brief review of the sociological approach, which is a data acquisition approach that can help to obtain both qualitative and quantitative data using specific design methods. The second approach that is used for data collection is a monitoring approach, which is a measuring tool to acquire quantitative data from real life. Finally, the analytical approach, including the main analytical methods used to analyse and evaluate the acquired data from both sociological and mentoring approaches will be briefly reviewed.

2.5.1 Sociological approach

The sociological approach refers to data collection using questionnaire surveys or interviews, which differ from the physical measurement used in the monitoring approach. The sociological approach could be independently applied through a questionnaire or jointly conducted through interviews to enhance the other used approaches and measurements. Both these methods are reviewed in detail in the following subsections.

2.5.1.1 Questionnaire

Questionnaires are the most popular method to collect data. As stated by Huang (2006), questionnaire approaches are data collection techniques that aim to discover the exact estimations of the prevalence of significant parameters. Moreover, a questionnaire can be conducted to answer the questions of what, where, when and how. However, it cannot meet the why questions (Bell, 2010). Examples of this approach are found in studies (Pomeroy, 2007; Al-Sallal, 2004) which inform background data about the research topic to develop the research framework. Questionnaires are a quantitative data collection method, which can be distributed in paper form, sent by e-mail, or can be filled in during a face-to-face interview (Neuman, 2013).

The purpose of using questionnaires, according to Zeisel (2006), is to determine and establish the similarities between people matching their answers to the same question. The role of using “precise questions” is to provide a set of reliable measures (Neuman, 2013). There are two types of questionnaires: open-ended questions (unstructured, free response) and closed-ended questions (structured, fixed response). Both types have certain advantages and disadvantages; for example, open-ended questionnaires are considered time-consuming and closed-ended questions seem preferable because they save time and effort. However, the participants of closed-ended questions type may neglect or overlook crucial beliefs and feelings (ibid). The critical aspect here is not which form is best but in what circumstances it is most appropriate, and for what purposes and what are the practical limitations.

The questionnaire survey can be divided into objective and subjective parameters. The objective parameters include the age and gender of the subject and his/her family, how many hours/days are spent inside the building, and what time of the year they operate/shut off the cooling/or heating system. The subjective parameters include the occupant’s satisfaction with their thermal environment.

Another essential issue that needs to be taken into consideration when designing questionnaires is to create a specific and direct question in clear language and avoid hypothetical and personal questions (Sinclair, 1990). To obtain statistical strength, a large and representative sample size is required for the questionnaire-based approach (Cui, 2014). Santin et al (2009), for example, attempted to compare the holistic impact of occupancy and building characteristics on actual energy consumption. They used the Kwalitatieve Woning Registratie (KWR) database of the Housing Ministry in the Netherlands and they examined bills over three years from energy providers. The interview-based KWR national database included 15,000 households who were registered in a survey that included information on housing quality, household characteristics, and occupancy behavioural patterns. For Karjalaine's (2011) study of the indoor thermal environment, surveys were used to investigate determinants (e.g. gender, age, income and education levels) in an adaptive thermal comfort model. Furthermore, most of the identified occupancy-associated determinants have the potential to be considered in the development of building simulations (Wei, et al., 2014).

2.5.1.2 Case study: site visit-interviews

Case studies can be conducted to explore a phenomenon within its real-life context, especially when the relationship between the phenomenon and the context is unclear. This method has been used by many scholars to explore energy and environmental research (Groat & Wang, 2013). A case study method, for example, can be adopted to collect data about a building's characteristics, and the occupant's behaviours and habits. These stages are followed by making an analysis and possibly comparison to investigate information regarding the research issues (Moghaddam, et al., 2011; Pomeroy, 2007). As a strategy of research, a case study involves three main phases, each of which consists of a number of steps, as follows: (i) defining the design of the strategy, (ii) preparing and collecting data, and (iii) analysing the collected data and drawing conclusions (Alnusairat, 2018).

According to Hamel et al. (1993), Stake (1995), and Yin (2014), a case study is a place where researchers use design and control to observe and record real signs of people's comfort and satisfaction. In addition, because a case study method is ideal to answer the questions of Why and How in a contemporary setting (Gray, 2009), the nature and type of questions that the current research aims to answer suggest that a 'case study' is the most appropriate research method.

Generally, the case study approach may depend on qualitative or quantitative methodologies or both. In addition, it is adopted to provide interpretations regarding the researched subject (Stake, 1995; Yin, 2014). Although Yin (2014) argues that there is a slight difference between case study and fieldwork methods, this research regarded the concept of fieldwork as a data collection technique that is part of the case study method. Yin (Yin, 2014) p.13, in this context, defines fieldwork as "*an empirical inquiry that investigates a contemporary phenomenon within its real-life context*". Thus, the best way to deal with the research matter at hand was to carry out fieldwork through a case study method. With regard to the importance of the field study, (Shaffir & Stebbins, 1990) p.18 maintain that:

> *Unlike controlled studies, such as experiments, fieldworks avoid pre-judgement of the nature of the problem and hence the use of rigid data-gathering devices and hypotheses…Rather, their mission is typically the discovery of new propositions that must be tested more rigorously in subsequent research specially designed for this purpose.*

2.5.2 Monitoring approach: a field study

In general, the monitoring approach is a quantitative research method that includes measuring the building and measuring people. The data collected from the former measuring is considered to be objective data (physical parameters) involving energy metering, indoor environment/ outdoor weather parameters. While the data collected from measuring people could be either objective data (actions), such as survey building operation or/and diaries, or subjective data (perceptions), such as thermal comfort survey. The requirement for subjective and/or objective data will depend on the purpose of the study (Guerra-Santin & Tweed, 2015). To provide a better understanding of differences between the expected and actual performance of buildings, it is necessary to monitor the energy consumption, the behaviour of the occupants, their interaction with new technologies, and the resulting indoor thermal environment. Monitoring a building's performance can reduce the uncertainties related to differences between the expected and actual building performance (ibid).

The monitoring experimental approach deals with measurable phenomena, which can find the cause and effect relationship (Bell, 2010). Several methods have been adopted for experiments about the energy use and indoor thermal environment of the built environment. These methods, which are called full-scale methods, can use measuring techniques to investigate a performance under a controlled environment, such as laboratory experiments, or within an ambient situation, such as on-site/on-field measurement (Alnusairat, 2018). On-site measurements, which are the focus of the current research, employ measuring techniques to investigate a micro or specific area, where they are conducted in an existing building and real ambient environment (Groat & Wang, 2013). These techniques have proven to be valuable and acceptable for providing an understanding of the phenomenon in realistic situations. Several techniques have been developed to monitor building performance and conduct on-site measurements. However, most of these techniques are expensive, time-consuming, intrusive or require expert knowledge to analyse the data collected. Consequently, it has proven difficult to embed them in practice (Guerra-Santin & Tweed, 2015). While other researchers argue that with these disadvantages, on-site measurements present high validity and accurate methods for investigating energy use and indoor environment (including thermal) conditions (Almhafdy, et al., 2013; Cantón, et al., 2014). These methods can provide information that is more realistic compared to modelling methods and have a high potential for expressing the phenomenon in a realistic way.

On-site measurements can offer reliable and trustworthy results in terms of the real situation, which can be replicated and re-used. For example, Chun et al. (2004) used site measurement of air temperature, relative humidity and air velocity to construct laboratory conditions to investigate thermal comfort in urban transitional spaces. There is an extensive body of research analysing the divergence between real energy consumption and consumption as estimated through simulation, either by software recognised by the scientific community or the official software provided the different countries (Majcen, et al., 2013; Guerra-Santin, et al., 2013). This divergence, or 'gap', has generally been attributed to user behaviour and, to a lesser extent, to poor identification of the constructive characteristics of buildings (Zero Carbon Hub, 2010). To reduce the error rate and avoid this gap, it would be sufficient to carry out real measurements and relevant tests in the building. Recently, worldwide research has focused on improving occupancy data collection with two main purposes: (i) provide better data for building simulation to make more accurate energy and comfort predictions (Sun, et al., 2014; Lee & Malkawi, 2014), and (ii) use real-time data to control buildings and so to improve building performance (Domínguez, et al., 2013; Yang & Becerik-Gerber, 2014). In addition, another line of research focuses on monitoring buildings to explain better the effects of occupancy and building operation (Wei, et al., 2014), also aiming to change behavioural patterns (Jain, et al., 2013; Huebner & Jones, 2013). Other studies used large datasets of building monitoring data, which are usually measured at very small intervals, and they employ Internet/Intranet infrastructures and networks, see (Craig, et al., 2014; Morgenstern & Chiu, 2015) studies.

2.5.2.1 Definition of monitored parameters

Among the studies reviewed in this chapter, some studies measured multi-category parameters for comprehensive assessments of the respective research topics, while others concentrated on a certain type of parameters to conduct in-depth investigations. The scales, durations, and professional levels of monitoring vary depending on the purpose and aim of the specific studies (Cui, 2014). Depending on the current research field, aim and objectives, two types of parameters—energy use and environmental parameters—were selected and will be separately surveyed in the following subsections. Concerning the monitoring duration and based on certain limitations from the short-term monitoring, such as data loss due to equipment malfunctions, Hancock and Stevenson (2009) pointed out that monitoring results collected over the course of one year were possibly unable to represent typical post-occupancy conditions. The monitoring duration suggested by the Energy Saving Trust (EST) protocol (2009; 2011) was at least two heating seasons for the long-term assessment of a building's performance. The selection of monitoring parameters, duration and associated data acquisition approaches are further discussed in Chapter 3.

2.5.2.2 Energy use

Energy use can be measured in many different ways, according to the available resources and the accessibility to the building. For example, energy metering can be used to measure the delivered energy while energy sub-metering can be used to determine the usage distribution within the building. This division is important because it distinguishes between building-related (regulated) and user-related (non-regulated) energy consumption in building regulations, certifications and indicators. The data can be collected from energy meters and sub-meters in several different ways, such as energy readings, high-frequency energy logging and building management systems (BMS). High-frequency data collection is required when more detailed information about energy use is needed, such as on a high-frequency basis (i.e. every 5 min) and in a very long span of time. The advantage is that this can be coupled with information about indoor thermal environment conditions and outdoor weather conditions and building operation. It can also provide a better image of how the building is operated. High-frequency meter readings have several potential uses (Brown, et al., 2010): (i) the provision of accurate and timely data; (ii) access to trading and variable rate tariffs; (iii) identification of systems' inefficiencies and failures; (iv) quantifying net export from on-site renewables (if existing); and (v) long-term benchmark and monitoring.

The measurement of energy use in different studies relates to the project scale, equipment standards, house numbers involved, and research purposes. For example, Voss et al. (2007) studied information on the energy use of heating, ventilation, air conditioning and lighting in office buildings that were generated using five years of site measurements. Meanwhile, other studies have explored the relationship between energy use and environment conditions. Breesch et al. (2005), for example, used the monitoring technique to collect information regarding the impact of surface temperature and air temperature on energy use in buildings. While the field measurement of both energy use and thermal comfort was employed by Cantón et al. (2014) to evaluate the effect of different open space design parameters on the energy consumption to obtain comfort conditions in the interior space. Wright and Firth (2007) investigated to what extent the monitoring intervals of power supply and draw, when renewable microgeneration is used on-site, would suit research objectives in the built environment. By using one-minute power profiles from seven houses and performing a time-averaging process to convert the data to five-minute, 15 minute, and 30-minute data prior to superimposing them for comparisons, Wright and Firth (2007) concluded that the five-minute interval can suffice for the monitoring purpose of renewal power supply but not for that of house use because the averaged power draws of house use were found to be skewed in some instances. How and why the current study selects the appropriate monitoring interval that suits the research topic of suppressed energy demand, energy use, and the indoor thermal environment was taken into consideration in the experimental work in this study. The associated methods and applications' results are further discussed in Chapters 3 and 6.

2.5.2.3 Indoor thermal environment

Generally, there are two main methods to collect data for the evaluation of indoor thermal environment: (i) measurements of indoor environment parameters and (ii) application of thermal comfort surveys. The first method involves physical monitoring of the building (thus, objective data). Meanwhile, the second method uses surveys to gather subjective data from the occupants, and to gather their preferences for the thermal environment and to gauge the differences between individuals. The indoor environment parameters that can be easily measured with the technology available are dry bulb temperature, relative humidity, CO_2 concentration, and airspeed. The outdoor weather parameters include temperature, relative humidity, CO_2 level, solar radiation, wind speed and direction, and precipitation. Measurements of outdoor weather parameters are required when the adaptive model is used to determine the comfortable thermal environment. Outdoor weather measurements can also help to understand unexpected indoor environment measurements and building operation. For example, a winter day with high solar radiation would explain lower energy consumption due to solar heat gains. These measurements can be taken in two ways: at a determined interval from minutes to hours, or spot measurements were taken only at one time. The type of measurement will depend on the type of data required for the investigation (Guerra-Santin & Tweed, 2015). Regarding the research at hand, environmental parameters, including temperature and relative humidity, are used to achieve its aim and objectives. Environmental parameters are usually monitored outdoors as part of weather parameters, in addition to being measured in indoor living zones. The monitoring purpose of environmental parameters varies from the assessments of building fabric to the examinations of indoor thermal environment, such as in the Retrofit for the Future (RFF) and Building Performance Evaluation (BPE) programmes of the Technology Strategy Board (TSB, 2013).

Thermal environments investigation, with respect to duration, can be divided into two types. First, short-term measurements, which are usually enough when then investigation requires linking the indoor environment/outdoor weather parameters with a thermal comfort survey applied at the same time than the measurements. Moreover, short-term measurements can be used when long-term measurements are not possible, such as to avoid high costs or being intrusive. In these cases, short-term measurements can give an indication of the parameters. For example, for airspeed, it is common to take only short-term measurements. Furthermore, short-term measurements are sometimes necessary when the investigation needs more detailed information, such as to more accurately calculate the operational temperature or the air temperature (e.g. measuring the temperature at different heights). The second type of thermal environment investigation, in terms of duration, are long-term measurements. These measurements are useful when the objective of the monitoring is to determine the performance of the investigated parameters over a long period of time, such as over the course of a season or year (Alshaikh, 2016). Some indicators require knowledge of how many hours of overheating occur in the building per year. These types of measurements are possible when the users accept monitoring devices in their homes/ buildings. Given the amount of data that can be collected, long-term measurements tell us more about the performance but they have several disadvantages, such as the users might not want to have the devices/cables around, the devices can be broken, and the users might feel under constant vigilance, which will reduce their willingness to take part in the study (Cui, 2014). In short, long-term measurements can provide more detail about the investigated parameter. ASHRAE standard 55 (2007) suggests taking measurements in the centre of the room, where the occupant spends most of their time. However, long-term measurements of temperature are usually only taken in a non-disruptive location in the room (e.g. on a shelf) and only in one location/height.

A brief description of some studies related to the investigation of the indoor thermal environment by focusing on environmental parameters follows. Yohanis and Mondol (2010) conducted indoor temperature monitoring in 25 houses in Northern Ireland using four environmental loggers in the bedroom, living room, hall and kitchen areas of each house from January 2004 to December 2005. The measurements over a one-year monitoring period were used to analyse seasonal, monthly and daily average temperatures. Yohanis and Mondol (2010) focused on examining the proportion of homes that were under heated, overheated, or maintained comfortable by using 21ºC as a point of reference. Karava et al. (2012) explored mixed-mode cooling strategies in buildings with hybrid ventilation in building with motorised façade openings integrated with an atrium by utilising the field measurement of thermal performance. For example, an on-site measurement technique was used in Almhafdy et al. (2013) to study the effect of geometry on the thermal performance of the building. In-use monitoring has been developed and applied to three case studies representatives of the typology, constructive system and climate of southern Spain. Through this monitoring, real use and occupancy patterns are defined to develop energy simulation models adjusted to the real behaviour of this housing stock, significantly reducing the 'performance gap' between real and estimated consumption. In summary, the in-situ data collection of environmental parameters is essential for the evaluation of the indoor thermal environment of the case studies (Escandón, et al., 2017).

2.5.3 Analytical approach for evaluation

For comprehensive assessments, measured multi-category parameters require multi-analytical approaches and methods. This part of the chapter focuses on the multi-analytical approaches used to analyse and evaluate the monitoring measurements because they represent the main part of this study. To define the monitoring techniques to be used, the depth on the study also has to be defined, which determines the type of data required and therefore the data collection techniques (as reviewed in the previous subsections). Furthermore, the data required for evaluation will be dependent on the available performance indicators, which can be quantitative and/or qualitative (as shown earlier). However, in some cases, and for high-quality results, indicators should be translated into other indicators that can be measured during building operation.

For example, if building regulations are prescriptive and only specify a minimum U-value[2] (instead of a target for energy consumption), then a method of calculations might be required to determine the expected energy consumption. Examples of building performance quantitative indicators include energy consumption in kWh/m^2·year, number of hours with indoor temperatures above the recommended level, CO_2 concentration limit and so on. However, performance intentions (such as healthy indoor environment) are qualitative and should be translated into quantitative indicators, such as by relying on standards for quantitative analysis (Guerra-Santin & Tweed, 2015).

An evaluation process relies on several factors, including (i) the objective of the evaluation, (ii) the subjects to be evaluated, (iii) the type of feedback, (iv) the performance indicators available, and (v) the resources available to carry out the monitoring activities. In general, the monitoring of performance can be indicative, investigative, or diagnostic (Preiser, 2001), where the nature of the study is highly related to the objective of the monitoring activity. Studies to verify performance are indicative in nature because they help to broaden the knowledge base. Studies to provide lessons for future projects and provide feedback to those interested in the subject are investigative, and studies to improve the performance of a building are diagnostic. According to Gupta and Chandiwala (2010), the nature of study reflects its depth, for example, an investigation is considered the deepest study because four levels of investigation can be applied, including basic, core, advanced and detailed.

2.5.3.1 Analyse energy use

Evaluation of building in-use performance usually assesses energy performance by making a comparison between energy use (i.e. per year) and a pre-determined indicator. The indicator can be based on a benchmark, design calculations, national or international standards or energy requirements from national regulations (e.g. British regulations), building certifications (e.g. Passivhaus) or qualitative indicators (e.g. BREEAM or LEEDS) (Guerra-Santin & Tweed, 2015). Several methods can be used to evaluate energy use and performance during occupancy consumption. This section presents an overview of the most common methods:

- End-use energy peak demand,
- Total annual energy use demand,

[2] U-value or thermal transmittance is the rate of heat transfer through a structure, divided by temperature and area. U-value (unit: W/m2K) describes how much heat passes through a unit area (typically 1 m²) of a construction due to a unit temperature difference (typically 1 degree kelvin) (Laustsen, 2008).

- End-use annual energy use,
- Normalised energy use or energy costs,
- Primary energy use equivalent, and
- Life cycle assessment (including embodied energy demand).

For the most basic energy evaluation, it is necessary to determine how much energy is consumed per end-use (e.g. space heating, space cooling, tap water heating, electricity for household appliances, lighting, fans, etc.) according to the period of study (e.g. yearly, seasonally, monthly, weekly, etc.). These decisions depend on two factors: (i) the indicator (e.g. yearly basis), and (ii) the available resources for the monitoring (e.g. installing sub-meters). Obtaining the amount of energy consumption is quite straightforward, but some considerations should be taken into account when evaluating energy consumption and use, as follows:

- **A benchmark**

In energy performance evaluation, benchmarks can be a straightforward way of assessment. A benchmark provides a reference energy consumption that is easy to understand and compare with the measured energy consumption. However, it is often unknown what the benchmark entails. Therefore, some of the questions should be asked when using a benchmark (Guerra-Santin & Tweed, 2015):

- How similar or different is the reference case study (building) in comparison with the monitored case study?
- How old is the benchmark? Are new technologies considered in energy consumption?
- Is it a best-case scenario or an average scenario?

Answering these questions can help to make the benchmark more useful.

- **The normalisation of energy use**

With statistical methods, the energy consumption can be analysed in relation to the occupants' behaviour or characteristics, or in relation to the building's characteristics. There are many influences on behaviour related to energy use and thermal environment (Tweed, 2013; Tweed, et al., 2014), this makes it difficult to account for behaviours in a definitive way. The normalisation of energy consumption per building characteristics (e.g. useful living area or per type of building) allows evaluating energy consumption when different types of buildings are being studied. Moreover, normalisation of energy for certain aspects of occupant behaviour or occupant characteristics allows evaluating energy consumption in similar buildings (i.e. houses) while controlling for differences in occupancy.

- **Primary energy**

Some indicators are given in terms of primary energy consumption or carbon emissions. Therefore, it is necessary to convert the delivered energy into primary energy and carbon emissions equivalents. The factors to make this transformation will depend on the country and sometimes on the tool utilised. The energy metered during building performance monitoring is the delivered energy, which could be a useful indicator when the design of the building and its occupancy are being assessed. However, with the introduction of performance-based energy regulations, the designer is allowed to choose the solution to reach the minimum performance. Given the great diversity of solutions to reach the performance and the large effect that the efficiency of systems and installations can have on energy consumption, it is sometimes also necessary to evaluate the primary energy consumption. This is especially important in developments and buildings that utilise energy generating technologies, and more options for energy for cooling and/or heating are available in the area or given the size of the building (e.g. when district heating is available of when the size of the building/development will make possible the use of heat pumps). Primary energy consumption evaluation is necessary in studies that involve more than one building, to generalise results to a wider population, to give feedback for industry and designers, or for comparative projects focusing on technologies (Guerra-Santin & Tweed, 2015).

- **Heating and cooling degree hours**

Heating (or cooling) degree hours are important in post-occupancy building evaluation when the actual energy consumption is compared against a benchmark, which needs to be based on a reference year. However, it is sometimes difficult to find the reference year for a benchmark. Therefore, the researcher should carefully consider whether using a benchmark is appropriate for building evaluation. For example, if the building monitoring was carried out in a colder or warmer than usual year, then a comparison against a benchmark would be unreasonable (Guerra-Santin & Tweed, 2015).

In summary, selecting the best method for energy evaluation would depend on the purpose of monitoring exercise and investigation. The end-use method is important when the management and use of the building are being assessed. Heating degree hours and normalisation are more useful to verify performance because they enable comparisons with other buildings or periods.

2.5.3.2 Analyse energy suppressed demand

Although suppressed demand can be estimated as a percentage of the difference between what is actually consumed and the desired (unmet) consumption (which is constructed by considering the energy consumption of a hypothetical household) (LDC Environment Centre, 2013), this estimation is not subject to a specific rule but instead relies upon the local circumstances of the case study. Concerning the availability of calculation methods of energy suppressed demand, very few published studies have attempted to quantify the suppressed energy demand for residential electricity demand in developing countries. Consequently, the research area still lacks comprehensive studies to establish the suppressed demand. Another related study was conducted by Mohammed (2018), where a long-term model was built to provide the yearly unsuppressed load forecast in Iraq. The forecasting used to estimate the annual suppression energy demand for different sectors relied on the annual electricity consumption data provided from the Iraqi Ministry of Electricity for the period 1988–2013 for the residential, commercial, industrial, agricultural and governmental sectors. The results showed that the total estimated suppressed consumer demand was 49.15%, while the domestic suppressed demand was 14% of the actual annual maximum peak. However, providing an hourly estimation for the long-term suppressed energy demand based on monitored data represents a key contribution of this study.

2.5.3.3 Analyse the indoor thermal environment

This section presents the types of evaluation that can be used for the indoor thermal environment via environment conditions. Starting with standards for thermal comfort, which can be found in EN 15251 and ASHRAE standard 55, which define the two thermal comfort models used for the design and assessment of buildings, firstly, the predicted mean vote (PMV), and the predicted percentage of dissatisfaction (PPD) model. Secondly, the adaptive model. The former was developed by Fanger (1970) and takes into account other aspects of the indoor environment, as well as the human condition. The latter takes into account the adaptiveness of people depending on outside temperature and the control of their environment. These models can be used instead of indoor temperatures for a more comprehensive assessment because they offer a criteria range for indoor environment parameters (operative temperature, relative humidity and CO_2 concentration level). The PMV, which is calculated with the measured temperature and relative humidity, is compared with the ranges of acceptable PMV that are defined in the standards. To use the adaptive model, the measured indoor temperature is compared with the calculated ranges of adaptive temperature, thus the ranges of acceptable temperature are not prescribed in the standard but are instead calculated based on the ambient temperature (AT).

It is worth mentioning here that it would be impossible to specify a thermal environment that will satisfy everybody all of the time (CEN, 2005). For example, if the criteria range for the PMV–PPD and operative temperature are to be met at all times, then the heating and cooling capacity of the HVAC systems would be relatively high. Therefore, the long-term evaluation of thermal environment takes into account the percentage of time that the building is outside the specified ranges for buildings based on their categories (i.e. existing buildings, new buildings and renovations). It would be accepted if the indoor environment conditions are out of the ranges for 3–5% of the time (CEN, 2007).

The duration of the building evaluation by using these thermal comfort models depends on its objectives and the available resources, which can be short term or long term. Short-term studies usually employ a combination of spot measurements, which are taken a pre-determined number of times, and thermal comfort questionnaires. The main difference with long-term measurements is that the questionnaire on thermal comfort has to be applied to the subjects of study while measurements of indoor environment (and outdoor weather) parameters are taken. Long-term comfortable thermal environment evaluation often consists of post-occupancy and in-use performance evaluations, which include a thermal comfort questionnaire that can be coupled to longitudinal or seasonal measurements of indoor environment conditions, such as temperature and humidity, whose purpose is to evaluate the performance of the building for a determined period of time. Seasonal monitoring can be done by repeating the short-term procedure seasonally or by splitting the long-term monitoring data per season (Guerra-Santin & Tweed, 2015)

A large number of comfortable thermal environment studies have been conducted in buildings in all types of climates, were carried out in tropical, subtropical and temperate climate zones (Al-Ajmi & Hanby, 2008a; Hwang, et al., 2006), while others were performed in cold climate zones (Wang, 2006; Donnini, et al., 1996). However, research of indoor thermal environment in buildings for countries located in dry-desert climates is still limited, although some studies can be mentioned (see, e.g. (Cena & De Dear, 2001). In particular, Saeed a (1993) and Saeed b (1996) conducted research in the dry-desert region in Riyadh, Saudi Arabia and measured thermal comfort for classroom students in King Saud University during the hot season. The results indicate a fairly good agreement with Fanger’s model in both studies. In the (Al-Ajmi & Loveday, 2010) study, the field experiments were conducted in 25 air-conditioned domestic buildings using survey questionnaires and physical measurements to collect data during the summers of 2006 and 2007. This study also takes into account the clothing insulation values that were calculated by Al-ajmi et al. (2008a; 2008b).

2.6 Summary

Suppressed energy demand is a significant challenge in many developing countries. The domestic building stock is the most vulnerable to this challenge because suppressing the actual energy demand of households has adverse environmental, social, and economic impacts. This review has shown that several studies have recently presented suppressed energy demand as one of the most important factors on residential energy use in developing countries. However, there are few experimental studies to provide an accurate estimation of hourly suppressed energy demand based on real data in scientific studies. Moreover, there is less attention to the thermal performance of the dwellings under suppressed energy demand, especially in hot arid climate zones such as Iraq. Therefore, further research is needed to provide an accurate estimation of the suppressed energy demand in residential buildings and to determine its impact on indoor thermal environment, which will provide recommendations and solutions to reduce the impact. Accordingly, this study intends to determine the quantity of hourly suppressed energy demand in kWh and it will investigate how it affects the indoor thermal environment. Therefore, it is important to understand the principles, processes, conditions, and control parameters of suppressed energy demand in residential buildings in hot arid climate regions, which will be discussed in the next part of this thesis. Consequently, the next chapter will describe the method that is used to test the research design, which is created to answer the research questions. In addition, the next chapter also involves describing the used method to extract the dwelling prototypes to conduct in-site monitoring.

Chapter 3: Research method

This chapter focuses on the adopted approaches in the research to fulfil and answer its questions. The starting will be with used methods for data collection, including the sociological method, which used here as a supplementary method. A transverse questionnaire –as a first part of the sociological approach- is used for two purposes: first, to obtain findings that associate with bi-directional relationship between the energy use and the social and economic dimensions of residential buildings; and second, a questionnaire was employed to explore and extract the selected case studies that present the common housing prototypes in Iraq, which used for monitoring. The case study approach is presented in this study as the second part of the sociological approach. Seven pilot dwellings across Baghdad city are considered in this research in order conducting the monitoring approach. Long-Term monitoring for both energy use and indoor environment conditions were carried out to accomplish the following objectives. First, to provide an accurate estimation of hourly suppressed energy demand in residential buildings. Second, to examine the influence of suppressing the energy demand on the indoor thermal environment in a hot aid climate zone such as Iraq. Finally, the approach used to analyse and present the monitoring results is defined and is followed by a summary.

3.1 Background

Suppressed energy demand could be associated with energy use and the indoor thermal environment, which are affected by the building's characteristics and the socio-economic characteristics of the occupants. Multiple research approaches—including monitoring, sociological, and analytical methods—have previously been applied, as reviewed in Section 2.5. This study seeks, first, to estimate both energy use and suppressed energy demand to provide an accurate estimation of the actual energy demand of domestic buildings. Second, to examine the implementation of suppressing the energy demand on energy use and the indoor thermal environment. It is important to select appropriate methods, where the methodological features can suit the research topic and data required for the study. The mixed-method research approach advocated by Bryman (2012), which combines quantitative and qualitative strengths, was applied in the process of data acquisition and analysis. As regards the first aspect, quantitative approaches in this research were applied to explore the energy-use patterns emerging from data measurements of seven purposefully selected case studies. Meanwhile, qualitative approaches have been adopted to interpret the mutual effect between the social, economic and buildings characteristics and both energy use and indoor thermal environment.

The qualitative and quantitative approaches in this research were not clearly divided because both were used to provide a better understanding regarding the interaction among all these aspects. For example, a comprehensive questionnaire and formal interviews were used to corroborate physical measurements (i.e. energy use, outdoor weather and indoor environment conditions). Both approaches were used to enhance the integrity of the findings, while the use of quantitative findings enriched the qualitative information via illustration. The qualitative information was used to improve the utility of the quantitative findings because quantitative approaches were more prominently used in this research. The selected research approach and the associated analysis techniques (including the data collection, long-term monitoring in case studies) are justified in this chapter.

3.2 Method adopted for the research

The monitoring, sociological, and analytical approaches are employed to ensure a clear understanding of the characteristics of domestic energy use with suppressed actual energy demand and its implications on the indoor thermal environment. Case studies are undertaken to assess the selected parameters in this research. Meanwhile, both monitoring and sociological approaches are used to obtain accurate and supportive data, especially in the actual living environment. The analytical approach, in the context of this research, refers to various types of numerical and analytical methods that are used in the process of data analysis. Consequently, this research is divided into multiple stages. In each stage, a specific research question is answered. In addition, a specified objective can be fulfilled by employing a specific approach. The first stage identifies the main social, economic, energy and physical characteristics of domestic buildings in Iraq, which was used for two main purposes. The first purpose is to justify the selection of case studies used in the next stages. Given that this study is concerned with the issue of energy use in Iraq’s domestic sector, it was essential in the second stage to determine the crucial parameters influencing the energy use in existing domestic buildings, which can later explain the monitoring findings. The following stage investigated the energy use and then estimated the suppressed energy demand in these selected dwellings. Finally, it is important to evaluate the influence of the suppressed energy demand on the indoor thermal environment.

According to Kothari (2004), these stages can be divided into two categories of research methods, which are:

- Methods concerned with data collection, which are typically employed in cases where the available data are insufficient to identify a viable solution;
- Statistical techniques, which are used to investigate the relationships between the data and the research problem.

Applying this classification could help the current research to achieve its main aim, which is to identify a given problem and offer a solution, taking into account the available data and the relationship between that data and the problem gaps.

3.3 Method of data acquisition

The approaches used to acquire the required data are based on the fulfilment stages of the research objectives. The first stage conducted a comprehensive and transverse[3] questionnaire to obtain information related to the household's socio-economic aspects, the building's characteristics, and energy use issues.

3.3.1 Questionnaire: supplementary sociological methods

In the current research, and based on the required data, the use of questionnaire interviews is preferred because they can ensure that a sufficient number of questionnaires are gathered, due to people's unwillingness to volunteer such information unless they are in a face-to-face situation. They also make it easier to ask questions, discuss the responses, and deal with potential cases of illiteracy. In addition, this study suggests using a closed-ended questionnaire because it would be more helpful to meet the research aim, accomplish the research objectives and answer the research questions. The questionnaires were primarily distributed to, and completed by each participant involved in the interviews.

In addition, this comprehensive survey was conducted as the first stage of this study in order to diagnose the factors influencing energy use and consumption in the domestic buildings in Iraq. This stage addresses the following overarching research objectives:

[3] Two fundamental surveys are included in the field study: transverse and the longitudinal surveys. The former involves collecting data from a large number of respondents, with only one assessment at a particular time, whereas the longitudinal survey is used to collect data from relatively few respondents and repeating the survey with the same respondents over a period of time (Alshaikh, 2016).

- Objective one: investigate the behavior of the occupants in response to the current situation of energy use in typical housing in Iraq.
- Objective two: identify the physical characteristics that result in high energy demand and inadequate thermal environment.
- Objective three: identify the main energy sources used by households for their main daily activities.
- Objective four: identify the contribution of the socio-economic dimensions in formulating domestic energy use.
- Objective five: identify the satisfaction level of households regarding energy and thermal environment of their dwellings.

Comprehensive information related to social characteristics, building design and physical characteristics, energy use, environment systems, and economic dimensions are needed and were sought from people of different ages, education levels, and locations, as elaborated below.

The questionnaire used in this study is based on the following five sections:

Section A (demographic information): Background and personal information, which elicited the demographic data about the subjects and their families, and other general information, such as the social network of families. The results of this section are explained in section 4.2 and subsection 4.3.1.

Section B (dwelling characteristics): General information about the dwelling, which involved data about the dwelling type and built date, and other factors, plot area, number of storeys and rooms, construction details, and the thermal environment in general in the dwelling. Subsection 4.3.2 describes the results of this part of the questionnaire.

Section C (energy use and environmental systems): This section is divided into five parts: first, the main source of energy used daily activities; second, the peak period of using cooling and heating systems over the months of year; third, identifying the main cooling and heating systems used by households; fourth, the households were asked to list the appliances which a household might have and which energy source they used for their operation; the final part concerns the households assessment regarding both cooling and heating in terms of safety, health and ease of use. The results of this section are explained in subsections 4.3.3 and 4.3.4.

Section D (economic dimensions): These questions asked about the monthly expenditure rate on energy, including all type of energy used, and the percentage of the total monthly household income spent on buying energy. The results of this section are explained in subsections 4.3.5.

Section E (assessment of occupant satisfaction): This section focused on the households' satisfaction regarding specific aspects of dwelling, including physical characteristics, environmental aspects (indoor thermal environment and environmental systems for cooling and heating) and the cost of energy consumption. Subsection 4.3.6 describes the results of this part of the questionnaire.

For the purpose of the present work, the participants were asked to add any notes or comments that might help the researcher to understand more about the energy use and environment aspects, besides people's social life. This information would help to explain any sociological reasons for people's responses to their environment (based, for example, on their background, demographic features, and economic level). The questionnaire has been translated into the Arabic language and then the translated words used in the scales were also tested in a pilot study and by experts before being distributed among the residents in the Baghdad city, Iraq. The reasons for the pilot study (or testing questionnaires) are as follows:

1. To test the respondent's comprehension of each question;
2. To ensure using the right translation of the adopted terminologies;
3. To revise and simplify the wordings of questions in accordance with the feedback, to avoid ambiguity; and
4. To test the validity of the questions, which may contribute to the research objectives.

After testing the questionnaire, it was found that question 36 in Section C was neglected. This question was ignored due to the difficulty of determining the specific period of using cooling and heating systems among households during the day for different seasons. The questionnaire responses were analysed using SPSS and Microsoft Excel. The results were analysed by descriptive analysis, including frequency and percentage methods. The missing answers were not analysed in the assessment and the missing values are not significant to be interpreted in this survey.

3.3.2 Case study approach

Based on the energy monitoring protocol of the Energy Saving Trust (2011), long-term monitoring refers to the frequent measurement of energy use and indoor environment / ambient conditions conducted over the required period. This method of research is used by building service researchers to investigate and predict the changes in the operational energy of non-domestic buildings (Brown, et al., 2010; De Wilde & Augenbroe, 2011). The energy-use data of buildings and associated parameters are collected using various metering devices, rather than being gathered by researchers themselves as in sociological studies. Consistent data profiles from and permitted accessibility to the studied buildings are the basis of an effective long-term monitoring method. Therefore, it is less commonly used in research on domestic buildings, especially when various building technologies and statistically sufficient building numbers are considered to be parameters in holistic investigations on the energy use and indoor thermal environment.

Short-term and long-term monitoring were discussed in subsection 2.5.2.1 and 2.5.2.3, respectively. Due to the limitations from the short-term monitoring, this research sought to apply the long-term monitoring, which defined in the Energy Saving Trust (EST) protocol as one-time monitoring for fabric and mechanical elements, and frequent measurements of energy use and indoor environment/ ambient conditions over at least two heating seasons (EST, 2009). The research gap in applying the long-term approach to a small scale of housing stock led to formulate the following research questions:

- How is energy, especially electricity used in Iraqi dwellings? and how does it vary temporally and compare regionally?
- How do occupants interact with the building and its systems to maintain a comfortable indoor environment?
- How do ambient conditions and suppressed energy demand affect the indoor thermal environment?

The fact that this is a ‘how’ type of question justifies the inclusion of case studies as an appropriate research method. Yin (2014) defined the case study as a type of empirical method to answer a ‘how’ research question that comprehensively investigates a contemporary phenomenon, over which a researcher has little or no control, in the real-world context. Energy use and related indoor thermal environment in actual homes fit the case studies method definition. Yin (2014) also pointed out that a case study inquiry relies on multiple sources of evidence with acquired data converging in an integrated method. Mixed-method research on energy use and related indoor thermal environment integrates qualitative and quantitative approaches to corroborate research findings, meaning that case studies can feasibly be applied within this context. Bryman (2012) stated that case study research frequently includes monitorable elements. Therefore, the long-term features (see subsection 2.5.2) are compatible with the case study method. In addition, case study design involves the selection between single-case and multi-case studies, and the levels' justification of adaptation allowed during the data acquisition process (Yin, 2014). Therefore, the nature and type of questions that this research aims to answer suggest that a case study is the most appropriate research method.

In the following subsections, the selection of appropriate case studies and long-term data acquisition approaches are discussed on the basis of the case study design required for this research and its context.

3.3.3 Research case studies

To generate comparable measurements, it is important to select case studies that fit the research context and are representative or 'exemplifying', rather than purely emphasising the sample size. Resource restrictions in terms of time and cost also need to be considered in the case study design stage and number (Bryman, 2012; Yin, 2014). After taking these factors into consideration, and including the other limitations that will be explained in the following sections into this chapter, it was found that seven case studies that represent the typical homes in Iraq were an appropriate number for this research.

Energy use, external weather conditions, and indoor thermal environment are the interactive factors that need to be considered in the selection of the case studies. Although each case study features unique microclimate characteristics to a certain extent, choosing geographically building sites with similar external temperatures enables a comparison of performance difference from the perspective of the other two factors of energy use and indoor thermal environment. The identical service performance of houses within the same case studies highlights the impact of energy supply scenarios on actual energy use and the indoor thermal environment. In addition, the cooperation with, and the support from case study homes are of great importance for data quality maintenance, which is closely associated with the frequency of the site visits and proper equipment management. The seven case studies that are presented here and in Chapter 5 were selected based on these aspects.

Case studies, for the purpose of this research, aim for more realistic descriptions, which can be integrated with the results from the questionnaire. They have been employed to investigate in further detail a limited number of houses, where they can be used as explicit and illustrative examples from the wider sample in term of the current situation of energy use. The relationship between the occupants and their environments is crucial. Therefore, if the occupied space is “atypical or of unusual design”, then this may influence the field result in terms of validity and reliability (Nicol, 1993). This is why this study was careful in looking for typical contemporary dwellings in Baghdad city. Moreover, this study had an opportunity to perform site measurements, and draw up plans and take photos, for more realistic descriptions that can be integrated with the questionnaire’s results. This study aims to estimate the suppressed demand, and measure its impact on indoor thermal environment in domestic buildings. However, according to (Cena, 1994) conducting such extensive study in private homes can be difficult, due to the natural desire of many people not to have their domestic affairs interfered with. This issue is critical, especially in countries with unique cultures and special customs, such as in Iraq. The choice of the dwellings to be used as case studies was based on the following criteria:

1. Located in Baghdad, as the most important urban centre in Iraq (see subsection 2.4.2).
2. Built in different and common periods.
3. Typical in terms of design and material as far as possible.
4. Typical in terms of energy sources for cooling and heating.
5. Mixed-mode air-conditioned and naturally ventilated homes. Air-conditioning is typically used during summer and by households that can afford it. On the other hand, natural ventilation is used during transitional or intermediate seasons, spring and autumn and in spaces such as kitchens. More details are shown in subsections 4.3.3 and 5.2.3.

It is worth mentioning here, that criteria 2 to 5 rely on the findings of the questionnaire, as explained in Chapter 4.

3.3.4 Distribution of the case studies

The questionnaire results were used to target typical dwellings so that they could be used as a representative for other dwellings of almost similar characteristics and operation. Case studies' selection and monitoring were arranged during the visit to Iraq in winter 2017, in the city of Baghdad, where the availability of volunteers for the practical fieldwork was gathered in advance. The first step to implement the fieldwork was to obtain permission to conduct this field experiment in each home, which was never an easy task without prior arrangements because this subject is not familiar to Iraqis. Two of the householders whose houses were initially selected based on the location did not agree to conduct the field experiments in their homes. Consequently, the choices were limited based on the locations and householders of the houses who permitted the researcher to conduct the physical measurement without any conditions. In addition, the limited number of available instruments was another added limitation of the monitoring. These criteria were crucial factors in the determination and selection of the cases. Moreover, for privacy and cultural reasons, there were further limitations to find available places for taking measurements without disturbing the family and special arrangements had to be made to secure these units for investigation. Whenever a detailed analysis is carried out that involves long campaigns of monitoring energy use and indoor environment parameters of dwellings, it is difficult to have a large sample of case studies because of financial and time constraints (Guerra-Santin & Tweed, 2015; Escandón, et al., 2017). Consequently, seven existing and occupied dwellings were selected from seven different municipalities across Baghdad city, which are: Al-Rasheed, Al-Dora, Al-Adhamyia, Al-Mansur, Al-Ghadir, Al-Shualla, and Al-Krrada. The distribution of these case studies was within a radius of 7 miles and 115 sq mi (mi^2) within the city of Baghdad (33°20′N, 44°23′E), in the middle region of Iraq, as shown in Figure 3-1. It is worth mentioning that each pilot house in the case studies was given a unique code, to be referred to hereafter throughout the thesis, see Table 3-1. The next stage of the case study approach was a site visit, which was added as part of the case study to meet other research objectives. The site visit of each case study was conducted individually to obtain concrete data regarding the case studies, as will be explained in the next subsection.

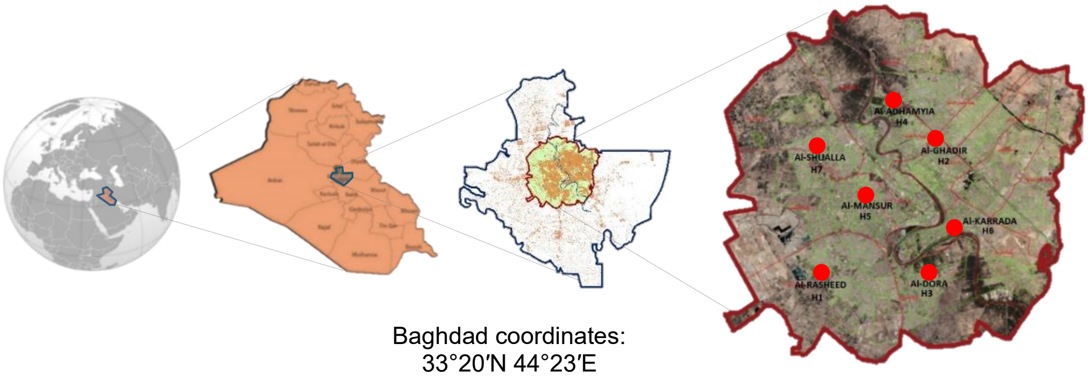


Figure 3-1. The geographical location of the selected pilot studies. The seven existing and occupied dwellings were selected from seven different municipalities across Baghdad city within a radius of 7 miles and 115 sq mi (mi²).

Table 3-1. Code used for each case study in research.

Case study	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**
Code	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**

3.3.5 Site visit and interviews

Regarding the supplementary sociological research methods, the questionnaire-based interviews were conducted as the first stage of sociological approach in this research for data collection. Together with the questionnaire, the interviews enhanced physical monitoring to achieve the research purpose. The site visit and structured interviews were carried out with the dwellers of selected houses as case studies for fieldwork during January and February of 2017 to establish an in-depth understanding of their energy use, indoor thermal environment, and to gain insight into their general lifestyles regarding these two aspects. The participants were asked questions regarding their routines and everyday behaviour using a questionnaire. Another target of conducting the interviews was to observe the building layout — as described in the next section—, the conditions of the building's structures. The interviews mainly focused on three relative aspects: description of the dwelling, the occupants' social and economic profiles, and their energy use and indoor thermal environment aspects. During this stage, this study aimed to analyse the factors in different houses that influence the energy use from the dwellers' perspective. An attempt was also made to provide initial perception regard to energy-use patterns in the residential sector in a hot-arid zone such as Iraq, as represented by Baghdad city. However, data collection at this stage was one of the greatest challenges faced by the researcher, as described in the conclusion. The researcher managed the timescale with the residents to gather the necessary data within a limited timeframe based on their convenience. The main data required to be collected during this stage described (i) the architectural layout and construction plans for the seven cases, (ii) interviews with family members in each pilot house, and (iii) installing monitoring systems and devices of each case based on the required data to be collected (as illustrated in subsection 3.3.7). It is necessary to mention here that the research suggested the interview method because it is difficult to collect the required data from governmental institutes since some of it is unavailable or sensitive. Therefore, the researcher collected the data directly from householders who respected and valued the study.

This study used a site visit to carry out data collection at the dwellings, with the respondents sitting with the researcher. Given that this type of research study is not familiar in Iraq, the interviews started by giving an introduction to the occupants of the homes, explaining the objectives of the research to be performed and its importance for residential buildings in Iraq. The participants were also assured that their identity would not be disclosed in the research. The questionnaires for the interviews were made available in English as well as in Arabic, to further encourage participation in the research, and both versions were used. Because the energy use varied depending on the layout of the houses, and the floor area could be used to identify the actual level of energy-use patterns (in kWh per square meter), the floor plans for all dwellings were drawn by the researcher after taking the required measurements of the floor plans using AutoCAD software —see subsections 5.2.2 and 6.3.3. Drawing the floor plans of the monitored houses helped to obtain more realistic descriptions and data analyses, which can be integrated with the results from the other data collection approaches. In the same context, the researcher was also able to address some related issues with the dwellers, such as how the buildings are designed, and which construction system and materials are used in each case. This ensured that the selected dwellings could be representative and exemplify the housing prototype in Iraq, and also fit the research context.

3.3.6 Layout description

This section is focused on the layout description of selected case studies in terms of space organisation and their daily use by the households, which can influence both energy use and indoor thermal environment. The physical characteristics, such as plot, built, and floor area, orientation, and constructional materials are illustrated in Chapter 5 within the results of the site visits and interviews. This research sought to use dwellings in its fieldwork that represent the common characteristics of domestic building in Iraq based on the literature review and questionnaire outcomes. These aspects are discussed in Chapters 4 and 5. Starting with the type of houses, all of the selected dwellings were two-storey attached single-family houses. Although the monitored dwellings were built in different periods, starting from 1970 to 2014, with different occupation dates, they all share almost the same construction system and materials. Subsection 2.4.2 reviewed the significant evolution of the layout of Iraqi houses by illustrating how and why the space configuration has changed over the last 100 years. Based on this historical evolution of the house layout, the selected houses in this study could be considered modern houses in terms of architectural design.

All of the pilot houses are attached and adjoined to other houses on three sides. Hence, they all have a front façade that contains two main entrances, one entrance is for guests via entrance space, which is used as the main and public entrance. The other is a private entrance that is used by family members via the kitchen space. Second, looking at the ground layouts of the selected houses (Figure 3-2 and Figure 3-3), it can be seen that the space configuration can generally be divided into three main zones: (i) a private-social zone, which is located at the back part of the house and includes the bedrooms and bathrooms; (ii) a transitional zone, which consists of mediator, transitional and services spaces, such as halls, corridors and staircase; and (iii) a public-social and service zone, which includes the guest, family rooms and kitchen space, which are located at the front of the house. The location of these spaces is between zone (i) and (iii) because they represent a link between theses main zones. Moreover, as all of the selected houses represent the contemporary architectural design of housing in Iraq, all of them have a walled garden and garage, which are both located beside the front façade. The patio spaces represent an additional new design feature of Iraqi housing design, by which the house can obtain natural ventilation and lighting.

A detailed description of the selected houses' layout follows: the ground storey for each house has a guest room, family room, kitchen and master bedroom with bathroom and toilet. The first storey contains the other bedrooms with bathrooms and the staircase to go up to the flat roof. This formation and organisation of residential spaces has had a fundamental impact on the functionality of the house's spaces and can, in turn, affect the psychological, social, and environmental aspects of domestic buildings. In this case, it is important to clarify the impact how household members use spaces and how that affects their social habits and behaviour, which in turn represent one of the most important factors affecting energy consumption (as evidenced later in this section and subsection 3.3.8). It is worth mentioning in this context that the historical evolution of houses layout in Iraq revealed a significant fact—the functional role of the kitchen space has experienced a significant change over time, reflecting its increasing functional efficiency and position as one of the most vital spaces in the modern home. The kitchen space has become a functionally more efficient space. The conversion from a private-social and service space to a public-social and service space, and from one functional space to a multifunctional zone, has allowed for many activities, such as cooking, storage, and seating.

The architectural design style of the selected houses is regarded as a common housing design in Iraq, regardless of the plot area and dimensions. The interviews revealed many facts that helped to select the monitored spaces within each case study. The first fact is that, based on the households' answers, there are some common uses of specific rooms and spaces, such as the sitting area, but the duration for which these are used differs from one family to another. Generally, the guest room is an infrequently used space, while both family rooms and kitchen are frequently used spaces during the day and for the dwellers, they represent the preferable spaces for social interaction. Second, it is a typical characteristic of all of these houses that the bedrooms are slept in during the night and are empty while the occupants are working or at school in the day. Consequently, the selected spaces that are used for the environmental parameters' monitoring in each case study were the living room and the kitchen space on the ground floor. The third selected space for monitoring was the bedroom. However, because all of the case studies have bedrooms on both the ground floor and first storey, the bedroom in the first storey was selected for monitoring to investigate the difference of thermal environment between the ground floor and first floor. After choosing the main spaces that are used for monitoring, the following subsections will discuss the long-term field monitoring method in detail, including a description of how the monitoring systems and devices were deployed.

In summary, this study of the design and room arrangements shows that a typical housing design is used in most homes. It was also clear that most of the occupants have little understanding of the thermal and energy implications of room location and zoning. Furthermore, the concepts of architectural design in Iraq's contemporary houses does not necessarily reflect religious, cultural, and climatic interactions, as well as the size of the property and its number of rooms and their functions, depend on the family income and social status.

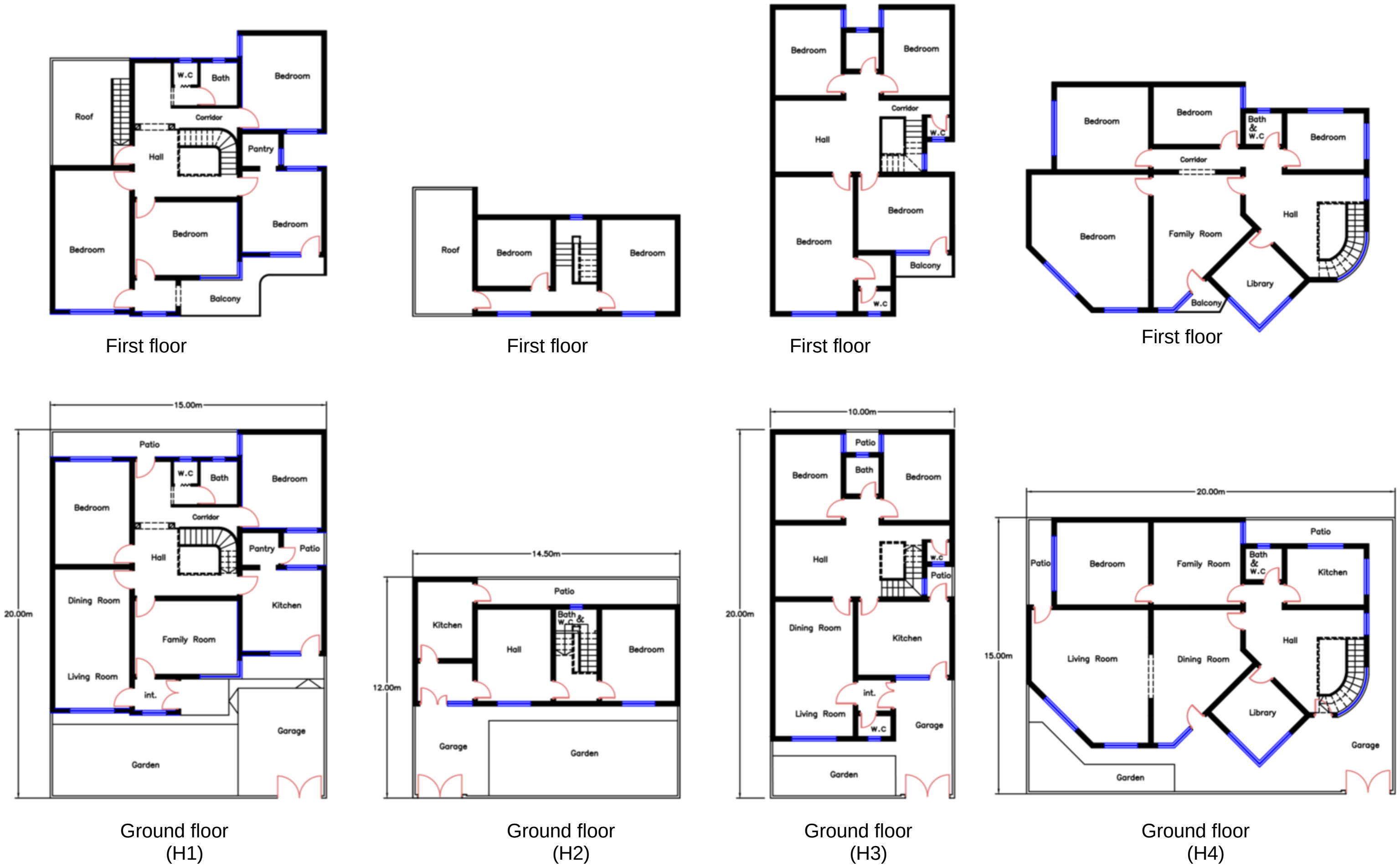


Figure 3-2. The design layout of dwellings H1, H2, H3, H4. Most of the houses are attached and adjoined to other houses on three sides with one front façade that contains two main entrances and the spatial configuration can generally be divided into three main zones: (a) a private-social zone (back part), (b) a transitional zone, and (c) a public-social (front part).

Figure 3-3. The design layout of dwellings H5, H6, H7. The houses are attached and adjoined to other houses on three sides with one front façade that contains two main entrances and the spatial configuration can generally be divided into three main zones: (a) a private-social zone (back part), (b) a transitional zone, and (c) a public-social (front part).

3.3.7 Long- term field monitoring

The last few years have brought a great variety of techniques to monitor building performance, especially due to the availability of more affordable mobiles, wireless networks, sensors and meters (Naghiyev, et al., 2014; Spataru & Gauthier, 2014), as well as due to the integration into building research of software engineering (Chen & Ahn, 2014; Martani, et al., 2012; Chen, et al., 2012) and computer sciences, such as data mining and pattern recognition (Zhao, et al., 2014; Shih, 2014; Xiao & Fan, 2014) However, many monitoring techniques are still expensive, time-consuming, intrusive or require expert knowledge, and thus it has been difficult to embed them in practice. Nowadays, the issues that are studied are those in which (i) there is a serious complaint and the evaluation is initiated by those who interested, or (ii) they are considered exceptional issues and therefore worth studying.

Without field measurements, survey data cannot fully reveal the features of socio-technical phenomena (Yohanis, 2012). A field measurement is a form of observational instrument, which represents the most basic and most direct method of obtaining data. The monitoring technique is used regularly in behavioural studies where the aim is to examine a specific pattern for performance and is usually conducted in a natural setting that is associated with the issues that are under investigation. Therefore, according to Humphreys et al. (2015), the priority for researchers who are anticipating conducting fieldwork is that they should have a clear idea of what to measure and how to measure it. In fact, conducting field measurements in real life is not an easy task to accomplish, especially when people are engaged with jobs, children and other life activities (Escandón, et al., 2017). In this research method, the energy-use data of buildings, for example, is collected using various metering devices rather than by the researcher (as in sociological studies). Concerning the long-term monitoring approach used in this study, although this form of monitoring features the merits of direct acquisition of physical measurements, it cannot feasibly be as widely implemented in as large a number of houses as questionnaire-based data acquisition.

Unlike other studies (Cui, 2014; Afonso, et al., 2017; Voss, et al., 2007) that used monitoring approach to test the effectiveness of certain types of building technology or retrofitting techniques, the research at hand aims to investigate actual energy-suppressed demand associated with actual energy use and its impact on the indoor thermal environment. For the current study, it is important to know two main facts. First, the monitoring parameters relating to building fabric performance are not directly associated with the research topic and were thus excluded. Second, the research gap in applying the long-term approach to a sample of housing stock in Iraq will help to show how it would be effective to apply the long-term approach in small-scale research, especially a study on energy use and indoor thermal environment there.

3.3.7.1 Criteria of monitoring system selection

Sensors and loggers' function as the observer in monitored houses to detect and record the targeted occupancy activities. Considering the experimental environment in actual homes, the selected devices should be as inconspicuous and unobtrusive as possible. In addition to creating less inconvenience in the daily life of the monitored homes, less-intrusive monitoring schemes are expected to objectively reflect the targeted occupancy activities (Marceau & Zmeureanu, 2000). Hence, this subsection will provide an overview of the general principles of system selection for the long-term field monitoring that will be used in this research. The following subsections focus on the device selection of each monitoring category, including energy use, and indoor thermal environment parameters.

The major criteria for the device selection and system configuration are:

- The selected devices should be non-intrusive or less intrusive in terms of installation and maintenance, in addition to meeting the fundamental measuring requirements of the research;
- The monitoring systems and devices should feature low costs in terms of equipment procurement and post-installation maintenance;
- The monitoring systems and devices should feature transferable techniques that enable the straightforward application of the system in other similar monitoring environments.

A non-intrusive or less-intrusive monitoring system could bring a direct advantage, which is that the equipment has no or limited visible or aesthetic impact on the monitored households. An indirect but crucial benefit is that the residents are expected to behave naturally under the monitoring circumstances. The actual behaviours revealed by the measuring results are thus insusceptible to the impact of psychological attention given by the residents of the monitored houses. Therefore, this type of monitoring fulfils one of the major stated objectives of this research, which is an investigation of the actual behaviours associated with energy use and indoor thermal environment in a real domestic circumstance. After taking all these considerations into mind (e.g. the equipment should be easily distributed, less intrusive, and self-powered), off-the-shelf equipment was selected for this research project. However, a distributed and less-intrusive monitoring system could bring some disadvantages. The first disadvantage is device management and maintenance. The second disadvantage is related to battery-powered monitoring equipment, where battery failure can lead to data loss. Finally, the downloaded measuring results may potentially be flawed if the residents have moved the portable loggers to other locations without the researcher being notified (Cui, 2014).

Furthermore, more attention should be given to the data transmission and storage, where the distributed equipment stores the data of the real-time measurements in a centralised database using manual downloads. If wireless communication takes place among the system components, then proper installations and periodical examinations can sustain network stability and reduce the probability of data loss (Afonso, et al., 2017). For the current research, the lack of a continuous Internet connection was another limitation, where it was the main reason to stop the monitoring process, which was planned to last for two years. Moreover, the monitoring systems and device used in this study were provided by the researcher and was financed by the Cardiff School of Engineering and they shipped to Baghdad to carry out the experiments starting from January 2017 to August 2018. The main energy and environmental parameters measured by using these monitoring devices and systems are given in the following subsections.

3.3.7.2 Energy-use

Basically, the level of data collection for energy use is to take energy readings at the beginning and end of the period of study, or on a regular basis. Although this method is straightforward, easy, and cheap, the main disadvantage is that mistakes can occur during the readings. The energy reading can be taken when there are already sub-meters in place and on-site, otherwise, the installation of sub-meters is expensive and would require ensuring the safety of users and functioning of the building energy systems during and after the monitoring period. The energy data collection relies on the type of the project; for example, for renovation projects, it is necessary only one reading at beginning of the intervention and one at the end (Stevenson & Leaman, 2010). Meanwhile, for a holistic evaluation, one-year-long monthly readings are recommended. For in-use evaluation, it is necessary to at least take readings every month to look at the differences between seasons. High-frequency data collection is required when more detailed information about energy usage is needed, such as on a high-frequency basis (e.g. every 5 min) and in a very long span of time. The advantage of this measurement is that it can be used with information about the indoor thermal environment and ambient conditions and building operation. It can also provide a better understanding of the way that the buildings are operated.

According to Brown et al. (2010), high-frequency meter readings have several uses, as follows:

- To provide accurate and timely data;
- To access trading and variable rate tariffs;
- To identify systems' inefficiencies and failures;
- To quantify net export from on-site renewables; and
- To obtain a benchmark of tong-term monitoring.

Energy readings can be used to compare actual and expected performance in total or for different final uses (where sub-meters are in place). The amount of energy used by a household not only depends on the ownership levels of domestic appliances but also relates to the use of patterns of appliances, such as operational frequency and duration. The electric energy demand distributed over various lengths of time forms a series of unique energy consumption curves/profiles for the appliances or for the entire household. Therefore, provided with more informative data regarding energy consumption, householders can be enlightened about the energy use profiles of their different daily activities. This feedback of energy use may encourage householders to achieve domestic energy savings through behavioural changes. These changes could be implemented by adjusting the usage patterns of appliances and switching off identified unnecessary standby loads (Matthews, et al., 2008). In general, the knowledge of energy-use patterns can bring benefit for both stakeholders and common consumers of power systems. However, this research focuses on the common consumers, who are represented by the case study householders. Meyers (2010) pointed out that the similar portfolios of domestic appliances and relative consistency of energy end-uses facilitated energy reduction strategies in the domestic sector, as compared with the commercial and industrial sectors. However, end-user monitoring is beyond the scope of current research, where the energy use monitoring in this study involves the overall energy consumption.

As mentioned in subsection 1.1.5, Iraqi households rely on two electricity supply sources—NG and CG. Hence, the current study used two whole-house meter systems to monitor the total energy use from these two supply resources. Therefore, these systems only monitor and display the overall energy use for the measured home without identifying the ways in which individual occupant behaviours consume energy. The energy use from both NG and CG were monitored by a general use meter in the electrical panel, by which the general electrical use was measured every 12 seconds—which accounts for the time needed for measurement, local data storage and uploading to the

Cloud— over 19 consecutive months. To analyse the quantitative data, the hourly values of energy in kilowatt-hour (kWh) were used in this study (subsection 3.3.9.1 details the steps of calculating the hourly values of energy use in (kWh). This helps to provide a detailed pattern on energy use and investigate the relationships between indoor thermal environment and ambient conditions, as will be discussed in Chapter 6. It is important to mention that the monitoring equipment were installed by the researcher in all case studies. Prior to the installation in case study houses in Iraq, a sample monitoring system was installed at a residence in Cardiff to test for safety and reliability. Checks were made to ensure that the data were being uploaded to the Cloud.

3.3.7.3 Energy monitoring system

In general, residential energy monitoring systems consist of: (i) a sensing unit that measures energy consumption; (ii) a display readout or software platform that provides numerical and graphical data of power or totalised energy use; and (iii) some means of communication between the two, whether it be wired or wireless. Some devices employ a multitude of sensors that are plugged into the wall outlet to measure each appliance's consumption. In contrast, some have only one sensor installed into a home's switchboard circuits, electrical meter or breaker box measuring the total household electricity use and provide occupants with the aggregated data (Josué, et al., 2011; Guo, et al., 2013).

To achieve the aim of this study, whole-house energy consumption is considered and implemented using two monitoring systems. The first-meter system is an OWL Intuition LC, which is used to monitor the total electric energy consumption from the NG and allows monitoring of three-phase electricity usage across home and displays individual readings for each phase. The second-meter system is an OWL Intuition-e, which is used to monitor the electricity from CG and monitors a single-phase electricity usage across home and displays readings for that phase. Both monitoring systems were installed into each home's electrical meter to measure the total household electricity use. The specifications of the used electricity monitoring system in this research are shown in Table 3-2. Regarding the reading, both monitoring systems provide graphs showing both historical and peak usages. This allowed the users to identify when they have been using the most energy, which can potentially show them how to reduce their energy use. The dashboard of the monitoring system gives the users access wherever they go, as long as they have Internet access.

Table 3-2. The electricity monitoring system used in this research (photo sources: researcher).

OWL Intuition LC and e		
Name	**Picture**	**Specifications**
Transmitter unit 3 channels for NG and single-channel for CG 64mm x 95mm x 40mm		• OWL Intuition products are manufactured to ISO-9001 Quality Assurance Standards. • Power source: 3 x 1.5V Alkaline AA batteries. • Operating temperature range: 0°C to +40°C • Relative humidity: 25% to 95% non-condensing. • Refreshes live readings at 12-second intervals and a historical account of the usage. • Provides graphs showing both historical and peak usages, allowing users to identify when they've been using the most energy and potentially how to reduce this.
Sensor clamp – 3 for NG and one for CG 50mm x 50mm x 30mm		
Network OWL Gateway with external antenna		

As shown in Figure 3-4 the architecture of the monitoring system that was used has two parts: the sensor network and the cloud-based data storage and retrieval system. The sensor network, or the data acquisition device, has a gateway with an external antenna, transmitter unit and a standard sensor clamp. While the cloud-based data storage—a software application interface—is used to display the data. A broadband router wirelessly links with the sensor network through a transmitter, where the energy data is automatically and continuously collected and stored within the Intuition Cloud. Real-time and accumulated data can be viewed via a web browser (including iPad, iPhone and Android device).

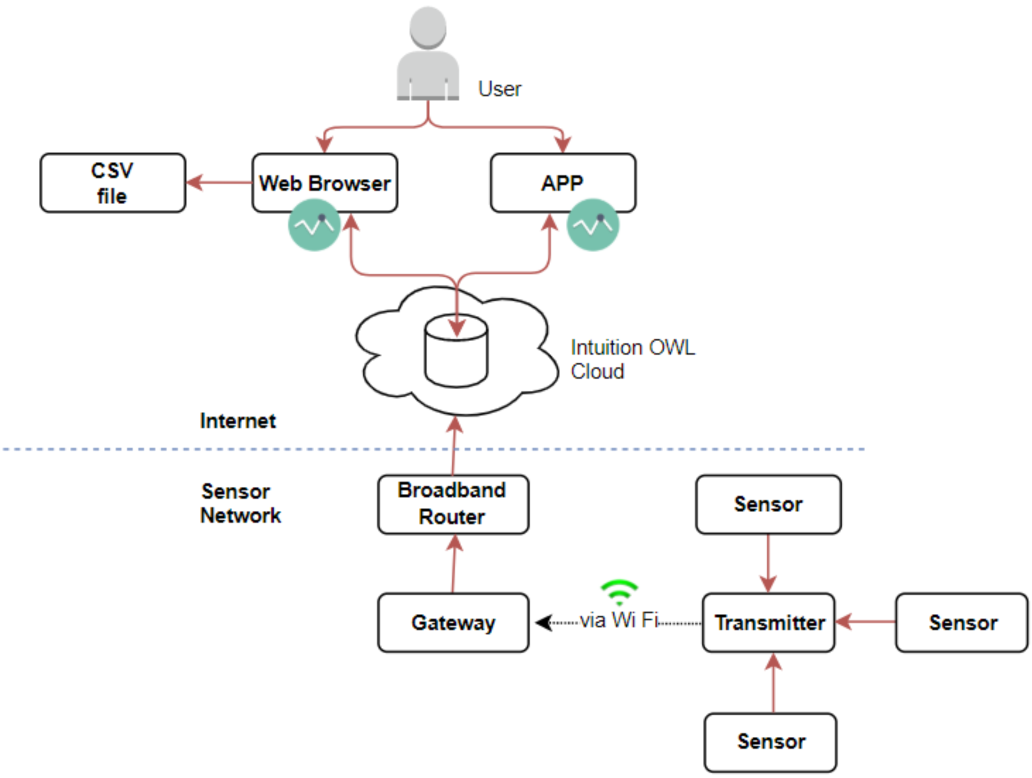


Figure 3-4. The architecture of the electricity monitoring system.

This can give the user access on-the-go and read the measurements. Regarding the instrument software, it is necessary with the enormous amount of data to transfer them for further analysis. Network OWL simply plugs into the user's existing broadband router and wirelessly links with the transmitter and sensor. Moreover, the monitoring system provides easily readable graphs with detailed values, allowing the user to print or download the graphs, as well as supporting a block tariff based on usage (see Figure A-1 in Appendix A-3). The device used comes with software that downloads the recorded data from the instrument, where the live readings are refreshed at 12-second intervals on a continuous basis. It has integrated Bluetooth wireless and offers both real-time and logged (recorded) data that can be transferred wirelessly and operated by OWL Interface. When the data is downloaded, the recorded data is initially presented in a form of comma-separated values (.csv). The structure of the file is assumed to be the same as shown in Table A-1 in Appendix A-3. The downloaded data can easily be exported into programs such as Microsoft Excel, which allows the user to convert the data into a table form or graphs. In this study, the first readings began in January 2017 and came to an end in July 2018. Nearly all of the smart meters sent consumption data. The last readings were received on 31 July 2018. The analysis has been carried out at each hour point of the day (starting from 00:00 to 23:00).

3.3.7.4 Environmental parameters

Through physical monitoring, the actual conditions if the building can be measured and recorded, which can give insight into the way the building is operated. For example, (apart from indoor dry-bulb temperature (DBT), relative humidity (RH) levels, and CO_2 concentration, heat or water flows, opening of doors and windows, the presence of people in the building, noise, lighting and energy usage for appliances and devices can all be monitored (Guerra-Santin & Tweed, 2015). An environment providing thermal comfort can make the occupant comfortable, depending on their comfort factors (Djongyang, et al., 2010). In addition, the connection between energy efficiency and the comfortable thermal environment is a major target that is considered in buildings to promote the occupant's comfort and wellbeing (Antoniadou, et al., 2018). Comfortable thermal environment is affected by two types of parameters, which are defined by Macpherson (1962) as: (i) physical (ambient) parameters, which are objective and can be measured and predicted; and (ii) social (personal) parameters, which are subjective and are related to occupants' activities and clothes, and may differ from one person to another. Meanwhile, Auliciems and Szokolay (2007) detailed the factors that affect comfortable thermal environment into three groups: environmental factors (air temperature, air movement, relative humidity, and radiation); personal factors (metabolic rate and clothing); and contributing factors (food and drink, acclimatisation, body shape, and also age and gender). For the current study, the monitoring parameters relating to social (personal) behaviour are not directly associated with the research topic and were thus excluded.

Monitoring building thermal environment can help to reduce the uncertainties related to the thermal performance of buildings. Several benefits can be obtained from searching thermal environment and related parameters, some of these benefits were listed by Raw and Oseland (1994) as follows:

- The environment will be controlled by people.
- The internal air quality will be improved.
- More energy saving will be achieved.
- The harm from emitting CO_2 into the environment will be reduced.
- The efficiency of the building's occupants will be enhanced.
- Improving or changing standards will be reasonably advanced by recommendations.

In this part of the chapter, the related environment parameters to energy use will be defined, while the methods to evaluate the level of comfort will be discussed in subsection 3.3.9. Meanwhile, the optimum conditions for human comfort emphasising thermal comfort will be discussed in detail in Chapter 7. This investigation is important to determine the impact of energy use and suppressing of demand on the indoor thermal environment. Another benefit could be obtained from monitoring the indoor environment parameters is the ability to assess the comfort level in residential buildings in Iraq based on real data. Furthermore, the influence of natural or mechanical (if used) ventilation on the indoor environment is reflected in the tracking trajectory between ambient conditions (AT and RH) and indoor variations of DBT and RH. Under the same microclimate and built-form conditions in each case study, fluctuations of the indoor DBT and RH in selected living zones are important indicators for energy-related occupancy behaviours in the study homes, such as heating, cooling and ventilation activities in different seasons. In addition, the building's thermal performance can be reflected in the comparison of indoor environment conditions of DBT and RH of different case studies against their respective outdoor weather conditions. Therefore, the ambient conditions, indoor DBT and RH were selected as the major environmental parameters in this research project, which excluded other indoor environment conditions relating to comfortable thermal environments, such as air quality.

- **Air temperature**

According to Auliciems and Szokolay (2007), air temperature is the most important environmental aspect in field measurements. The air temperature is the average temperature of the air surrounding the person at a specific location and time. The ASHRAE standard 55 defining the location as a spatial average depends on the ankle, waist, and head levels for seated or standing occupants. Time is defined as a temporal average that is based on three-minute intervals. Dry-bulb temperature (DBT) of air is commonly used for environmental monitoring. A dry thermometer shielded from radiant exchanges is used for measuring DBT. In energy calculation studies, indoor DBT should be specified to evaluate the thermal comfort level (e.g. British Standard BS EN 15251:2007 2008). A comfortable temperature is one of the most important factors to be considered in building environments (Shahzad, et al., 2018).

The readings of DBT that are measured alone in a field survey will have been influenced, to some extent, by the mean radiant temperatures of the nearby surfaces (Alshaikh, 2016). The mean radiant temperature (MRT) is the temperature that is related to the amount of radiant heat transferred from a surface. This radiation depends on the surface material's ability to absorb or emit heat, or its emissivity. In addition, it depends on the temperature and emissivity of the surrounding surfaces, as well as the amount of the surface. Therefore, the MRT experienced by a person in a space with the sunlight streaming in varies based on how much of the body is in the sun (Alnusairat, 2018). In fact, several researchers used only DBT in their comfort studies, due to the high correlation between DBT and other forms of measurements. Nicol (1994) in their Pakistan field survey indicated that MRT and DBT were quite similar. Therefore, the current study measured and used DBT to assess the indoor thermal environment.

- **Relative humidity**

The other physical indicator is RH, which is defined as the percentage of moisture contained in the air at a specific temperature and pressure. The comfort level of indoor humidity is in the range of 30% to 60%. The RH of space affects the human body, particularly the skin. For example, high RH causes sweating of the skin as a mechanism to lose heat, whereas low RH or a dry environment affects mucous membranes. Hensen (1990) pointed out that the impact of humidity on thermal sensation is perhaps expected as a slight effect. However, when temperatures are inside or near the comfort zone, variations in RH from 20% to 60% do not have any impact. However, it can be crucial when environments become warmer (Gonzalez & Gagge, 1973). De Dear et al. (1997) found that occupants feel cooler immediately when RH decreases, and warmer immediately when it increases.

A number of studies of the role of humidity in comfort in tropical regions have been published, including those by (De Dear, et al., 1991; Fountain, et al., 1999; Nicol, 2004; Givoni, et al., 2006). They concluded, in line with the field studies on which they are based (i.e. (Busch, 1992)), that comfort can be experienced in hot and tropical regions, even with humidities and temperatures that are high when judged against Western standards. Meanwhile, US designers have identified humidity as a primary cause of summer discomfort and air-conditioning systems have increasingly been designed not only to cool the air but also to manage its humidity. These designers decided that 55% RH was the maximum level to strive for, which is still the standard for controlling humidity (ASHRAE, 2008). The consequence of this assumption was to push systems to use two-phase conditioning systems, first chilling down the air to remove humidity by condensation and then reheating it to further reduce its RH. But the cost of this was significant energy inefficiency to get the air to the required temperature. In addition, living in a high humidity environment could increase the concentrations of specific types of mould bacteria and/or high populations of dust mites inside homes, which can directly affect health (Porteous, et al., 2014). Moreover, if the core concern is occupant comfort, then the subsequent researches have often contributed to the confusion about the actual role and impact of humidity at high temperatures (Humphreys, et al., 2015). In the present study, RH was one of the measured parameters and, initially, the results were analysed in terms of RH and DBT.

- **Air velocity**

In mixed-mode ventilation spaces, especially in a hot climate, air movement might have a slight influence on the thermal environment of subjects (Alshaikh, 2016). Therefore, in the present study, and due to the limitation of the instruments, the amount of air velocity used is based on what was reported in other studies, such as (Rashid, et al., 2018; Alshaikh, 2016) and (ASHRAE 55, 2004)[4].

- **O_2 concentration**

Buildings are accountable for around half of the total global CO_2 emissions (Roaf, et al., 2009). The CO_2 concentration and RH are used to evaluate the quality of the indoor air (CEN, 2005; ASHRAE, 2007). Although the monitoring systems used in this study provided readings of CO_2 concentration level beside DBT and RH, the measured CO_2 level in the case studies was excluded because the aim of this study is to evaluate the indoor thermal environment rather than studying the indoor air quality.

3.3.7.5 Monitoring system for indoor environment conditions

Two types of indoor environmental loggers were used to measure the indoor DBT and RH in this research project. Netatmo's Weather Station consists of two elegant aluminium units—one indoor and one outdoor sensor. It uses the home wi-fi connection and is fully automatic. The indoor unit monitors the quality of the environment inside, measuring the room's temperature, humidity, CO_2 and noise levels. Meanwhile, the smaller outdoor sensor keeps track of the ambient conditions (Dry-bulb temperature, relative humidity and barometric pressure). The technical features of the environmental monitoring system used in this research are shown in Table 3-3.

[4] The average air velocity measured by (Rashid, et al., 2018) was 0.17 m/s in winter, while in summer was 0.24. For (Alshaikh, 2016) study, the average air velocity measured was alike in both cool and hot seasons, at 0.3 m/s. Per ASHRAE standard 55, 1.5 m/s is the max comfortable air velocity and 0.2 m/s is the min indoor air velocity to effect indoor comfort.

Table 3-3. The environmental monitoring system used in this research (photos sources: researcher).

Netatmo Weather Station		
Name	**Picture**	**Specifications**
Indoor module: 45x45x155 mm		• Records frequency: every 5 minutes. • Temperature (indoor): - Ranges from: 0°C to 50°C / 32°F to 112°F - Accuracy: ± 0.3°C / ± 0.54°F • Humidity (indoor and outdoor): - Ranges from: 0 to 100% - Accuracy: ± 3%
Outdoor and additional indoor module: 45x45x105 mm		• Wireless connection between modules: long-range 100 m (without obstacles). • Power and batteries - Indoor module powered by USB wall adapter. - Outdoor module powered by 2 AAA batteries (up to a 2-year lifespan).

Figure 3-5 shows the architecture of the environmental monitoring system that was used in this study. The user can monitor all the current and historical data in real-time on their smartphone or computer using the free Netatmo web or mobile app. The wireless Weather Station is easy to set up via wi-fi and the app is free to use for life. Cloud data storage is available from multiple devices and there is no storage limit. Given that the environmental variables do not change significantly at lower timesteps and 15 min is widely considered to be high resolution for the purposes of environmental monitoring (Ahmad, et al., 2016), the lowest available temporal resolution of the environmental sensors was 5 min. The outdoor module wirelessly sends its measurements to the indoor module using a radio signal. Using the wi-fi access point, the indoor module then sends both its own measurements and the outdoor module's measurements to the user's personal online Netatmo account. When the user launches the Netatmo app, these measurements are downloaded from their personal Netatmo account and displayed by the app. When the data is downloaded, the recorded data is initially presented as a comma-separated value (.csv) file. The downloaded data can easily be exported into programs such as Microsoft Excel, which allows the data to be converted into a table or graph.

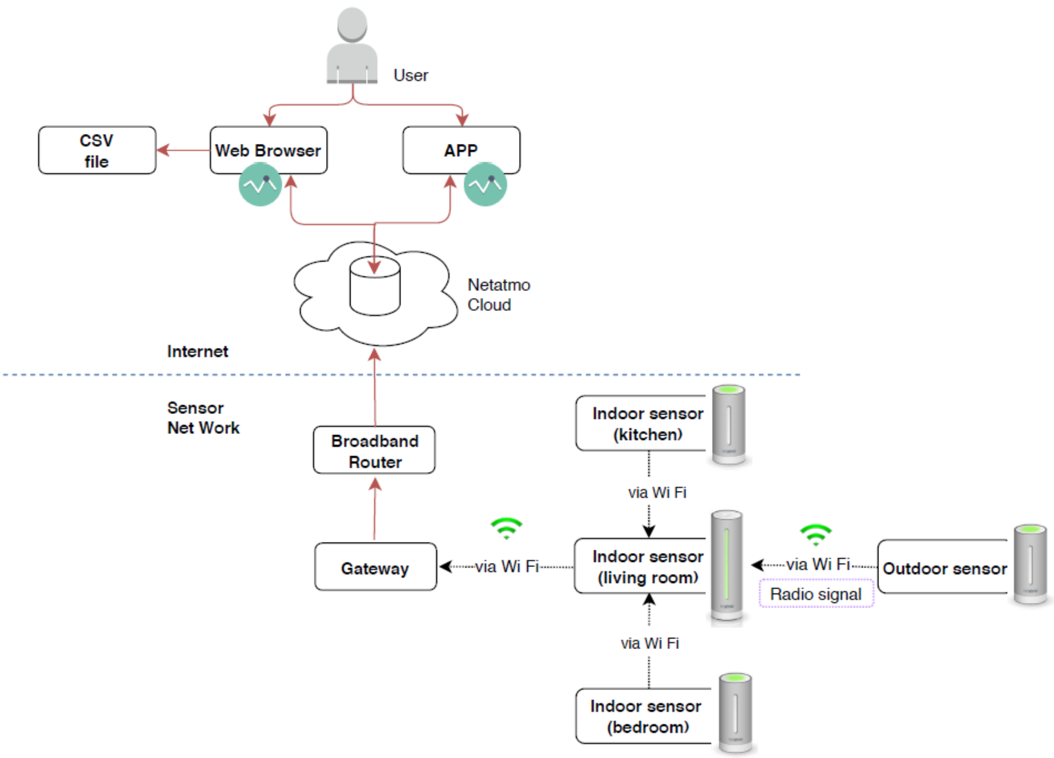


Figure 3-5. The architecture of the monitoring system.

It is noting that the Wi-Fi and electricity went down several times, which caused the loss of some data. Given the intermittent nature of electricity supply and the Internet, this situation was inevitable. The missing data due to the loss of internet connectivity was imputed using a combination of regression and artificial neural network (ANN). The specific method was chosen based on the timing and length of missing data. Regression methods such as linear, cubic, cubic spline, cubic polynomial were used to fill in gaps with less than 5 consecutive hours. ANN was used to fill in missing data between 5 and 12 consecutive hours.

3.3.8 Deployment of monitoring equipment

According to the information acquired in the interviews that were conducted during the site visits, the residents tended to spend most of the time during the day in specific spaces such as living rooms and kitchen, while bedrooms are only used at night. As shown in subsection 3.3.6, the layout description of selected case studies reveals two main facts, all living rooms and kitchens are on the ground floor and most of the bedrooms are on the first floor. Therefore, and to capture the required energy-related indoor thermal environment, the two indoor environmental loggers were deployed in living room and kitchen on the ground floor and a third logger was installed in a bedroom on the first floor. Because all of the selected houses are attached to other houses on three sides, with only an external front façade, the outdoor weather loggers were installed on the front façade to measure the outdoor weather conditions.

Figure 3-6 and Figure 3-7 show the location of the monitoring sensors in the dwellings. In the current study, Dry-bulb temperatures were measured in degrees centigrade (°C), RH was measured in (%) and CO_2 concentration was measured in parts per million (ppm).

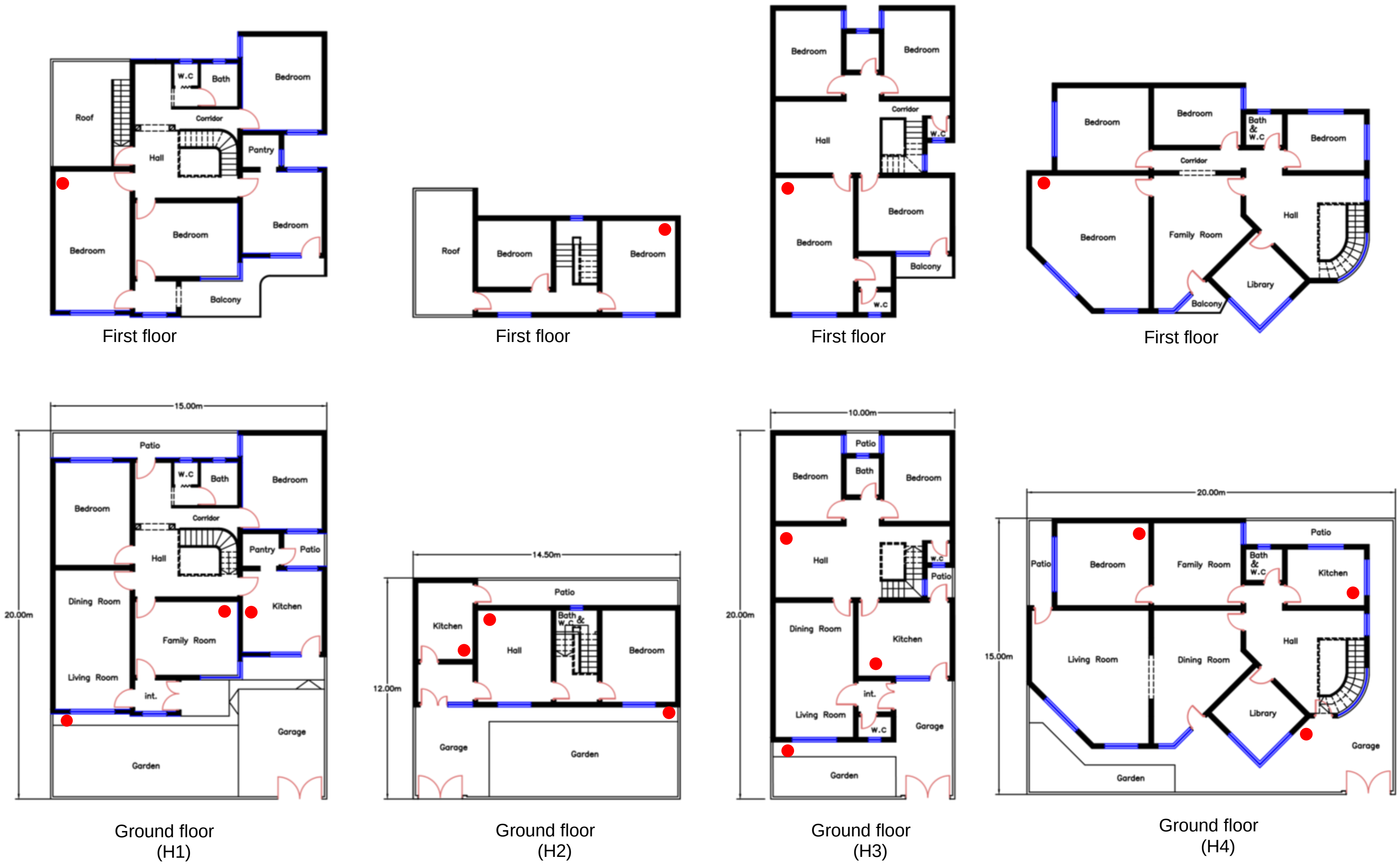


Figure 3-6. The location of the environmental monitoring sensors in dwellings H1, H2, H3, and H4, where (●) refers to the monitoring sensors.

Figure 3-7. The location of the environmental monitoring sensors in dwellings H5, H6, and H7, where (●) refers to the monitoring sensors.

The previous sections of this chapter have revealed that both energy use and comfortable thermal environment are major aspects that needed to be considered when estimating the energy-suppressed demand. This includes the indicators that are employed to reveal how energy use could be suppressed and how this suppressed demand could affect the indoor thermal environment in these occupied spaces. Studying the suppressed energy demand and its environmental implications can be defined by the heating and cooling demands of the building. Therefore, this study considered those parameters. Evaluating these parameters is related to defined benchmarks. For example, the DBT and RH in the occupied space define the level of the comfortable thermal environment. It is important to note that in this study the level of comfort will be determined with regard to general occupied spaces because comfort limits have not been specified for each space. Hence, the next subsection will discuss the potential methods to analyse, evaluate and present the measured data of energy use to be used when estimating the energy-suppressed demand in the first step. The second step involves analysing, evaluating and presenting both ambient and indoor environment conditions. The final step investigates how well the indoor thermal environment affected by suppressing the energy demand.

3.3.9 Data analysis methodology

The different monitoring parameters that were acquired using the long-term monitoring approach required a different analysis and presentation methods to serve the research aim and objectives. This section focuses on how the raw data that was acquired using the monitoring approach was processed, as well as the analysis and visualisation methods that were applied within this process. Meanwhile, the actual examination results of the monitoring data analysis for energy use and how it does affect the indoor thermal environment with demand suppression are discussed in Chapters 6 and 7, respectively. In this study, the measurements were analysed in both short (hourly) and long (seasonally, yearly) scales to provide insights into some of the basic features of energy use and indoor thermal environment in the monitored houses. For example, the long-scale analysis of energy use and indoor environmental measurements over the entire monitoring period can assist in revealing time-series features, such as seasonality and trend. In the short-scale analysis, certain features of energy use from both the NG and CG can be indirectly inferred from the visualisation-based examinations of the environmental parameters. Based on the long-scale analysis and presentations, data profiles of certain days with specific energy use and environment features or characteristics can be selected to perform short-scale inspections by comparing the simultaneous measurements of energy use and indoor environment conditions. The tracking trajectory between the indoor environment and ambient conditions not only results from energy-related occupancy activities but also relates to specific building characteristics. For example, the indoor environment conditions in unoccupied circumstances track the ambient conditions via the influence of the building's performance and characteristics, such as whether or not insulation has been installed. In an occupied environment, some energy-intensive occupancy activities (e.g. space cooling or heating) are featured by localised variations in the indoor environment conditions. Similar microclimatic conditions of multi-adjacent case studies can facilitate a cross-comparison of short-scale analysis and presentation of simultaneously measured data profiles in different houses. The evaluation process in this research refers to the process of using proper methods to investigate the data profile. Three main types of inspections were conducted on the measurements of energy use and indoor environmental conditions in the case study homes, while the analysis methods were sourced from the fields of statistics and related studies. This section aims to present these evaluation methods based on the different purposes for monitoring in this research, which are:-

- Investigate the energy use and its temporal variability in existing dwellings and determine if the supply meets the needs of the occupants;
- Develop a method to estimate the suppressed and the actual electricity demand and investigate their diurnal, seasonal and annual variability;
- Evaluate the effects of ambient conditions and suppressed energy demand on the indoor thermal environment after individually evaluating both ambient and indoor conditions.

The importance of analysing the acquired data required specific analytical approaches to be employed in this study. These analytical approaches are able to deal with numerical coding and offer useful tools that can process a huge body of information in small periods and does so accurately. Furthermore, it can provide a tool for determining the energy use and the amount that is suppressed. Moreover, another direction used in this research is to integrate (couple) the parameters, thus the validity of the results will be high. These approaches allow a better understanding of the energy consumed, suppressed and required for an acceptable thermal environment inside a house. This type of analysis could be used to optimise the design of the building and to predict energy usage.

Visual examination of the measurements is used in this research to give the researcher a clear idea of the energy use and any environmental problems in the houses (e.g. difference in primary energy from both NG and CGs, or rooms in the house that are too cold or too warm). In addition, the visualisation-based presentation of the acquired data was used to recognise the distributions and interrelationships of data with the assistance of appropriate scales of display (i.e. hourly, daily, seasonally).

3.3.9.1 Estimating the suppressed energy demand

This study aims to quantify the suppressed demand and investigate its temporal variability. The hourly use for different seasons in Iraqi domestic buildings is estimated in kWh at 12-sec intervals from both NG and CGs over a one year and 7 months. The results were then used to estimate the suppressed energy demand and the actual demand for electricity by adding the estimated suppressed demand. The energy use from NG represents the desired consumption (actual demand), while the electricity consumed from CGs reflects the actual energy use. Importantly, outage hours were taken into consideration during the calculation process because their existence affected the total energy consumption. All of the data were analysed and presented by Microsoft Excel and Python software which was chosen as the language for data analytics as it is open source and does not require a paid license. The intention is to release the data, along with the analysis codes to the public domain after the completion of the PhD with the hope that other researchers, especially from developing countries can make further use without being restricted by having to pay for software such as MATLAB.

The calculation of the suppressed demand started by collecting real-time data of energy from both NG and CG. The next step was to create the time series of energy consumption for each minute. Given that the measured data represents the accumulated energy consumption power since midnight in Wh, the energy consumption in minutes was calculated by subtracting the previous reading from the following reading. Then, the hourly energy consumption in kWh for both NG and CG was calculated to create the hourly average profile for all days of the monitoring period, which then categorised into weekends, weekends, months, seasons and finally per year. The last step was to calculate the suppressed demand, where the following steps were taken to prepare and analyse the data, and to calculate suppressed demand:

1- Collect real-time cumulative energy data from both national grid (NG) and the community grid (CG) at 12 s timestep.

2- Resample the data at 1 min timestep, resulting in two separate cumulative time series.

3- Calculate 1-min energy use time series by subtracting the cumulative measured data of the previous timestep from the following timestep.

4- Calculate hourly energy use time series in kWh by aggregating the minutely energy use for both NG and CG separately.

5- Estimate the following descriptive statistics for further analysis:

- Hourly average, minimum, and maximum profiles for all days of monitoring period; and
- Daily, weekday, weekend, monthly, seasonal and annual profiles of energy use.

6- Estimate suppressed energy demand by applying the following steps:

7- **Calculate the seasonal average hourly uninhibited or actual energy demand:** Energy from the national grid is considered to be uninhibited as households are able to draw on as much as energy as they need (up to the level allowed by the 1- or 3-phase connection). As discussed in subsection 1.1.4, energy sourced from NG represents the uninhibited or actual demand for energy. The hourly energy use (in kWh, from Step 4) from NG was used to

$$E_{\mathrm{U},i} = \frac{\sum E_{\mathrm{N},i}}{N_{\mathrm{N},i}}, \qquad E_{\mathrm{N},i} > 0 \; and \; i = 1...24 \tag{3-1}$$

where $E_{\mathrm{U},i}$ is uninhibited energy demand in hour i. $E_{\mathrm{N},i}$ is hourly energy use from NG in hour i, and $N_{\mathrm{N},i}$ is the number of days in a season when energy from NG was available in hour i.

For example, in winter, the number of days where the electricity from NG was available ($N_{\mathrm{N},i}$) when i = 3:00 AM was 70 days out of 90 possible days of the winter season. 188.68 kWh was the total energy use from NG ($\sum E_{\mathrm{N},i}$) during these 70 days when i = 3:00 AM. Therefore, the seasonal average of uninhibited demand for energy at 3:00 am in winter was:

$$E_{\mathrm{U},i} = \frac{188.68 \text{ kWh}}{70} = 2.69 \text{ kWh} \quad \text{when} = 3{:}00 \text{ AM in winter}$$

8- The resulted the seasonal average of uninhibited demand for energy ($E_{\mathrm{U},i}$) in hour *i*, from Equation 3-1, and the hourly energy use in *i* from Step 4 were used to calculate the suppressed energy demand at *i* of the same season using Equation 3-2.

$$SD_i = E_{\mathrm{U},i} - E_{\mathrm{A},i} \qquad E_{\mathrm{A},i} \geq 0 \; and \; i = 1\ldots24 \qquad (3\text{-}2)$$

where SD_i is the estimated suppressed demand of energy in hour i. $E_{\mathrm{A},i}$ is the actual energy use in hour i.

The estimated hourly suppressed energy demand, which resulted from equation 3-2 could be one of the following three outcomes:

- The hourly suppressed demand SD_i is zero in hour = *i* when $E_{\mathrm{A},i} \geq E_{\mathrm{U},i}$ and that only occurs when the energy is available from NG.
- The hourly suppressed demand SD_i equals $E_{\mathrm{U},i}$ in hour = *i* when $E_{\mathrm{A},i} = 0$ and that only occurs during the hours of outages.
- The hourly suppressed demand SD_i equals ($E_{\mathrm{U},i} - E_{\mathrm{A},i}$) in hour = *i* when the $E_{\mathrm{U},i} > E_{\mathrm{A},i}$ and that only occurs when the energy is available from CG.

Following the above example, the ($E_{\mathrm{U},i}$) in hour = 3:00 AM is 2.69 kWh, and if the energy use ($E_{\mathrm{A},i}$) in hour = 3:00 AM sourced from CG and was 1.1 kWh. Therefore, and according to the above three possibilities of outcomes, the estimated SD_i when i = 3:00 AM is zero when the energy use is sourced from NG. secondly, the estimated SD_i when i = 3:00 AM equals to the calculated $E_{\mathrm{U},i}$, which is 2.69 kWh if there is an outage of energy in hour = 3:00 AM. The third possibility is that, the estimated SD_i when i = 3:00 AM equals:

$$SD_i = 2.69\ \mathrm{kWh} - 1.1\ \mathrm{kWh} = 1.59\ \mathrm{kWh} \quad \mathrm{when}\ = 3{:}00\ \mathrm{AM\ in\ winter}$$

The above steps were applied for the daily hours in all seasons to calculate the hourly suppressed demand, which is used for the following descriptive statistics for further analysis:

- Hourly average, minimum, and maximum profiles of the suppressed energy demand for all days of the monitoring period.
- Daily, weekday, weekend, monthly, seasonal and annual profiles of suppressed energy demand. These different time scales profiles of actual energy use, suppressed energy demand and the actual demand of energy were used for comparative study as it will be illustrated in Chapter 6.

3.3.9.2 Analysing the indoor thermal environment

Comfortable thermal environment evaluation is often presented as a part of the post-occupancy and in-use performance evaluations. In addition, it is also used to evaluate the performance of the building for a determined period of time within specific conditions. This evaluation, similar to energy use evaluation, can also include long-term and short-term monitoring or seasonal measurements of indoor environment conditions, such as temperature and humidity, which can be coupled to thermal comfort questionnaire if required (Guerra-Santin & Tweed, 2015).

The level of comfortable thermal environment can be evaluated in spaces based on the following:

- Evaluations based on single parameters: this method depends on testing physical parameters such as air temperature, air velocity, RH or MRT in spaces individually. The results are then compared with the standard comfort requirements to predict the level of indoor thermal comfort (Djamila, 2017).
- Evaluations based on combined temperatures: this method can indicate comfort by combining air temperature and MRT as an output for the temperature of the space. This is defined as the uniform temperature, which is measured by a globe thermometer that is an ordinary thermometer with its bulb surrounded by a hollow sphere painted matt black on the outside. The black sphere is non-reflective and absorbs all of the radiation reaching it from the enclosure, as well as air temperature. Thus, the occupant would exchange (gain or loss) the same amount of heat by convection and radiation, combined as in the real environment (De Dear, 1998). This is known as environmental temperature according to CIBSE Guide A (2005), or operative temperature[5] in ASHRAE standard 55 (2007).
- Evaluations depend on the relationship between DBT against RH and use bioclimatic comfort charts and psychometric charts to analyse the local climatic conditions at a given place (Givoni, 1992).
- Evaluations based on combining the physical, environmental parameters and the personal ones of clothing and activity in a single index, for example: (i) predicted percentage of dissatisfied (PPD); (ii) predicted mean vote (PMV), which depends on the average judgement of comfort level in the environment

[5] Environmental temperature or operative temperature reflects the equivalent temperature to which a body can gain or lose heat by convection and radiation combined.

in question; and (iii) adaptive comfort (Alnusairat, 2018).

The current study focuses on the comfortable thermal environment in specific climatic conditions (i.e. a hot-arid climatic region) and the monitored environmental parameters include DBT and RH. Therefore, this research has adopted the relationship between DBT against RH by using the bioclimatic comfort charts and psychometric charts to evaluate a comfortable thermal environment level in the selected houses.

A review of the previous studies related to the thermal environment in Iraq revealed that there is a lack in this research area. In summer 1962, Webb carried out a comfort study of nine subjects who were living in rooms equipped with only ceiling fans, or with an evaporative cooler[6] in few cases. (Webb, 1964). After one decade, some observations of thermal comfort in Baghdad, beside Roorkee, some observations of thermal comfort in Baghdad and India were made by Nicol (1974) to identify the thermal comfort in these regions. The main findings from these studies are: first, the greatest variability of the global temperature that was recorded by Nicol was in Baghdad. Second, both studies agreed that the individuals who live in a hot and dry climate were most comfortable at a globe temperature of 32°C during summer. However, due to the changes that have occurred in comfort perception (Al-Jawadi, 2002). Furthermore, following the development of thermal comfort models, Webb's and Nicol's study can only be used as a starting point for further studies in this field. One of the recent studies was conducted by Rashid et al. (2016). Based on standards, occupant survey, indoor environment measurements and building simulations, this study aimed to define the boundary conditions and comfort criteria in some selected residential buildings in Baghdad. The findings of this study show that the indoor air temperature measurements sometimes exceeded 37°C during summer in cooled rooms. The results of this study also show that the occupants may experience higher temperatures than those defined in ASHRAE standard 55. A comparison of the relationship between measured indoor air temperature in some monitored houses and the weighted running mean outdoor temperature for the same period with the adaptive comfort range defined in ASHRAE standard 55 showed that the achieved indoor environment in the heating and cooling season was for over 1500 hours outside the defined 80% acceptable comfortable range, even though the observed room was mechanically heated and cooled. However, it has to be asked if

[6] An evaporative cooler is a cooling mechanism that only uses water as the working fluid to cool air—the simple evaporation of water is used to cool the room. Because evaporative cooling is based on saturating air with moisture, it is most effective in hot and dry climates where there is enough room moisture to be absorbed by the air, which allows evaporation to take place (Watt & Brown, 1997; ASHRAE, 2007).

these indoor temperatures are acceptable in the hot climate of Iraq?

An exploration of more studies that have been carried out in other countries with similar climate conditions revealed that a long-term survey was conducted by Alshaikh (2016) in Saudi Arabia by ASHRAE's RP-884. The reason why ASHRAE's RP-884 was adopted by Alshaikh is that this standard includes the work of De Dear et al. (1997), which included measurements in different climate conditions—including the hot-arid climate in Pakistan. In addition, comfort conditions in Pakistan were also subjected to investigation by Nicol and Roaf (2005). Furthermore, the Iraqi code for cooling is based on the standards defined by ASHRAE standard 55 (ESCO, 2012). Therefore, a comfort zone has been assumed in this study based on the ASHRAE standard 55 as explained in section 7.3. Moreover, because the monitoring data of the environment conditions in this study only aimed to investigate how the suppressed energy demand influenced the indoor thermal environment, the limits of comfortable thermal environment that were used here were adopted from the ASHRAE standard 55. The ranges of environmental parameters in this standard for group C (existing buildings) were employed to evaluate the thermal environment of the selected houses. Therefore, the comfort zone is defined as between 19 °C and 25 °C, and 20 to 70% in winter. Meanwhile, in summer the comfort zone is defined as between 22 °C and 27 °C, and 20 to 70%. The PMV and PPD ranges in the standards for existing buildings are $-0.7 < PMV < 0.7$ and the PPD is <15% (Guerra-Santin & Tweed, 2015).

3.3.9.3 Energy use vs indoor thermal environment

This section focuses on establishing the relationship between indoor environment conditions, ambient conditions, energy use and suppressed energy demand of the selected case studies. To relate these parameters of the case studies, the hourly data captured during the monitoring period between January 2017 to August 2018 have been considered. A statistical bivariate correlation analysis is an important method applied to evaluate the association between parameters (Elbayoumi, et al., 2014). The correlation between the parameters is reported with the Pearson correlation after testing its normality distribution, where the data considered normally distributed since the value (sig.) number more than 0.05 (all *p*-values > 0.05). The Pearson coefficient (*R*) is used to measure the strength of the correlation between the two parameters (Özbay, 2012), which can be expressed as:

$$R = \frac{\sum(x-\bar{x})(y-\bar{y})}{(x-\bar{x})^2(y-\bar{y})^2} \qquad (3\text{-}3)$$

where x and y represent parameters, and $\bar{x}$ and $\bar{y}$ represent the mean of the parameters. In this study, the Pearson (correlation) coefficient (R) is used to express the relationship between the parameters including (indoor environment conditions, ambient conditions, energy use and suppressed energy demand). The results will be discussed in section 7.4.

3.4 Summary

This chapter has described the methods that were used to estimate the energy-suppressed demand and evaluate its impact on indoor thermal environment in monitored houses located in a hot arid climate. This chapter has described the techniques that were explored for this research. It also included the criteria behind the design of the questionnaire and the reason behind using structured and formal interviews. In addition, the instruments and monitoring systems that have been used in the fieldwork have also been described. The last part of this chapter presented the methods that were used to analyse the monitoring data. These details have been explained in this chapter to present in a clear way the link to the following chapter, which describes the sequence of the fieldwork procedures of the research project. The previous review strengthens the combination of multiple data sources due to the potential of each method, both individually and collectively. Considering the aim and objectives of this study, the availability of the facilities, and the time allowance, three main sources of data are used in this study—a comprehensive questionnaire, case studies, and monitoring.

A questionnaire approach was used to obtain information that can be analysed to extract patterns and make comparisons. In addition, the questionnaire results were also used to define the most affordable prototype of houses in Baghdad in terms of this study's perspective. To minimise the limitations of this approach, objectivity is considered to avoid bias and explore the questionnaire results to select multiple cases that have the same features in the same context. Case studies are used to address the objective of the study related to energy use and indoor thermal environment. Therefore, seven pilot houses were investigated to allow an exploration of real estate buildings. The most important benefit of using this approach is to define the common prototypes of homes in the research context and to formulate the theoretical approach of the research. Other benefits include exploring several features of these buildings, such as geometry (the form, shape, area, and proportion), orientation, configuration within the horizontal section of the building, and the other supported elements such as construction systems and materials. Two methods were used in the case study approach to capture multiple sources of data—site visits and structured interviews with dwellers. The data are evaluated and analysed in different forms based on the measured parameters, which are used to compare the different issues. The results of this phase are described in Chapter 5.

A field measurement is carried out to investigate the use of energy inside the monitored houses, and to measure its impact on the indoor thermal environment of these houses. A monitoring approach was recommended: first, to deal with questions related to real-world contexts; and second, a monitoring approach can be used to diagnose and investigate the degree to which the problem of suppressing energy demand exists and affects these aspects. Field measurements are used to accomplish the second, third, and fifth objectives of this study regarding energy use, suppressed demand, and indoor thermal environment. This is discussed in more detail in Chapters 6 and 7 to describe the interconnections between the mixed method that is used in this study. Furthermore, it shows how a combination of quantitative and qualitative methods can be used to investigate the energy and environment performance, which allows the answers from both datasets to be combined.

Chapter 4: Dwellings characteristics, energy use and socio-economic influences

This chapter records the data that have been collected from the occupants during the subjective questionnaires to understand the social, economic, physical, and environmental aspects of domestic buildings in Iraq from the perspective of their energy use. This chapter aims to understand the factors that influence and affected by energy use in these households. The results from the questionnaire will be employed to select the representative case studies, which will then be used to conduct the monitoring process for both energy use and indoor thermal environment. This chapter is structured into five main sections, as follows: demographics of respondents, the background of households and the social network of Iraq households, the background of dwellings, energy background, and finally the summary.

4.1 Background

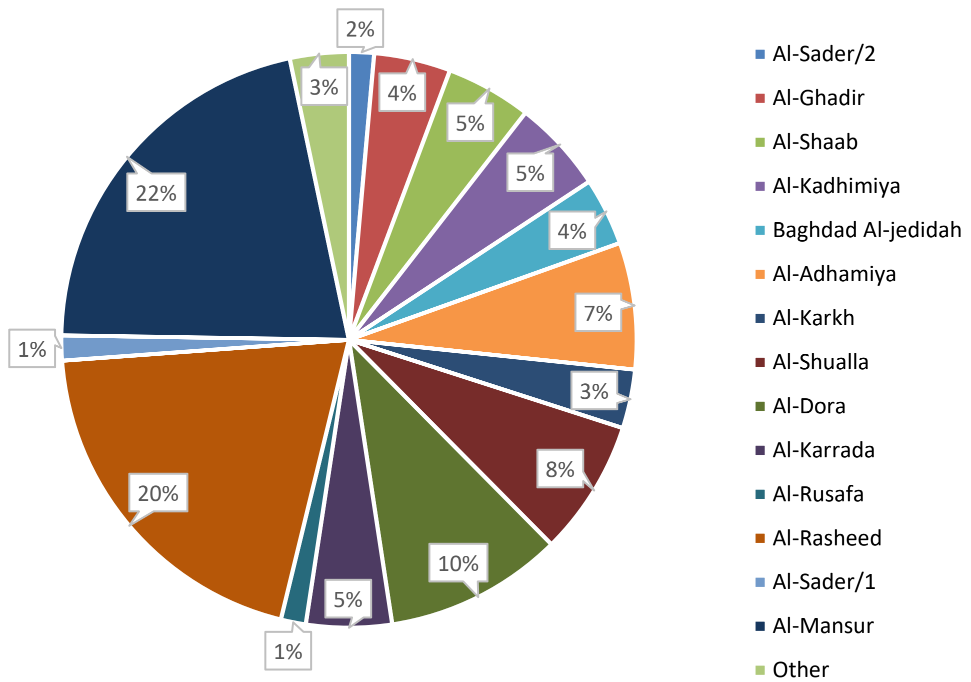
It is important to understand the factors that affect energy use in domestic buildings in Iraq, including the socio-economic, physical factors and thermal environment parameters (as discussed in subsections 2.3, 2.4.3). Additionally, residential energy use in Iraq has recently received special attention because of the insufficient energy supply from the NG, which requires households to rely on costly generators distributed within residential areas (as illustrated in subsection 1.1.5). The complexity of energy supply and use needs to be investigated and discussed from the public's point-of-view by carrying out a large-scale and comprehensive survey across Baghdad city (the study region). This survey was implemented through using a questionnaire that was distributed randomly to the heads of households with different ages, levels of educational attainment, and municipalities of residence in Baghdad (as described in subsection 3.3.1). The total sample of responses numbered 223 participants, 210 of whom (94.2%) completed the questionnaire. The questionnaire focused on the existing and occupied building stock. Therefore, the questionnaire was designed to obtain information on the occupants, which will be helpful in explaining the energy use profile of these dwellings. Consequently, the questionnaire included questions related to the personal profiles of the participants (i.e. heads of households), the socio-demographic information and economic characteristics of the households, the house type and its physical characteristics, and the occupants' end-use energy and indoor thermal environment issues.

4.2 Demographics of the respondents

The research sought to cover the 14 municipalities that constitute Baghdad city. Copies of the questionnaire were filled in by a team of architects to ensure completion, to guarantee the data quality, and to cover most of Baghdad's residential areas within the limited time that was available. However, the participation proportions in the questionnaire varied among municipalities. The number of participants in Al-Mansur municipality was the highest at 22%, followed by Al-Rasheed municipality with 20%. While the proportion of participants in the other 12 municipalities ranged from 10% to 1%. This variation of participants was attributed to the mobility and safety challenges faced by the team members. This is noted as a limitation. However, the analysis of the remaining municipalities did not demonstrate a difference. Therefore, it can be said that the lack of representation of some municipalities had a little or no impact on the conclusion. One of the initial findings of the questionnaire was that 97.6% of the participants live in an urban area, while 1.4% and 1% of participants live in rural and suburban areas, respectively. The distribution of the completed respondents across Baghdad is presented in Figure 4-1.

Figure 4-2 shows the demographical data of participants—the heads of the households— from the questionnaire. The age of the subjects ranged from 21 to over 80 years old. In detail, 50% of the heads of households who participated in this questionnaire were aged between 41 and 60 years old, and around 25% and 20% came from the age groups 26–40 years old and 61–70 years old, respectively. Moreover, the households that were headed by men account for 81.4% of the total households involved in the questionnaire, while 18.6% of families were headed by women. The census of building and dwellings in Iraq that was conducted by the Iraqi Ministry of Planning in 2011 revealed that 7.7% of total households in Iraq are headed by women (CSO, 2011). The question asking about occupation revealed that 58.1% of the heads of households were governments employees, and less than 15% were self-employed. The outcome of the educational attainment question showed that 65.2% of participants have an undergraduate degree, while 30% is equally divided between the head of households who have a post-graduate degree and those who have high school certificate.

The next sections will present the questionnaire's results according to the identified categories: the first category of questions sought to highlight the nature of the social network of Iraqi households. Exploring the physical environment of dwellings constituted the second category of questions. The third part focused on the dwellings' energy characteristics. Meanwhile, the final category of questions asked about the economic characteristics related to the household's energy use. These questions will help to provide a clear image of domestic energy use with associated factors. The questionnaire outcomes helped later when selecting the houses to serve as representative case studies to implement the monitoring approach.



Location Urban 97.6% Sub-urban 1% Rural 1.4%

Figure 4-1. The location of the respondents.

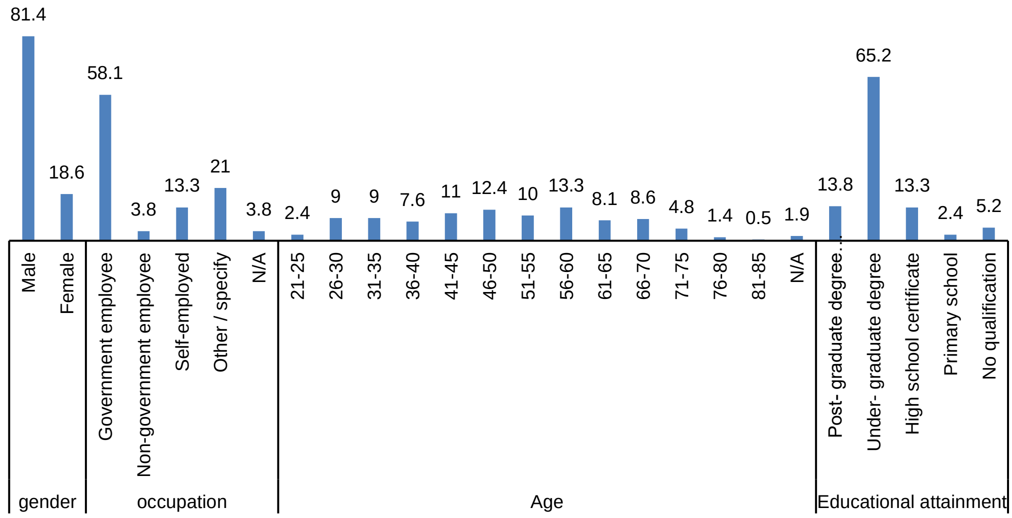


Figure 4-2. Distribution of the participants' demographical data from the questionnaire (%).

4.3 Dwellings characteristics, energy use and socio-economic influences

The analysis of the questionnaire results provided an initial explanation of the status quo of energy use in Iraq's residential sector, as elaborated below.

4.3.1 Social network analysis of Iraqi households

This section will discuss the occupants' demographic characteristics in the households that participated in the questionnaire. Around 30% of the occupants were aged between less than 1 year and 15 years old. Given that the presence of children significantly affects energy use (as illustrated in subsection 2.3.1), this percentage needs to be taking into consideration while studying residential energy consumption. The demographic results of the questionnaire also revealed that 55% of the occupants are labour aged (i.e. 16–65 years old). This percentage may positively be represented in the economic level of these households. However, the results of the residents' employment status show that 30% of families' members were students, 18% of females were housewives, 13.7% of children were preschool age, while just 28% were employed. Furthermore, the demographic information asked about the length of occupation and when the houses were built. Around 60% of families have lived in their current home between 1 and 15 years, with 35% of it for families have lived in their home from 1 to 5 years. The built-year showed that 68% of these houses were built between 1980 to present, while around 17% of families did not answer, either because they bought the houses after they had been built or because they rented their house. In addition, only 18% of the respondents were renting their dwellings, 78% either owned their homes or were living in their parent's property. Figure 4.3 shows more details of these results.

To better understand the social features that can influence energy use, the number of households and their members in each property were investigated. In addition, the findings of the social questions in this questionnaire revealed one of the key social characteristics that can have an impact on energy use in domestic building in Iraq, which is the distinguished social network of Iraqi society. The heads of these households were asked about their relationship with each family member. The outcomes of this question revealed that 50% of households live as one family in one house, while the rest likely allow a sub-family to live in the same house, not compound house as two, three, or four families with 30%, 15%, and 5%, respectively. This result matched the previous studies such as (Al-bayati, 2016; EASO, 2019).

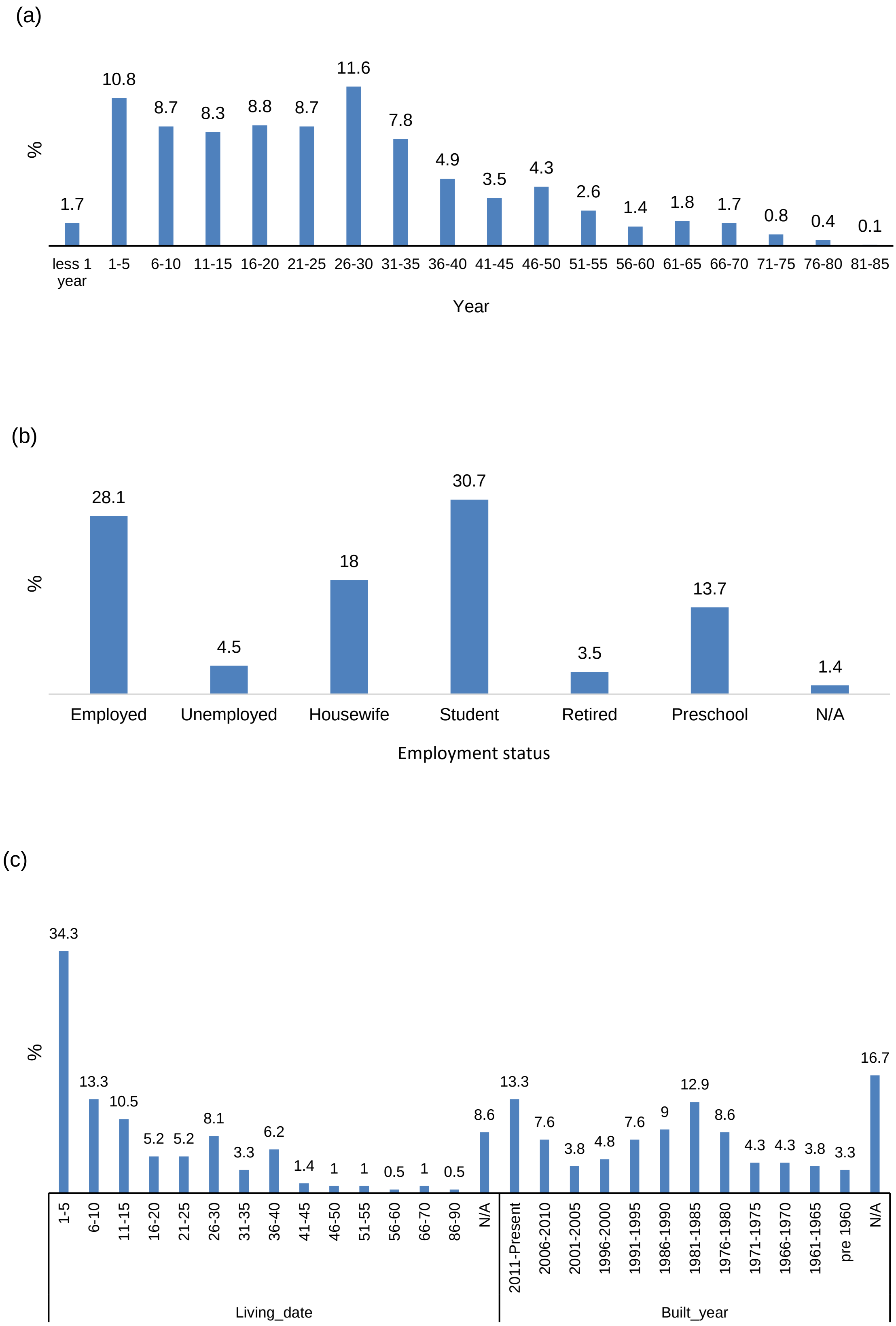


Figure 4-3. Demographic information of households: (a) the age of families' members, (b) the employment status of families' members, and (c) the living-date in and the built-year of the dwellings.

Figure 4-4 shows the key relationship of the head of households with their family's members.

The total number of each household was directly proportional to the total number of households in these dwellings, as can be seen in Table 4-1. The number of households who live in each dwelling was used as an indicator to study the environmental, economic and energy aspects of domestic buildings in Iraq, where using G1, G2, G3, and G4 codes refer to one, two, three and four households, respectively (as will be seen in the following sections of this chapter).

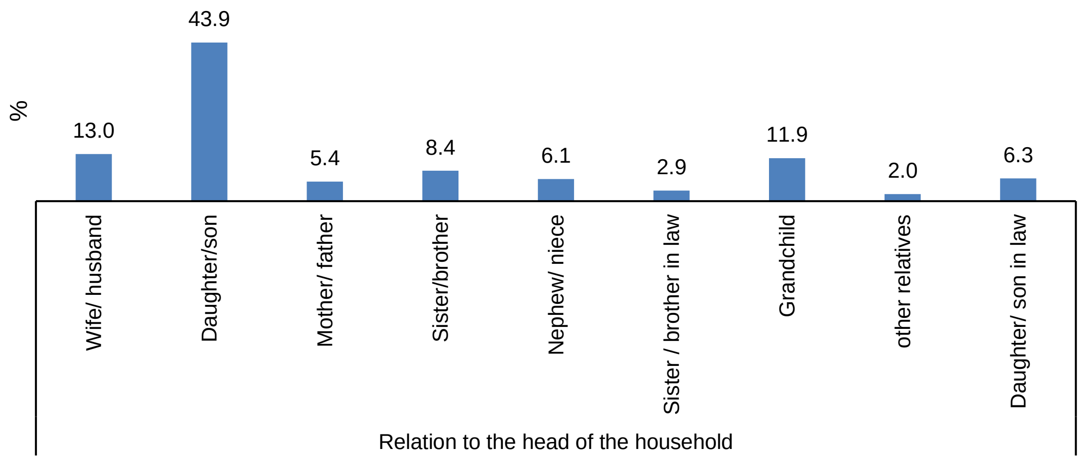


Figure 4-4. The members' relationship to the head of the household.

Table 4-1. Number of families as a function of the number of occupants in the property. This relationship reflects a direct proportional between families number and number of occupants.

Category	**G1**[1]		**G2**[2]		**G3**[3]		**G4**[4]	
	Frequency	**Total (%)**	**Frequency**	**Total (%)**	**Frequency**	**Total (%)**	**Frequency**	**Total (%)**
Households (#)	105	50	62	30	32	15	11	5
Person (#)								
two persons	15	14.3						
three persons	11	10.5						
four persons	30	28.6	3	4.8				
five persons	24	22.9	6	9.7				
six persons	14	13.3	14	22.6				
seven persons	9	8.6	13	21				
eight persons	1	1	7	11.3	5	15.6		
nine persons	1	1	9	14.5	5	15.6		
ten persons			4	6.5	4	12.5	1	9.1
11-15 persons			6	9.7	15	46.9	6	54.5
16-20 persons					3	9.4	3	27.3
21-25 persons							1	9.1
Notes: [1] G1: single-family in one house, [2] G2: two families in one house, [3] G3: three families in one house, and [4] G4: four families in one house.								

4.3.2 Physical characteristics (used rooms)

The research survey aimed to identify, assess and determine the physical factors that might influence the energy use and performance in Iraq's domestic buildings. The results of this part of questionnaire highlighted a number of factors related to building type, house type (if the residents live in a house), number of storeys and rooms, land and built area, shape and the size, and the construction and finishing materials. First, it is important to note that the majority of people who participated in the questionnaire live in a single-family house (96%), while just 4% live in flats. This outcome matches the information from the Iraqi Ministry of Planning (2007) and IKN (2012), where it reported that single-family houses constitute approximately from 80% and 87% of the total residential type of home in Iraq. Townhouses (terraced) were occupied by 73% of the households who participated in this questionnaire. This percentage matches (Al-Hafith, et al., 2018) in his study. In the same context, 72% of surveyed houses were two-storeyed — which is considered the typical dwelling unit typology that widely used in Iraq based on (Mohamed, et al., 2015; Abbood, et al., 2015), while 16% of in the houses were three-storeyed. Houses with three storeys (floors) are a recent phenomenon due to the housing deficit. It is worth noting that the townhouses are usually attached to other houses on three sides, which restricts the effects of solar radiation on exterior walls (ibid). These attached/shared walls act like interior walls. The construction and finishing materials will be described later in this section. In the same context, only one façade is open towards the street. This front façade of the house contains a number of climatic design elements, such as balconies, horizontal and vertical canopies, and cantilevers. This housing design shows the compactness and shared walls of modern dwellings in various residential areas within Iraqi cities. Moreover, the findings show that although the highest average of the total number of bedrooms was for two bedrooms with 26%, there was a positive relationship between the total number of bedrooms and the number of households living in the dwelling. For houses occupied by one family (G1), the total number of bedrooms ranged between two to three bedrooms, with 33.4% and 27.6%, respectively. The percentage of bedrooms for houses that are occupied by two families showed 29%, 30.6%, and 11.3% for three, four and five bedrooms, respectively. The highest number of bedrooms for houses with three families was 31.3% for five bedrooms. The total number of bedrooms for houses occupied by four families showed a remarkable increase in the total number of bedrooms, where the highest percentages were 36.4%, 27.3%, 18.2% for five, six and seven bedrooms, respectively. This increase in the total number of used bedrooms based on the total number of families who live in the house increases the household electrical energy demand, due to the significant and positive relationship between the number of bedrooms and domestic energy use (as illustrated in subsection 2.3.3). See Table 4.2 for more details.

Table 4-2. Details of the respondents' dwellings, based on the total number of families living in the house.

parameter	Scale (%)	G1[1]	G2[2]	G3[3]	G4[4]	Mean
Dwelling type (-)	House	90.5	96.8	100	100	**96**
	Flat	9.5	3.2	0	0	4
House type (-)[5]	Detached	2.9	6.5		9.1	6
	Semi-detached	25.7	21	21.9	18.2	22
	Townhouse/ terraced	69.5	70.9	78.1	72.7	**73**
	N/A	1.9	1.6			2
Storeys number (#)	One storey	21.7	9.7	3.1	9.1	11
	Two storeys	71.6	82.3	81.3	54.5	**72**
	Three storeys	6.7	4.2	15.6	36.4	16
Bedrooms (#)	One	13.3				13
	Two	**33.4**	17.7			**26**
	Three	27.6	29	25	9.1	23
	Four	17.1	**30.6**	25	9.1	20
	Five	8.6	11.3	**31.3**	**36.4**	22
	Six		8.1	9.4	**27.3**	15
	Seven		3.2	6.3	18.2	9
	Eight			3.1		3

Notes: [1] G1: single-family in one house, [2] G2: two families in one house, [3] G3: three families in one house, and [4] G4: four families in one house, [5] Detached house type is unattached house, Semi-detached is attached to other houses on two sides, Townhouse/ terraced is attached to other houses on three sides.

The size of the houses showed that there was a significant variation in its relationship to the number of families in the household. For the houses that were occupied by one family, the highest percentage had land areas of 76–100 m^2 and 176–200 m^2, with 18% for each land area group. Around 20% of the houses occupied by two families had an area larger than 300 m^2, followed by 16% with an area of 176–200 m^2. The highest percentage of the land area of houses that occupied by three families had an area that was larger than 300 m^2, with around 305 m^2, followed by 20% with an area of 267–300 m^2. However, the highest percentages of house sizes that were occupied by four families were divided between 176–200 m^2 and more than 300 m^2, with 27% for each group. This variation did not show a positive relationship between the family size and the area of the houses, which could be attributed to the families' income. Similarly, the built area of the houses showed a variation in its relationship with the total number of families. The house-built areas ranged between 76–200 m^2 for most of the samples, see Figure 4-5 for more details. The length of the land area was 6–10 m of most of the hoses and 16–20 was the most popular width for most of these homes, see Table 4-3 for more details. The questionnaire also covered the direction of the front elevation of houses. This relationship between the size of the household and the land and built area shows that it is important to investigate the impact of this relationship on the total energy consumption, especially after observing that the total floor area is the parameter with the third-largest explanatory

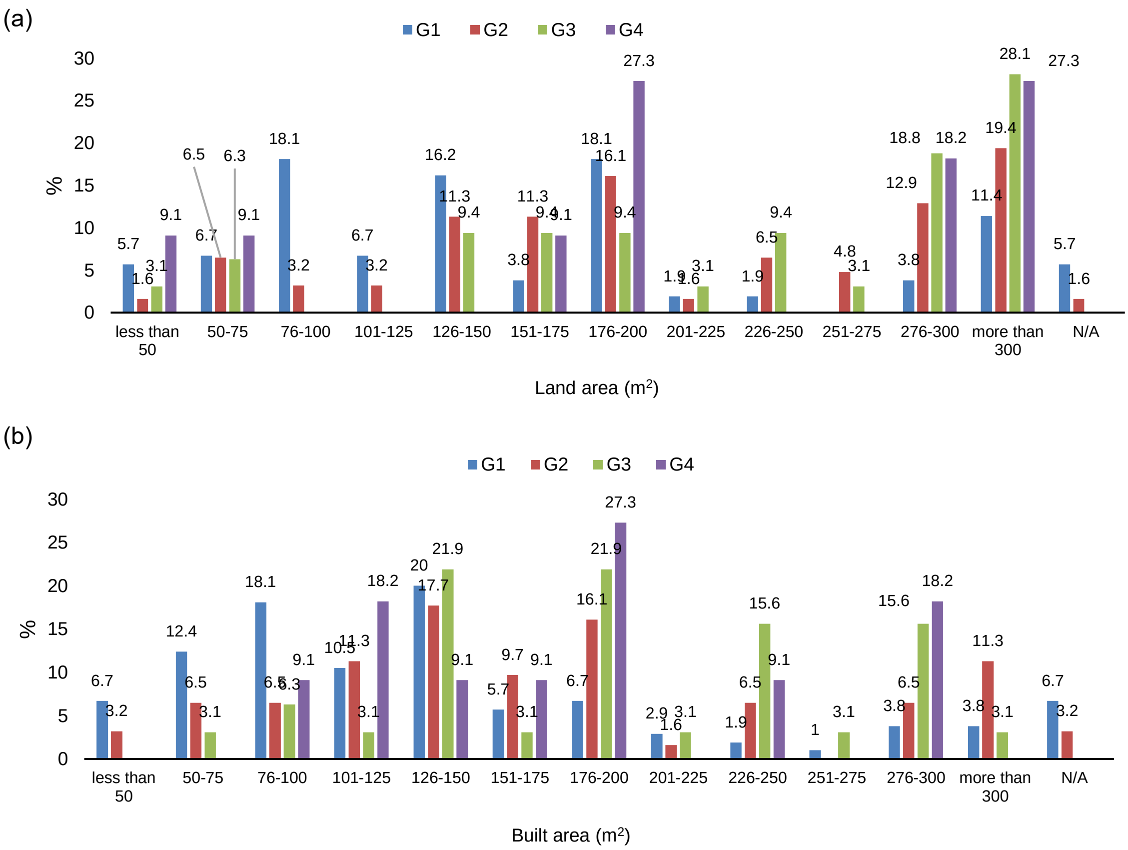


Figure 4-5. Size of the respondents' dwellings: (a) land area, and (b) built area based on the size of the households.

Table 4-3. The length and width of the houses.

Length of land area (%)						**Width of land area (%)**					
Scale (meter)	**G1[1]**	**G2[2]**	**G3[3]**	**G4[4]**	**Mean**	**Scale (meter)**	**G1[1]**	**G2[2]**	**G3[3]**	**G4[4]**	**Mean**
1-5	19	8.1	9.4	18.2	13.7	6-10	11.4	1.6			6.5
6-10	**53.3**	**56.5**	**37.5**	**36.4**	**45.9**	11-15	14.3	8.1			11.2
11-15	10.5	16.1	34.4	27.3	22.1	16-20	**41.9**	**38.7**	**68.8**	**63.6**	**53.3**
16-20	5.7	11.3	18.8	18.2	13.5	21-25	11.4	19.4	15.6	9.1	13.9
21-25		1.6			1.6	26-30	7.6	19.4	9.4	18.2	13.7
N/A	11.4	6.5			9.0	more than 30	1.9	6.5	6.3	9.1	6
						N/A	11.4	6.5			9
Notes: [1] G1: single-family in one house, [2] G2: two families in one house, [3] G3: three families in one house, and [4] G4: four families in one house.											

power for electricity consumption in residential buildings (based on what mentioned in subsection 2.3.3). Many previous studies have confirmed that the shape of the building constitutes a major factor determining its energy consumption. Therefore, the survey included questions related to the length and the width of the houses, and also their land area, which can help to determine the total area of the exposed surfaces. This result affects the thermal performance of the whole building, especially for houses in hot arid climatic regions such as Iraq. The results revealed that the length of the plot area of around half of the surveyed houses was within 6–10 m, and in more than 50% the width of the land area was within 16–20 m. These dimensions need to be taken into consideration during the house design process, especially when the subject is directly related to the processes of heat transfer and comfortable thermal environment, which can, in turn, affect the total energy consumption. In addition, the participants were asked to indicate the direction of the front elevation of their houses with help from the survey team members. Figure 4-6 illustrates the outcome of the orientation statement. The survey almost covered all of the orientations that can affect the thermal environment and energy use levels.

The previous studies that were reviewed in Chapter 2 showed how the total energy consumed significantly increased because of the poor thermal performance of these buildings, due to the weakness in building envelop and construction materials. Therefore, the physical category of the survey's questions explored the construction system and materials of Iraq's housing stock. One of the key facts that were revealed in this section is that most of the surveyed houses shared the same construction system and materials regardless of the built-year. Although these houses were built in different periods, starting from 1960 to present, neither construction systems nor used materials have witnessed any significant change over this period. Brick material constituted 95% of the construction materials for the internal and external walls, while reinforced concrete casting represented the main construction material for ceilings and roofs (88%). These outcomes match the studies conducted by CSO in (2011) as a monitoring system of social and economic conditions in Iraq, and Najim's study in (2014). In addition, the materials for external and internal finishing have not observed any significant change in terms of use and construction. In around 70% of these houses, their external walls were rendered with cement material, while both stone and ceramic or marble tiles were used to finish the external walls in 30% of households.

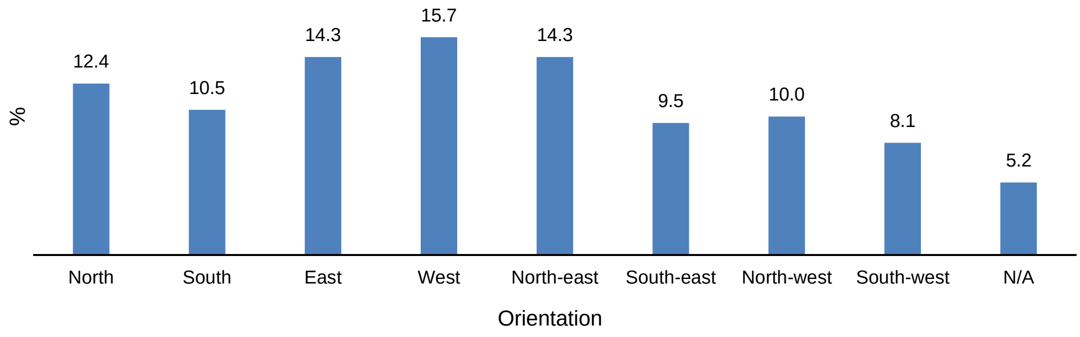


Figure 4-6. The direction of the front elevation of the houses.

It is worth noting that this part of the questionnaire is designed to allow for more than one answer to see if some of the houses had used different materials for construction and finishing. More than 97% of the internal walls were finished with plaster, which was mainly used as a finishing method in most of the house spaces, except for the kitchen and bathrooms. Ceramic tiles were used by 70% of the sample as an internal finishing material mainly in the kitchen spaces and bathrooms. Mosaic cement tiles were used by Iraqi households to finish the floors of the main spaces and rooms, where the results showed that this material used by 75% of the sample. Ceramic tiles were mainly used to finish the floors in bathrooms (41%). Both timber and steel were used as the framing material for the main doors, with 90% and 92%, respectively. However, the window frames were constructed from steel or aluminium, with 88.6% and 16%, respectively.

Given that this research examines the factors that affect thermal performance, and thus the energy use, the participants were asked about the availability and use of components that may influence the domestic energy performance. It was found that low energy light bulbs were used by 91.4% of the participants. Interestingly, a single glazing layer was used by 100% of the homes. Insulation materials were only used in half of these houses, mainly to provide better thermal insulation in the roofing elements. The roofs of these building are usually flat and represent the main element that is exposed to outdoor weather conditions, especially the high temperatures in the summer season. These findings confirm that there is a need to raise the awareness of how to reduce energy consumption and improve the thermal environment of buildings by applying new construction technologies and adopting the related standards (see Table 4-4 for more details).

Table 4-4. The fabric and physical characteristics of the houses.

Construction					
parameter	**scale [1]**	**Total %**	**parameter**	**scale**	**Total %**
Walls	Concrete	3.3	Ceilings	Reinforced concrete casting	88.1
	Brick	95.2		Jack arching	13.8
	Cement blocks	4.8		Steel	0.5
	Sandwich panel	2.4		Sandwich panel	2.9
	Stone	0.5			
	Thermo-stone	0.5			
Finishing					
External Walls	Cement rendering	69	Internal Walls	Plaster	97.6
	Stone	15.7		Ceramic tiles	70.5
	Ceramic, marble tiles	17.1		Brick	1.4
	Brick	6.2		Stone	1.9
	Precast	0.5		Cement rendering	2
	Sandwich panel	0.5		Sandwich panel	0.5
	Painting	8.1		Gypsum board	0.5
	without finishing	1.9		Marble	0.5
Floors	Mosaic cement tiles	75.2	Windows	Frame: Steel	88.6
	Ceramic tiles	41		Frame: Aluminium	16.7
	Concrete casting	5.2		Frame: PVC	8.1
	Floor flat bricks	1.4		Frame: timber	1.4
	Marble	12.9	Doors	Frame: Steel	92.9
	Granite	6.7		Frame: Aluminium	21.9
	Porcelain	3.8		Frame: PVC	20
				timber	90.5
Component	Single glazing layer	100	Insulation material	Roofs	52.9
	Low energy light bulbs	91.4		Walls	1.9
	False ceilings	22.9		Floors	1
	Insulation material	53.8		Ceilings	2.9
Notes: [1] the question is designed to allow for more than one answer.					

4.3.3 Energy use

The survey asked questions to effectively map out the energy use correlated with certain daily activities. The participants were asked to answer questions regarding routines and their everyday behaviour with respect to energy use with the aim of exploring the energy characteristics of domestic buildings in Iraq. This part of the chapter will present the participants answers in terms of: (i) the sources of energy according to the households use for the main domestic activities, (ii) the main method(s) of cooling and heating used in these dwellings, (iii) the appliances that a household might have and the energy used in their operation. Regarding the first question in this part of the questionnaire, the respondents were asked to list the main energy sources that they used to perform the key household activities, such as lighting, heating, cooling, cooking and heating water. The results revealed that 98% of sample rely on NG electricity as a primary energy source for heating water, mainly in the winter season. In addition, electricity from the NG was used by more than 75% of surveyed households as a primary energy source for lighting, while 72% of households relied upon the local CGs as a secondary energy source for lighting. In winter, both kerosene and the electricity from the NG constituted the main energy sources for heating, with 51% and 46%, respectively. Liquid gas cylinder is the main energy source for cooking and is used by around 97% of surveyed families, while around 45% of the sample used electricity from the NG as a second source for cooking. During the questionnaire, the families revealed that cooling activity represented the key concern for them, especially in summer. When the families were asked to rank the energy sources that they used for cooling, their answers were that around 85% of them rely on the NG as a primary electricity source used for cooling the spaces, while for around 70% of families the local CGs represent the alternative source used to provide electricity for cooling. Table 4-5 illustrates the main domestic activities with the main energy sources used. The electricity from both the NG and local CGs represented a key energy source to implement most of the domestic daily activities in Iraq. This outcome matches the information from the (COSIT, 2007), where it reported that 89% of relying on the NG as a primary electricity source used for cooling the spaces, while 98% of households rely on NG for lighting. 84% of Iraqi use liquid gas cylinder (LGC) as the main energy source for cooking. The kerosene was used by more than 85% of Iraqi households as a primary energy source for heating. As illustrated in subsection 2.4.3.3, since the energy consumption in Iraq is seasonal, more energy is required for cooling and heating spaces during summer and winter than any other activity. However, based on the families who participated in this comprehensive questionnaire, the consumed energy for space cooling is relatively high and represents the major source of energy consumption, especially when given that Iraq has a very hot and aggressive environment that requires mechanical ventilation and air conditioning.

Investigating the cooling and heating systems used in the properties revealed four main findings. First, all of the households showed the same pattern in terms of using cooling and heating systems, regardless of the size of the families that live in the same dwelling. Second, the majority of families use air conditioners and evaporative coolers as a main cooling method in the summer season, without any reliance on natural ventilation. The air conditioner is used when the electricity is available from NG, while the evaporative cooler is used when the families receive electricity from CGs because an evaporative cooler requires less electricity for operation. The third finding is that both fan (ceiling/standing) and natural ventilation are mainly used during the intermediate seasons (spring and autumn), especially at night. Finally, it is worth noting that this part of the questionnaire, like many other parts, is designed to allow for more than one answer and, therefore, the findings revealed that oil heaters are used as the main method for space heating (i.e. 87% use kerosene heaters). Meanwhile, both electric heaters and air conditioners are used for heating by more than 80% and 50% of participants, respectively.

The use of air conditioners and electric heaters indicates that there is an increase in energy use in winter, which in turn reflects more reliance on electricity. Table 4-6 gives more details.

Table 4-5. The sources of energy according to the households' usage for the main domestic activities.

Parameter		**Energy sources (%)**				
Name	**parameter**	**NG[1]**	**CG[2]**	**PG[3]**	**K[4]**	**LGC[5]**
Primary energy source	Hot water	**98**		0.5	1	0.5
	Lighting	**77.6**	22.4			
	Heating	45.7	1.4	0.5	**51.4**	0.5
	Cooling	**84.3**	15.2	0.5		
	Cooking	1.4			1	**97.6**
Secondary energy source	Hot water	0.5	3.3		1.4	10.5
	Lighting	21.4	**71.9**	1.4		
	Heating	**39**	26.7	0.5	18.1	0.5
	Cooling	13.8	**68.6**	1.9		
	Cooking	44.3	1.9	0.5	1.4	0.5

Notes: [1] NG: national grid, [2] CG: community generator, [3] PG: privet generator in the house, [4] K: kerosene, and [5] LGC: liquid gas cylinder

Table 4-6. Cooling and heating methods used in these houses.

Name	**parameter[1] (%)**	**G1[2]**	**G2[3]**	**G3[4]**	**G4[5]**	**Mean**
Method of cooling	Air conditioner	87.6	88.7	100	90.9	91.8
	Evaporative cooler	88.6	90.3	90.6	100	92.4
	Fan (ceiling/pedestal)	96.2	96.8	100	100	98.3
	Natural ventilation	73.3	79	84.4	63.6	75.1
Method of Heating	Air conditioner	47.6	53.2	40.6	54.4	49
	Oil heater	86.7	85.5	93.8	90.9	89.2
	Electric heater	83.8	85.5	93.8	81.8	86.2
	Gas heater		4.8	3.1		4

Notes: [1] the question is designed to allow for more than one answer. [2] G1: single-family in one house, [3] G2: two families in one house, [4] G3: three families in one house, and [5] G4: four families in one house.

To understand the domestic energy use in Iraq, the last part of the energy section in the questionnaire focused on the main appliances used by the households and the energy source used for their operation. Tables 4-7 illustrates that most of the used appliances by households rely on electricity for operation, except for a cooker oven and tandoori oven, where a liquid gas cylinder is used for these appliances. These findings enhance the results of previous parts and confirm that electricity represents the main energy source used in domestic buildings in Iraq. The next section will explore the environmental systems that can influence domestic energy use.

Table 4-7. The list of appliances used by households with the main energy source for operation.

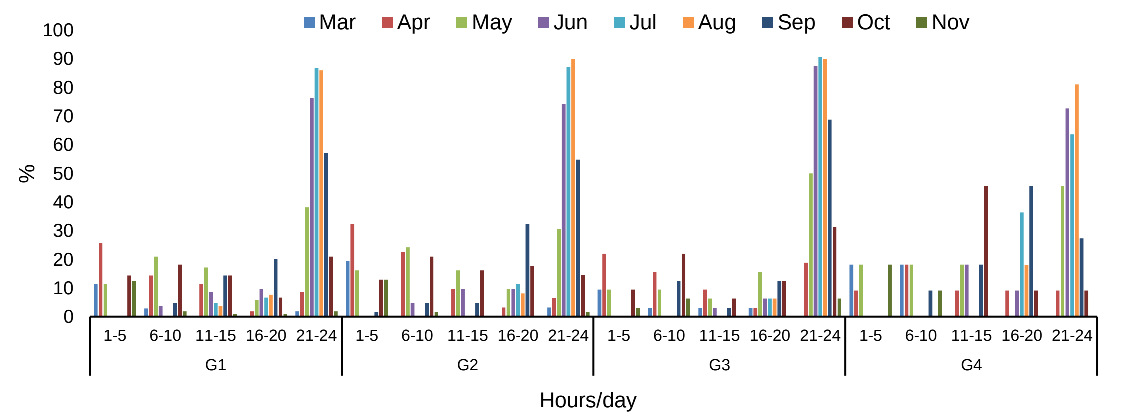
appliances	**Energy source used (%)**			**appliances**	**Energy source used (%)**		
	Electricity	**Liquid Gas**	**N/A**		**Electricity**	**Liquid Gas**	**N/A**
Evaporative cooler	91.4		8.6	Tablet	51.4		48.6
Fridge	99		1	Iron	97.1		2.9
TV	99		1	Microwave	54.8		45.2
Cooker oven	3.3	90	0.5	TFM [1]	95.7		4.3
Hot water boiler	95.2	1	1	Oven	53.8	5.2	40
Water cooler	77.1		22.9	Grill	22.9	2.9	71.9
Fan	98.6		1.4	Tandoori oven	1.4	30	68.6
Window type	65.7		34.3	Swing machine	46.7		53.3
Split unit	72.4		27.6	Water filter	64.3		35.7
Extractor fan	92.9		7.1	Water pumping	92.9		7.1
Chest frozen	83.8		16.2	Mill	63.8		36.2
Washing machine	99		1	Juicer	66.2		33.8
Vacuum cleaner	86.7		13.3	Mixers	94.3		5.7
PC	78.1		21.9	Mincer	10.5		89.5
Router modem	92.4		7.6	Toaster	10.5		89.5
Game console	36.2		63.8	Notes: [1] TFM: Telephone fixed-mobile			
Satellite	97.1		2.9				

4.3.4 Environmental systems

The energy part of questionnaire investigated the most energy-consuming daily activities. The results showed that the heating and cooling of spaces represented the main energy use for households. Based on the findings the space cooling is the most energy-consuming activity, especially in the summer months when people start using air conditioners and evaporative coolers. In addition, the common belief was that the Iraqi families used oil heaters, with kerosene as the main heating method in winter. However, the results of this questionnaire revealed that electric heaters were almost as common as oil heaters, which shows that there is more demand for electricity in the winter as illustrated in Table 4.5. Consequently, the questionnaire asked about the peak period of heating and cooling usage. The results of this question would help to understand when the highest level of energy is required, based on the indoor thermal environment of houses. One of the survey questions was designed to assess the period of operation of both heating and cooling systems. Table 4-8 illustrates the period during which the cooling system is used in the home. Regardless of the number of families who live in a

Table 4-8. Period cooling system use in these dwellings.

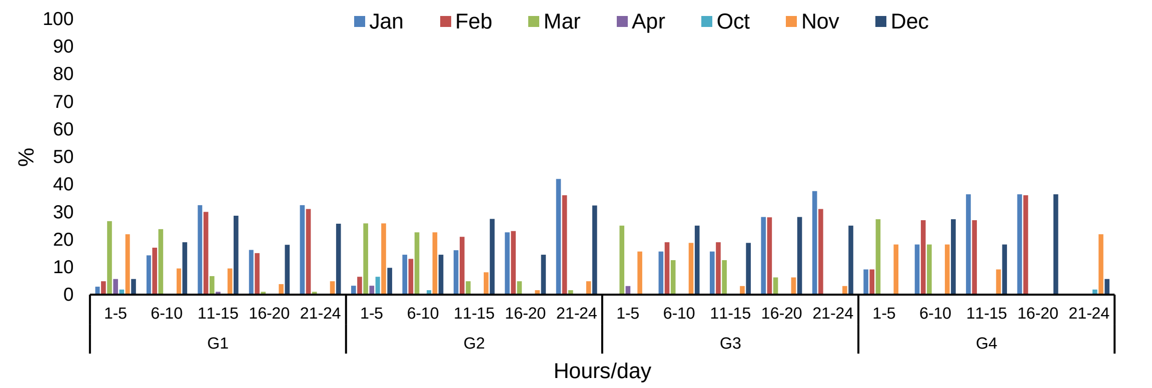
Case		Winter (%)			Spring (%)			Summer (%)			Autumn (%)			Mean
		Dec	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	
G1	**1-5**				11	26	11					14	12	15
	6-10				3	14	21	4			5	18	2	10
	11-15					11	17	9	5	4	14	14	1	9
	16-20					2	6	10	7	8	20	7	1	8
	21-24				1.9	9	**38**	**76**	**87**	**86**	**57**	**21**	2	**42**
G2	**1-5**				19	32	16				2	13	13	16
	6-10					23	24	5			5	21	2	13
	11-15					10	16	10			5	16		11
	16-20					3	10	10	11	8	32	18		13
	21-24				3	7	**31**	**74**	**87**	**90**	**55**	**15**	2	**40**
G3	**1-5**				9	22	9					9	3	10
	6-10				3	16	9				13	22	6	12
	11-15				3	9	6	3			3	6		5
	16-20				3	3	16	6	6.3	6	13	13		8
	21-24					19	**50**	**88**	**91**	**90**	**69**	**31**	6	**56**
G4	**1-5**				18	9	18						18	16
	6-10				18	18	18				9		9	14
	11-15					9	18	18			18	**46**		22
	16-20					9		9	36	18	46	9		21
	21-24					9	**46**	**73**	**64**	**81**	**27**	9		**44**



property, over 45% of respondents use cooling systems between 21 to 24 hours a day, especially in the summer season. The daily period of using cooling in summer months (June, July and August) was the highest against other months of the year, where between 75% to 90% of surveyed families tended to use cooling methods between 21 to 24 hours/day. Table 4-9 illustrates the period during which the heating system used at home. The highest period of using heating mechanisms was confined to the winter months (December, January, and February). A few of these families used heating for more than 20 hours a day in these months, which represent the coldest months in a year. Another important fact that could be revealed from this table is there is no predominant peak period of using heating systems during the winter among the families. The hours of using

Table 4-9. Period of heating system use in these dwellings.

Case		Winter (%)			Spring (%)			Summer (%)			Autumn (%)			Mean
		Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
G1	1-5	6	3	4.8	27	6						2	22	10
	6-10	19	14	17	24								10	17
	11-15	27	32	30	8	1							10	18
	16-20	18	16	15	1								4	11
	21-24	26	32	31	1								5	**19**
G2	1-5	10	3	7	26	3						7	26	12
	6-10	15	15	13	23							2	23	15
	11-15	27	16	21	5								8	15
	16-20	15	23	23	5								2	13
	21-24	32	42	36	2								5	**23**
G3	1-5				25	3							16	15
	6-10	25	16	19	13								19	18
	11-15	19	16	19	13								3	14
	16-20	28	28	28	6								6	19
	21-24	25	37	31									3	**24**
G4	1-5		9	9	27								18	16
	6-10	27	18	27	18								18	22
	11-15	18	36	27									9	23
	16-20	36	36	36										**36**
	21-24	6										2	21	



heating were distributed over several different scales of periods, starting from 1–5 hours/day to 21–24 hours/day, and there is no a specific scale of time achieved more than 50% of using by families. In contrast, the time scale of 21–24 hours per day was the highest period where people used the cooling mechanism in summer. The main results that could be extracted from these tables are that the cooling system was used in the home for a longer period than the heating system. This reflects the amount of energy being used to operate both air conditioners and evaporative coolers during the summer period.

4.3.5 Economic dimensions of energy use

As mentioned in subsection 2.3.2, the bi-directional relationship between energy use and economic factors can be explored either at the national scale or at the individual household scale. The current study focused on the latter because it is located within the study's scope. Exploring this level required questions that could help to understand the significant role that the economic factor of households plays in determining energy use. This part of the questionnaire involved questions about: (i) the total monthly expenditure on buying energy in all its forms (i.e. electricity, gas, kerosene and others if used). (ii) the type of expenditure on energy (i.e. electricity from a private generator at home, kerosene and liquid gas cylinder) and their monthly cost. As mentioned in subsection 2.4.3.4, although the price of electricity from the NG (as a primary source of electricity supply) is heavily subsidised, the payment discipline for electricity is relatively weak. The questionnaire sought to explore this issue from the consumer's perspective, where the surveyed families were asked to determine the payment period for electricity from the NG. In addition, the households' reliance on local CGs has added extra economic burdens on households because the cost of electricity from these generators is anywhere between 10 to 15 times more than the cost of NG electricity. Therefore, the last questions in this part of the questionnaire focused on this aspect. The total expenditure of electricity from NG and the monthly cost of electricity from the local CGs in both winter and summer seasons were discussed with the participants in detail. Moreover, the number of amperes that each household bought from the CGs in winter and summer were also discussed during with the families while conducting the questionnaire. It is worth mentioning that the number of families that live in a dwelling was used as a function to analyse the results of this part of the questionnaire.

The results of the monthly energy expenses showed that the highest mean of expenses was 18.8% for households who spent from 21% to 25% of their monthly income to buy energy in all its forms. This percentage of expenses was the same for the households who live in two and four family households. In the dwellings that were occupied by three families, the maximum monthly expenses of energy were between 26% and 30% from their monthly income, which is the highest percentage compared to the other groups. The minimum monthly expenses for buying energy was for households who live as a single-family. These results reflect the positive relationship between the number of occupants and the expenditure on energy. Table 4-10 shows the percentage of the total household income (of all earning members) spent on energy. In the case of multi-family households, income may come from more than one family, but the percentage represents the share of all incomes, (see Table 4-10 for more details).

Table 4-10. Percentage of the total household income (of all earning members) spent on energy. In the case of multi-family households, income may come from more than one family, but the percentage represents the share of all incomes.

Energy expenses/month (%)	**G1[1]**	**G2[2]**	**G3[3]**	**G4[4]**	**Mean**
0-5	2.9	3.2		9.1	5.1
6-10	10.5	14.5	6.3		10.4
11-15	**18.1**	9.7	12.5	**27.3**	16.9
16-20	10.5	8.1	9.4	9.1	9.3
21-25	19	**19.4**	9.4	**27.3**	**18.8**
26-30	8.6	9.7	**15.6**	18.2	13
31-35	5.7	3.2	12.5		7.1
36-40	11.4	4.8	12.5		9.6
41-45	4.8	17.7	12.5	9.1	11
>45	5.7	8.1	6.3		6.7
N/A	2.9	1.6	3.1		2.5
Notes: [1] G1: single-family in one house, [2] G2: two families in one house, [3] G3: three families in one house, and [4] G4: four families in one house.					

Table 4-11 illustrates the cost of different type of energy sources used by these households. The majority of families do not use a private generator at home; therefore, this source of electricity was excluded in this study, which focused instead on the electricity supplied from both NG and CGs as main energy supply sources. The monthly cost of liquid gas cylinders (which is mainly used for cooking) was the lowest compared to the other energy used in these households, where the range of its cost for all categories was from 11,000 to 30,000 IQD (£7 to £20) per month. Regarding the consumption of kerosene, its monthly cost showed a significant variation within the same group and among other groups. This could be attributed to the main use of kerosene for heating during the winter, which makes its use seasonal. In addition, most of the residents use an electric heater and air conditioner (when the electricity from the NG is available) for heating in addition to kerosene. It is important to mention here that buying kerosene was directly proportional to the number of families that live in the same property. Moreover, the previous section showed that the NG and CGs were used as a primary and secondary energy source for most of their residential activities. This is the reason why the participants were asked about how much they spend on electricity sources. The households who they do not pay bills for electricity from NG were around 35%, which confirms what mentioned in subsection 2.4.3.4 regarding the billing systems in Iraq's energy system. Furthermore, the payment periods of these bills were almost monthly or per two months, and in some cases, the bills were paid every three months (see Table 4-12 for more detail).

Table 4-11. The type of household spending on energy sources and their monthly cost.

Cost	**G1[1] (%)**			**G2[2] (%)**			**G3[3] (%)**			**G4[4] (%)**		
IQD(000)[5]	**PG[6]**	**LGC[7]**	**K[8]**	**PG**	**LGC**	**K**	**PG**	**LGC**	**K**	**PG**	**LGC**	**K**
0	**63.8**	1	11.5	**72.6**	3.2	1.6	**68.8**	6.3	3.1	**81.8**	9.1	9.1
10	2.9	**40.1**	16.2	4.8	14.5	14.5		3.1	18.8			
11-20	4.9	**41.1**	13.4	3.2	**41.9**	20.9	3.1	25	15.6	9.1	9.1	18.2
21-30	14.3	17.2	**21.1**	3.2	29	17.8	6.3	**47**	3.1	9.1	**36.4**	9.1
31-40	3.9		1.9	1.6	6.4	4.8		9.3	3.1		18.2	
41-50	4.8		13.3	8.1	3.2	**27.4**	15.6	6.2	6.2		9.1	18.2
51-60		1	3		1.6			3.1	**21.8**			18.2
61-70			1.9	1.6		1.6			3.1		9.1	
71-80	1								6.3			**27.3**
81-90			1									9.1
91-100	1		10.5	3.2		4.8			12.5			
101-110												
111-120						1.6			3.1			
121-130	1		1.9				3.1					
131-140												
141-150	1.9		2.9	1.6			3.1					
151-300	1		2			4.8			3.1			

Note: [1] G1: single-family in one house, [2] G2: two families in one house, [3] G3: three families in one house, and [4] G4: four families in one house.[5] IQD: Iraqi Dinar. [6] PG: private generator in the house, [7] LGC: liquid gas cylinder, and [8] K: kerosene

Table 4-12. The payment period of electricity form NG.

Payment period for NG (%)	**G1**	**G2**	**G3**	**G4**	**Mean**
One month	**22.9**	16.1	**21.9**	**36.4**	24.3
Two months	**19**	**29**	**21.9**	27.3	24.3
Three months	12.4	16.1	3.1	9.1	10.2
Four – one year	10.5	3.2	6.2		8.4
More than 1 year		1.6			1.6

The monthly expenses for electricity from CGs in winter showed a noticeable variation among households, with a maximum range between 51,000 and 150,000 IQD (£33–£96 per month). Conversely, the monthly expenses for electricity from CGs during summer was the highest compared to other expenses for electricity (e.g. from NG and from CGs in winter), where it was between 251,000 and 300,000 IQD or £160 to £193 per month for some households. These results match the previous studies, which stated that the cost of electricity from CGs is the highest compared to the cost of other energy supply sources. Table 4-13 (a) summarises the type of household spending on electricity sources and the percentage of their cost.

As explained in subsection 3.3.9.1, estimating the suppressed energy demand basically relies on the difference between the energy supplied from NG and the CGs. Consequently, the households were asked to determine the number of amperes that they bought from the CGs in winter and summer. This would enhance the monitoring results and enable a comparison to be made between the primary energy provided by the local CGs against the primary energy from NG. The results of this question revealed that the highest average of the number of amperes bought by the residents during winter and summer was between 6 and 10 amperes, with 37% and 34%, respectively. However, the details are based on the total number of families who live in the same home. For single -families, 51% of them used between 1 to 5 amperes in winter and 47% of single-families used from 6 to 10 amperes in summer. The dwellings that occupied by two families, around half of them received between 6 to 10 amperes in winter and summer. Around 44% of the surveyed houses that resided by three families bought from 6 to 10 amperes during winter. In summer, the electricity that they consumed observed a significant increase, which can be divided into three categories: 6–10, 11–15 and from 16–20 amperes with 32%, 19% and 16%, respectively. The highest number of amperes consumed in winter and summer by homes with four families was from 11 to 15 with 37% and 55%, respectively. These results showed that most of the families in Iraq tend to consume more electricity from CGs during summer than winter. Moreover, the amount of supplied energy from CGs was directly proportional to the total number of families in these dwellings. Table 4-13 (b) shows the number of amperes used per month in both winter and summer seasons.

Table 4-13. The type of household spending on electricity sources and the percentage of their cost.

(a) Cost	**Groups (%)**												**Mean**		
	G1			**G2**			**G3**			**G4**					
IQD (000)[1]	**NG[2]**	**CGS[3]**	**CGW [4]**	**NG**	**CGS**	**CGW**	**NG**	**CGS**	**CGW**	**NG**	**CGS**	**CGW**	**NG**	**CGS**	**CGW**
0	36	5	5.4	32	3.2	11.3	44	3.1	12.5	27	9.1	9.1	**33**	4	8
10	2		1	9.6			3.1			9.1			5		1
11-50	31.3	9	25	20.6	3.2	9.6	24.9		9.4	36.2		9.1	27	5	12
51-100	13.6	21	43.9	8	24	35.1	11.4	25	24.9	18.2	18.2	27.1	11	21	**31**
101-150	6.8	30	17	9.7	24.2	17.8		9.4	15.6	9.1	27.3	18.2	8	21	16
151-200		21	2.9	4.8	11.3	14.5	9.3	12.5	15.7				6	13	10
201-300	5.8	13	3.8	9.6	24.2	8	6.2	28.2	9.3		27.1	18.2	6	**22**	8
301-400	2.9	1	1		8	3.2		6.2	3.1				2	4	2
>401	1			4.8	1.6			15.6	9.3		18	18	2	10	12

(b) Community generator

Season	**Ampere/ month**	**G1 (%)**	**G2 (%)**	**G3 (%)**	**G4 (%)**	**Mean**
Winter	0	5.7	11.3	12.5	9.1	9
	1-5	51.4	22.6	12.5	9.1	22
	6-10	36.1	48.4	43.8	27.3	37
	11-15	4.8	12.9	12.5	36.4	16
	16-20	1	4.8	9.4		4
	21-25	1		3.1		1
	26-30			6.3	18.2	11
Summer	0	5.7	11.3	12.5	9.1	8
	1-5	39	19.4	9.4		21
	6-10	46.7	46.8	31.3	18.2	34
	11-15	1	14.5	18.8	54.5	20
	16-20	1.9	6.5	15.6		5
	21-25	4.8	1.6	3.1		2
	26-30	1		9.4	18.2	10

Note: [1] IQD: Iraqi Dinar. [2] NG: national grid, [3] CGS: community generator (monthly payment in summer), and [4] CGW: community generator (monthly payment in winter).

4.3.6 Assessment of occupant satisfaction

After covering all of the questionnaire parts, starting from discussing the main features of the social network of Iraqi society and other social characteristics that can play a significant role in determining the domestic energy use in Iraq, the results of the physical characteristics of houses in Iraq were also discussed to highlight their impact on energy use. This was followed by discussing the answers of questions related to the energy features that can characterise the Iraqi domestic energy system in general. Moreover, the questionnaire attempted to provide a clear image of the indoor thermal environment of these houses based on the occupant's behaviour in terms of operating the cooling and heating systems. The penultimate part of the questionnaire discussed the economic characteristics with respect to energy use to understand the bi-directional relationship between these aspects. The last part of the questionnaire aimed to assess these characteristics from the occupant's point-of-view. This part sought to conclude the questionnaire by obtaining information on the user-satisfaction regarding the following issues: first, the energy cost for both cooling and heating; second, indoor thermal environment aspects in both winter and summer seasons; and finally, the physical characteristics of these houses, which asked the occupants about their satisfaction with the total area, built area, and open area of dwellings and the number of rooms in their houses.

The results of this question, like previous questions, were analysed based on the number of families who live in the same property. The results revealed that around 40% of the participants were dissatisfied with both cost of energy in total and energy cost used for heating in winter, while 35% and 38% of sample strongly disagreed and disagreed with the cost of cooling energy, respectively. Moreover, the thermal behaviour of these houses during winter and summer was assessed by the occupants, where 46% were strongly unsatisfied with indoor environment conditions of their houses in the summer season, while 31% of participants were dissatisfied with the thermal performance of their houses during winter. Living in extended families did not show a significant difference with respects to energy cost and thermal performance of these properties. However, living in extended families was directly proportional to the occupants' disagreement with respect to the total area, built area, open area, and the total number of rooms of houses. The households with one family and two families showed an acceptable satisfaction with these physical aspects, while the families in groups G3 and G4 assessed these aspects as bad and very bad, respectively. Table 4-14 illustrates the participants' views in regard to these points.

Table 4-14. Occupants' satisfaction with different aspects of their home.

parameter	scale	G1[1]	G2[2]	G3[3]	G4[4]	Mean
Total energy cost	Strongly disagree	26	24	31	27	27
	Disagree	**42**	**52**	**47**	18	**40**
	Neither agree nor disagree	13	6.5	9	**36**	16
	Agree	16	16	9	18	15
	Strongly agree	2	2	3		2
Cooling energy cost	Strongly disagree	31	36	**47**	27	**35**
	Disagree	44	44	38	27	**38**
	Neither agree nor disagree	11	7	6	36	15
	Agree	12	13	6	9	10
	Strongly agree	2	2	3		2
Heating energy cost	Strongly disagree	17	23	31	18	22
	Disagree	46	40.3	44	27	**39**
	Neither agree nor disagree	15	13	13	36	19
	Agree	19	23	13	18	18
	Strongly agree	30	2			2
Thermal environment in summer season	Strongly disagree	38	**52**	**60**	**36**	**46**
	Disagree	40	27	31	27	32
	Neither agree nor disagree	10	3	3	27	11
	Agree	12	11	3	10	9
	Strongly agree		7	3		5
Thermal environment in winter season	Strongly disagree	13	23	22	27	21
	Disagree	30	36	22	36	31
	Neither agree nor disagree	27	15	25	27	23
	Agree	30	24	28	9	23
	Strongly agree	1	3	3		2
Total area	Strongly disagree	15	21	25	**27**	22
	Disagree	14	13	22	**27**	19
	Neither agree nor disagree	9	2	**28**	18	14
	Agree	**50**	**48**	16	18	**33**
	Strongly agree	12	16	9	9	12
Total built area	Strongly disagree	17	21	**31**	**27**	24
	Disagree	15	15	22	**27**	20
	Neither agree nor disagree	11	8	19	18	14
	Agree	**46**	**42**	22	18	**32**
	Strongly agree	11	15	6	9	10
Open area	Strongly disagree	22	24	**34**	**36**	**29**
	Disagree	29	**29**	19	27	26
	Neither agree nor disagree	11	7	19	27	16
	Agree	**31**	27	22	9	22
	Strongly agree	9	13	6		9
Rooms number	Strongly disagree	17	23	**31**	27	24
	Disagree	20	19	19	**46**	26
	Neither agree nor disagree	7	13	16	27	14
	Agree	**47**	**31**	**31**		**36**
	Strongly agree	10	15	3		9

Notes: [1] G1: single-family in one house, [2] G2: two families in one house, [3] G3: three families in one house, and [4] G4: four families in one house.

4.4 Questionnaire results and research problem

As presented in earlier chapters, the energy sector in Iraq has been suffering from serious problems regarding generation and supply, which have inversely influenced other sectors—including the residential sector. The current research focuses on the deficit of electricity supply in domestic buildings and the factors that hinder households to meet their actual demand, and thus how well the indoor thermal environment of these dwellings responded to the current situation of energy supply. Therefore, a comprehensive survey was used as the first step of a mixed methodology of research to highlight these issues from the public's point-of-view. This section will discuss how the questionnaire's results confirmed the problem that was raised by this research, which can promote the significance of this research. Moreover, the questionnaire was a first step of the sociological approach that was used in this study and it paved the way to the next steps of the research method (i.e. case study and monitoring) to meet the research aim and objectives.

A number of factors that directly link to the energy problem in Iraq's domestic buildings have been identified by carrying out this questionnaire. These facts are discussed based on their importance in the trajectory of this search, including energy use, the environmental implications, social-economic barriers, and physical characteristics. Thus, this section will be divided into four main categories, mirroring the formulated research questions:

- **Energy use**

As shown in subsection 4.3.3, the electricity supplied from the NG constituted the primary energy source for the main domestic activities, including heating water, lighting, and cooling during summer months. Meanwhile, it was an alternative energy source for space heating in winter. However, the frequent outages have imposed the households to use CGs as a replacement electricity source for lighting and cooling. Based on these results, the following question could be raised: To what extent have the CGs succeeded in covering the lack of electricity supply from NG and meet the household's actual demand for electricity? Especially after recognising that this replacement source is limited in terms of supply capacity and operation periods. Furthermore, CG, for most families, is a costly energy supply source compared with NG. The answer to this question will be discussed in Chapter 6, which focuses on the estimated suppressed energy demand.

Another relevant issue revealed through conducting the questionnaire is that the majority of respondents use air conditioners and evaporative coolers as a main method for space cooling in their homes. Additionally, the operating period of these cooling systems exceeded 20 hours/day during the summer seasons, which can adversely affect the amount of energy consumed or required in a home. Therefore, it is important to create solutions that reduce the energy demand for cooling by using, such as efficient insulation or intervening penetration of solar energy.

- **Energy use and indoor thermal environment**

The indoor thermal environment of these dwellings was assessed by the occupants as bad in winter and the worst during hot summer. This can be attributed to the following factors: inefficient thermal behaviour of domestic buildings against the AT, the lack of energy supply from NG, and the insufficient and expensive energy supply from the CGs. These factors have all inversely influenced the indoor thermal environment.

- **Energy use cost**

The outlook of electricity use refers to an expected increase in electricity demand due to the expected income growth in Iraq. However, analysing the economic impacts of residential energy use in Iraq showed that there was a high dependency on CGs, given the increase of frequent blackout hours in electricity supply from the NG. This dependency has imposed more economic burdens on households, especially in extreme summer periods where the demand reaches its peak and results in more electricity outages. This is why most of the participants reported high dissatisfaction with the energy cost for cooling in summer.

- **Energy use and the social environment**

Living in extended families means that there is an increase in the total number of people living in a housing unit, which causes an increase in energy use (as indicated by previous studies). However, this aspect is beyond the scope of the current research and it is recommended that further research should be conducted in this area.

- **Energy use and the physical environment**

The majority of the surveyed families live in a single-family house, while 73% of them live in a townhouse (terraced) houses with two storeys. Energy use in domestic buildings in Iraq can be linked to the evolution of the construction system and materials that are used. The conventional construction method and the type of materials used have not experienced a remarkable change over the last 75 years or more. The results regarding this aspect showed that there is low use of insulation solutions within the house envelope or its components. Consequently, the prevailing physical characteristics of houses play a key role in increasing energy use, especially for cooling in the summer months. These results also confirm that there is a lack of awareness concerning energy issues, such as energy efficiency and energy saving.

4.5 Summary

This chapter has outlined the results of the data collected during the comprehensive survey from the occupants of their dwellings in terms of their energy use. The current energy supply context and the basic domestic uses of energy, the relationship of energy use to the key factors which lead to high energy use were discussed. Moreover, the barriers that may hinder the individuals to meet their actual energy – in the form of electricity– demand, and thus ensure the indoor thermal environment were examined. The results were first discussed individually to provide an overview of energy use in Iraq's domestic buildings, as well as to answer the research question: "How do the social, economic and physical characteristics influence the energy use of Iraq's dwellings?" The following chapters will describe the sequence of the experimental procedures of the research project, where the monitoring equipment and devices were installed during the site visits to the selected case studies and conducting the interviews. The measured data will be presented and discussed in Chapters 6 and 7, based on their priorities in achieving the research aim and objectives.

Chapter 5: Case studies: site visit-interviews

This chapter represents the starting point of the fieldwork. It analyses the data collected from existing homes, which were selected as case studies for monitoring in different locations across Baghdad. This was achieved by describing the results of the individual site visits to these representative dwellings and then interviewing the dweller of each case study separately. This chapter outlines the results of the data that was collected during the subjective site visits and structured interviews. The analysis of the results in this chapter first aims to enhance the comprehensive questionnaire's results to achieve the proposed aim and objectives in studying the factors that influence and affect energy use. Second, the results form the basis of extraction and selection of the representative case studies, which will be used later to conduct the monitoring process for both energy use and indoor thermal environment. This chapter is structured into five main sections: the demographic details of the respondents, the background of the households, the dwellings' physical description, the energy use background, and the environmental and economic dimensions of the current situation of energy use in these selected pilot houses. Finally, a summary is given.

5.1 Background

Key information regarding energy use and the factors that influence it were collected by a questionnaire, as discussed in the previous chapter. However, the research aim of this study is reliant upon extensive data collection, it was, therefore, necessary to study the energy use and its environmental implications in some occupied dwellings. In the first stage of the sociological approach that was adopted in this study, it was necessary to identify those factors that influence energy use in the domestic sector in Iraq. This approach required a comprehensive questionnaire. However, to identify the actual energy use and its influence on indoor environment conditions in Iraq's residential buildings, it was necessary to pursue an additional approach. Consequently, a site visit and interview were added as part of the case study and sociological approaches to meet the other objectives and answer some of the research questions.

Understanding how these households use energy can help to enhance their energy efficiency. Specifically, to avoid wasting energy in homes, the main problem is that the occupants usually ignore the need to control their energy use while trying to achieve a comfortable thermal environment, especially in the summer months in hot-arid climatic regions such as Iraq. The occupants are partly responsible for consuming extra energy to operate their homes. Therefore, one objective of this research was to deploy a tested monitoring scheme in the case study groups to generate effective raw data of their energy use and environmental conditions to facilitate in-depth analysis and create accurate figures. The other aim of conducting monitoring is to obtain a clearer understanding of the mixed-method approach that can be used to collect data on both energy use and environmental measurements. An application test of the selected monitoring equipment and configured systems was proposed in this research, which represents the third aim of implementing the monitoring approach in this research. Chapter 3 focused on the selection and configuration of monitoring systems and devices. Case studies were justified as an appropriate research method in Chapter 3, and their distribution and layout description were also discussed. Chapter 4 provided an overview of energy use from the occupants' perspectives and it paved the way to identify the key selection criteria for the case studies that were used later in the monitoring test. This present chapter builds on these results by introducing the extracted case study houses where the selected equipment for monitoring was installed in specific occupied zones in the monitored houses. The actual deployment of the selected devices in the case study homes was followed by the pre-processing of the monitoring's raw data. Consequently, the collected results from the processing are analysed and evaluated in Chapters 6,7.

5.2 Case studies' socio-economic, physical characteristics and energy use

The results acquired from the formal and structured interviews during the individual site visits for each case study home will be presented in the following sub-sections. The data at this stage include: (i) the demographic information regarding the dwellers, (ii) the physical description of case studies, (iii) the dwellings' energy use, (iv) the operational cost of energy use in these dwellings, (v) the households' attempts to provide the acceptable thermal level in their homes, and (vi) the dwellers' satisfaction regarding the (ii, iii, iv, v) above aspects.

5.2.1 Households composition (Demographic information)

From the social aspect, choosing these houses was expected to represent the biggest challenge because this selection was expected to cover and represent the main characteristics of the whole of Iraqi society. As was discussed in subsection 4.3.1, 80% of surveyed houses are occupied by either a single-family (50%) or two families (30%). Therefore, the houses were selected on the basis that each should contain either one family or two families. Following this selection, three case studies are one family households and the other four case studies are extended households with two families. Regarding the total number of occupants, the average of the total number of occupants for all case studies was seven people in each household. However, another question has been added to determine the factors leading to high energy use in relation to the number of occupants (household size). The actual number of occupants varied among the case studies, ranging from 2 to 11 people in each household. The number of males ranged from one to four males, with an average of three males. The number of females was between one to eight, with an average of four females. In addition, all of the households of the selected case studies are headed by men, who helped to provide a clear image of their families' profiles during the individual interviews with each family member. The age of the residents ranged from 1 to more than 70 years old, excluding the range between 51 to 60 years old. Another social aspect that was discussed with these families was the employment status of the family members. The outcomes of this question showed that six of seven households have from two to three employed members, while the case study (H1) has one unemployed person. Six of the selected families have housewives, ranging from one to three housewives, while in the case study (H6) the two parents are employed. There were between one to four students in six case studies, and the only retired person was in the case study (H5). Case studies (H4) and (H7) have children of preschool age, with two and three children, respectively. The last question in the demographic part of the interviews surveyed the time that the family had been living in the accommodation. The results are two families had lived 1 to 5 years in their house, two families had lived 6 to 10 years in their house, two families had lived 11 to 15 years in their house, and just one family has been lived in their dwelling for over 35 years. Table 5-1 provides the demographic details of each case study. Finally, five of the households owned their homes and just two of case studies are renting their swellings.

5.2.2 Physical characteristics (used rooms)

The second part of the structured interviews asked about the physical environment and design parameters that influence both energy use and indoor thermal environment. The findings are summarised in Table 5-2. As mentioned in subsection 3.3.6, all of the dwellings in the case studies were attached single-family houses with two stories, built between 1970 to 2014, and the length of occupation ranged from 3 to 33 years. The floor areas of the accommodation ranged from 101 to 300 m^2. Both built and floor area varied among the selected case studies. Case study (H2) has the smallest built area with 85 m^2, while the case study (H7) has the smallest floor area with 112 m^2. In general, the average of built area and floor area of all the selected case studies were 151 m^2 and 250 m^2, respectively. In the same context, the questionnaire results for the total number of bedrooms are directly proportional to the number of family members.

Table 5-1. Demographic characteristics of the monitored dwellings.

Parameter		**Case**							**Mean**
Name	**Range**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	
Demographic characteristics									
Number of households		2	1	2	2	1	1	2	
Number of occupants		9	4	7	7	2	6	11	**7**
Gender (-)	Male	4[1]	2	3	4	1	3	3	**3**
	Female	5	2	4	3	1	3	8	**4**
Age (years)	1-10	1[1]			2		2	4	**2**
	11-20	2		3			2	1	**2**
	21-30	1	2		2				**2**
	31-40	3			1			3	**2**
	41-50	1		3			2	2	**2**
	51-60								
	61-70		2		2	2			**2**
	>71	1		1				1	**1**
Employment status (-)	Employed	3	2	3	3		2	3	
	Unemployed	1							
	Housewife	2	1	1	1	1		3	
	Student	3	1	3	1		4	2	
	Retired					1			
	Preschool				2			3	
Time lived in the property (year)	1-5					√	√		
	6-10		√		√				
	11-15	√		√					
	31-35							√	
Note: [1] Number of people									

However, the interviews showed that four of the case studies have between two to three bedrooms that are not used by the families. This emphasizes that the size of the property, the number of rooms and their function depends on the family's income and social status.

According to (Al-dossary, 2015), built houses are regarded as contemporary houses (i.e. not more than 30 years old). However, the questionnaire results showed that around 70% of the surveyed houses were built between 1980 and 2015, and around 15% of the sample was built between 1979 and pre-1960. As expected, the construction systems and materials used have not experienced any significant change over the last 70 years. Therefore, the selection of case studies to be employed as representative homes for monitoring should match the questionnaire results.

Table 5-2. Physical characteristics of the monitored dwellings.

Parameter		Case						
Name	**Range**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**
Physical characteristics								
Built year (-)	2011-Present						√	
	2006-2010				√			
	2001-2005	√						
	1991-1995			√				
	1981-1985		√					√
	1971-1975					√		
Land area (m^2)	101-175		√					
	176-200			√		√		
	151-175							√
	276-300	√			√		√	
Built area (m^2)	85-207 (mean 151 m^2)	191	85	153	199	115	207	106
Floor area (m^2)	**112-410 (mean 249 m^2)**	**357**	**145**	**205**	**285**	**230**	**410**	**112**
Orientation (-)		NE	SW	S	SW	E	SW	W
Bedrooms in use (#)		4	3	3	3	1	5	4
Bedrooms not in use (#)		2		3	3	2		
Structural characteristics								
Walls	Brick	√	√	√	√	√	√	√
Ceilings	Reinforced concrete casting	√	√	√	√	√	√	√
External Walls	Cement rendering	√	√	√	√	√		√
	Ceramic tiles				√			
	Stone			√			√	
Internal Walls	Plaster	√	√	√	√	√	√	√
	Ceramic tiles	√	√	√	√	√	√	√
Floors	Mosaic cement tiles	√		√	√	√		√
	Marble						√	
	Ceramic tiles	√	√	√				
Windows	Frame: steel	√	√	√	√	√	√	√
	Pane: Single glazing	√	√	√	√	√	√	√
Doors	Frame: steel	√	√	√	√	√	√	√
	Frame: aluminium				√			√
	timber	√	√	√	√	√	√	√
Insulated elements	Roof	√	√	√	√	√	√	√

The construction materials that are used are mainly brick for walls and reinforced concrete for ceilings and roofs. Cement rendering is used for external finishing, while the internal walls are finished with plaster. Ceramic tiles were used to cover the internal faces of the kitchens and bathrooms. The frames of the windows in all of the case studies were made from steel and their panes were single glazed, while both timber and steel were used for doors. The final questions in this part of the interview asked about the insulation solutions that are available and which are used. The results showed that in all of the pilot houses, the roofs were the only insulated elements.

5.2.3 Energy use

A comprehensive study of the energy use in the selected case studies also requires data regarding: (i) the energy sources used to implement the main domestic activities and end-use in the houses used for monitoring, (ii) the main cooling and heating methods used by the residents, and (iii) the main methods used by the residents for cooling and heating the spaces selected for the installation of the environmental monitoring devices. Information acquired from the formal interviews during the site visits to the pilot houses revealed that the residents in all case studies relied on electricity from the NG for water heating. For lighting, four of seven families consider electricity from the NG as a primary energy source, while the other three families used electricity from CGs as a primary energy source for lighting. Kerosene was used as the main energy source to heat the home spaces in four case studies, while two case studies relied on electricity from NG as the main source for heating in winter and the CGs were used as the main energy source for heating in just one case study. In all case studies, liquid gas cylinder was predominantly used as the main energy source for cooking. Interestingly, the primary energy source used for cooling the home was NG in four case studies, while the other three case studies used electricity from CGs for cooling. It is worth noting that none of the participated households uses a battery or electric vehicle to store electricity from NG, when available, to use later during blackouts. Table 5-3 (a) illustrates the primary and secondary energy sources used in the monitored homes for the main daily activities and end-use of energy.

Based on the residents' needs and priorities, cooling and heating were the main end-use of energy in the monitored houses. Therefore, both the cooling and the heating mechanisms used by these households were discussed during the interviews. A summary of the results is given in Table 5-3 (b), which correspond with related results of the questionnaire in subsection 4.3.3. Mechanical ventilation was operated in all of the pilot houses to cool spaces. Meanwhile, air conditioner units and evaporative coolers were used in some rooms of the house. All of the rooms are covered by suspended ceilings, which are generally used with natural ventilation during the intermediate seasons (spring and autumn). The discussion with dwellers regarding their use of air conditioner units and/or evaporative coolers revealed that the alternate use of air conditioner units and evaporative coolers is basically reliant on the energy supply source. In more detail, air conditioner units were used when electricity from the NG is available, while evaporative coolers are used for cooling when the house receives electricity from the local CGs.

Table 5-3. (a) Energy sources against activities and end-use in the monitored houses. (b) The main cooling and heating methods used by occupants.

Parameter		**Case**						
Name	**parameter**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**
(a) Energy sources								
Primary energy source	Hot water	NG[1]	NG	NG	NG	NG	NG	NG
	Lighting	NG	NG	CG[2]	CG	NG	NG	CG
	Heating	K[3]	K	K	CG	NG	NG	K
	Cooling	NG	NG	CG	CG	NG	NG	CG
	Cooking	LGC	LGC	LGC[4]	LGC	LGC	LGC	LGC
Secondary energy source	Hot water							
	Lighting	CG	CG	NG	NG	CG	CG	NG
	Heating	NG	NG		K	NG	CG	CG
	Cooling	CG	CG	NG	NG	NG	CG	NG
	Cooking							
(b) Cooling and heating methods used								
Method of cooling	Air conditioner	√	√	√	√	√	√	√
	Evaporative cooler	√	√	√	√	√		√
	Fan (ceiling/pedestal)	√	√	√	√	√	√	√
	Natural ventilation	√	√	√	√			√
Method of Heating	Air conditioner					√	√	√
	Oil heater	√	√	√	√	√		√
	Electric heater	√			√	√		√
	Gas heater							
Notes: [1] NG: national grid, [2] CG: community generator, [3] K: Kerosene, and [4] LGC: liquid gas cylinder.								

Regarding the heating mechanism, oil heaters were the main heating method for just two households, while the air conditioners were used by one household as the main heating method. Given that this question was designed to allow for more than one answer, four of the targeted houses reported that an electric heater was used in addition to an oil heater to heat spaces, while an air conditioner used in two houses as an additional heating method to oil heaters. The use of both air conditioners and/or electric heaters basically depended on the availability of electricity from the NG.

Room use was discussed during the interviews to establish a particular user profile for each room in the property. The resulting user profiles were revealed to be almost similar in terms of the rooms' function, the usage occupancy of the rooms (duration and equipment) depended on the activity of the house members and their lifestyle. Subsection 3.3.8 illustrates the selection of the specific rooms in the case studies to conduct the monitoring test. The living room, kitchen and bedroom were selected for the environmental monitoring equipment to record the energy-related environmental behaviour. The interviews included a question about the specific methods that were used to cool or heat the selected spaces because they represent the spaces that were most usually occupied by the residents during the day. Table 5-4 shows how the living room, kitchen and bedroom are heated or cooled over the year to provide the indoor thermal environment that was excepted by the dwellers. Regarding cooling, ceiling fans were found in all monitored spaces in all case studies. Air conditioners and evaporative coolers were only found in living rooms and bedrooms in all case studies except H6, where the household just relied on air conditioners for cooling. Natural ventilation was mostly used in kitchens in all case studies. Oil heaters were the main heating methods for six case studies, where the air conditioners in the case study (H6) as well are used for heating the spaces in this house. In three case studies, electric heaters were used as an alternative method by the households to provide heating in all of the monitored spaces.

Table 5-4. Cooling and heating methods used in monitored spaces for each use case.

Case	**Monitored space**	**Cooling method**				**Heating method**		
		Air conditioner	**Evaporative cooler**	**Ceiling, standing fan**	**Natural ventilation**	**Air conditioner**	**Oil heater**	**Electric heater**
H1	LR[1]	√	√	√			√	√
	BR[2]	√	√	√			√	
	KS[3]			√	√		√	
H2	LR	√	√	√	√		√	√
	BR	√	√	√			√	√
	KS			√	√		√	√
H3	LR	√	√	√			√	
	BR		√	√			√	
	KS			√	√		√	
H4	LR	√	√	√	√	√	√	√
	BR	√	√	√		√	√	√
	KS			√	√	√	√	√
H5	LR	√	√	√		√	√	√
	BR	√	√	√		√	√	√
	KS			√	√		√	√
H6	LR	√		√		√		
	BR	√		√		√		
	KS			√	√	√		
H7	LR	√	√	√		√	√	√
	BR	√	√	√		√		
	KS			√	√			
Note: Notes: [1]LR: Living room, [2]BR: Bedroom, and [3]KS: Kitchen space.								

5.2.4 Environmental system

After investigating the main energy sources and the methods used for cooling and heating, the next part will show how the selected case studies operate during the year in terms of the occupants. This information was obtained by means of one-to-one interviews with the occupants in each selected case. With regards to the amount of electricity consumed, the householder stated that they occupied and cooled almost all rooms during summer. They stated in the interviews that they started to operate the cooling system from April and continued until October during the daytime, and from March to October during the night-time. It is evident from Table 5-5 that the time of the year when people are consuming the most energy is from June until August. During the cool season months, the mean duration of using cooling systems in the studied dwellings was more than 20 hours/day. In April, May, and September the duration of cooling system use varied among the case studies, ranging from 6 to 10 hours/day to 20 to 24 hours/day. Regarding the mean duration of using heating systems in these dwellings, it is clear from the results that the heating systems are only used in the winter months (i.e. December, January, and February) with a maximum average duration of 20 hours/day in some cases, while in general, the use ranged between 6 to 10 hours/day to 11 to 15 hours/day.

5.2.5 Economic dimensions of energy use

To obtain a clear image regarding the energy use in the representative houses used in this study, the economic dimensions of the energy used (in all its form) were explored in the site visit and in the interviews with the households. The first question asked about the share of the energy expenditure of the total monthly income for each household. The results showed a variation in the amount of expenditure among the case studies, which ranged from 6 to 10% of the total household’s income to 31 to 35%. This variation reflects the disparities in household income in general and their actual needs for energy in its different forms. For more detail in this aspect, the households were asked to detail the overall expenditure based on the energy form and source. For example, the monthly cost of using liquid gas cylinders for cooking was the lowest cost among other energy sources. The cost of consuming liquid gas cylinder ranged between 7,000 IQD (£4.6) and 28,000 IQD (£18.5), with mean 16,000 IQD (£10.57). As mentioned in the previous sections, kerosene is mainly used for heating in the winter months (Jan, Feb, and Dec). The monthly expenditure for kerosene came in second place in terms of the expenditure level, where the mean of buying kerosene among these seven houses was 43,000 IQD (£28.4). The minimum expenditure was 25,000 IQD (£16.5) in the case study (H6) and the maximum was in the case study (H2) with 65,000 IQD (£43).

Table 5-5. Duration of daily use of cooling and heating systems. The number of hours represents the average duration in a particular month, as reported by the respondents.

Case	Winter			Spring			Summer			Autumn		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Cooling system												
H1					1-5	6-10	20-24	20-24	20-24	6-10	1-5	1-5
H2						11-15	20-24	20-24	20-24	16-20		
H3					20-24	20-24	20-24	20-24	20-24	20-24	20-24	
H4					1-5	20-24	20-24	20-24	20-24	20-24	20-24	
H5					6-10	11-15	20-24	20-24	20-24	16-20	6-10	
H6				1-5	6-10	11-15	20-24	20-24	20-24	11-15	11-15	
H7					1-5	6-10	11-15	16-20	16-20	16-20	11-15	1-5
Heating system												
H1	16-20	16-20	16-20	1-5								
H2	6-10	6-10	6-10									
H3	16-20	16-20	16-20	6 -10								
H4	16-20	16-20	16-20	11-15								
H5	1-5	1-5	1-5	1-5								
H6	11-15	11-15	11-15									
H7	6 -10	6-10	6-10	1-5								

The third expenditure that discussed with residents was the expenditure for electricity from both sources (NG and the local CGs). As expected, the total payment of electricity was the highest compared to previous expenditures. However, the results of electricity payments showed a significant variation based on the supply sources. The cost of electricity from the NG was at the end of the electricity expenditure list. The reasons behind that are that, first, NG-based electricity is heavily subsidised by the local government and is relatively cheap compared with electricity sourced from private and CGs. Second, the payment discipline for NG-based electricity is relatively weak, where we can see that there are two case studies they do not pay for electricity from NG and the others pay in different durations, ranging from 1 month as in case study (H5) and 3 months in case studies (H2 and H6). The monthly payment of the CG-based electricity during winter was higher than the payment for NG-based electricity if the amount of electricity from both sources is taken into consideration. When the households were asked about their monthly electricity payment of CG during the summer season, all of the participants replied that during the summertime their expenditure is often the highest and ranged between 90,000 IQD (£60) to 450,000 IQD (£296) per month, this expenditure is basically for cooling the spaces. Despite the fact that the cost of CG-based electricity was the highest, the amount of electricity from this supply source was limited—the maximum limits of electricity were 12 and 18 amperes in winter and summer, respectively. Table 5-6 summarises these results.

Table 5-6. Energy expenditure of the monitored dwellings.

Parameter	Case							Mean	St.D
	H1	H2	H3	H4	H5	H6	H7		
Energy expenditure by source (IQD-000[1]) (monthly)									
National grid		120[2]	30[3]		160[4]	400[5]	18[7]	-	-
Community grid / winter	140	50	75	180	60	150	70	103	52
Community grid/ summer	175	125	125	450	125	250	90	191	125
Liquefied gas cylinder	21	14	16	15	7	15	28	16	6.5
Kerosene	60	65	50	35	30	25	40	43	15
Share of household's monthly income (%)	31-35	16-20	6-10	26-30	26-30	31-35	21-25	-	-
Note: [1] IQD: Iraqi Dinar, [2] The payment is for 3 months, [3] The payment is for 2 months, [4] The payment is for 1 month, [5] The payment is for 2 months, [6] The payment is for 3 months, [7] The payment is for 1 month.									

5.2.6 Assessment of occupant satisfaction

The individual interviews with the households concluded by asking to what extent the following features are satisfactory for the households: (i) the indoor thermal environment; (ii) energy expenditure; and (iii) physical characteristics. In general, a study of the energy aspect involves asking the respondents about their opinions about the indoor thermal environment. For example, asking if the occupants like a certain feature or not can help to determine their satisfaction or dissatisfaction with the environment. In the interviews, the environment features of the dwellings included the daylight in rooms, where almost all residents in the selected case studies were satisfied with this indoor thermal environment. In addition, it was found that most of the occupants were dissatisfied with the indoor thermal environment of their dwellings during winter. The thermal environment of the respondents' houses during summer was assessed as the worst thermal environment, their answers ranged between very dissatisfied and dissatisfied. Thanks in part to the poor level of thermal environment in these houses in summer, the total energy payment for cooling was high in most of the targeted residents. The assessment was the same for the total energy payment for heating and the total energy expenditure.

The residents' views of the physical characteristics varied (i.e. total area, total built area, open area, and rooms number). In some case studies, the residents were satisfied with these features, while others were dissatisfied. This can be explained by the fact that the size of the property and its number of rooms depends on the family's income and social status.

Table 5-7 presents the details of the occupants' satisfaction with different aspects of their dwellings.

Table 5-7. The occupants' satisfaction of indoor thermal environment, energy expenditure and physical aspects.

Category	Parameter	Response[1] by case							Mean
		H1	H2	H3	H4	H5	H6	H7	
Indoor thermal environment	Thermal environment during summer	1	1	1	1	2	2	1	1
	Thermal environment during winter	4	2	1	1	4	4	1	2
	Daylight in rooms	4	4	4	5	4	3	2	4
Energy expenditure	Cooling	1	2	4	1	2	1	1	2
	Heating	1	3	4	1	2	2	2	2
	Total	1	2	4	1	2	2	1	2
Physical characteristics	Total area	4	4	1	5	4	4	1	3
	Total built area	4	3	4	5	4	4	1	4
	Open area	4	1	1	4	4	2	1	2
	Rooms number	4	4	4	5	2	4	1	3
Note: [1] 1: Very dissatisfied, 2: Dissatisfied, 3: Neither satisfied nor dissatisfied, 4: Satisfied, 5: Very satisfied									

5.3 Summary

This chapter represents the second and final part of the implemented sociological approach. Together with the questionnaire, the site visit and interviews paved the way for the monitoring approach by providing an extensive database of energy use and its related factors.

Regarding the energy use, the interview results matched those of the questionnaire. In particular, they indicate that all of the selected houses used energy in the form of electricity as the main energy source for most daily activities (i.e. heating water, lighting, and cooling) and as a secondary energy source after kerosene to heat these spaces. However, both water and space heating tended to be used in the winter months (i.e. 3 months). The main concern for households was how to maintain an acceptable level of the indoor thermal environment when they are using cooling, which lasts around 6 months rather than the 3 months of the summer season. In addition, the long period when the cooling systems were used results in increased energy demand, especially in summer where the cooling systems were in use for more than 20 hours per day. Similarly, the use of air conditioners for cooling was considered to be energy-consuming, increased the energy demand, and thus led to frequent blackout hours during the day. The significant reliance on local CGs represented the households' attempts to meet their actual demand. However, using this alternative supply source is fraught with many challenges, such as the limited supply capacity and operation periods and the high cost in comparison with the electricity from NG (especially in summer, where the price of electricity from CGs is significantly higher). The third challenge was the inability to provide the required level of the indoor thermal environment during summer, where the residents expressed their sense of dissatisfaction with that aspect.

The physical characteristics of the selected case studies also matched with the questionnaire results in terms of this aspect. Although the selected houses were built in different periods, starting from 1971 and running through to 2015, the construction method in all case studies followed the same system and used almost the same materials. The case study region is characterised by its hot-arid climate, which required appropriate thermal insulation to maintain the indoor thermal environment in the building for longer periods of time without the need to use a cooling system, especially during the periods between the seasons. However, it was apparent from the results that the application of these insulation strategies has witnessed little improvement during the periods of construction. The roofs were the only insulated elements, which used a traditional insulation solution[7]. These results reveal that the residents lack awareness about the importance of energy conservation in buildings, such as by adopting optimal construction strategies. Moreover, the energy use patterns (in kWh per capita, square meter, and year) were one of the main objectives of this study and, therefore, one of the main targets of the interviews was to observe the building layouts and where necessary to establish the floor area, which is important to identify the actual level of energy use patterns (in kWh per square meter). The measurements of the floor plans of each case study were taken while carrying out the individual interviews. The total number of occupants to quantify the energy use per capita was discussed as well during the interviews.

The following chapter will discuss the results of the first part of the monitoring process in terms of energy use and suppressed and actual demand.

[7] The traditional insulation solutions consist of the following materials, arranged from bottom to top (waterproof layer after the reinforced concrete slap, polyethylene layer, polystyrene (Styroboard), polyethylene layer, clean soil, clean sand, and concrete tiles) (Najim & Fadhil, 2015).

Chapter 6: Energy use and suppressed energy demand

Chapter 3 introduced the monitoring systems and equipment selection and the deployment of experimental work in the existent and occupied case study homes. Chapters 4 and 5 highlighted the results of the employed sociological approach in this study. This chapter discusses the results of the first parameter's category of the monitored approach, which is the measured data of energy use. This chapter comprises four sections: the first section presents the results of the measured energy use; the second section is devoted to discussing the estimated energy suppressed demand based on the results of the first part in this chapter; in the third section, the actual energy demand is estimated by using the results of both the total energy use and the estimated suppressed energy demand. In the fourth section, the average energy use and the actual energy demand after adding the estimated energy suppressed energy demand of both floor area and capita are compared with some benchmarks in neighbouring countries. A summary of the key remarks and contributions of this chapter is given at the end of the chapter.

6.1 Background

In the current research, the analysis of energy use monitoring data included evaluating energy use, estimating energy suppressed demand, and the actual energy demand. In light of these requirements, the main purpose of this stage is to address the households' energy use in their homes with exciting energy suppressing demand. This aim is achieved through the following main objectives (see Section 1.3):

- Investigate the energy issue (supply sources and daily supply scenarios) of existing representative homes in Baghdad city,
- Define the energy use in the homes in kWh for different scales (hourly, daily, seasonally, per capita, per square meter), and
- Estimate the suppressed energy demand and then the actual energy demand in these selected homes.

Achieving these objectives requires the following steps to be observed, starting from the case study selection, installing the monitoring equipment, and ending with receiving monitoring data for analysis. The acquired raw data from field measurements were then subjected to pre-processing prior to being used in the subsequent analyses. All of these stages were discussed in Chapter 3, while this chapter is devoted to discussing the final findings.

6.2 Energy supply

Receiving electric energy from two different sources in terms of supply capacity and period (i.e. NG and CG) may affect the total energy consumed, thus impacting on the possibility to meet the user's actual demand. According to previous associated studies, suppressed demand can be estimated as a percentage of the difference between what is actually consumed and the desired (unmet) demand (LDC Environment Centre, 2013). Therefore, in the current study, desired demand refers to the consumed energy when the energy from the NG is available, while both outages and the energy use based on the supplied energy from CG represent the period when the energy demand is suppressed.

Since the aim of this study is reliant upon extensive data collection, the monitoring process started in January 2017 and the last reading was received at the end of July 2018. Table 6-1 (a) shows the horizon of the monitoring process, ranging from 472 and 553 days, with an average of 529 days. Hourly, the monitoring horizon was between 10,248 and 13,212 hours, with an average of 12,683 hours. The data measured during the monitoring duration were analysed on the basis of supply sources and scenarios. The following subsections will examine the current situation of electric energy supply and how it affects the energy use, and thereby the energy suppressed demand amount and its temporal variation.

6.2.1 Energy supply sources

The measurements captured during the monitoring process, which lasted around 19 months, were normalised to extract the total energy use for one year. This analytical process will help to compare the results with the benchmarks. Another benefit of normalising the data was helping to reveal the contribution (in percentage) of both the NG and the CGs to the total energy supply, in tandem with the proportions of outages that occurred during the same period of monitoring. The findings of the total annual energy supplied show that although the availability of energy from the NG varied significantly among the monitored houses, NG represents the main and uninhibited supply source of energy for households—its contribution was 51% to the total annual energy supplied. This variation of energy supply from NG among the case studies can explain the supply disparity in terms of time not capacity among residential sectors in Baghdad. This variation cast its shadow on the contribution of CGs to the total annual energy supply for each case study, and thus the blackout duration. The share of both the energy supplied from CG and the blackout duration in the total annual energy supplied were 22% and 27%, respectively.

Since the concern of the current study is the temporal variability of energy supply and use, the total energy supply was analysed seasonally. The results of the seasonal analysis of energy supply reveal that the dependency on CGs in summer was higher than in other seasons, with around 33% (followed by 24% in winter). This high dependency can be attributed to the deficit of the energy supply from NG to meet an exceptional growing demand during summer months because of the significant increase of the AT, which will be discussed in the next chapter. In addition, the energy supply from NG showed a decrease in the summer season. Then, the supply patterns of NG during the year for each case study reflect the instability of energy supply from this source throughout the year. Table 6-1 (b) summarises the energy supply by source and outage.

Providing an accurate hourly and daily estimation of energy use required an investigation of the main daily scenarios. Meanwhile, the contribution of both NG and CGs in each scenario assists in developing an understanding of hourly and daily energy use, as discussed in the following section.

6.2.2 Energy supply scenarios

Analysis of hourly and daily electric energy supply has highlighted the main daily energy supply scenarios that the households observed over the monitoring period. The reliance on two different energy supply sources, coupled with outages hours that occur during the day contributed to four main daily energy supply scenarios. These four scenarios are discussed based on the suppressed actual energy demand. In the first scenario, which is the best and optimal scenario of electricity supply, the households receive energy for 24 hours per day from NG. Given that the NG is an uninhibited supply source—where the there is no a specific limit of electricity sourced from NG per household— and is heavily subsidised by the Government, the consumed energy in this scenario represents the desired energy use for the households and its amount is equal to the actual demand. However, the proportion of this scenario within the total energy supply over the year was the lowest compared to the other scenarios—its proportion was just 12%. Seasonally, this scenario also showed the lowest proportion compared to other scenarios in winter, spring, and autumn, with 15%, 15%, and 16%, respectively. Interestingly, none of the households in the monitored houses was able to receive energy from the NG for 24 hours per day in all summer days, while its proportion in this season was zero for all case studies. This situation is a reflection of the NG's inability to provide the required energy in this season—which is characterised as a hot dry summer—where the energy demand reaches its peak to keep up with the exceptional demand for cooling to maintain the indoor thermal environment. This may indicate that the suppressed demand increases in summer.

Table 6-1. Monitoring horizon and the seasonal electric energy supply with the outage.

Category	Sub-category	Case							Mean
		H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	
(a) Monitoring horizon and electricity supply with outages for each case study from Jan 2017 to Aug 2018									
Monitoring horizon (#)	Days	551	552	553	535	546	538	427[1]	529
	Hours	13197	13212	13269	12840	13101	12912	10248	12683
(b) Electricity supply by source and outages (%)									
Annual (Jan–Dec)	NG[2]	65	**65**	34	**56**	**53**	34	**50**	51
	CG[3]	26	28	30	10	29	28	1	22
	Outages	9	7	**36**	34	18	**38**	49	27
Winter (Dec–Feb)	NG	57	**77**	31	**91**	**47**	38	43	55
	CG	**37**	20	**38**	4	26	**41**	1	24
	Outages	6	3	31	5	27	21	**56**	21
Spring (Mar–May)	NG	66	**70**	**56**	41	**56**	10	43	49
	CG	27	12	18	5	18	26	1	15
	Outages	7	18	26	**54**	27	**64**	**56**	36
Summer (June–Aug)	NG	52	40	19	30	39	27	49	37
	CG	29	**55**	34	26	**52**	**37**	0	**33**
	Outages	19	5	**46**	**44**	9	36	**51**	30
Autumn (Sep–Nov)	NG	**86**	**75**	28	**63**	**72**	**61**	**68**	65
	CG	9	24	29	5	20	9	1	14
	Outages	5	1	**43**	32	8	30	31	21
Note: [1] The last readings in this case study were received at the end of March 2018, due to the technical reasons, [2] NG: National grid, [3] CG: Community generator.									

The lowest amount of suppressed electric energy demand occurred within the second scenario. This scenario includes the days where both NG and CG alternate to supply energy for 24 hours per day without any blackouts. The amount of energy suppressed demand in this scenario represents the difference between the consumed energy from the NG (the desired demand) and the consumed energy from the CG (unmet demand). At 32%, the frequency of this scenario over the year was more than double of the first scenario and its proportion was in the two case studies 64% and 60%, respectively. Similarly, the percentage of this scenario showed almost the same trend of frequency in the different seasons, where the percentage was 33%, 25%, 35%, and 38% in winter, spring, summer, and autumn, respectively. The third scenario appeared when analysing the energy supply in monitored homes and it describes a situation where the electric energy provided by both the NG and CG failed to keep pace with the required demand for the whole day, where the households suffer from frequent blackouts during the day. As a result, the energy suppressed demand in this situation is higher than in the second scenario, where the suppressed energy demand is the difference between amount of the desired consumed energy (from NG) and both the consumed energy from CG and the outages period (where the suppressed demand in this period is 100%). The proportion of this scenario accounted for the largest part of the total electric energy supply compared to other scenarios, with 46% over the year. For the different seasons, this scenario also constituted the largest percentage in winter, spring, summer, and autumn, with 48%, 46%, 53, and 40%, respectively. It is worth mentioning here that the frequency of the third scenario in summer was the highest, which confirms that the energy suppressed demand in summer is higher than in other seasons. The fourth scenario is the worst in terms of suppressing the energy actual demand for households. In this scenario, the households were deprived of energy supply for the whole day, resulting in 100% suppressed demand. This is why the suppressed demand in this scenario records the highest percentage of suppressed demand. While 9% was the frequency of this scenario over the year, its percentage in winter, spring, summer, and autumn with 4%, 14 %, 11%, and 7%, respectively.

Despite the growing demand for electric energy during the hot summer months, where cooling systems are used for more than 20 hours per day, all the supply scenarios that included suppressing the energy demand (2nd, 3rd and 4th scenarios) recorded the highest frequency in summer's days. Table 6-2 illustrates the energy supply scenarios for different aggregations. This research seeks to build a concrete database of energy use, whereby the suppressed energy demand could be estimated. Therefore, the next section is devoted to discussing the outcomes of the readings of energy use that were captured in the monitored houses. These real data were analysed and presented in different time scales to provide a better understanding of how the households responded to the current situation of energy supply, which was discussed in the previous sections.

6.3 Energy use

The duration of electric energy supply from the NG was higher than the duration of energy supply from by CG in most of the monitored dwellings, as demonstrated in Section 6.2. However, this difference in supply's proportions between NG and CG does not give any sign if whether or not the actual energy demand of households was met. Moreover, as mentioned in subsection 1.1.5, one of the mean key differences between NG and CG is the difference in supply capacity. Analysis of the supply proportions of each source in the total energy supplied to the households and the basic scenarios that emerged based on these propositions have not given any indication of the difference of supply capacity between NG and CG. Therefore, this section will investigate this problem in more depth by analysing the real data of energy use from both NG and CG in all case studies while using different time steps. This will assist in explaining why and how the actual energy demand was suppressed.

Table 6-2. Energy supply scenarios for different aggregation. Scenario 1 refers to getting 24 hours electricity from NG, Scenario 2 is getting 24 hours from NG and CG, Scenario 3 is getting 24 hours of electricity from NG and CG with outages, Scenario 4 is the inability to get electricity for the whole day.

Parameter		**Case**							**Mean**
Aggregation	**Scenario[1] (%)**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	
Annual (Jan–Dec)	S1: NG[2] only	12	21	8	23	5	4	5	12
	S2: NG + CG[3]	36	**64**	29	15	**60**	22	0	32
	S3: NG + CG + Outages	**51**	10	**52**	**52**	27	**57**	**73**	**46**
	S4: No electricity	1	5	11	10	9	17	6	9
Winter (Dec–Feb)	S1: NG only	0	37	1	**61**	0	0	0	15
	S2: NG + CG	47	**54**	27	9	**48**	39	0	33
	S3: NG + CG + Outages	**53**	9	**72**	30	41	**55**	**66**	**48**
	S4: No electricity	0	1	0	0	12	7	1	4
Spring (Mar-May)	S1: NG only	21	25	29	8	8	2	11	15
	S2: NG + CG	37	**49**	23	14	**50**	0	0	25
	S3: NG + CG + Outages	**42**	10	**46**	**50**	21	**66**	**88**	**46**
	S4: No electricity	0	16	2	29	21	32	1	14
Summer (June–Aug)	S1: NG only	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	S2: NG + CG	24	**82**	**40**	15	**69**	11	0	35
	S3: NG + CG + Outages	**76**	16	24	**78**	31	**78**	**61**	**53**
	S4: No electricity	1	2	36	8	1	11	6	11
Autumn (Sep–Nov)	S1: NG only	30	22	3	22	11	14	8	16
	S2: NG + CG	**35**	**73**	27	22	**72**	**38**	0	38
	S3: NG + CG + Outages	35	5	**64**	**52**	15	30	**76**	**40**
	S4: No electricity	0	0	6	4	2	18	16	7
Note: [1] For a full day; i.e. 24 hours, between 00:00 and 23: 59, [2] NG: National grid, [3] CG: Community generator.									

6.3.1 Hourly energy use

The profiles of the hourly energy use analysis for both NG and CG during the target continued period of monitoring (Jan 2017 to August 2018) revealed several important findings. First, in general, the hourly consumed energy from NG was significantly higher than that from CG in all case studies, by two to three times in some cases. Over the target period, the average of hourly use from NG ranged between 0.67 kWh and 3.07 kWh, while the hourly average of energy from CG was between 0.48 kWh and 1.72 kWh. Similarly, the maximum amount of hourly consumed energy from NG during the monitoring period recorded higher values compared with the maximum energy use per hour from CG. For example, 38.6 kWh was the highest amount of energy consumed from NG, as captured in the case study H4, while the highest amount of energy consumed from CG was 12.55 kWh, which as well recorded in case study H4. This significant difference between the hourly energy use from NG and CG can be attributed to the difference of the supply capacity between NG and CG (as mentioned in subsection 1.1.5).

In view of the seasonal use patterns, the summer season experienced an increase in hourly use for both NG and CG compared to other seasons, which reflects an increase in demand during summer. The highest average of hourly use from both NG and CG was captured in the summer season in all case studies. This average ranged from 0.7 kWh to 5.5 kWh for the energy consumed from NG, and from 0.6 kWh to 2 kWh for the energy consumed from CG. In comparison with the average of hourly energy use in other seasons, the highest recorded average of hourly energy use from NG was 3.3 kWh in the case study H4 in the winter season, and the highest recorded average of hourly electricity use was 1.7 kWh, which was also recorded in the case study H4 in the winter season. In addition, an investigation of the standard deviation of the hourly use of energy for different seasons showed that the hourly use of energy in summer experienced a significant variation compared to other seasons, which reflects the adverse impact of the continuous outages during summer days. Table 6-3 illustrates the hourly use in all case studies for different seasons.

Table 6-3. Statistical summary of the hourly energy use for different seasons.

Category	**Subcategory**	**Case**														**Mean**		
		H1		**H2**		**H3**		**H4**		**H5**		**H6**		**H7**				
		NG[1]	CG[2]	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	Total
Target period (Jan/17-Aug/18)	Mean	3.07	1.00	1.91	0.96	2.34	0.66	2.78	1.72	0.67	0.48	2.66	0.61	1.11	1.44	2.1	1.0	1.5
	St.D	2.03	0.45	1.61	0.58	2.30	0.38	2.45	1.17	0.95	0.22	3.04	0.47	0.90	0.91	1.9	0.6	1.2
	Max	21.6	4.7	24.9	5.24	16.8	2.1	34	12.55	23	1.87	23.4	3.24	14.7	3.85	23.3	4.8	14.0
	Min	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Winter (Dec–Feb)	Mean	2.9	0.7	**2.5**	0.8	1.6	0.5	3.3	1.7	1.1	0.3	2.2	0.5	**1.4**	1.3	2.1	0.8	1.5
	St.D	1.8	0.41	1.7	0.4	1.2	0.3	2.4	0.7	2.1	0.2	2.7	0.3	0.9	0.5	1.8	0.4	1.1
	Max	14.3	2.6	24.9	5.24	11.2	3.1	25.2	3.6	23	2	15.7	1.74	8.6	2.25	17.6	2.9	10.2
	Min	0.15	0.01	0.01	0.1	0.6	0.05	0.01	0.04	0.01	0.01	0.01	0.01	0.02	0.04	0.1	0.01	0.1
Spring (Mar–May)	Mean	2.8	1.1	1.4	0.5	1.6	0.7	1.9	1	0.5	0.4	2.3	0.5	0.4	1.5	1.6	0.8	1.2
	St.D	2	0.4	1.4	0.3	1.5	0.5	2.1	0.9	0.2	0.2	2	0.3	0.5	1.2	1.4	0.5	1.0
	Max	21.6	4	23.9	5.01	16.8	7.9	34	4.34	1.64	1.32	18.3	1.89	5.77	3.85	17.4	4.0	10.7
	Min	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.07	0.01	0.01	0.01
Summer (June–Aug)	Mean	**3.9**	**1.2**	2.3	**1**	**4.9**	**0.8**	**3.4**	**2**	0.7	**0.6**	**5.5**	**0.9**	1.2	**1.7**	**3.1**	**1.2**	**2.2**
	St.D	3.1	0.4	1.9	0.6	3	0.3	2.4	1.2	0.3	0.2	3.4	0.6	0.8	0.9	2.1	0.6	**1.4**
	Max	**18.4**	**4.7**	**16.4**	**5.05**	**14.9**	**2.1**	**28.8**	**12.55**	**2.7**	**1.87**	**21.9**	**3.24**	**5.25**	**2.86**	**15.5**	**4.6**	**10.1**
	Min	0.01	0.03	0.01	0.4	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.01	0.1	0.01
Autumn (Sep–Nov)	Mean	2.8	1	1.8	1.4	3.2	0.5	2.5	1.2	0.6	0.5	1.5	0.5	1.4	1.5	2.0	0.9	1.5
	St.D	2	0.4	1.2	0.6	2.9	0.3	2.7	0.8	0.3	0.2	2.8	0.4	1	0.9	1.8	0.5	1.2
	Max	21.6	1.7	22	2.65	12.5	1.7	38.6	4.6	2.3	0.92	23.4	1.72	14.7	3.26	19.3	2.4	10.8
	Min	0.01	0.01	0.1	0.1	0.05	0.05	0.01	0.04	0.05	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Notes: [1] NG: national grid, and [2] CG: community generator.																		

The hourly energy use during the weekdays and weekends for all case studies were also analysed. The results of this part of the analysis showed that the pattern of hourly energy use during winter days from both NG and CG experienced an increase in energy usage from 8 AM to 10 PM, which was due to the use electric heaters over this period. Conversely, the hourly energy use pattern in summer days exhibited a similar pattern for the whole day, which was due to the use of cooling systems for more than 20 hours per day to maintain the indoor thermal environment level. The hourly energy use in intermediate seasons (spring and autumn) in terms of the energy consumed from NG showed almost the same use pattern, it was stable throughout the day thanks to the significant improvement of energy supply from NG during these seasons. However, the energy consumed from CG in spring season showed a remarkable increase during both the weekdays and weekends for the whole day's hours. This can be attributed to staring the use of cooling systems, as mentioned in subsection 5.2.5. In the autumn season, the energy use from CG observed a remarkable decrease during both the weekdays and weekends, where the reliance on CG to provide electric energy was at its lowest level due to lower temperatures than in the summer, which reduced the use of energy for cooling these spaces.

Figure 6-1 shows the hourly energy patterns for both NG and CG at the weekdays and weekends for different seasons in case study H1. The detailed figures regarding the rest of the monitored homes are shown in Appendix B. Figure 6-2 details the average, maximum and minimum of the hourly use for both NG and CG at the weekdays and weekends for different seasons, using case study H1 as an example. This figure reveals that the average energy use from NG fluctuated during the day in both summer and winter. This fluctuation could be justified by the impact of the frequent outages occur in these seasons. This fluctuation in use reflected its impact on energy use from CG in both seasons. Conversely, the average energy use during spring and autumn seasons from NG experienced significant stability during the day on both weekdays and weekends. The detailed figures for the other monitored homes are shown in Appendix B.

The current research is strongly reliant on a database of energy use in Iraq's domestic buildings, through which the energy suppressed demand is estimated. Therefore, the daily energy use of the monitored exciting homes was also calculated and analysed to better understand the present energy use in these buildings, due to the dependence of different supply sources. The daily energy use is discussed in the next section.

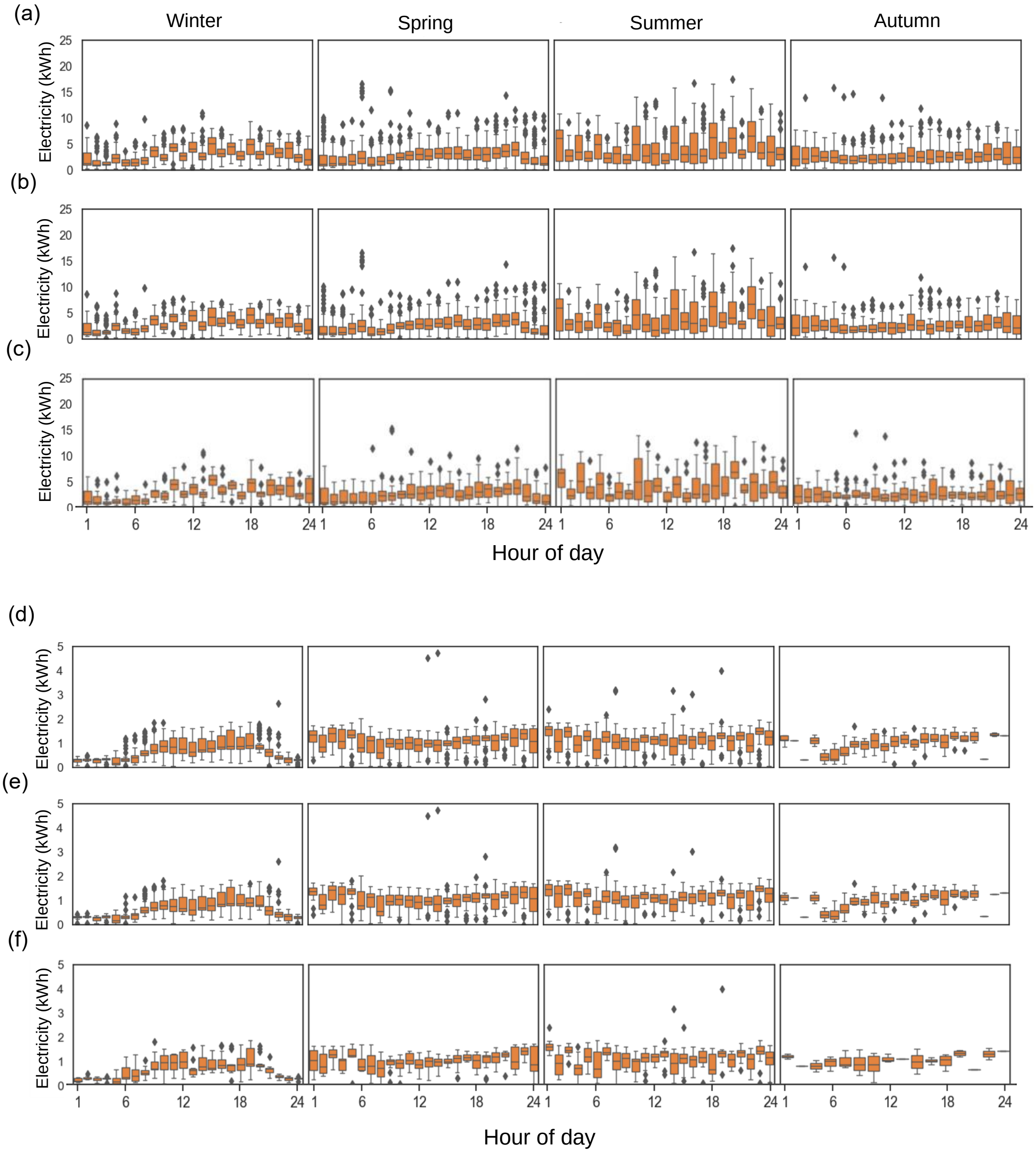


Figure 6-1. The hourly energy use for different seasons in H1 case study: (a-c) the hourly energy use from NG during all days of the week, weekdays, weekends, (d-f) the hourly energy use from CG during all days of the week, weekdays, weekends.

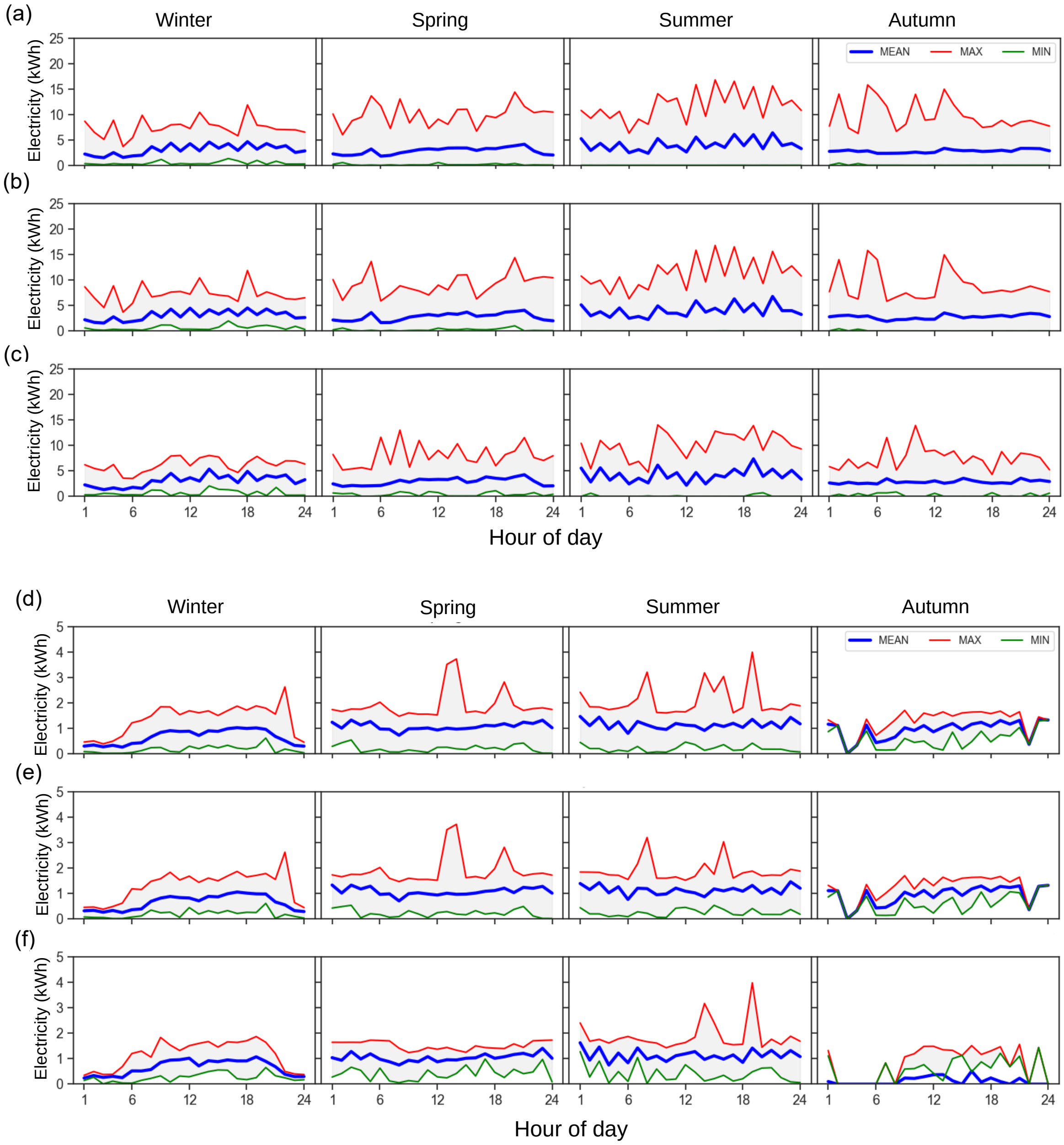


Figure 6-2. The maximum, minimum and mean hourly energy use for different seasons in H1 case study: (a-c) the maximum, minimum and mean hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the maximum, minimum and mean hourly energy use from CG during all days of week, weekdays, weekends. The average energy use from NG fluctuated during the day in seasons. This fluctuation could be justified by the impact of the frequent outages occur in these seasons.

6.3.2 Daily energy use

The calculation of hourly energy use over the target period for all case studies has been used to calculate the total daily energy use. This research has two methods to calculate the total daily energy use. The first method is reliant on the energy supply scenarios, as presented in subsection 6.2.2. The amount of energy using this method depends on the number of hours when energy is available, regardless of the type of supply source. However, applying this method does not show the difference of energy use based on the type of supply source, such as whether it is NG or CG, and thus will not help this research to meet its aim of providing an accurate estimation of suppressed energy demand based on the supply source. Therefore, to provide data that can help to achieve the research aim, the total daily energy use from both NG and CG was calculated separately for the whole target monitoring period, regardless of the daily energy supply scenario. The resulting difference of daily energy use is based on the source of energy supply and it provides an initial sign of the suppressed energy demand of households by comparing the amount of consumed energy from both sources of supply. The second benefit of adopting this calculation method is that the results can be used to calculate the hourly energy suppressed demand by categorising the energy use based on the supply source. The result obtains three readings for the same hour: the first reading is the energy consumed from the NG, which is the desired use; the second reading is the amount of energy use from CG in case the energy is not available from NG at the targeted hour, this amount of consumed energy refers to the energy use with suppressing demand, which is calculated and presented as the third reading for that particular hour.

A comparison of the results of daily energy use from both NG and CG in the case studies revealed that the consumed energy from NG was higher than that from CG in all cases studies: the average of daily energy use based on NG was 32.5 kWh, while the average of daily energy use from CG was 7.3 kWh. The standard deviation of energy consumed from NG was 19.8 kWh compared to 6 kWh in the case of energy consumed from CG. This variation can be explained as a result of the supply alternation between NG and CG during the day. The maximum daily energy use also showed the difference in energy amount the households can consume from NG or CG. The maximum energy use from NG was 163 kWh in H2 case study, while the maximum daily energy use from CG was 52 kWh in the H4 case study. These readings indicate that the consumed energy from NG was significantly higher than that from CG, by two to three times in all cases.

Seasonally, the daily electric energy use for each case study depends on the actual needs of households compared to the supply periods in the days of that each season. For example, the summer season experienced higher use than other seasons from both NG and CG to meet the increase in the need for energy for cooling: the total averages were 36.8 kWh and 11.5 kWh, respectively. However, the daily average of energy use from NG did not show a remarkable difference among seasons, where it was (in ascending order) 36.8 kWh, 35.8 kWh, 34.5 kWh, and 25.7 kWh for summer, autumn, winter, and spring, respectively. Conversely, the energy consumed from CG showed a significant variation among seasons. The highest average of daily energy use based on CG was recorded in summer at 11.5 kWh, followed by 6.3 kWh in winter, 4.5 kWh in spring and the lowest amount of energy consumed from CG was in autumn, where the supplied energy from NG observes a significant availability in autumn and spring, see Table 6-4 for more details. Figure 6-3 shows the daily energy use for different seasons from both NG and CG in H1 case study, which can give evidence of the difference in use from NG and CG. Meanwhile, the figure shows as well that energy use in the hot summer was the highest for both NG and CG. The detailed figures of the daily energy use from both NG and CG in different seasons for the other monitored homes are shown in Appendix B.

Furthermore, the research classified the amount of energy consumed based in two categories (weekdays and weekends)[8] to investigate the difference between these categories in terms of daily use of energy. No significant difference between the weekdays and weekends regarding the daily energy use has been observed. This may have happened because of the demographic characteristics of the monitored households, where six out of seven case studies have housewives who spend most of their time at home.

[8] In Iraq, the weekend days are Friday and Saturday.

Table 6-4. Statistical summary of the daily energy use for different seasons.

Category	**Subcategory**	**Case**														**Mean**		
		H1		**H2**		**H3**		**H4**		**H5**		**H6**		**H7**				
		NG[1]	CG[2]	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	Total
Target period (Jan/17-Aug/18)	Mean	46.5	8.5	31.7	9.1	40	6.6	45.60	9.2	9.5	4.3	38	7.1	16.1	6.2	32.5	7.3	20
	St.D	20.1	6.1	15.7	8	26.5	5.5	29.5	10.7	9.2	3.3	29.3	5.5	8.5	3.2	19.8	6	13
	Max	131	25.5	73.4	37.4	163	26.8	138	52.1	138	13	151	28.5	49.5	11.3	121	28	74.2
	Min	0.13	0.05	1.42	0.19	1.6	0.06	0.02	0.01	0.04	0.1	0.01	0.01	1.1	0.07	0.62	0.07	0.3
Winter (Dec–Feb)	Mean	39	6.7	**45**	7.7	24.1	4.4	**69.7**	9	**13.7**	2.5	33.3	5.9	**17**	**8.1**	34.5	6.3	20
	St.D	14	3.3	14.8	3.7	12.5	2.2	29.7	9.1	18.5	1.6	25.3	3.2	6.6	1.8	17	3.6	10.5
	Max	75	16.2	73.4	15	58	9.91	138	28.7	138	10	110	12.8	32.3	**11.3**	89	14.8	52
	Min	0.5	0.06	6.98	0.76	1.6	0.14	8.48	0.04	0.11	0.2	0.01	0.01	2.2	6.2	2.8	1.1	2
Spring (Mar–May)	Mean	45.1	7.9	27.8	2.9	32.1	6	30.5	3.3	8.5	2.5	27.9	5.9	8.3	5.3	25.7	4.8	15.3
	St.D	16.8	6.9	12	2	11.9	6.2	17.7	5.9	4	2.4	19.6	4.5	6.7	3.9	12.7	4.5	8.6
	Max	82.5	24.8	58.5	9.6	59.5	26.8	70.7	45.3	20	12	71.7	17.6	29	10.6	56	21	38.5
	Min	0.7	0.05	7.2	0.19	3.47	0.06	0.02	0.01	0.04	0.1	0.01	0.9	1.1	0.07	1.8	0.2	1
Summer (June–Aug)	Mean	46.5	**14.4**	24	**14**	**66.4**	**12.4**	41	**14.6**	7.2	**7.4**	**58.6**	**11.8**	14.2	6.1	**36.8**	**11.5**	**24.2**
	St.D	26.9	4	15	9	27.4	5.2	28.7	12	2.8	2.6	32.7	5.5	5.6	3.9	19.9	6	**13**
	Max	**131**	**25.5**	**73.4**	**37.4**	**123**	**23.3**	**106.4**	**52.1**	**14.9**	**13**	**151**	**28.5**	**35.32**	10.7	**90.7**	**27**	**59**
	Min	0.13	3.19	1.42	2.5	14.9	0.6	0.28	0.02	0.63	0.7	0.32	0.05	1.8	3.5	2.8	1.5	2
Autumn (Sep–Nov)	Mean	**57.9**	3.6	33	1.1	60.2	4.2	40	4	10.4	2.8	27	1.9	22.4	5.6	35.8	3.3	19.6
	St.D	15.5	2.8	11	0.4	41	3	22	4.3	4	2.3	21	2	8.6	2.7	17.6	2.5	10
	Max	105	10.1	54.9	1.83	163	11	103	17.6	20.5	9.2	101	7.8	49.5	8.4	85.3	9.4	47.4
	Min	29.7	0.18	11.2	0.28	10	0.06	0.3	0.28	0.7	0.2	4.2	0.03	4.4	3.2	8.6	0.6	4.6

Notes: [1] NG: national grid, and [2] CG: community generator.

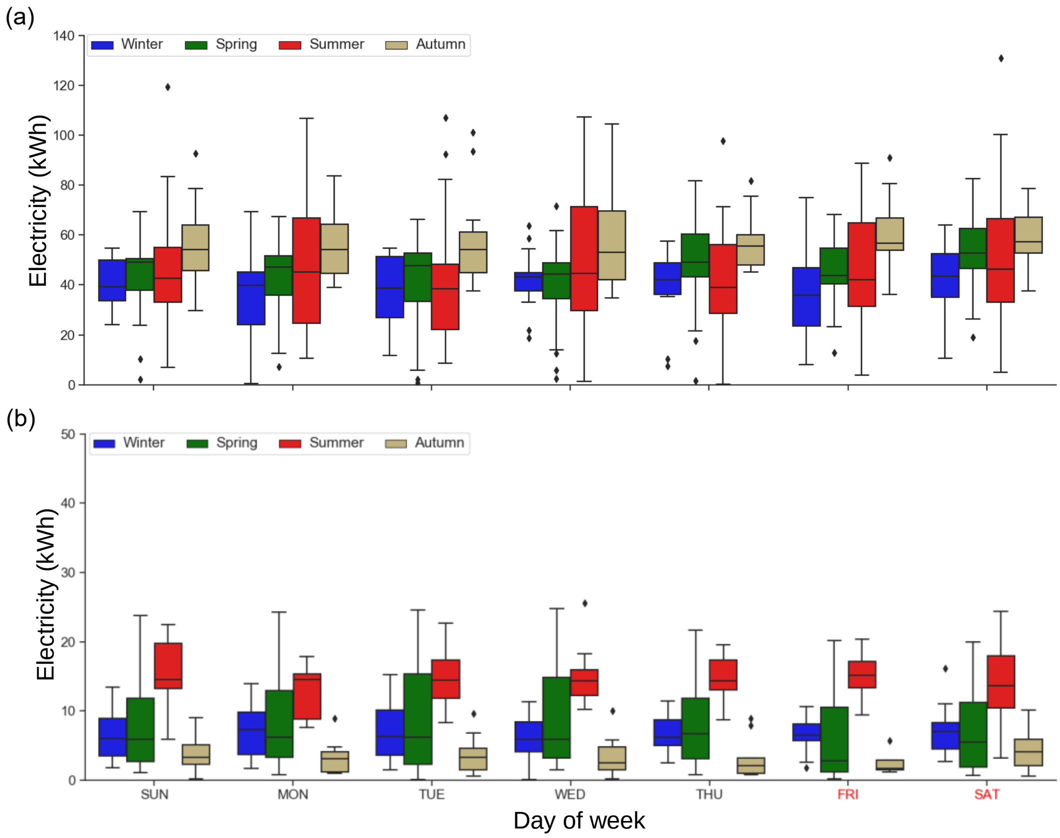


Figure 6-3. The daily energy use from NG and CG (kWh) for different seasons in H1 case study: (a) the daily energy use from NG, and (b) the daily energy use from CG.

6.3.3 Overall energy use

The last step in investigating the energy use focused on calculating the overall energy use from each supply source on an annual basis. The annual energy use was calculated after normalising the monthly use of energy over the monitored period (19 months), to obtain the energy use for one year (12 months). This study sought to determine the factors leading to high energy use in relation to the number of occupants (household size) and the floor area in (m^2) of these houses. Therefore, analysis of the annual energy use helps to identify the level of energy use (in kWh per capita, square meter) of the representative case studies, which is considered one of the unique and significant contributions of the present study. The identified level of energy use (in kWh per capita, and m^2) were then used to conduct a comparison against the domestic energy use in other countries with a similar hot arid climate. The information required to achieve this objective was obtained from dwellers during the individual site visits and in interviews during each case study, as demonstrated in subsections 5.2.1 and 5.2.2.

The results of the total annual consumed energy from the NG and CG by the households to meet their actual energy demand can be seen in Table 6-5. In all of the monitored dwellings, the annual energy use from both NG and CG showed a significant variance with an annual average 8,750 and 1,486 kWh, respectively. This variance may be a sign of what the households desire to consume (the energy from NG) and what they had already consumed (the energy use based on CG). This variance was calculated as the suppressed demand, as presented in the following section. Additionally, the significant difference in the total energy use from NG among cases (in the range of 2,987-16,570 kWh) can be attributed to the difference in the supply period from one residential sector to another within the same city and the total number of households. In contrast, the total energy use from the CGs ranged from 1,180 to 2,584 kWh for six houses, which reflects the limitation in a generation, supply, and operation capacities. The energy use from the CG in case study H7 was 88 kWh, which was due to the inability of the household to receive energy from the CG for technical reasons and is considered to be one of the key limitations of this study and will be explained in the conclusion. In the same context, the average annual residential energy use of all case studies was 10,242 kWh, where the proportions of NG and CGs contribution were 85% and 15%, respectively. Moreover, the contribution of both NG and CG to the total annual energy use showed a significant difference in all case studies, where the NG contributed with a percentage ranging from 72% to 89% if the case study H7 excluded, while the CG contribution in the total annual energy consumed by households was between 11% and 20%, with the highest contribution during summer season. Table 6-6 shows the total annual and seasonal energy use for each of the monitored houses in different scales (kWh, kWh/m², and kWh/capita).

Regarding the annual energy use in kWh/m², the results revealed that the energy use rate per annum in kWh/m² of the consumed energy from NG was 38 kWh/m², ranging from 13 kWh/m² in H5 case study (with floor area 230 m²) to 72.4 kWh/m² in H2 case study (with floor area 145 m²). However, the average of the annual energy use in kWh/m² of the consumed energy from CG was 7 kWh/m², ranging from 3.4 kWh/m² in H6 case study (with floor area 410 m²) to 17.8 kWh/m² in H2 case study (with floor area 145 m²) after excluding case study H7. The calculated average of the total annual energy use in kWh/m² from both NG and CG was 22 kWh/m² (with the total average 249 m^2) compared to the calculated average of the total annual energy use from NG, which was 38 kWh/m². These findings demonstrate how the use of CG has contributed to suppressing ~58% of the actual energy demand per m².

Table 6-5. The share of NG and CG in the total annual energy use in kWh for each case study.

Parameter		Case							Mean
		H1	H2	H3	H4	H5	H6	H7	
Electricity source (kWh)	NG[1]	16,570	10,501	7,232	12,496	2,987	7,290	4,216	8,756
	CG[2]	2,042	2,584	1,581	1,528	1,180	1,400	88	1,486
	Total	18,614	13,086	8,815	14,024	4,167	8,691	4,304	10,243
Electricity source (%)	NG	**89**	**80**	**82**	**89**	**72**	**84**	**98**	85
	CG	11	20	18	11	28	16	2	15
Note: [1] NG: National grid, [2] CG: Community generator.									

Reviewed studies in subsection 2.3.1 show that family size has a significant effect on the total electric energy use. Therefore, the present study has analysed the average household energy use rate per capita. Table 6-6 also illustrates the annual energy use rates per capita, by dividing the total energy use by the size of the average family (number of occupants) into the selected case studies. It can be seen that the share per person of the total amount of energy consumed in all case studies from the NG was 1,482 kWh/capita per annum, which ranged between 383 kWh/capita in case study H7 (11 persons) and 2,625 kWh/capita per annum case study H2 (4 persons). Conversely, the total rate of the annual energy use (kWh per capita) from the CG for all case studies was 307 kWh/capita per annum, which ranged between 8 kWh/capita in case study H7 and 646 kWh/capita in case study H2. The share per person of the total annual energy use from both NG and CG was 895 kWh/capita (with the total 7 of seven persons) compared to the calculated share per person of the total annual consumed energy based on NG, which was 1,482 kWh/capita. These findings prove that the use of CG has adversely affected energy use per capita with 60%.

Table 6-6. The energy use from NG, CG for different seasons.

Category	**Subcategory**	**Case**														**Mean**		
		H1		**H2**		**H3**		**H4**		**H5**		**H6**		**H7**				
		NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	NG	CG	Total
Annual (Jan–Dec)	Total (kWh)	16,571	2,043	10,501	2,585	7,233	1,582	1,2496	1,528	2,987	1,179	7,290	1,401	4,216	88	8,756	3,841	6,299
	kWh/m^2	46.4	5.7	72.4	17.8	35.3	7.7	43.9	5.4	13	5.1	17.8	3.4	37.6	0.79	38	7	22
	kWh/cap	1,841	227	2,625	646	1,033	226	1,785	218	1,494	590	1,215	234	383	8	1,482	307	895
Winter (Dec–Feb)	Total (kWh)	3,080	484	3,431	361	1,018	336	4,938	113	827	128	1,500	321	1,062	30	2,265	253	1,259
	kWh/m^2	8.63	1.35	23.66	2.49	4.96	1.64	17.33	0.40	3.60	0.56	3.66	0.78	9.48	0.27	10	1	5.6
	kWh/cap	342	54	858	90	145	48	705	16	414	64	250	53	97	3	402	47	224
Spring (Mar–May)	Total (kWh)	4,128	625	2,125	141	2,054	291	1,754	124	606	151	502	272	249	27	1,631	233	932
	kWh/m^2	11.56	1.75	14.65	0.97	10.02	1.42	6.15	0.43	2.63	0.66	1.23	0.66	2.22	0.24	7	1	3.9
	kWh/cap	459	69	531	35	293	42	251	18	303	76	84	45	23	2	278	41	159.4
Summer (June–Aug)	Total (kWh)	4,096	737	1,920	1,371	2,176	618	2,324	1,153	616	687	3,309	713	891	14	2,190	**756**	**1,473**
	kWh/m^2	11.5	2.1	13.2	9.5	10.6	3.0	8.2	4.0	2.7	3.0	8.1	1.7	8.0	0.1	9	**3**	**6**
	kWh/cap	455	82	480	343	311	88	332	165	308	344	551	119	81	1	360	**163**	**261**
Autumn (Sep–Nov)	Total (kWh)	5,267	197	3,025	712	1,985	337	3,480	138	938	213	1,979	95	2,014	17	**2,670**	244	1,457
	kWh/m^2	14.8	0.6	20.9	4.9	0.3	1.6	12.2	0.5	4.1	0.9	4.8	0.2	18.0	0.1	**11**	1	6
	kWh/cap	585	22	756	178	284	48	497	20	469	106	330	16	183	2	**443**	56	250

6.4 Estimated suppressed energy demand

This section will discuss the quantified energy suppressed demand based on the results of the energy use, which explained in the precedent section. The estimated suppressed energy demand per hour is discussed at the beginning of this section, followed by a discussion of the daily suppressed demand of energy. The estimated hourly and daily suppressed demand rates are compared with hourly and daily energy use rates. Finally, this section adds the estimated suppressed demand amount to the supplied amount and presents it as the total energy actual demand while making a comparison with domestic energy use in some neighbouring countries that share Iraq's climate.

6.4.1 Estimated hourly suppressed energy demand

The method used to calculate the hourly suppressed demand for different seasons is based on the actual hourly energy use from both NG and CG, see subsection 3.3.9.1 (pp. 92–94). The hourly energy suppressed demand rate during the targeted period was 1.95 kWh, which ranged between 0.5 kWh in case study H5 and 2.9 kWh in case study H6. The deviation from the mean was 1.1 kWh, which ranged between 0.4 kWh in case study H5 and 1.7 kWh in case study H6. The maximum hourly energy suppressed demand was 8.5 kWh in case study H6. These results can be attributed to the fact that the dwellers of H6's homes used air conditioners for cooling and heating, as illustrated in subsection 5.2.3.

The seasonal distribution of the hourly energy suppressed demand showed that the summer months experienced the highest estimated amount of suppressed energy demand. The suppressed demand rate of the case studies in summer season was 2.7 kWh followed by winter, autumn, and spring, with 1.8 kWh, 1.4 kWh, and 1.3 kWh, respectively. In the same context, the maximum amount of hourly suppressing demand also occurred during the summer season, where it was 5.5 kWh followed by spring, winter, and autumn with 3.5 kWh, 3.4 kWh, and 2.9 kWh, respectively. The reason behind the increased energy suppressed demand in summer is that in this extreme period the demand reaches its peak, resulting in more energy outages and reliance on CGs as a replacement supply source. Table 6-7 demonstrates the hourly energy suppressed demand for the whole monitoring period and for the different season in the selected case studies. The frequent blackout hours in summer and winter seasons result in significant fluctuation in hourly suppressed demand in these seasons, especially in summer.

Table 6-7. Statistical summary of the hourly estimated suppressed energy demand.

Category	Subcategory	Case							Mean
		H1	H2	H3	H4	H5	H6	H7	
Target period	Mean	2.76	1.33	2.81	2.34	0.51	2.86	1.03	1.95
	St.D	1.25	0.79	1.65	0.96	0.42	1.74	0.52	1.05
	Max	7.4	4.5	7.3	8.2	2.3	8.5	3.4	5.9
	Min	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Winter (Dec–Feb)	Mean	2.5	1.8	1.4	2.6	1	1.9	1.4	1.80
	St.D	0.9	0.8	0.4	1	0.4	0.8	0.4	0.67
	Max	5.4	4.5	2.8	5.6	2.3	1.1	2.2	3.41
	Min	0.03	0.2	0.03	0.1	0.01	0.01	0.01	0.06
Spring (Mar–May)	Mean	2	1.2	1.4	1.9	0.4	2.1	0.4	1.34
	St.D	0.8	0.5	0.5	0.6	0.2	0.8	0.2	0.51
	Max	4.3	4.1	3.4	3.8	0.9	4.4	3.4	3.47
	Min	0.1	0.01	0.01	0.01	0.01	0.02	0.1	0.04
Summer (June–Aug)	Mean	**3.3**	**1.4**	**4.6**	**2.8**	**0.3**	**5.1**	**1.2**	**2.67**
	St.D	**1.4**	**0.9**	**1**	**1.1**	**0.3**	**1.3**	**0.3**	**0.90**
	Max	**7.4**	**4.5**	**7.3**	**8.2**	**1.2**	**8.5**	**1.8**	**5.56**
	Min	**0.3**	**0.01**	**1.6**	**0.01**	**0.01**	**0.8**	**0.03**	**0.39**
Autumn (Sep–Nov)	Mean	0.7	0.8	3	2.4	0.3	1.4	1.3	1.41
	St.D	0.7	0.6	0.8	0.6	0.2	0.5	0.2	0.51
	Max	3.6	2.8	5	3.9	0.9	2.5	1.9	2.94
	Min	0.5	0.01	0.8	0.02	0.01	0.01	0.04	0.20

The fluctuation is shown in Figure 6-4 and Figure 6-5. Figure 6-4 shows the hourly energy suppressed demand for the different season in the case study H1, while Figure 6-5 illustrates the maximum, minimum and mean hourly energy suppressed demand for different seasons in H1 case study. The hourly suppressed demand of energy of the other case studies showed almost the same pattern of case study H1, with some seasonal exceptions in several of the case studies. The detailed figures of the hourly energy suppressed demand in different seasons for the other monitored homes are shown in Appendix B.

6.4.2 Estimated daily suppressed energy demand

To investigate the temporal variability, the estimated hourly suppressed demand was used to estimate the daily suppressed demand for the target monitoring period and different seasons. In general, the daily suppressed demand rate varied in each case study, where it ranged from 6 kWh in the case study H5 to 47 kWh in case study H6. The standard deviation as well observed a significant difference among the case studies, which ranged from 5 kWh in the case study H5 to 22 kWh in case study H3. However, the total average of the daily energy suppressed demand for all case studies was 26 kWh. Significantly, the maximum value of the estimated daily suppressed demand also

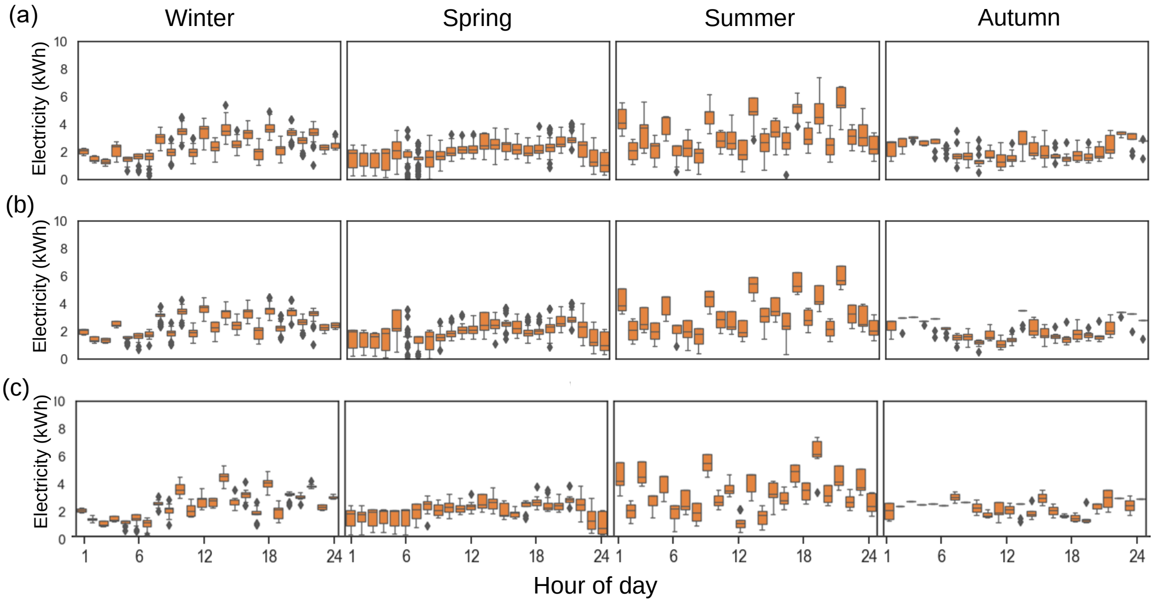


Figure 6-4. The hourly suppressed energy demand for different seasons in H1 case study: (a-c) the hourly suppressed energy demand during all days of the week, weekdays, weekends.

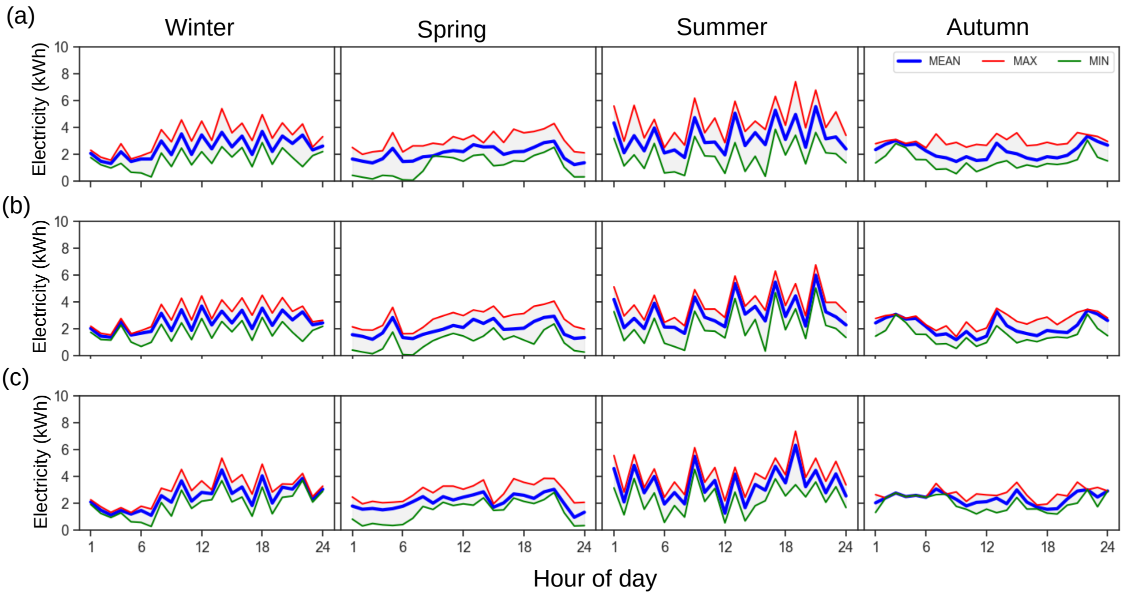


Figure 6-5. The maximum, minimum and mean hourly suppressed energy demand for different seasons in H1 case study: (a-c) the maximum, minimum and mean hourly suppressed energy demand during all days of the week, weekdays, weekends.

observed a remarkable variation over the whole monitoring period. For example, in the case study H6, the maximum value of the daily suppressed demand was 135 kWh, while it was 27 kWh in case study H5. This variation can be attributed to the difference in energy supply sources and period among the case studies.

Moreover, there are two main findings of the seasonal analysis of the estimated daily suppressed demand in the monitored houses. First, the significant variation of the daily suppressed demand that emerged during the targeted period of monitoring among the case studies reflected its impact on the of the daily suppressed demand for different seasons. For example, in the spring season, the daily suppressed demand rate in case study H5 was just 4 kWh, while it was 45 kWh in case study H6. Second, analysis of the estimated daily suppressed demand of energy for different seasons showed that the summer season recorded the highest amount of suppressed demand of energy in all seven case studies. The total daily suppressed demand rate in summer was 44 kWh, while in winter, spring, and autumn the total rates were 21 kWh, 20 kWh, and 18 kWh respectively. This temporal variability reflects the inability of energy supply from NG to keep pace with rising demand in the hot summer seasons, which resulted in an increase in continuous blackouts and more reliance on CGs. This restricted supply to households led to the suppression of their actual demand, which continued until the energy from NG became available again.

The seasonal variability of the daily suppressed demand also reflected on the standard deviation of daily suppressed demand among the different seasons, where the standard deviation was 19 kWh in summer, followed by 12 kWh in both winter and autumn and 10 kWh in spring. This difference can be attributed to the increased electricity outages in summer, which imposed the households to use the limited CG supply as a replacement electricity source to the NG. In the same context, the maximum amount of daily suppressed demand of electricity as well occurred in summer. The total average of all case studies in summer was around 76 kWh, which ranged between 17.7 kWh in case study H5 and 135 kWh in case study H6. Conversely, the total averages of all case studies in winter, autumn, and spring were 48 kWh, 42 kWh, and 35 kWh, respectively. This finding supports the view that the electricity demand is seasonal, which is an additional challenge for Iraq's electric energy supply network. During the summer, the highest peak occurred as a result of very high temperatures in much of the country. The peak energy demand could be expected to exceed the average demand level, which increased the gap between grid-based energy supply (operating at capacity) and the actual household demand.

Table 6-8 summarises the daily estimated suppressed demand for the target monitoring period and for different seasons. Figure 6-6 shows the seasonal variability of the daily suppressed demand for different seasons in H1 case study. The detailed figures of the daily energy suppressed demand in different seasons for the rest of monitored homes are shown in Appendix B.

Table 6-8. Statistical summary of the daily estimated suppressed energy demand.

Category	**Subcategory**	**Case**							**Mean**
		H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	
Target period	Mean	24	14	46	29	6	47	14	26
	St.D	19	9	22	20	5	20	5.5	14
	Max	95	61	121	83	27	135	34	79
	Min	0.3	0.1	1	0.4	0.01	0.6	0.3	0.01
Winter (Dec–Feb)	Mean	28	17	23	15.4	14	30	21	21
	St.D	14	10	13	12	8	18	8	12
	Max	73	61	43	44	27	52	34	48
	Min	6.8	1.6	1	2	1.3	3	4	3
Spring (Mar–May)	Mean	19	13	20	29	4	45	7	20
	St.D	7.5	12	15	18	4.7	11	4	10
	Max	41	36	40	47	12.7	53	18	35
	Min	0.3	0.1	1	0.5	0.01	1.7	0.3	1
Summer (June–Aug)	Mean	**42**	**19**	**89**	**44**	**4.5**	**96**	**15**	**44**
	St.D	**19**	**10**	**33**	**28**	**3**	**35**	**4**	**19**
	Max	**95**	**54**	**121**	**83**	**17.7**	**135**	**28**	**76**
	Min	**2.8**	**3**	**24**	**1.6**	**1.2**	**8.6**	**6**	**7**
Autumn (Sep–Nov)	Mean	10	6	52	27	2	16	11	18
	St.D	8	4	28	21	3	14	6	12
	Max	32	27	89	62	14	38	33	42
	Min	1.3	1	2	0.4	0.1	0.6	1	1

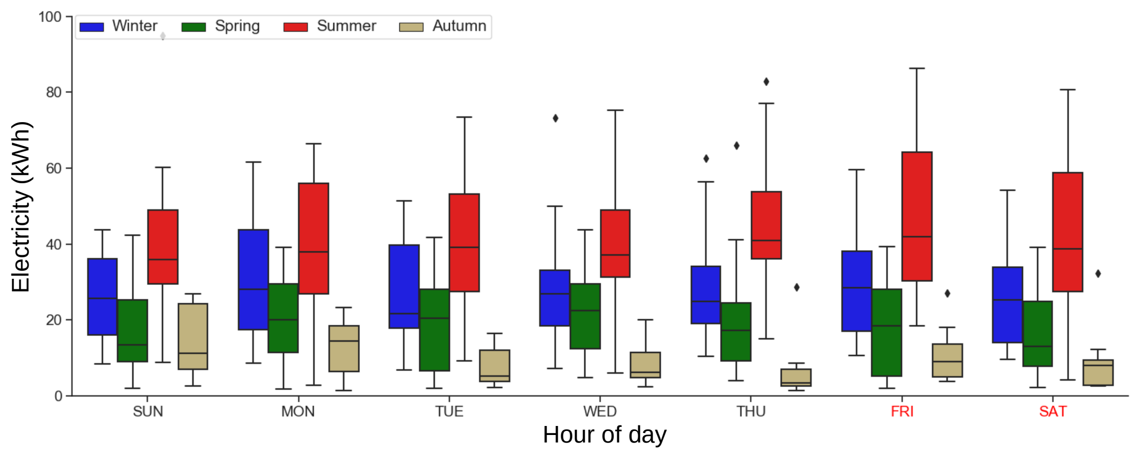


Figure 6-6. The daily suppressed energy demand for different seasons in H1 case study.

6.4.3 Overall estimated suppressed energy demand

To fulfil the research objectives, the total suppressed demand per annum for each monitored home was estimated. The data provided in the previous sections enable the annual suppressed energy demand (in kWh, kWh/m², and kWh/capita) of each selected case study to be presented, investigated and discussed. Table 6-9 makes a comparison between the total annual and seasonal energy suppressed demand for each of the seven houses (in kWh, kWh/m², and kWh/capita). Based on the results, the annual energy suppressed demand differs between houses, where its average for all case studies was 7,846 kWh. The total annual suppressed demand ranged from 1,940 kWh to 15,997 kWh. In addition, it can be seen that the suppressed electricity demand per annum (in kWh/m²) showed a significant variation between houses, where it ranged from 8.4 kWh/m² to 78 kWh/m² with a total average 33.4 kWh/m². In the same context, the electricity suppressed demand per annum (in kWh/capita) also differed in each case study. For example, in the H7 case study, the share per person of the total annual suppressed demand was 337 kWh/capita, while in case study H6 the share per person of the total annual suppressed demand was 2,519 kWh/capita. The total amount of energy consumed by households was reflected in the total amount of suppressed energy demand for each case study.

Furthermore, the temporal variation was present in the results of the seasonal energy suppressed demand. The value of the overall average of the suppressed energy demand for all case studies was 3,860 kWh in the summer season. However, in spring, autumn, and winter, the overall averages of the suppressed energy demand for all case studies were 1,553 kWh, 1,421 kWh, and 1,348 kWh respectively. Similarly, the suppressed demand of electricity (in kWh/m², and kWh/capita) almost followed the same seasonal variation pattern of the total suppressed demand of energy. The suppressed demand rates for all case studies in summer season (in kWh/m², and kWh/capita) were 15 kWh/m², which ranged between 1.7 kWh/m² and 40 kWh/m², and 601 kWh/capita, which ranged between 80 kWh/capita and 1312 kWh/capita. In spring the suppressed demand rates for all case studies were 5.7 kWh/m², which ranged between 1.6 kWh/m² and 10 kWh/m², and 257 kWh/capita, which ranged between 35 kWh/capita and 685 kWh/capita. These values were followed by the values of suppressed energy demand rates in both autumn and winter with 6.6 kWh/m², 214 kWh/capita, 6.3 kWh/m², 214 kWh/capita, respectively. A comparison between the energy use per annum and the annual estimated of suppressed energy demand will be conducted and discussed in subsection 6.5.3. The correlation between energy use from both NG and SGs, and the estimated suppressed demand in both hourly and daily time scales will be described separately in the following section.

Table 6-9. The estimated suppressed energy demand for different seasons.

Category	**Subcategory**	**Case**							**Mean**
		H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	
Annual (Jan–Dec)	Total (kWh)	7,713	3,743	15,997	9,045	1,940	15,113	3,705	7,846
	kWh/m^2	21.6	25.8	78	31.7	8.4	36.9	33	33.4
	kWh/cap	859	936	2,285	1,292	970	2,519	337	1,303
Winter (Dec–Feb)	Total (kWh)	1,998	812	1,784	427	**978**	1,912	**1,522**	1,348
	kWh/m^2	5.60	5.60	8.70	1.50	**4.25**	4.66	**13.58**	6.27
	kWh/cap	222	203	255	61	**489**	319	**138**	241
Spring (Mar–May)	Total (kWh)	1,452	839	1,303	2,424	365	4,113	381	1,553
	kWh/m^2	4.07	5.78	6.36	8.50	1.6	10.03	3.40	5.67
	kWh/cap	161	210	186	346	182	685	35	257
Summer (June–Aug)	Total (kWh)	**3,639**	**1,662**	**8,303**	**4,265**	400	**7,874**	877	**3,860**
	kWh/m^2	**10.2**	**11.5**	**40.5**	**15.0**	1.7	**19.2**	7.8	**15.13**
	kWh/cap	**404**	**416**	**1186**	**609**	200	**1312**	80	**601**
Autumn (Sep–Nov)	Total (kWh)	642	430	4,607	1,929	197	1,214	926	1,421
	kWh/m^2	1.8	3.0	22.5	6.8	0.9	3.0	8.3	6.61
	kWh/cap	71	108	658	276	99	202	84	214

6.5 The estimated suppressed energy demand vs energy use

This section is devoted to the patterns of energy use in different time scales (hourly and daily) against the patterns shown by the energy suppressed demand for the same period and time scales. This could help to better understand why and how the actual demand was suppressed.

6.5.1 Hourly suppressed demand vs hourly energy use

The hourly average of the calculated energy use from both NG and CG besides the hourly average of the suppressed demand over the targeted period were analysed and presented for all case studies. This analysis aims to explain how the energy use amount and patterns of NG and CG affected the amount and the pattern of suppressed energy demand per hour. Figure 6-7, for example, shows the average of hourly energy use during the weekdays and weekends for a different season of case study H1, where the positive values refer to the hourly average of energy use from NG and SG, while the negative values define the hourly average of suppressed energy demand for the same period. Detailed figures of the hourly energy use and suppressed demand in the other selected studies are shown in Appendix B.

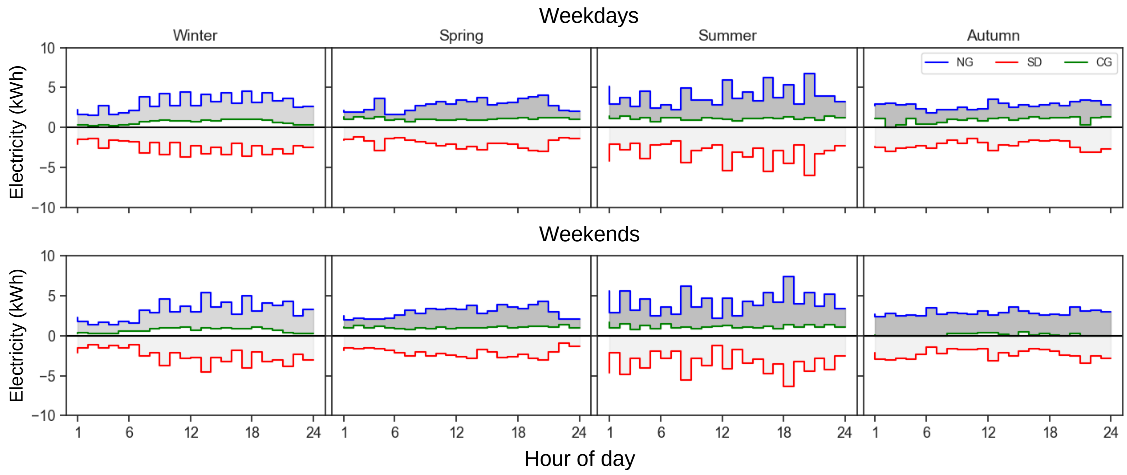


Figure 6-7. The hourly average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H1 case study.

In general, the hourly average of both energy use and suppressed energy demand for different seasons differed between case studies. Each case study helps to explain the correlation between energy use and suppressed energy demand. Some case studies, for instance, showed high hourly energy use and suppressed energy demand in specific seasons rather than other seasons. This can be seen in house H3, where the hourly average energy use and suppressed demand in summer and autumn were higher than the hourly average energy use and suppressed demand in winter and spring. Both case study H1 and H2 showed almost the same patterns of the hourly average energy use and suppressed demand in all seasons, with a slightly different in summer season period. The highest amount of hourly average energy use and suppressed energy demand in case study H6 occurred in summer seasons, while the other season showed almost the same pattern. In the case studies H4 and H7, the correlation between the hourly average energy use and suppressed energy demand was almost the same in all seasons. Finally, the winter season experienced the highest amount of hourly average energy use and suppressed demand in case study H5. However, from analysing the hourly average energy use and suppressed demand for different seasons it can be seen that all of the figures of all of the case studies indicated a significant fluctuation in energy use from both NG and SG during the day in all seasons. This fluctuation reflected its impact on the estimated hourly suppressed demand for the same period. This may happen because this inconstancy of hourly energy use represents the variation of energy supply from NG among the case studies, which can explain the supply disparity among residential sectors in Baghdad. This variation caused frequent blackouts hours, which differ from case study to another in terms of its number and the time of occurrence because each case study has a different time schedule of energy supply.

In addition, the variation of the hourly energy supply from NG affected the contribution of CGs to the hourly energy supply for each case study, beside the blackout duration. The share of hourly energy supplied from CG had a higher proportion in the summer season than any other season, which reflects the growing demand for energy in the summer.

6.5.2 Daily suppressed energy demand vs daily energy use

A comparison of the daily rate of the energy use from both NG and SG against the rate of the estimated suppressed energy demand for the same days in different season for all case studies provided more details of the inability of households to meet their required demand during the days of the week for different seasons. For example, Figure 6-8 illustrates the daily average of energy use for different seasons in case study H1. The positive values in the figure denote the daily average of energy use from NG and SG, while the negative values indicate the hourly average of suppressed demand for the same target period. Detailed figures of the daily energy use and suppressed demand of the other six selected houses are presented in Appendix B. The results from the analysis of daily energy use and suppressed demand show that in the weekdays and weekends, none of the cases studies experienced a significant difference of the daily average of the energy use from both NG and SG during the days of week in all seasons. Seasonally, the daily average of the energy use patterns of NG during the same season differed in each case study. For example, some case studies consumed more energy during the days of the winter season, such as H2 and H4 case studies, while others their highest energy use was in summer, such as H3 and H6 case studies. The household in case study H1 consumed more energy in autumn, while both H5 and H7 case studies showed almost constant patterns of daily energy use. This difference reflects the variation of energy supply from that source between the case studies. The figures of the daily averaged of energy use and estimated suppressed demand also showed that all the case studies consumed more energy from CGs in the summer season than other seasons, which reflects the increasing reliance on this supply source to cover the insufficient supply from NG during the extreme summer season.

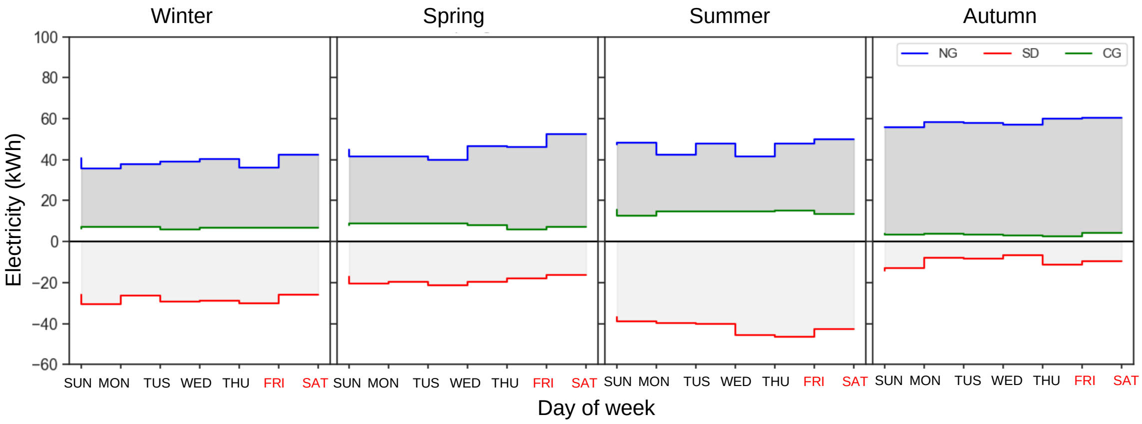


Figure 6-8. The daily average of energy use from the NG, CG and the suppressed energy demand for different seasons in H1 case study.

Regarding the daily rate of estimated suppressed demand, the highest amount of suppressed demand occurred during the days of summer seasons in the most of case studies, such as H1, H2, H3, H4, and H6. These results support the fact that although these households need more energy in the summer season, they are unable to meet their actual demand. However, case studies H5 and H7 showed more suppressed demand during the days of the winter season. For case study H5, in winter the family had eight members, while in the following seasons it dropped to two members. The technical problems that faced the monitoring process in case study H7 resulted in the monitoring coming to an end on March 2018, which is the reason why their suppressed demand in winter was higher than other seasons.

6.5.3 Total estimated suppressed energy demand vs total energy use

The total energy use per annum of all case studies was presented and discussed in subsection 6.3.3. This section will provide a comparison between the real energy use and the estimated suppressed demand for each case study and in total. The results indicate that the annual estimated suppressed demand exceeded the amount of the annual energy use in two of seven case studies, which are H3, and H6, with ~181%, and 174%. However, the values of the total estimated of the suppressed energy demand of H1, H2, H4, H5, and H7 case studies were constituted what is equal to 41%, 29%, 65%, 47%, and 86% of their total energy use per annum. The total average of the annual estimated suppressed demand for all case studies was equal to ~77% of their total annual energy use rate. Table 6-10 shows more details regarding the comparison. It is evident that according to the analysis results, there is a high suppression of the actual demand in the selected houses.

Table 6-10. The total annual energy use and the estimated annual suppressed energy demand.

Category	Sub-category	Case							Mean
		H1	H2	H3	H4	H5	H6	H7	
(a) The total energy use per annum (kWh)									
Total (kWh)		18,614	13,086	8,815	14,024	4,167	8,691	4,304	10,243
kWh/m^2		52	90	43	49	18	21	38	45
kWh/cap		2,068	3,271	1,259	2,003	2,084	1,448	391	1,789
(b) The total estimated suppressed energy demand per annum (kWh)									
Total (kWh)		7,713	3,743	15,997	9,045	1,940	15,113	3,705	7,846
kWh/m^2		21.6	25.8	78	31.7	8.4	36.9	33	33.4
kWh/cap		859	936	2,285	1,292	970	2,519	337	1,303
(c) The proportion of the total energy use to the total estimated suppressed energy demand (%)									
Annual (Jan–Dec)		41	29	181	65	47	174	86	**77**

The biggest issue causing a suppressed demand for electricity is how far the energy supply from NG is available in sufficient level for consumers and to what extent the SG helped to cover the inefficient supply from NG. The lack of energy supply with frequent blackouts has caused this high suppressed demand.

Both the total energy use and estimated suppressed energy demand in different time steps were analysed, investigated and discussed in the previous sections of this chapter. The last part will present and discuss the total actual demand for energy, which is estimated based on the available data from the previous sections.

6.6 Estimated the actual energy demand after adding suppressed energy demand to the consumed

As reported in the first chapter, in some developing countries, which suffer from suppressed energy demand, the available statistics of energy use do not imply that the actual demand has been measured because there is considerable unmet demand due to the supply shortages that these countries experience. Therefore, the current research sought to provide a reliable estimation of the suppressed energy demand, which in turn can help to construct the curve of the actual demand for energy. This research adopted the notion that the suppressed energy demand is eliminated when the suppressed demand curve and the actual use curve merge into one actual demand curve.

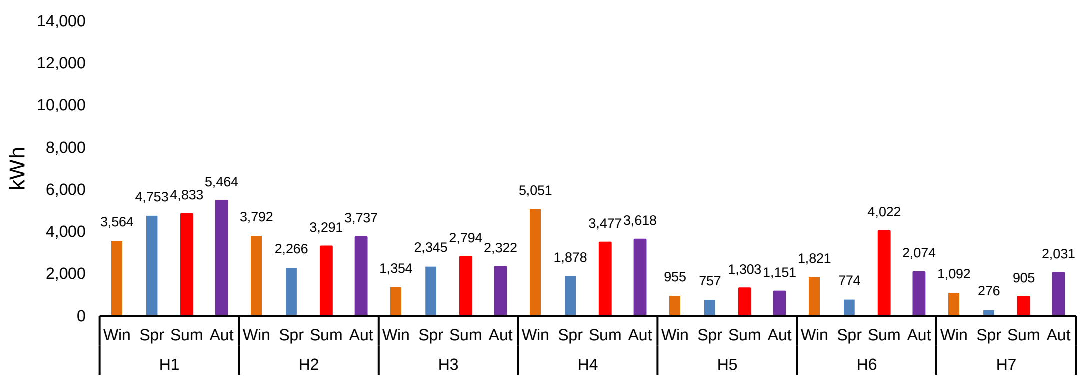
Table 6-11 compares the energy use measured during the monitoring process with the actual demand of energy that was estimated after adding the estimated suppressed demand for the same period. For the annual time step, the estimated actual demand rate was 77% higher than the actual use from both NG and CG, while the difference between the estimated annual actual demand rate and the annual actual use for case studies ranged from 29% in case study H2 to 181% in case study H3. It is worth mentioning here that the estimated actual demand significantly differed from the measured energy use over the seasons, especially in summer, followed by autumn and spring seasons. In the case studies H3, H6, H4, H7, H1, H2, and H5, the estimated actual demand was higher than the measured energy use in the summer season with 297%, 196%, 123%, 97%, 75%, 51%, and 31%, respectively. This difference between the estimated actual demand and the measured energy use over the season period in all case studies reflected the growing energy demand in that extreme season. In addition, the variation of the amount of the estimated actual demand among the case studies could be attributed to the variation of energy supply from NG and the contribution of SG to cover this lack of supply from one case study to another. Figure 6-9 illustrates a comparison between the estimated actual energy demand and the measured energy use over the year and seasons.

The energy use that was measured during the monitoring process cannot be considered as actual energy demand due to the existence of suppressed demand. Furthermore, one of the key objectives of the present study identified the energy use (in kWh/capita·year, kWh/m^2·year) of Iraqi domestic buildings and compare them against regional domestic buildings to determine if this use is deemed to be low, or very low, based on the results. Therefore, to fulfil this objective, this research has utilized the estimated actual demand after adding the suppressed demand to the energy consumed to identify the energy that was supposed to be consumed by these households. This identified level was then used to assess the energy use level through conducting a comparison with the energy use level in domestic buildings in some countries that share Iraq's hot arid climatic conditions. The total average of the estimated energy actual demand (in kWh/capita·year) was 3,094 kWh/capita (in the range of 728–4,223 kWh/capita), as Table 6-11 shows. Compared to other countries with a similar hot arid climate, Iraq had the lowest result. For example, the share per person of the annual amount of energy consumed in KSA was 4,784 kWh/capita, in UAE was 4,656 kWh/capita and in Kuwait, it was 7,000 kWh/capita (SCD, 2017; Ali & Alsabbagh, 2018). These results agree with the studies in the literature review in subsection 2.4.3.1. Where they reported that Iraq has the lowest energy use per capita, where the energy use per capita per year was 1100 kWh, compared to the use in neighbouring countries.

Table 6-11. Estimated energy actual demand after adding suppressed energy demand to the consumed.

Category	**Subcategory**	**Case**							**Mean**
		H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	
(a) The total energy use before adding suppressed demand to the consumed (kWh)									
Annual	Total (kWh)	18,614	13,086	8,815	14,024	4,167	8,691	4,304	10,243
	kWh/m^2	52	90	43	49	18	21	38	45
	kWh/cap	2,068	3,271	1,259	2,003	2,084	1,448	391	1,789
(b) The estimated energy actual demand after adding suppressed demand to the consumed (kWh)									**Mean**
Annual	Total (kWh)	26,327	16,830	24,812	23,069	6,106	23,804	8,010	18,089
	kWh/m^2	74	116	121	81	27	58	72	78
	kWh/cap	2,927	4,223	3,544	3,295	3,053	3,967	728	3,094
(c) The proportion of the total energy use to the estimated energy actual demand after adding suppressed demand to the consumed (%)									
Annual (Jan–Dec)		41	29	181	64	47	174	86	**77**

(a)



(b)

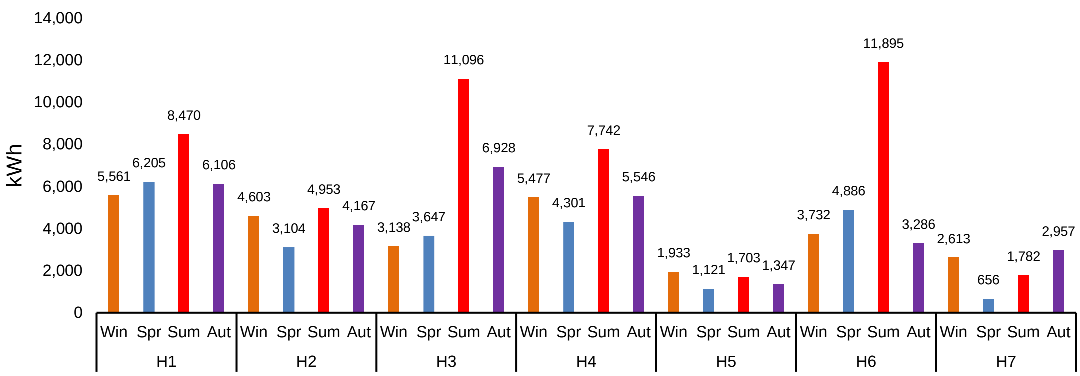


Figure 6-9. (a) The annual energy use calculated for different seasons and (b) estimated annual energy actual demand after adding suppressed demand to the consumed energy for different seasons. (win: winter, Spr: spring, Sum: Summer, Aut: Autumn)

In the current study, the average of square meter residential energy use was also calculated after adding the suppressed demand. The average was 78 kWh/m^2 (in the range of 72–121 kWh/m^2), while it was 176.5 kWh/m^2 (in the range of 27- 401 kWh/m^2) in KSA (Alrashed & Asif, 2014). Another study found that the average energy use of the typical residential building in KSA was around 185 kWh/m^2 (Al-Aidroos & Krarti, 2015). In UAE its range was 204–271 kWh/m^2, based on Rakhshan & Friess's (2017) study, while Giusti & Almoosawi (2017) stated in their study that the average energy use of the typical residential building in UAE is 326 kWh/m^2 (in the range of 186–498 kWh/m^2). In Kuwait, it was 244 kWh/m^2 (Ameer & Krarti, 2016). Another related study showed that the average in Kuwait was 374.9 kWh/m^2 (in the range of 238–485 kWh/m^2) (Al-Ragom, 2003), while in Jaffar et al.'s (2014) study the average of square meter residential energy use in Kuwait was 264 kWh/m^2. Based on these results, the square meter residential energy use in the case studies is deemed to be low compared to the square meter residential energy use in some neighbouring countries.

6.7 Summary

This study aimed to provide a reliable estimate of suppressed energy demand based on real data from long-term monitoring, which in turn can be used to obtain an accurate estimation of actual energy demand for domestic buildings and support the design of future energy demand models. This can answer the following research questions: *How is energy, especially electricity used in Iraqi dwellings? and how does it vary temporally and compare regionally*? Consequently, the energy supply scenarios, the energy use (end-use), the estimated suppressed energy demand and then the actual energy demand in existing representative homes in Baghdad city after defining the energy use levels in these homes in kWh for different time steps (hourly, daily, seasonally, and per annum) and scales (per capita, per square meter) were presented, analysed and discussed.

The key results will be summarised in the following five main categories, mirroring the answers to the research questions:

- **energy supply sources**

The annual electricity supply revealed that the contribution made by the NG to the total annual electricity supplied was 51%, compared to 22% the contribution of CG and 27% represented by the blackout duration in the total annual electricity supplied. In addition, the seasonal analysis of the total electricity supply showed that the dependency on CGs in summer was higher than in other seasons, with around 33% (followed by 22% in winter). This high dependency was caused by the deficit of the electricity supply from the NG to meet the exceptional growing demand during summer months for cooling, where the ambient temperature observed a significant increase.

- **energy supply scenarios**

The analysis of the daily electricity supply has highlighted the main daily electricity supply scenarios that the households observed over the monitoring period. The reliance on NG and CG as the main electricity supply sources, coupled with outages hours that occur during the day, contributed to four main daily electricity supply scenarios. In the first scenario, the households receive electricity for 24 hours per day from NG. Although this scenario represents the optimal scenario of electricity supply where the households are able to meet their actual demand for electricity, its proportion within the total electricity supply over the year was the lowest compared to the other scenarios—with just 12%. Seasonally, none of the households in the monitored houses was able to receive electricity from the NG for 24 hours per day in all summer days, where its proportion in this season was zero for all case studies. The second scenario includes the days where both NG and CG alternate to supply electricity for 24 hours per day without any blackouts. In general, the frequency of this scenario over the year was 32%. The third scenario describes a situation where the electricity provided by both the NG and CG failed to keep pace with the required demand for the whole day, where the households suffer from frequent blackouts during the day. The proportion of this scenario accounted for the largest part of the total electricity supply compared to other scenarios, with 46% over the year. The fourth scenario refers to the situation when the households were deprived of electricity supply for the whole day, resulting in 100% suppressed demand. The frequency of this scenario was 9% over the year.

- **Energy use**

Over the target period (January 2017 to August 2018), the average of hourly use from NG in all case studies ranged between 0.67 kWh and 3.07 kWh, while the hourly use from CG was between 0.48 kWh and 1.72 kWh. This significant difference between the hourly energy use from NG and CG can be attributed to the difference of the supply capacity between NG and CG. Seasonally, the highest average of hourly use from both NG and CG was captured in the summer season in all case studies. This average ranged from 0.7 kWh to 5.5 kWh for the electricity consumed from NG, and from 0.6 kWh to 2 kWh for the electricity consumed from CG. A comparison of the results of daily energy use from both NG and CG revealed that the average of daily energy use based on NG was 32.5 kWh, while the average of daily energy use from CG was 7.3 kWh. Seasonally, the daily average of energy use from NG was (in ascending order) 36.8 kWh, 35.8 kWh, 34.5 kWh, and 25.7 kWh for summer, autumn, winter, and spring, respectively. Conversely, the highest average of daily energy use based on CG was recorded in summer at 11.5 kWh. Furthermore, the annual energy use from both NG and CG, in all of the monitored dwellings, showed a significant variance, with an annual average 8,750 and 1,486 kWh, respectively.

The energy use rate per annum in kWh/m² of the consumed energy from NG was 38 kWh/m². However, the average of the annual energy use in kWh/m² of the consumed electricity from CG was 7 kWh/m². These findings demonstrate how the use of CG has contributed to suppressing ~58% of the actual electricity demand per square meter. Moreover, the annual energy use rates per capita from both NG and CG revealed that the share per person of the total amount of energy consumed in all case studies from the NG was 1,482 kWh/capita per annum, Conversely, the total rate of the annual use (kWh per capita) from the CG for all case studies was 307 kWh/capita per annum. These findings also prove that the use of CG has adversely affected the actual electricity demand per capita by ~60%.

- **Estimated suppressed energy demand**

The hourly rate of the suppressed energy demand during the targeted period was 1.95 kWh. Seasonally, the summer season experienced the highest estimated amount of suppressed electricity demand with was 2.7 kWh followed by winter, autumn, and spring, with 1.8 kWh, 1.4 kWh, and 1.3 kWh, respectively. In addition, the daily rate of the suppressed energy demand during the targeted period was 26 kWh. The total daily suppressed demand rate in summer was 44 kWh, while in winter, spring, and autumn the total rates were 21 kWh, 20 kWh, and 18 kWh, respectively. The average annual suppressed demand for all case studies was 7,846 kWh, which was equal to ~77% of the total annual energy use rate for all case studies. The total average of the suppressed energy demand per annum (in kWh/m^2) was 33.4 kWh/m^2, while the total average of the suppressed energy demand per annum (in kWh/capita) was 1,303 kWh/capita.

- **Actual energy demand**

The average annual actual demand of energy for all case studies was 18,089 kWh, which was equal to ~77% of the total annual energy use rate for all case studies. The highest difference between the estimated actual demand and the measured energy use occurred in summer, which ranged between 31% and 297% for all case studies. The total average of the estimated electricity actual demand (in kWh/capita·year) was 3,094 kWh/capita compared to 1,789 kWh/capita as the total average of the energy use per annum. The total average of the energy use (in kWh/m^2·year) was 45 kWh/ kWh/m^2, while the total average of the estimated energy actual demand (in kWh/m^2·year) was 78 kWh/m^2·year The next chapter will focus on investigating the impact of suppressed energy demand on the indoor thermal environment in these homes, which will be achieved by empirically examining the impact of suppressed energy demand on the comfortable thermal environment of the monitored spaces.

Chapter 7: Suppressed energy demand vs indoor thermal environment

This chapter presents the second part of the fieldwork quantitative data. It analyses the collected data of the ambient and indoor environment conditions from the existing homes that were used as case studies. The nature of the interaction between these two environment parameters is investigated, while the relationship between each of these environment parameters and energy use and suppressed demand is also investigated. This was achieved by employing the measured data of the selected monitored spaces within the case studies. The discussion of the results in this chapter aims to evaluate the domestic indoor thermal environment and how well it was affected by the local climate conditions under the impact of suppressing the energy demand. It will then investigate the relationship between energy use, suppressed demand characteristics and the indoor thermal environment. This chapter is structured into five main sections: ambient conditions, indoor environment conditions, the relationship between ambient and indoor environment parameters, the relationship between the ambient conditions and energy use, the effects of ambient conditions and suppressed energy demand on indoor thermal environment, and finally the summary.

7.1 Background

The causal relationship between energy and environment was covered in chapter two subsection 2.3.4. Most of the related studies have explained this causality in one direction, which is running from the environment to energy and how climate conditions influence the energy demand. For example, the energy consumed by mechanical systems is specified by the difference of the outdoor weather conditions and the desired indoor environment conditions. However, studying the relationship in the opposite direction—from energy to the environment—needs more research, especially in the presence of suppressed energy demand. This study experimentally investigates this relationship by focusing on the impact of suppressing the required demand on providing the desired indoor thermal environment in a hot arid climate region such as Iraq.

In Chapter 4, the indoor thermal environment of Iraqi households was investigated and discussed. The results showed that most of the households started using cooling systems for more than 20 hours per day during the summer season to achieve acceptable indoor thermal environment and to mitigate the negative impact of the outdoor weather conditions during these months of the year. These subjective data were collected from the questionnaire and are supported by the data that was collected by monitoring the energy use, as shown in Chapter 6.

The discussed results of energy use revealed that high energy demand was required during the summer months for cooling these spaces. However, within this highly seasonal energy use, the residents showed their strong dissatisfaction regarding the indoor thermal environment, especially in summer. Consequently, this chapter is devoted to experimentally investigating how the indoor thermal environment affected by the local ambient conditions and to what extent the indoor thermal environment has satisfied the occupants. This chapter also seeks to examine the influence of the status quo of energy use under suppressed demand on the indoor thermal environment, and also to understand the interaction between the current situation of energy use and the ambient conditions. This analysis included just six of the seven case studies employed in this study because the case study H6 was excluded due to some technical problems affected the devices that were used to monitor the bioclimatic parameters, which lost more than 30% of the measured data.

7.2 Ambient conditions

Human comfort, both outdoors and indoors, is an important part of climatology studies. This is part of a larger topic in applied climatology entitled climates and built environments or bioclimatic architecture and the climate-adapted built environment. Generally, there are two methods for monitoring and analysing bioclimatic conditions. The first method is called the indices method, which is based on the empirical measurement and computational calculation covering a range of simple to complex indices. For example, Humidex is a simple index. Although various methods have been proposed to calculate this index, generally two parameters of temperature and RH are used (Carlucci & Pagliano, 2012; Ghanghermeh, et al., 2013; Orosa, et al., 2014). Humidex is an index that was introduced by Canadian meteorologists to quantify the perceived thermal discomfort of a person for ambient conditions and activities (Crowe, 1975). Humidex has been applied to heatwaves studies (Conti, et al., 2005; 2007; Anderson & Michelle, 2009; Giannopoulou, et al., 2014). The combined effect of temperature and humidity leads to representative assumptions about discomfort conditions of the indoor thermal environment. Rana et al. (2013) utilised the index to measure the indoor thermal environment and concluded its reliability for prediction in environments with high humidity. Researchers have combined Humidex with the mortality rates to investigate the role of temperature in the relationship between a heat stress index and human mortality (Rainham & Smoyer-Tomic, 2003; Barnett, et al., 2010). Furthermore, Humidex is used to assess children's health in outdoor areas because they are more easily affected by extreme values of ambient climate conditions (Vanos, 2015).

Humidex is expressed in °C, and its values ranges are determined by Masterton and Richardson (1979) to be 20°C–29°C as comfortable, 30°C–39°C as some discomfort, 40°C–45°C as great discomfort and over 45°C as dangerous with high possibility of heat strokes (Ghani, et al., 2017). The second method for monitoring and analysing bioclimatic conditions is based on using bioclimatic diagrams or charts. Building bioclimatic charts offer a convenient way to analyse and present the frequency of comfort zone, whether for ambient conditions or indoor thermal environment, which can suggest an appropriate strategy to achieve the required level of comfort. Identifying a suitable strategy for any given location can be done using bioclimatic charts (Al-Azri, et al., 2013). Victor Olgyay is one of the pioneers in designing comfort climate diagrams. To determine comfort outside of the building, Olgyay presented a diagram that was designed to determine the conditions of the outdoor thermal environment by considering parameters such as wind speed, radiation and humidity requirements (Olgyay, 1967). Olgyay's bio-climatic chart is strictly applicable only to outdoor conditions. However, Olgyay has made the comment that in his experience indoor temperatures are very close to the outdoor level. Therefore, he has suggested that these charts could be used also as guidelines, e.g., for the advisability of ventilation (Givoni, 1992). Roshan, et al. (2017) presented new threshold temperatures in order to calculate the degree day index required for heating and cooling by using Olgyay diagram to analyse mean daily data of outdoor temperature and relative humidity were used for the period of 1950-2010. These two methods were used in this study to achieve relative objectives.

The present study seeks to investigate how the outdoor weather conditions affect the indoor thermal environment in a hot arid climate area and under the current situation of energy use and suppressed energy demand. Therefore, this chapter starts by investigating the measured data of the outdoor weather parameters that have an impact on the indoor thermal environment of these homes, including AT and RH. These two climatic parameters have allowed the bioclimatic indices to be developed in different locations around the world. These studies have sought to determine the accepted outdoor thermal environment ranges and thresholds based on these ambient parameters, which are used to predict/define the personal acceptability of indoor thermal environment and to calculate the heating and cooling requirement. The comfort range ambient temperature differs from one region to another because of the variety of microclimatic data. For the ASHRAE standard, during the summer season, optimal comfort sensation is achieved when the AT is between 22.5°C–26°C and the wet bulb is at 20°C (ANSI/ASHRAE, 1995). Indraganti (2010) defined a comfort range ambient temperature of 26°C–32.45°C for the humid climate of India. In other tropical countries, such as

Bangladesh, where the humidity is normally higher than 70%, the range of comfortable outdoor thermal environment 28.5°C and 32°C (Ahmed, 2003). In hot arid environments, Cheng et al. (2012) set neutral AT under shade to be 28°C for high levels of RH (80%) for subtropical Hong Kong. However, in Iraq, this area of research lacks comprehensive studies to define the optimal ambient conditions. Therefore, the Humidex indices are utilised in this study as a first method to analyse the on-site measurements of AT and to assess the comfortable thermal environment range in this country.

The second method used in the current study was the Olgyay diagram, where outdoor thermal conditions are evaluated as a combination of the AT and the RH. This section will begin by describing the hourly patterns of both ambient parameters (AT and RH) monitored in this study before analysing the ranges of the comfortable outdoor conditions.

7.2.1 Hourly ambient conditions

From the analysis it was found that the hourly average of the daytime temperature varied significantly over the seasons; for example, the hourly average of AT in winter recorded 15.7°C with range from 14.4°C to 17°C, while in summer days the hourly average was 38.2°C with range between 36.4°C and 39.6°C. In intermediate seasons (spring and autumn), the measured hourly averages were 26.1°C with a range between 25°C and 27°C, and 28.8°C with a range between 28.3°C and 29.5°C, respectively. The maximum hourly AT recorded in the monitored houses was 49.9°C in (12:00:00 in 2017-08-04) and the minimum is 0.2°C in (6:00:00 in 2017-02-03). Table 7-1 shows the hourly AT details. As mentioned in subsection 2.4.3.3, one of the main facts that needs to be taken into consideration regarding the ambient temperature in Iraq is that the significant variation of hourly AT over the different seasons is coupled with a temperature that constantly fluctuates over the day/night times. Therefore, the daytime temperature variations should be taken into consideration during the dynamic analysis for both indoor environment conditions and energy use. Interestingly, the results of the data analysis have matched the previous studies. Figure 7-1 illustrates the hourly AT patterns for different seasons. These patterns revealed two main facts: first, in all seasons the ambient temperature observed a reduction during the night-time hours and reached the lowest value at 6 am. At 7 am, the temperature starts to rise, and it reaches the highest value at 4 PM and then starts to fall again till 6 am. The highest temperatures during each day occur between 12 noon to 8 PM. The values of temperature of each hour of day's hours observed a significant variation during the days of the transitional or intermediate seasons (spring and autumn), where the standard deviation of hourly AT was 6.2°C and 7.4°C, respectively. However, this variation of temperature values for each hour was less during both winter and summer, with a standard deviation of hourly AT 4.1°C for both seasons. Detailed figures of the hourly AT for the rest case studies during the target monitoring period are presented for different seasons in Appendix C.

Table 7-1. Statistical summary of the hourly ambient temperature.

Category	Sub-category	Case						Mean
		H1	H2	H3	H4	H5	H7	
Winter (Dec–Feb)	Mean	14.4	17	16	15.9	15.5	15.1	15.7
	St.D	3.9	5.4	3.7	4.2	3.3	4.2	4.1
	Max	24.6	32.7	25.7	29.4	24.3	27.8	32.7
	Min	1.1	4.3	2.8	4.2	5.3	0.2	0.2
Spring (Mar–May)	Mean	26.3	26.1	27	26.3	25.8	25	26.1
	St.D	6.2	6.1	6	6.3	5.9	6.5	6.2
	Max	42.8	42.4	42.1	44.5	42.2	41.4	44.5
	Min	11.4	11.6	12.8	10.8	12.5	10	10
Summer (June–Aug)	Mean	39	36.4	39.6	38.3	37.1	38.6	38.2
	St.D	3.9	5	3.7	4.6	3.9	3.7	4.1
	Max	48	49.9	47.9	49	47.4	46.9	49.9
	Min	26.5	24.1	28.4	25.2	26	27.3	24.1
Autumn (Sep–Nov)	Mean	28.3	29	29.5	28.8	28.5	28.8	28.8
	St.D	7.6	8	7.2	7.6	6.8	6.9	7.4
	Max	45.9	46.7	46.5	45.9	43.7	45.5	46.7
	Min	11	11.7	13.2	11.3	12.6	12.1	11

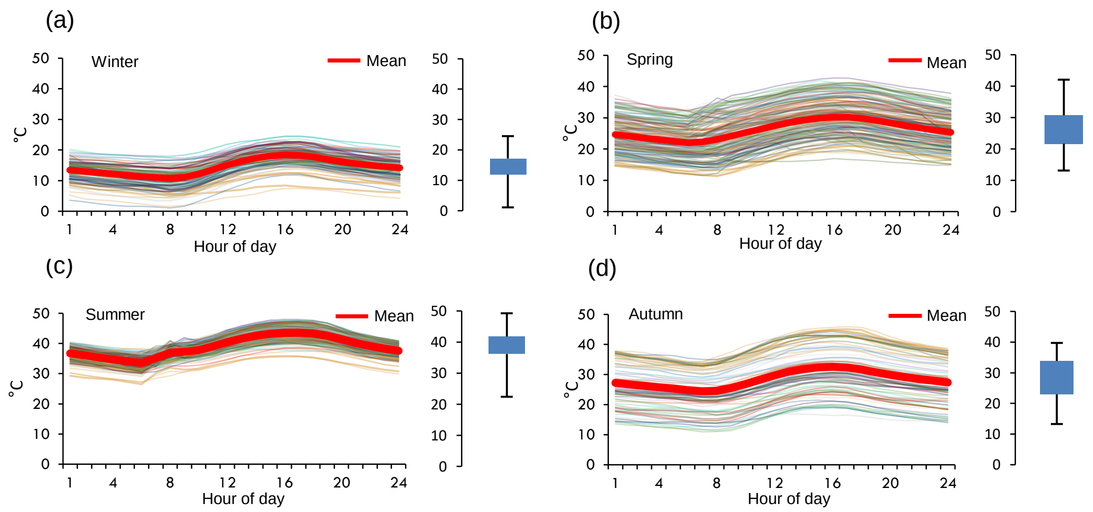


Figure 7-1. Hourly ambient temperature for H1 case study during the target monitoring period. (a)-(d) Hourly ambient temperature over the seasons.

Regarding the second monitored bioclimatic parameter (RH), it showed an adverse pattern comparing to the pattern of hourly AT during the monitoring period. Seasonally, the highest hourly average of RH was recorded in winter 48.8%, with a range from 46.9% to 51.6%. Conversely, in summer days the hourly average was the lowest compared to another season with 25.8%, which ranged between 21.9% and 29.8%. In the intermediate seasons (spring and autumn), the measured hourly averages were 41.9%, with a range between 40.1% and 45.3%, and 35.7%, which ranged between 34.6 and 36.3, respectively. The maximum hourly RH recorded in the monitored houses was 89.5% in (05:00:00 in 2018-04-28) and the minimum is 9.5% in (17:00:00 in 2017-04-30). Table 7-2 summarises the hourly outdoor RH measurements.

In addition to the significant variation showed by hourly RH among seasons, the daytime patterns of hourly RH in each season also observed a significant variation, as shown in Figure 7-2. In all seasons, the outdoor RH increased during the night hours to reach the highest value at 6 AM. At 7 AM, the RH starts to decrease to reach its lowest value at 4 PM and then starts to rise again till 6 AM. The highest value of RH during each day is measured between 12 noon to 8 PM. Moreover, the band of variation of each hour during the intermediate seasons' (spring and autumn) days was wider than in winter and summer, where the standard deviation of hourly RH was 14.9% and 10.7%, respectively. However, the standard deviation of hourly RH during winter and summer seasons was 10.6% and 6.8%, respectively. These results reveal that in summer the AT records its highest values, while the RH reaches its lowest values, and vice versa, in winter. In addition, during the day, the hourly AT pattern was inversely proportional to the hourly RH pattern for all seasons. Detailed figures of the hourly outdoor RH patterns for the rest case studies during the target monitoring period are presented for different seasons in Appendix C. However, presenting these patterns cannot show the frequency of temperature and relative humidity events of hours with the comfortable thermal environment. Therefore, this study used both Humidex indices and an Olgyay diagram to analyse the ambient parameters within comfort ranges.

7.2.2 Evaluate ambient conditions

7.2.2.1 humidex indices

The monitored period was categorised seasonally to investigate the comfortable thermal environment ranges for each season. Analysing the hourly AT in winter resulted in 14% of the total winter's hourly measurements in all case studies were referred to as comfortable based on Humidex indices. The rest of the measurements in winter 85% were located under 20°C, the lower limit of the comfortable zone. In spring, around 50% of the AT measurements were described as hours with "comfortable", 31% with "some discomfort", while "great discomfort" was 2% with the highest value of 44.5°C measured at 4 PM on May 28, 2018. Summer's hourly readings were the hardest, where they showed that 2% of the readings located within comfortable band, 55% of these readings

Table 7-2. Statistical summary of the hourly outdoor RH

Category	**Sub-category**	**Case**						**Mean**
		H1	**H2**	**H3**	**H4**	**H5**	**H7**	
Winter (Dec–Feb)	Mean	49	46.9	48.2	49	51.6	48.3	48.8
	St.D	10.9	12.6	9.9	11.6	9.8	8.5	10.6
	Max	81.5	86	78	81.5	80.5	72	86
	Min	19	19	20	15.5	21	22.5	15.5
Spring (Mar–May)	Mean	40.1	42.8	40	41.7	45.3	41.3	41.9
	St.D	15.3	15.2	14.9	15.9	15.9	12	14.9
	Max	80	87	84	88	89.5	73	89.5
	Min	10.5	12	13	9.5	12.5	15.5	9.5
Summer (June–Aug)	Mean	21.9	29.8	24.3	24.5	28.7	25.4	25.8
	St.D	5.9	7.2	5.7	6.4	10.3	5.4	6.8
	Max	45	54.5	47.5	49	58.5	44.4	58.5
	Min	10	13.7	13	10	14	13.9	10
Autumn (Sep–Nov)	Mean	34.6	36.3	35.2	35.6	36	36.2	35.7
	St.D	11.2	11.8	10.4	11.2	9.9	9.6	10.7
	Max	65	78.5	68	67.5	63	63.5	78.5
	Min	12.5	13.3	14.5	12.5	16.5	16	12.5

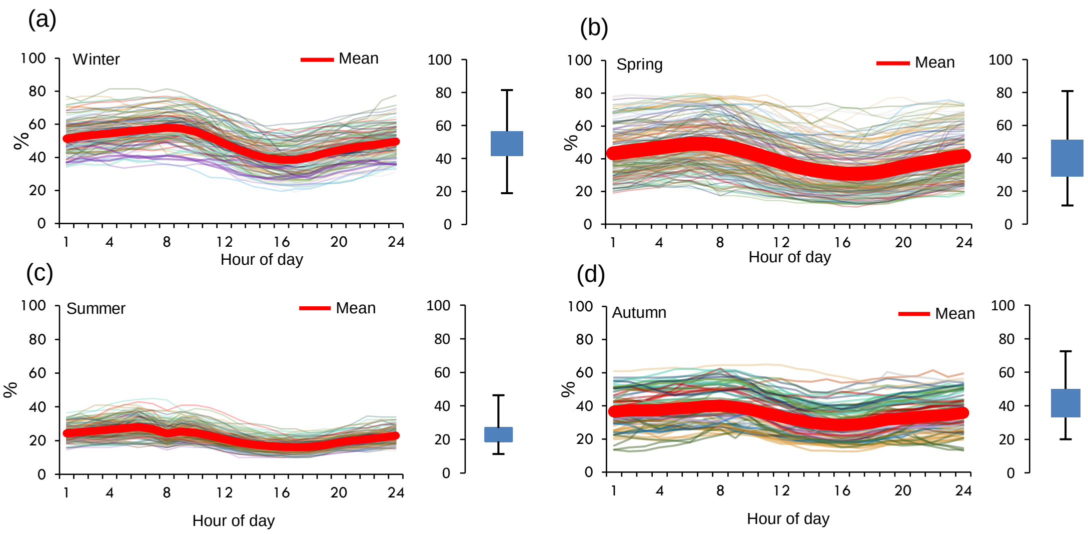


Figure 7-2. Outdoor hourly RH for H1 case study during the target monitoring period over the seasons. (a)-(d) Hourly RH over the seasons.

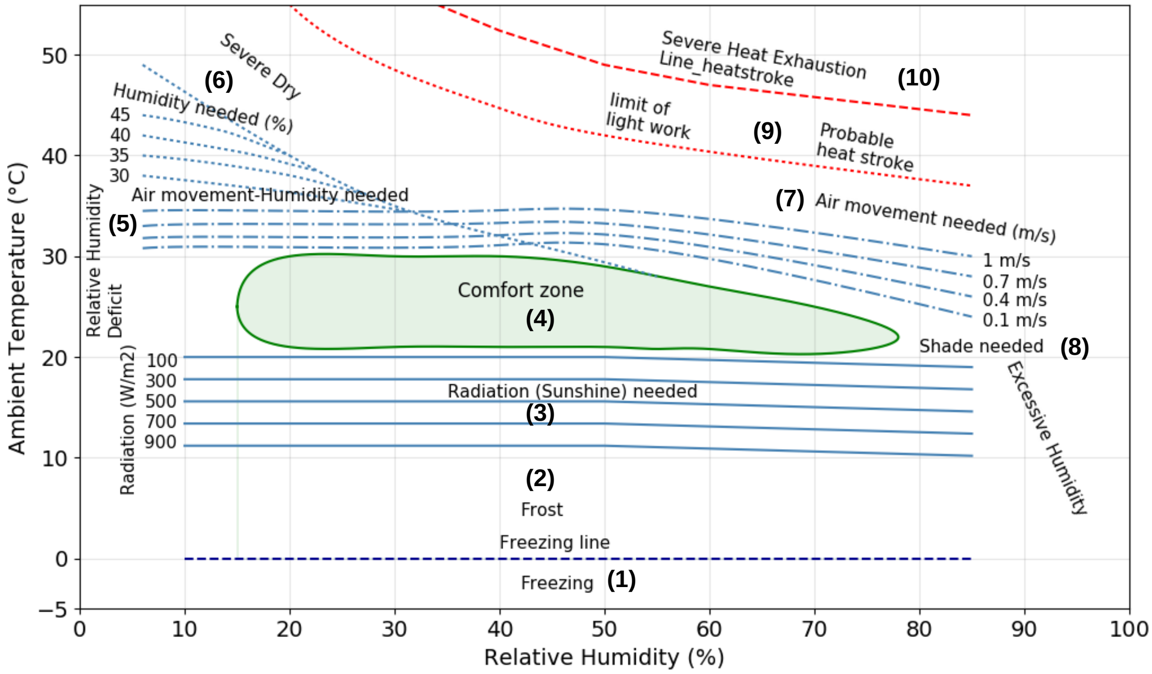
were classified as "some discomfort", 37% with "great discomfort", while "dangerous" was 6% with the highest value of 49.9°C measured at 12 noon on August 4, 2017. A total of 38% of autumn's hourly readings were referred as comfortable, 39% with "some discomfort", "great discomfort" was 9% with the highest value of 44.9°C measured at 1 PM on September 21, 2017, while "dangerous" was 1% with the highest value of 46.7°C measured at 1 PM on 4 September 2017. These results reveal that the most uncomfortable season with 98% within some discomfort, great discomfort and dangerous was in summer due to the high temperatures. Table 7-3 shows the analysis of Humidex indices of all six case studies.

Table 7-3. Humidex results of hourly ambient temperature.

Category	Sub-category	Case (%)						Mean
		H1	H2	H3	H4	H5	H7	
Winter (Dec–Feb)	G1[1]	6	24	15	17	9	12	14
	G2	0	3	0	0	0	0	1
	G3	0	0	0	0	0	0	0
	G4	0	0	0	0	0	0	0
	G0	**94**	**73**	**85**	**83**	**91**	**88**	**85**
Spring (Mar–May)	G1	**49**	**48**	**49**	**49**	**50**	**45**	**48**
	G2	31	31	35	30	30	29	31
	G3	3	2	3	3	2	1	2
	G4	0	0	0	0	0	0	0
	G0	17	19	13	18	18	25	18
Summer (June–Aug)	G1	0	4	1	1	2	1	2
	G2	51	64	45	56	63	54	56
	G3	41	28	46	34	35	42	38
	G4	8	4	8	9	1	3	6
	G0	0	0	0	0	0	0	0
Autumn (Sep–Nov)	G1	39	38	38	38	38	39	38
	G2	36	35	42	38	42	42	39
	G3	10	12	10	10	6	7	9
	G4	0	0	0	0	0	0	0
	G0	15	15	10	14	14	12	13
Notes: [1] G1: comfortable, G2: some discomfort, G3: great discomfort, G4: dangerous and G0: the temperature is less than 20°C.								

7.2.2.2 Olgyay chart

This section will evaluate outdoor comfort as a combination of the high temperatures and the RH using the Olgyay diagram. This section presents the results of the plots and frequency values of the monitoring data that were captured in the six case studies. Olgyay's bioclimatic chart Figure 7-3, developed in the 1950s, was one of the earliest attempts to specify different strategies at different combinations of RH and AT. Olgyay's chart sets the comfort zone between 20 and 30°C. The level of comfort is applicable to outdoor spaces and is divided into 10 bioclimatic and main design strategies, while the comfort zone is shown at the centre of the chart. The chart shows the effect of climatic factors such as the mean radiant temperature, wind speed, and solar radiation on thermal comfort. Above the lower boundary of the zone, shading is necessary to maintain a reasonable level of comfort. Up to 10°C below the comfort zone, comfort can be retained provided that there is enough solar radiation to offset the decrease in temperature. Likewise, to retain comfort up to around 10°C above the zone, wind speed can offset the increase in temperature. Evaporative cooling is another mean to retain



#	Bioclimatic & main design strategy zones		
1	Freezing	6	Humidity needed
2	Frost	7	Air movement needed
3	Radiation (sunshine) needed	8	Excessive humidity (shade needed)
4	Comfort	9	Probable heat stroke (limit of light work)
5	Air movement -humidity requirement	10	Severe heat exhaustion

Figure 7-3. Olgyay chart with the bioclimatic and main design strategy zones (source (Olgyay, 1963; Roshan, et al., 2017)).

comfort at high-temperature values but at low humidity.

The climatic chart is used in this study to investigate the frequency of occurrence of each of the bioclimatic classes based on the reported data for each case study. In addition, in this climatic diagram, the climatic comfort is determined by setting the top and bottom of the comfort borders as non-comfort zones. The frequency of occurrence of each of the bioclimatic conditions of the various six homes is presented in Table 7-4. Moreover, plotting the monitoring data of both bioclimatic parameters (AT and RH) on this diagram will help to define the dominant climatic frequency in each of the case studies. The occurrence of the bioclimatic conditions for different seasons of case study H1 is plotted and presented in Figures 7-4 and 7-5. Detailed figures of the distribution of hourly bioclimatic conditions (AT and RH) for different seasons during the target monitoring period for the rest case studies are plotted and presented for different seasons in Appendix C.

The findings of plotting the monitoring data based on the season revealed that the frequency of occurrence of each bioclimatic condition of the various six homes was as follows: in winter, the located hours with comfort zone was 8%, while 78% of the captured readings in all case studies ranged within the thresholds of radiation requirement, where more radiation should be provided to move the data up for climate comfort to be provided. However, in this season, there is no report of freezing, with the lowest event rate of 1%, while frosting included 8% of the frequencies. The hourly data of bioclimatic parameters in spring showed that about 53% of events have the potential for entering the comfort zone. Moreover, 34% of hourly data in spring required radiation to be in the comfort zone, while 12% was within zone 5, where more wind and humidity are required to move the data down to be within the comfort zone. In the summer season, just 8% located within comfort zone, around 59% of the bioclimatic measurements was in zone 6, where more humidity is required to move the data down to the comfort zone boundaries, 28% was in climate zone 5, where more wind and humidity are required to move the data down to be within comfort zone, while 4% of data in summer located within the severe dry" zone, where the ambient temperature value is higher than 45°C, while the RH value is less than 20%. Plotting the bioclimatic measurements for autumn revealed that 52% were referred as comfortable, 25% located within the radiation requirement zone, 21% located within windy-humidity requirement boundaries, while just 3% of captured data was in humidity requirement zone.

The results of analysing the monitoring data for both AT and RH parameters by utilising the bioclimatic zones for the Olgyay diagram matched the previous studies regarding this climate classification of Iraq, especially the Köppen climate classification of Iraq (see subsection 2.4.1). The results of this study showed that the values of hourly data in winter were typically characterised by cold, where providing of radiation requirement for ~80% of hours can provide the potential for the occurrence of comfort and temperature reaches freezing on some nights. However, in the case of summer, the climate is characterised by extremely hot and dry, where around 90% of the bioclimatic readings in summer were characterised as very hot and extremely dry, with maximum daily temperatures between 45–50°C in July and August, with large diurnal temperature variation. It is worth noting that in transitional or intermediate seasons the distribution of case studies comfort hours in the Olgyay diagram was almost similar in both seasons regarding the concentration of data, where more than 50% of hourly measurements were referred as comfortable in both seasons. However, the rest of the data for these seasons was divided between zone 3 radiation requirement and zone 5 windy-humidity requirement, which emphasise that these seasons represent intermediate seasons between winter and summer.

Table 7-4. The occurrence of each of the bioclimatic conditions of the various six homes for different seasons during the monitoring period according to the bioclimatic zones of the Olgyay chart.

		Cases (%)																											
		H1				**H2**				**H3**				**H4**				**H5**				**H7**				**Mean**			
#	**bioclimatic and main design strategy zones**	**W** [1]	**S**	**M**	**A**	**W**	**S**	**M**	**A**	**W**	**S**	**M**	**A**	**W**	**S**	**M**	**A**	**W**	**S**	**M**	**A**	**W**	**S**	**M**	**A**	**W**	**S**	**M**	**A**
1	Freezing					1				1				1								1				1			
2	Frost	19				10				10				12				9				14				11			
3	Sunshine needed	77	32		27	67	35		25	83	26		28	76	34		24	87	35		24	78	40		21	78	34		25
4	Comfort	4	56	6	53	20	45	15	46	6	61	4	53	11	51	9	53	4	55	8	52	7	47	5	55	8	53	8	52
5	Air movement - humidity needed		11	27	19	2	20	30	22		13	24	18		14	30	18		10	35	24		11	29	23	2	12	28	20
6	Humidity needed		1	67	1			55	7			72	1		1	61	5			56			2	66	1		1	63	3
7	Air movement needed																			1								1	
8	Excessive humidity (shade needed)																												
9	Probable heat stroke (limit of light work)																												
10	Severe heat exhaustion																												

Note: [1] W: Winter, S: Spring, M: Summer, and A: Autumn.

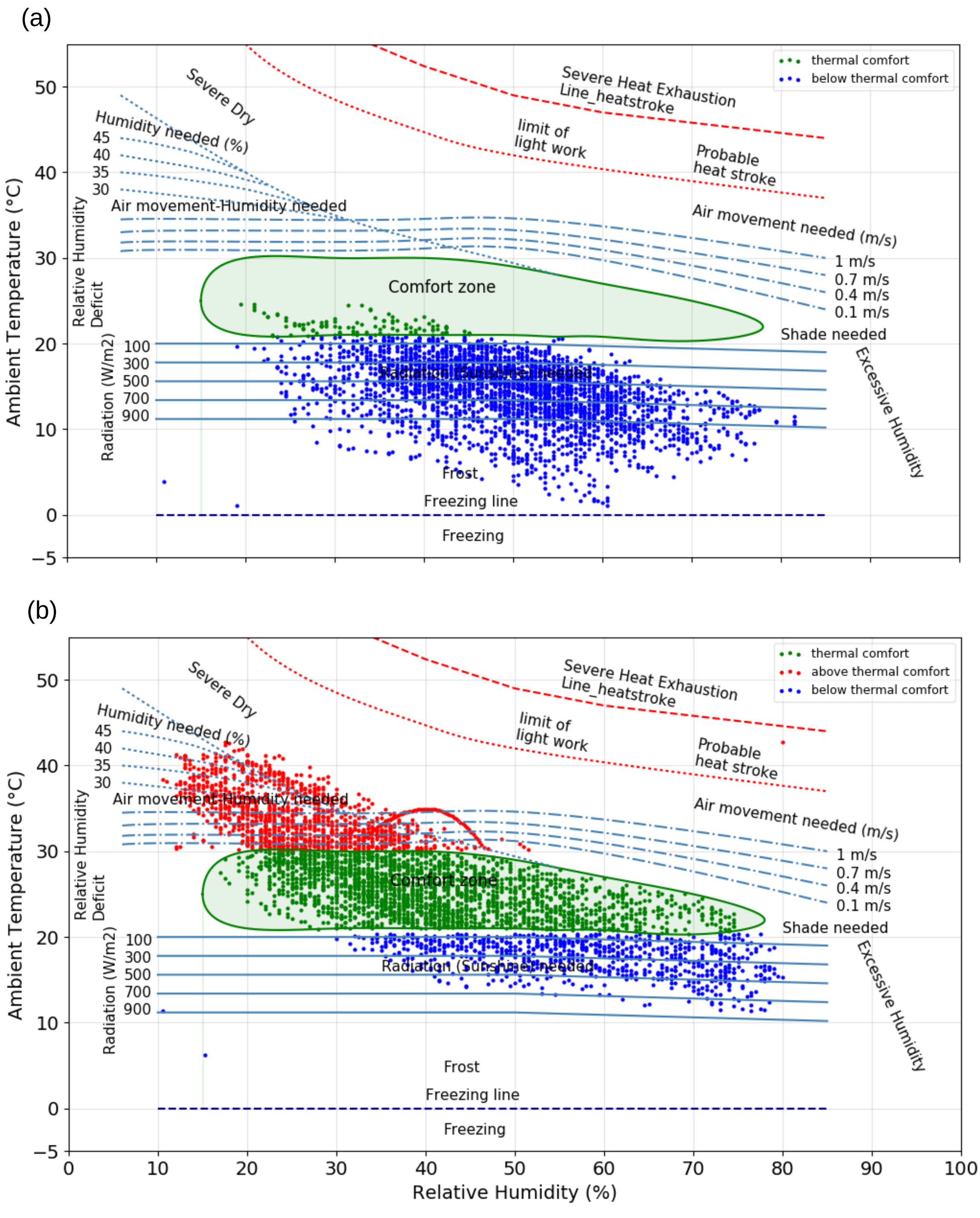


Figure 7-4. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H1 case study during the target monitoring period. (a) winter, (b) spring. The results showed the more radiation and sun sunshine are needed in winter.

(c)

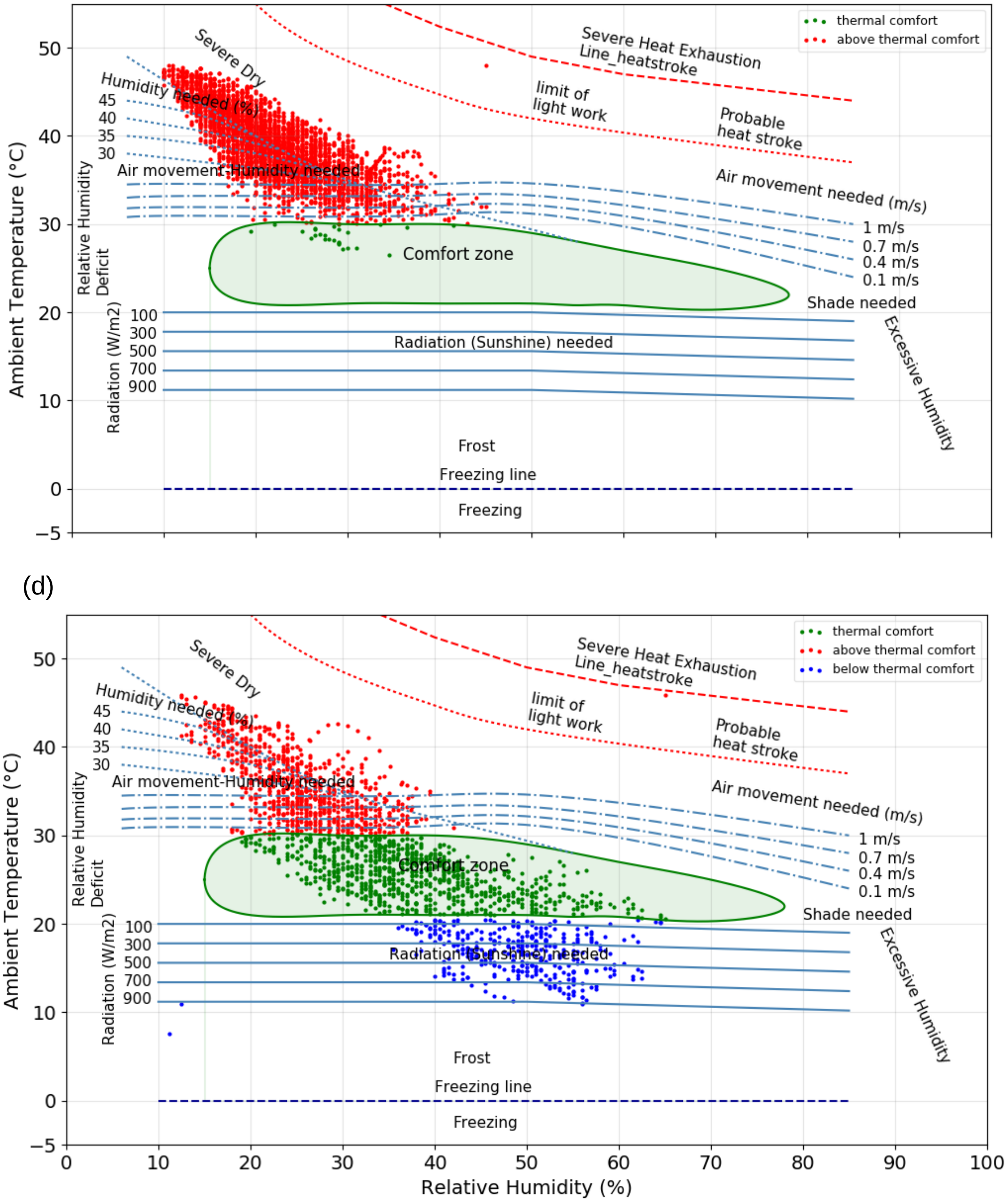


Figure 7-5. Distribution of hourly ambient conditions (AT and RH) for summer and autumn seasons of H1 case study during the target monitoring period. (c) summer, and (d) autumn. The results showed the air movement and humidity are needed in summer.

Another important issue revealed from analysing the outdoor weather parameters is the significant diurnal temperature differences, which should be taking into consideration in studies related to energy use and indoor thermal environment. In conclusion, with these extreme climate conditions, high energy use is required for cooling or heating the homes to reach comfortable indoor environment conditions.

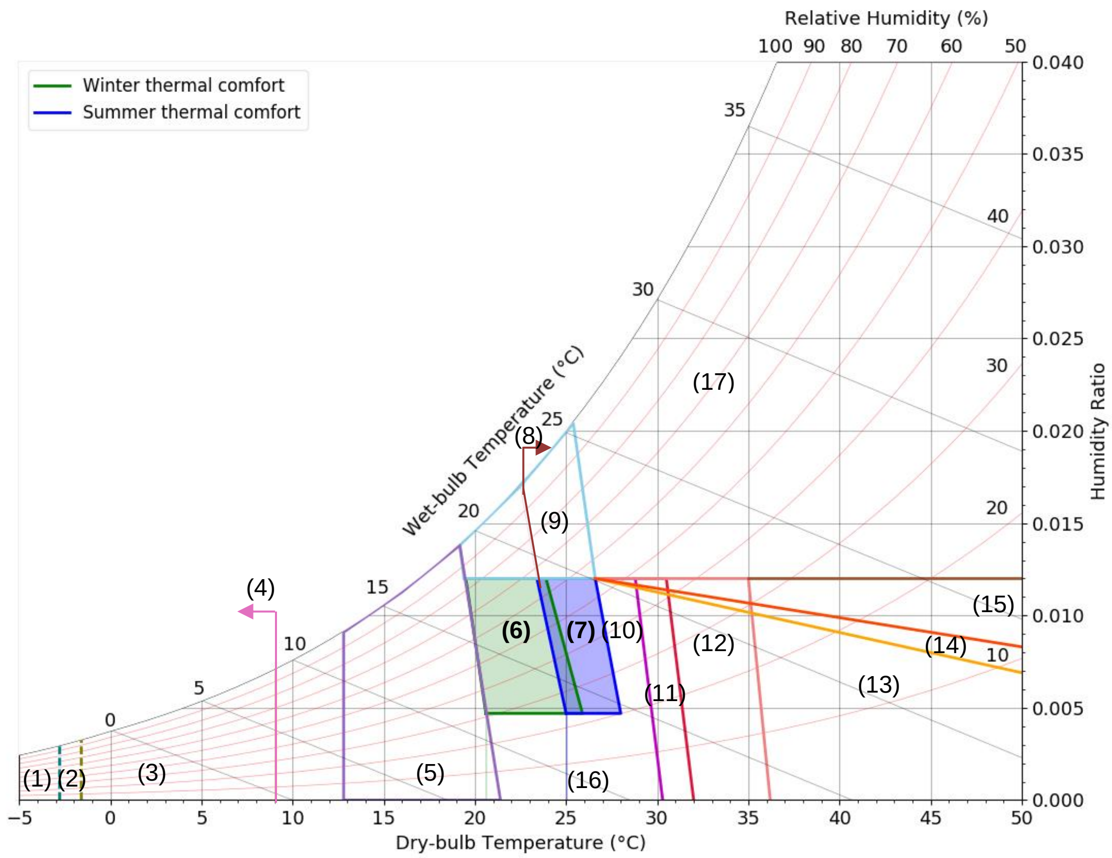
The next section will analyse, present and discuss the indoor environmental parameters to investigate how well the indoor thermal environment affected by these local extreme weather conditions and suppressing demand of energy over the year. This will help to provide a better understanding regarding the impact of the suppressed energy demand and ambient conditions on indoor thermal environment, especially in summer.

7.3 Indoor thermal environment

The most important aspect of monitoring the outdoor weather conditions results is that the cold period tends to be shorter than the warm and hot period. In Iraq, the extreme climate conditions and their variation over the year have indeed complicated the conditions for people with regard to comfort in such an environment. The hot arid conditions in summer, for example, requires extensive use of air conditioning systems to provide a comfortable indoor thermal environment, which is what the households do over the summer months (as discussed in subsections 4.3.5 and 5.2.5). However, achieving and maintaining the satisfactory level of indoor thermal environment would be even more challenging with suppressed energy demand, which distorts the energy use behaviour due to the insufficiency of supply. This leads to the loss of control of the indoor thermal environment, which is supposed to be under control as long as the mechanical systems are used whether for cooling or heating. After analysing the hourly energy use and suppressing demand, the hourly measurements of the outdoor weather parameters over the target monitoring period and for different seasons will be discussed. This section focuses on investigating the indoor thermal environment by employing the hourly measurements of indoor environmental parameters (i.e. DBT and RH) captured during the same monitoring period in occupied homes. This comprehensive study might help to provide an in-depth understanding of the indoor thermal environment of domestic building and enable us to understand to what extent it has been affected by both extreme climate conditions and the suppressed energy demand.

Subsection 3.3.9.3 reviewed the methods that were used to evaluate the thermal comfort level in spaces. One of these methods depends on the relationship between dry-bulb temperatures DBT against relative humidity RH and uses the psychometric chart to analyse the local climatic conditions at a given place. For example, Givoni's bioclimatic diagram of buildings was designed to improve the interior condition of a building based on the climatic condition of the site and with regard to changes in temperature and relative humidity (Givoni, 1969). The limitations of Givoni's diagram were investigated by Watson and Labs (Watson, 1983). The psychrometric chart has emerged as another widely used bioclimatic diagram (Al-Azri, et al., 2013). Figure 7-6 shows a psychrometric chart, with basic required design strategies to achieve comfortable indoor thermal environment.

This study has used this chart to investigate the frequency of occurrence of each of the bioclimatic zones based on the measured data for the monitored spaces in each case study. On the left-hand side of the comfort zone, heating is needed to restore comfort using either solar or mechanical heating. The high thermal mass effect is provided by heavy construction material that helps absorb heat and can be reversed in direction overnight (Szokolay, 2004). If the climate is hot and dry, then night ventilation will help by releasing heat through windows, assisted by fans if necessary. At high temperatures, mechanical air conditioning is necessary to maintain a habitable environment within buildings (Al-Azri, et al., 2013). Because of the broad diversity in the governing parameters that affect comfort, there has been no exact definition of a comfort zone. However, there is a range of humidity and temperature values within which the vast majority of people will feel thermally comfortable. Different authors might vary slightly in their delineation of the boundaries of a thermal zone, but they all agree on a vast common portion. For example, the comfort zone set by (ASHRAE, 2009) assumes no consideration to people's acclimatisation to different climates. According to ASHRAE standard 55, thermal neutrality is defined as the indoor thermal index value corresponding with a mean vote of neutral on the thermal sensation scale. Earlier works (Humphreys, 1978; Auliciems, 1981) defined temperatures at which thermal neutrality is achieved and is correlated to the external DBT. Comfort is achieved at these temperature values provided that other factors such as humidity and clothing are satisfied.



#	Design strategy	#	Design strategy
1	Heating, add humidification if needed (conventional heating)	10	Fan-forced ventilation cooling
2	Passive solar direct gain high mass or (active solar heating)	11	Natural ventilation
3	Passive solar direct gain low mass	12	Cooling through high thermal mass
4	Wind protection of outdoor spaces	13	Direct evaporative cooling
5	Internal heat gain	14	Two-stage evaporative cooling
6	Winter comfort	15	Cooling through high thermal mass with night cooling
7	Summer comfort	16	Humidification only
8	Sun shading of windows (solar protection)	17	Cooling, add dehumidification if needed (Air-conditioned)
9	Dehumidification only (Cooling natural and mechanical ventilation)		

Figure 7-6. A psychrometric chart with winter and summer comfort zones, as well as the basic, required design strategies to achieve indoor thermal environmental comfort (ASHRAE 55, 2004).

Bioclimatic zones have been identified based on ASHRAE standards 55- 2004 using the climate data of Baghdad/Iraq, which is available as an EPW weather file at the EnergyPlus Climate Data site. The name of each bioclimatic zone refers to the strategy that should be applied to move the data which are located within the zone to the comfort zones. For example, if the plotted data are located within bioclimatic zone 10, then the occupants only need to provide ventilation cooling by using fans. Moreover, a single strategy could be used rather than many other strategies to achieve an acceptable level of a comfortable thermal environment. The strategy of the bioclimatic zone (14), for example, could be used to move the data in bioclimatic zones 10, 11, 12, and 13 to within the comfortable thermal environment band. Moreover, these bioclimatic zones were gathered in four main required design strategies to ease understanding of the indoor thermal environment of the monitored spaces in the selected homes. The first design strategy is the heating strategy, which includes the zones from 1 to 5, where more heating is required to achieve a satisfactory level of comfortable indoor thermal environment. The second strategy includes the comfort zones for winter and summer 6 and 7, while zones 8 and 9 are included in the third strategy, which refers to the environment conditions with a high level of humidification, where cooling and dehumidification are required. Finally, cooling and humidification include zones 10 to 17. The boundaries of this strategy refer to the situation where more evaporative cooling and mechanical cooling are required to maintain an acceptable level of internal comfortable thermal environment, especially in the hot period (summer season).

As mentioned in subsection 3.3.8, that the three indoor environmental loggers in each case study were deployed in the living room and the kitchen on the ground floor, while a third logger was installed in the bedroom on the first floor. The measurements of each space will be analysed separately to capture the indoor thermal environment and link it with outdoor weather conditions, energy use and suppressed demand for the same period. In this study, the hourly environmental data of the six selected case studies were analysed to evaluate the occurrence of each strategy in these occupied homes, as shown in the next section.

7.3.1 Evaluate indoor thermal environment

The hourly readings captured during the monitoring period were plotted seasonally. Table 7-5 shows the findings of all the monitored spaces in each case study for each season. In winter months, DBT and RH were within the comfort range in kitchens for 57% of the time. In contrast, the parameters were within the comfort range in living rooms and bedrooms for 42% and 28% of the time respectively. The temperatures were below comfort threshold and required heating for the remaining time; i.e. 43%, 58% and 72% of the time in kitchens, living rooms and bedrooms, respectively. Internal heat gain from cooking and food preparation in kitchens may explain no heating required in the kitchens most of the time in winter, while for living rooms, the heating systems were used most of the winter times due to the continuous occupancy compared to the bedrooms, where they were heated just during the occupied period of the day. In addition, there is no report of dehumidification in winter, with a rate of 0% has been reported. Therefore, in the winter months of December to February, heating systems would be needed/used in the spaces just to keep them thermally acceptable during their occupation. In March, April and May (months of spring season), DBT and RH were within comfort zone bounds in living rooms, kitchen, and bedrooms, for 53%, 44% and 40% of the time respectively. During these months, 33%, 45% and 43% of DBT and RH measurements were above the comfort range, where evaporative and mechanical cooling needed to provide the satisfactory level of comfortable thermal environment in living rooms, kitchens, and bedrooms, respectively.

For the summer months, where the ambient temperature is high and its diurnal difference is significant, the majority of the hourly indoor measurements of DBT and RH were above comfort threshold, where evaporative and air conditioning were necessary for most of the summer months in the selected case studies with 86%, 99%, and 96%, of the time in living rooms, kitchens, and bedrooms, respectively. Plotting the hourly data of DBT and RH in autumn showed that about 44%, 24%, and 38% of the readings were referred as comfortable in living rooms, kitchens, and bedrooms, respectively. In contrast, the parameters were above comfort threshold, which for the 49%, 75%, and 57% of the time in living rooms, kitchens, and bedrooms, respectively. Figures 7-7 and 7-8 show the distribution of the hourly readings of DBT and RH in the monitored spaces (living room, kitchen, and bedroom) of the case study (H1) for different seasons. Detailed figures of the distribution of the indoor hourly average of (DBT and RH) for different seasons during the target monitoring period for the monitored spaces of the rest case studies are plotted and presented in Appendix C.

This section investigated the indoor thermal environment by analysing the hourly measurements of the environment conditions in specific spaces of the case studies. It is clear that although both heating and cooling methods were used in the monitored spaces, around half of the measurements in living rooms and kitchens of data for winter needed using heating strategies to maintain the indoor environment within a comfortable level, while the rest of the data were located within comfort zones thresholds. In the bedrooms, which are located on the first floor, the captured data revealed that more than 70% of the time the bedroom was within the cold bioclimatic zone, which reflected more need for heating systems, while around 30% were described as comfortable. For transitional or intermediate seasons (spring and autumn), the measurements in all spaces showed almost the same patterns with slight differences. Around half of time in these seasons were considered to be comfortable, while the second half reflected the need to utilise evaporative and cooling systems to provide the required indoor thermal environment in these spaces. However, the worst scenario of indoor thermal environment occurred in the summer period, where the majority (more than 90%) of captured hourly data in all monitored spaces located within climatic zones reflect a significant lack of indoor thermal environment, requiring extra energy to cool the atmosphere to the satisfaction of the occupants.

After separately investigating, analysing and discussing the energy use and suppressed demand, the profile of the ambient conditions and indoor environment conditions during the target monitoring period. The next step is devoted to investigating the impact of changing the outside weather conditions on the seasonal trend of energy use by investigating the relationship between the energy use characteristics and the ambient weather conditions. This will be followed by highlighting the influence the current situation of energy use on the indoor thermal environment through calculating the correlation between these parameters, as well as to answer the following questions—How well does the indoor thermal environment relate to the local ambient conditions and suppressed energy demand? And, how do the current energy use interact with both ambient conditions and indoor environment conditions?

Table 7-5. The occurrence of each design strategy of the case studies for different seasons during the monitoring period based on psychrometric chart zones.

Category	**Sub Category (%)** [1]	**Case**																		**Mean**		
		H1			**H2**			**H3**			**H4**			**H5**			**H7**					
		LR[2]	KS	BR	LR	KS	BR	LR	KS	BR	LR	KS	BR	LR	KS	BR	LR	KS	BR	LR	KS	BR
Winter (Dec–Feb)	Heating	62	60	87	48	12	23	21	30	78	17	45	67	98	61	91	98	45	83	**57**	**43**	**72**
	Comfortable	37	39	13	52	88	76	78	69	22	83	55	33	2	39	8	2	53	14	43	57	28
	Cooling + dehumidification	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cooling + humidification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Spring (Mar–May)	Heating	1	1	5	1	0	2	0	0	1	0	1	0	12	3	6	28	45	83	7	8	16
	Comfortable	61	39	57	50	40	45	54	33	34	60	48	47	52	48	42	42	53	17	**53**	**44**	**40**
	Cooling + dehumidification	10	1	1	8	3	1	12	1	0	1	0	0	4	15	4	4	0	0	7	3	1
	Cooling + humidification	28	59	37	41	57	52	34	66	65	39	51	53	32	34	48	26	2	0	33	45	43
Summer (June–Aug)	Heating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Comfortable	12	0	13	1	1	7	28	0	0	8	0	1	15	4	2	1	0	0	11	1	4
	Cooling + dehumidification	8	0	0	5	0	0	2	0	0	0	0	0	1	0	0	3	0	0	3	0	0
	Cooling + humidification	**80**	**100**	**87**	**94**	**99**	**93**	**70**	**100**	**100**	**92**	**100**	**99**	**84**	**96**	**98**	**96**	**100**	**100**	**86**	**99**	**96**
Autumn (Sep–Nov)	Heating	1	4	10	1	0	0	0	0	9	0	9	1	4	4	8	15	0	7	4	3	6
	Comfortable	63	21	54	35	20	62	46	23	26	34	21	34	48	35	32	40	24	20	44	24	38
	Cooling + dehumidification	7	0	0	4	0	0	9	0	0	0	0	0	0	1	0	1	0	0	4	0	0
	Cooling + humidification	29	75	36	60	80	38	45	77	68	66	79	66	48	60	60	44	76	73	**49**	**75**	**57**

Note: [1] Heating strategies: zones (1-5), Comfortable: zones (6 and 7), Cooling + dehumidification strategies: zones (8 and 9), and Cooling + humidification: zones (10-17). [2] LR: Living Room, KS: Kitchen spaces, and BR: Bedroom.

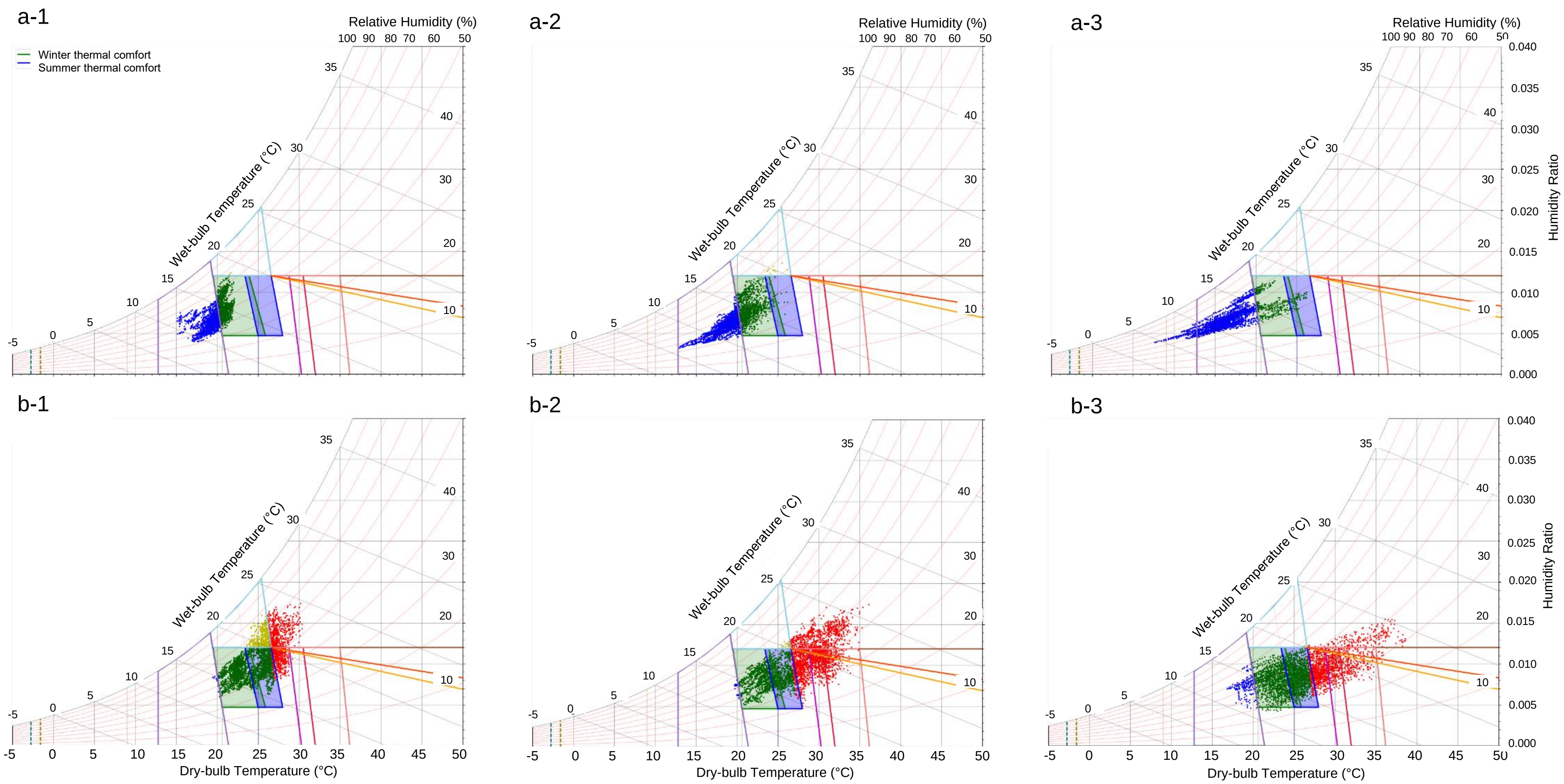


Figure 7-7. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in the living room, kitchen and bedroom of H1 case study for winter and spring. (a1, a2, a3) the indoor DBT and RH recorded in the living room, kitchen and bedroom for winter, (b1, b2, b3) the indoor DBT and RH recorded in the living room, kitchen and bedroom for spring.

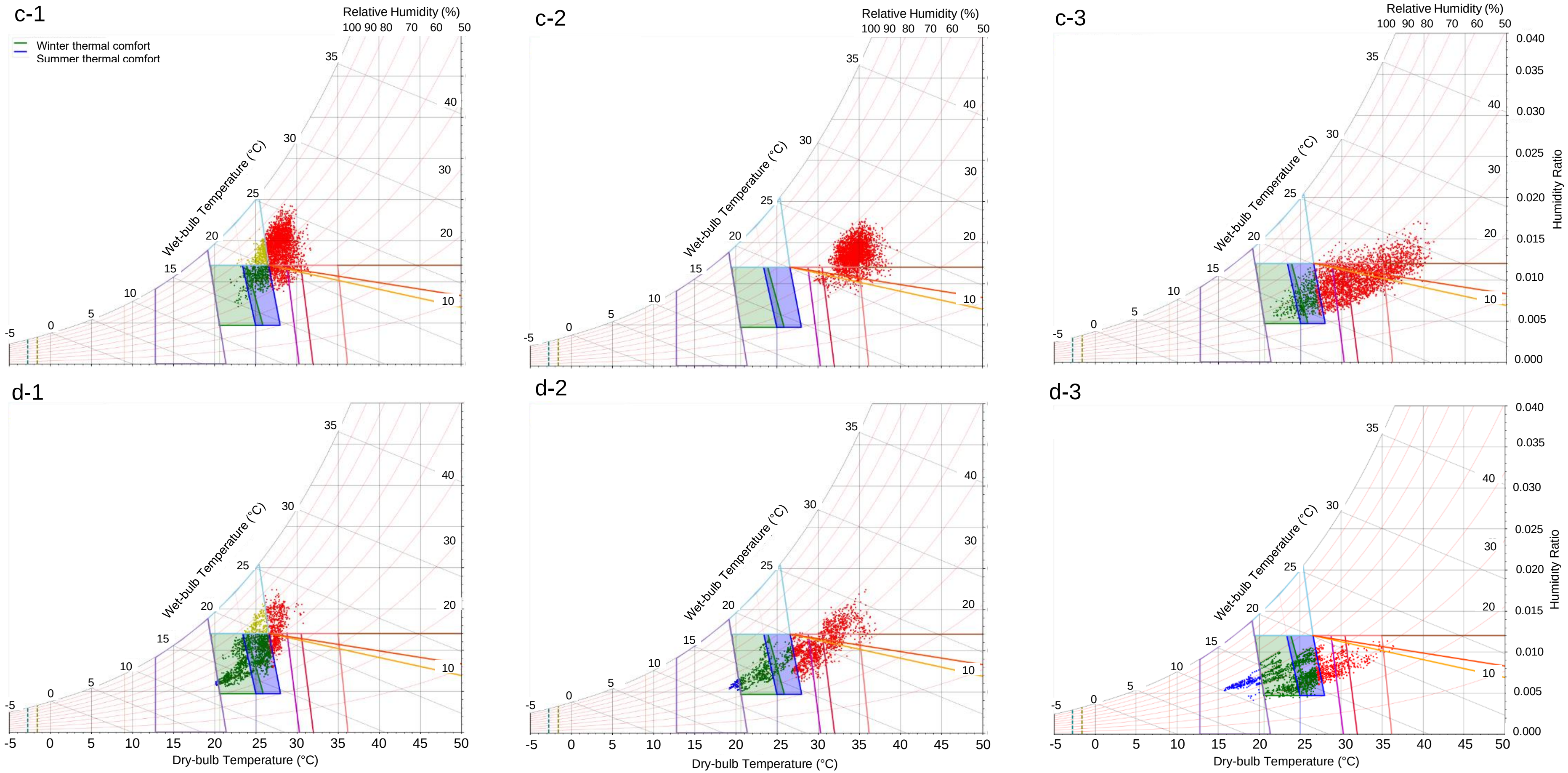


Figure 7-8. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in the living room, kitchen and bedroom of H1 case study for summer and autumn. (c1, c2, c3) the indoor DBT and RH recorded in the living room, kitchen and bedroom for summer, (d1, d2, d3) the indoor DBT and RH recorded in the living room, kitchen and bedroom for autumn.

7.4 The relationship between monitored parameters

This section focuses on investigating the relationship between indoor environment conditions, outdoor weather conditions, energy use and suppressed energy demand of the selected case studies.

7.4.1 Ambient conditions vs indoor thermal environment

For the current study to investigate how well the indoor environment conditions thermally respond to the local outdoor weather conditions, the correlation between these parameters was studied.

From the results, it can be found that both AT and DBT displayed a seasonal pattern for both indoors and outdoors, with a slight difference during the summer months (see Figure7-9). In contrast, indoor RH follows a similar seasonal pattern, but outdoor RH fluctuates with no consistent pattern (Figure7-10). Tables 7-6 and 7-7 indicate the relationship coefficients of the measured indoor environment conditions (DBT and RH) with outdoor weather conditions (AT and RH) for the six case studies in Baghdad for different seasons. The low p-values presented to confirm the high significance of the performed analyses. Seasonally, the *R* values revealed that the indoor temperature in all monitored spaces showed a strong linear correlation with the hourly average of ambient temperature in spring and autumn, where the *R* values ranged between 0.59 and 0.92. The hourly average of AT in these seasons was between (26.1 and 28.8°C) and the hourly average of the indoor BDT was almost within the same range. However, the relationship between indoor DBT and AT varied in winter season among all the monitored spaces, with *R* values ranging from 0.17 to 0.89, with an hourly average of AT 15.7°C, while the hourly average of indoor DBT in all spaces ranged between 16 and 22°C. The relationship was weaker in the summer season, with *R* values ranging from 0.02 to 0.74. Moreover, the weak correlation between indoor DBT and AT in summer varied from one space to another. The pattern of indoor DBT in the living rooms, for example, showed that indoor DBT observed a slight consistency from May to November, although the AT in summer months (June to August) was at its highest level, (Figure7-9, a). This result could be attributed to using the cooling systems (air conditioner and evaporative cooling) for more than 20 hours/day, as illustrated in subsection 5.2.5. However, the seasonal pattern of the hourly average of the indoor DBT in the kitchens was the worst (Figure7-9 (b)), where the majority of data for this space was either below the comfort zone (in winter) or above the comfort zone (in summer), as shown in subsection 7.3.1.

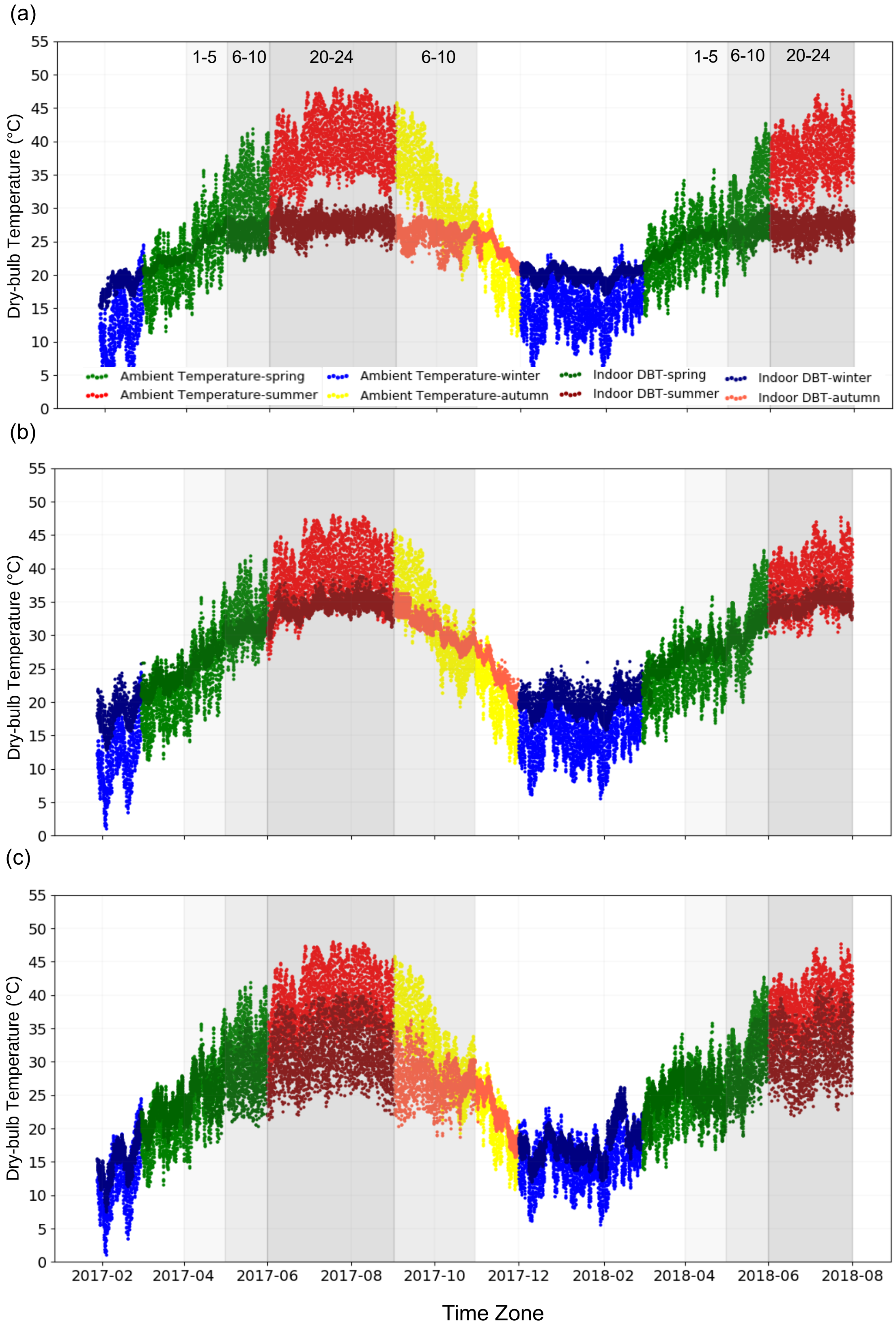


Figure 7-9. Scatter plot of hourly AT and indoor hourly DBT in (a) living room, (b) kitchen, and (c) bedroom with the daily time scales of using cooling system of H1 case study for the target monitoring period.

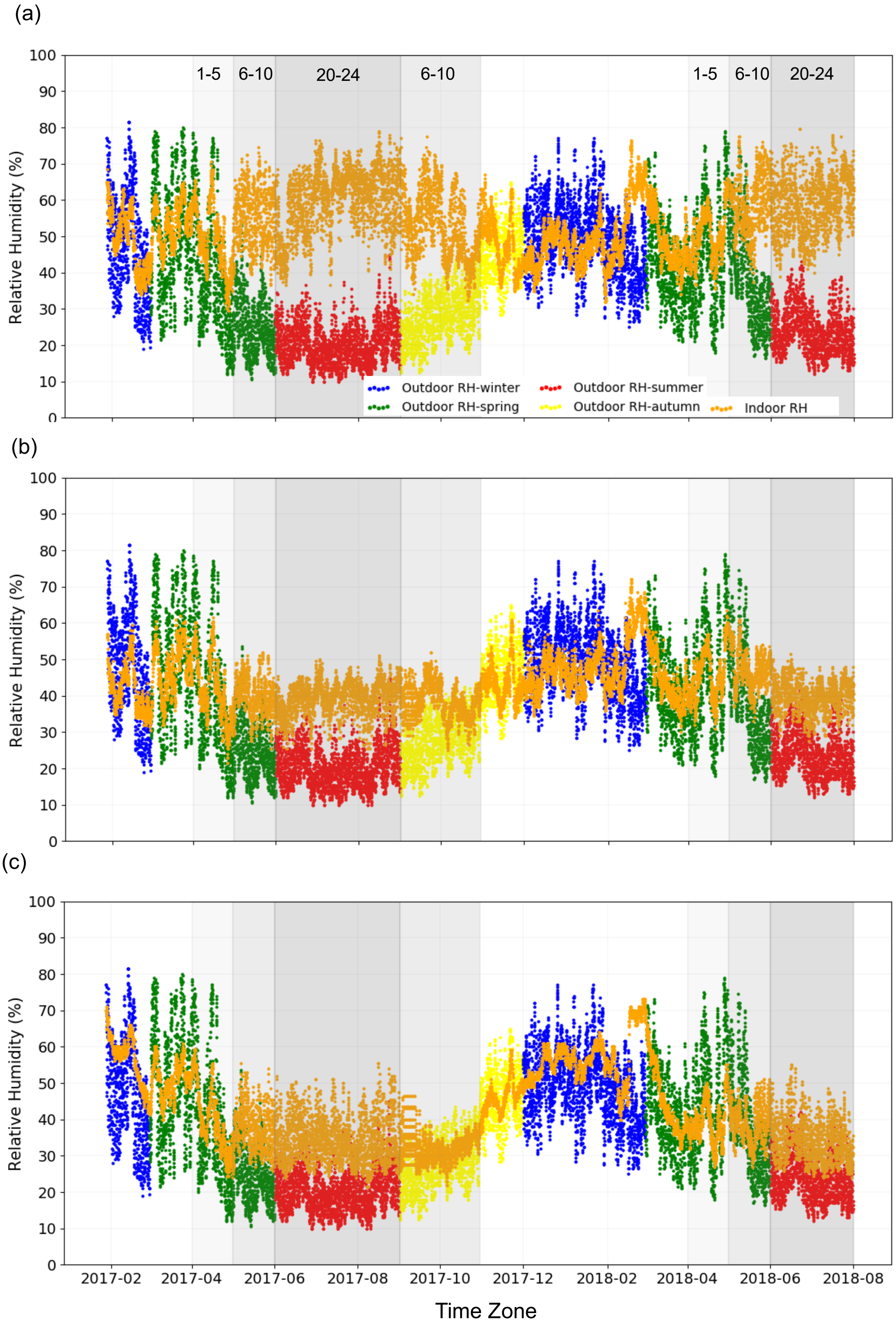


Figure 7-10. Scatter plot of outdoor and indoor hourly RH in (a) living room, (b) kitchen, and (c) bedroom with the daily time scales of using cooling system of H1 case study for the target monitoring period.

Table 7-6. Statistical summary of parameters in the monitored spaces for different seasons. (a) Pearson correlation of AT vs indoor DBT. (b) Pearson correlation of outdoor RH vs indoor RH in H1, H2, and H3 case studies.

Category	**Sub Category**	**Case**								
		H1			**H2**			**H3**		
		LR [1]	KS	BR	LR	KS	BR	LR	KS	BR
(a) AT vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R [2]	.620**	.719**	.679**	.445**	.284**	.336**	.718**	.701**	.672**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	.754**	.867**	.749**	.559**	.659**	.624**	.787**	.874**	.880**
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	.586**	.612**	.586**	.165**	.255**	.091**	.416**	.608**	.631**
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	.678**	.929**	.658**	.676**	.646**	.533**	.673**	.931**	.915**
(b) Outdoor RH vs indoor RH										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	.075**	.096**	.243**	.211**	.108**	.094**	.171**	.138**	.158**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	.377**	.704**	.634**	.262**	.631**	.639**	.440**	.664**	.697**
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.000	.000	.187	.000	.000	.000	.000
	R	.239**	.468**	.493**	-.073**	-.022	.212**	.456**	.432**	.570**
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	-.136**	.498**	.776**	-.329**	-.247**	-.277**	.086**	.593**	.840**

Note: [1]LR: Living Room, KS: Kitchen space, and BR: Bedroom. [2]**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 7-7. Statistical summary of parameters in the monitored spaces for different seasons. (a) Pearson correlation of AT vs indoor DBT. (b) Pearson correlation of outdoor (RH) vs indoor RH in H4, H5, and H7 case studies.

Category	**Sub Category**	**Case**								
		H4			**H5**			**H7**		
		LR [1]	KS	BR	LR	KS	BR	LR	KS	BR
(a) AT vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R [2]	.305**	.476**	.359**	.473**	.727**	.835**	.893**	.175**	.564**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	.704**	.760**	.732**	.744**	.830**	.908**	.818**	.755**	.752**
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.162	.000	.000	.000	.000	.000	.000
	R	.264**	.249**	.023	.237**	.241**	.428**	.575**	.745**	.601**
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	.733**	.812**	.804**	.686**	.828**	.846**	.912**	.922**	.912**
(b) Outdoor RH vs indoor RH										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.035	.000
	R	.221**	.279**	.340**	.234**	.413**	.536**	.509**	.039*	.402**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.475**	.540**	.372**
	R	.465**	.656**	.646**	.642**	.664**	.698**	.000	.000	.000
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.047	.000	.000	.000	.036	.232**	.461**
	R	-.096**	-.063**	-.033*	.292**	.402**	.574**	.092	.000	.000
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.324**	.416**	.878**
	R	.532**	.688**	.796**	.520**	.804**	.869**	.000	.000	.000
Note: [1]LR: Living Room, KS: Kitchen space, and BR: Bedroom. [2]**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).										

The reason behind that could be interpreted by relying on both ceiling, standing fan and natural ventilation as key cooling methods in this space, see Table 5-4 (p.132) for more information regarding the cooling and heating methods used in monitored spaces for each use case. The hourly readings of the bedrooms in all case studies observed almost the seasonal pattern of the kitchens, with a significant fluctuation during the days of the period from May to November. This daily fluctuation is a reflection of the time schedule of using bedrooms, where they are used for sleeping during the night and are empty while the occupants are working or at school in the day. Therefore, the operation of cooling and heating systems were limited and linked with the occupancy period, (Figure7-9, c). Detailed figures of scatter plot of AT and indoor hourly DBT in (a) living room, (b) kitchen, and (c) bedroom of the rest case studies with the different time scale of using the cooling system for different seasons during the target monitoring period are presented in Appendix C.

Regarding the seasonal correlation between indoor and outdoor RH, the indoor RH in all monitored spaces showed a significant weak linear correlation with the hourly average of outdoor RH in winter, where the *R* values ranged between 0.03 and 0.53 (see Figure7-10, a, b, c) and section (b) in Tables 7-6 and 7-7. However, the relationship between indoor and outdoor RH varied in spring and autumn seasons in both kitchens and bedrooms, where *R* values ranged from 0.24 to 0.7. The relationship was weaker in the summer season, where *R* values ranged from -0.13 to 0.8 (see Figure7-10, b, c). The seasonal pattern of the hourly RH in living rooms of all case studies revealed a higher correlation in all seasons, where the *R*-value was from 0.09 to 0.45 in summer, 0.2 in winter, in autumn ranged between - 0.13 and 0.53, while it was 0.0 to 0.69 in spring (see Figure7-10 (a)). This could be a reflection of the importance of the living room for the households' members because this space is occupied most of the time during the day. Therefore, they tend to keep the environment of this space thermally under control and maintain its comfortable thermal environment within their requirements most of the time. Detailed figures of the scatter plot of outdoor and indoor hourly RH in (a) living room, (b) kitchen, and (c) bedroom of the rest case studies with the different time scale of using the cooling system for different seasons during the target monitoring period are presented in Appendix C.

The results of correlation revealed *R* values indicate a stronger relationship of indoor DBT with AT, while the relationship of humidity showed a weak relationship. These results could be a consequence of the inadequate-quality design and poor-efficiency features that are common to the whole sample. The building physical characteristics provide ineffective thermal isolation to the indoor environment. Therefore, the indoor environment is highly influenced by the outside weather condition. Consequently, more electricity loads, especially cooling loads in summer, were required to thermally maintain the indoor environment. In addition, the findings of this section have affirmed the results from prior studies, which reported the inadequate thermally performance of the domestic building in Iraq against the local climate conditions. The physical properties of these buildings and the problem of suppressed electricity demand have failed to maintain the required comfortable thermal environment level by the residents.

7.4.2 Energy use and suppressed energy demand vs ambient conditions

Energy use is closely related to its AT (Fung, et al., 2006) where the latter represents one of the key factors influencing energy use. Energy demand is driven by differences between outdoor and indoor temperature—heating/cooling demand rises when the difference between outdoor and indoor air temperature is significant. Akbari (1992) reported that the peak cooling electricity load in some US cities increases between 0.5% and 3% per 0.6˚C ambient temperature. Santamouris (2001) observed that the cooling load of urban buildings in central Athens almost doubles in summer and heating load reduces up to 30%–55% in winter compared to the buildings located in non-suburban areas. These studies have concluded that the ambient temperature is a primary factor governing the rise and fall of energy use in urban areas (Badr & Nasr, 2001; Parkpoom, et al., 2004) Consequently, the relationship between energy use and outdoor weather conditions was analysed by calculating the correlation between these factors.

Tables 7-8 and 7-9 indicate the relationship coefficients of the hourly outdoor weather conditions (AT and RH) and the hourly energy use from both NG and CG separately for the selected six case studies. In general, the findings showed a significant weak relationship between the ambient conditions and the amount of energy consumed in different seasons from both NG and CG. However, in winter, although the correlation between AT and energy use from NG was weak with 0.1, its values were higher than the values of the correlation between AT and energy use from CG with 0.04. In contrast, the interaction between the energy use from CG and AT in the other three seasons showed a significant change, where it was stronger than the correlation of energy use from NG with AT. The correlation coefficient (*R*) of the interaction between the energy use from

CG and AT was 0.22, 0.04, and 0.21 in spring, summer and autumn, respectively. However, *R* showed negative values (-0.15 and -0.03) of the correlation of energy use from NG with AT in spring and summer, while in autumn the *R*-value was 0.03 of the correlation of energy use from NG with AT.

The correlation of hourly AT with the total energy use from both NG and CG and the estimated suppressed demand were also investigated. Table 7-8 and Table 7-9 show the results of this relationship for different seasons in all case studies. In general, the pattern of the AT showed a weak interaction with both energy use and suppressed demand, where the *R*-value of this interaction was less than 0.5 for all cases and all seasons. However, the *R*-value of this correlation was almost the same (0.1) in winter and autumn and was also the same for both energy use and the estimated suppressed demand. Interestingly, the response of the total energy use to the AT was weaker in both spring and summer seasons with *R*-values of -0.1 and 0.01, respectively. Conversely, the estimated suppressed energy demand showed a strong and positive correlation with the AT in both spring and summer, where the *R* values were 0.2 and 0.3, respectively. As shown in Table 7-8 and Table 7-9, the calculated *R* has low values. This supports the weak relationship between AT and energy use in total and from both NG and CG. Therefore, the outside temperature is not the appropriate factor to be used to developed models to predict the consequences of increasing AT on energy use.

Table 7-8. Statistical summary of parameters in the monitored spaces for different seasons. (a) Pearson correlation of AT vs energy use from NG and CG. (b) Pearson correlation of AT vs the total energy use and the suppressed energy demand in H1, H2, and H3 case studies.

Category	**Sub Category**	**Case**					
		H1		**H2**		**H3**	
(a) AT vs energy use from both NG and CG							
		NG[2]	CG[3]	NG	CG	NG	CG
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.005	.000	.003	.000	.000
	R [1]	.077**	.052**	.070**	.054**	.064**	.106**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	0.626	.000
	R	-.105**	.476**	-.130**	.127**	-.007	.372**
Summer (June–Aug)	Sig. (2-tailed)	.043	.000	.038	.000	.000	.000
	R	.033*	-.086**	.034*	.159**	-.072**	-.072**
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.526	.934	.000	.000	.000
	R	.110**	.014	-.002	.392**	.293**	.302**
(b) AT vs the total energy use and the suppressed energy demand							
		EC[4]	SD[5]	EC	SD	EC	SD
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	R	.098**	.099**	.088**	.074**	.098**	.076**
Spring (Mar–May)	Sig. (2-tailed)	.425	.000	.000	.000	.000	.000
	R	.012	.335**	-.113**	.389**	.090**	.057**
Summer (June–Aug)	Sig. (2-tailed)	.312	.125	.000	.000	.000	.000
	R	.017	.025	.110**	.179**	-.088**	.124**
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.115	.000	.000	.000	.000
	R	.117**	-.034	.219**	.225**	.341**	-.214**

Note: [1]**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed). [2]NG: National Grid, [3]CG: Community Generator, [4]EC: total energy use, and [5]SD: suppressed energy demand.

Table 7-9. Statistical summary of parameters in the monitored spaces for different seasons. (a) Pearson correlation of AT vs energy use from NG and CG. (b) Pearson correlation of AT vs the total energy use and the suppressed energy demand in H4, H5, and H7 case studies.

Category	**Sub Category**	**Case**					
		H4		**H5**		**H7**	
(c) AT vs energy use from both NG and CG							
		NG[2]	CG[3]	NG	CG	NG	CG
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.007	.000	.002	.000	.029
	R [1]	.159**	-.053**	-.090**	.057**	.186**	-.040*
Spring (Mar–May)	Sig. (2-tailed)	.000	.248	.000	.000	.000	.188
	R	-.182**	-.017	-.353**	.274**	-.135**	.024
Summer (June–Aug)	Sig. (2-tailed)	.002	.000	.000	.001	.000	.019
	R	-.051**	.064**	-.063**	.056**	.087**	.050*
Autumn (Sep–Nov)	Sig. (2-tailed)	.002	.000	.000	.000	.565	.001
	R	-.065**	.158**	-.138**	.315**	-.012	.068**
(d) AT vs the total energy use and the suppressed energy demand							
		EC[4]	SD[5]	EC	SD	EC	SD
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.799	.000	.000	.000	.000
	R	.155**	.005	-.085**	.127**	.177**	-.087**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	R	-.185**	.417**	-.222**	.322**	-.107**	.175**
Summer (June–Aug)	Sig. (2-tailed)	.227	.000	.196	.000	.000	.862
	R	-.020	.091**	-.021	.080**	.095**	.004
Autumn (Sep–Nov)	Sig. (2-tailed)	.039	.000	.051	.000	.851	.000
	R	-.044*	.385**	.042	.146**	-.004	.077**

Note: [1]**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed). [2]NG: National Grid, [3]CG: Community Generator, [4]EC: total energy use, and [5]SD: suppressed energy demand.

For more details regarding the interaction between these parameters, the standard visualisation techniques—carpet plots—are used to show how the total hourly energy use, energy use from NG and SG, suppressed energy demand (SD) response to the AT and RH measurements between January 2017 and June 2018 of all case studies. Figure 7-11 illustrates the carpet plots of these parameters in H1 case study, and it shows the change of energy use and suppressed demand with respect to temperature for the monitoring period. Detailed figures of carpet plots of the hourly energy use, energy use from NG and SG, suppressed energy demand (SD), ambient temperature (AT), and outdoor RH measurements of the other case studies during the target period of monitoring are presented in Appendix C. The hourly behaviour of AT and energy use reveals that temperature does not show a positive relationship as was expected . on the contrary to what happens in neighbouring countries, the maximum temperature in Iraq has a poor influence on energy use, due to suppressing the energy demand, especially in summer (as discussed in Chapter 6). In addition, the carpet plots of all cases showed a weak response of the total energy use and the energy consumed from NG. However, the energy use from CG, even though its amount was less than the amount of energy from NG, its heat map in most of the case studies showed a seasonal response to the AT, which in turn showed opposite patterns to outdoor RH. The heat map of the estimated hourly suppressed demand of energy revealed a high interaction with the seasonal difference in AT. This interaction could be attributed to the increased demand for energy in these dwellings, which was offset by a deficit in energy supply to meet this seasonal demand, especially in extreme summer periods when the demand reaches its peak.

7.4.3 Energy use and suppressed energy demand vs indoor thermal environment

This chapter also seeks to evaluate the domestic indoor thermal environment under suppressed energy demand. This can be done by examining the energy use patterns and their relationships with the indoor thermal environment in the monitored spaces of the case studies. Therefore, the researcher performed a correlation analysis between energy use and indoor DBT, while ignoring RH because it represents the key factors of a comfortable thermal environment. The analysis showed that inside DBT and energy use were not correlated. The results in Tables 7-10, 7-11, 7-12, and 7-13 show that indoor DBT in the monitored spaces for the six dwellings has little to no relationship with energy use, while some cases showed a negative relationship between these parameters. Figures 7-12 and 7-13 show the person correlation of energy use from NG and CG vs DBT and the total energy use and suppressed demand vs DBT in living room in different seasons of H1 case study. The detailed figures of these correlations in both kitchen and bedroom in different seasons of H1 case study are presented in Appendix C.

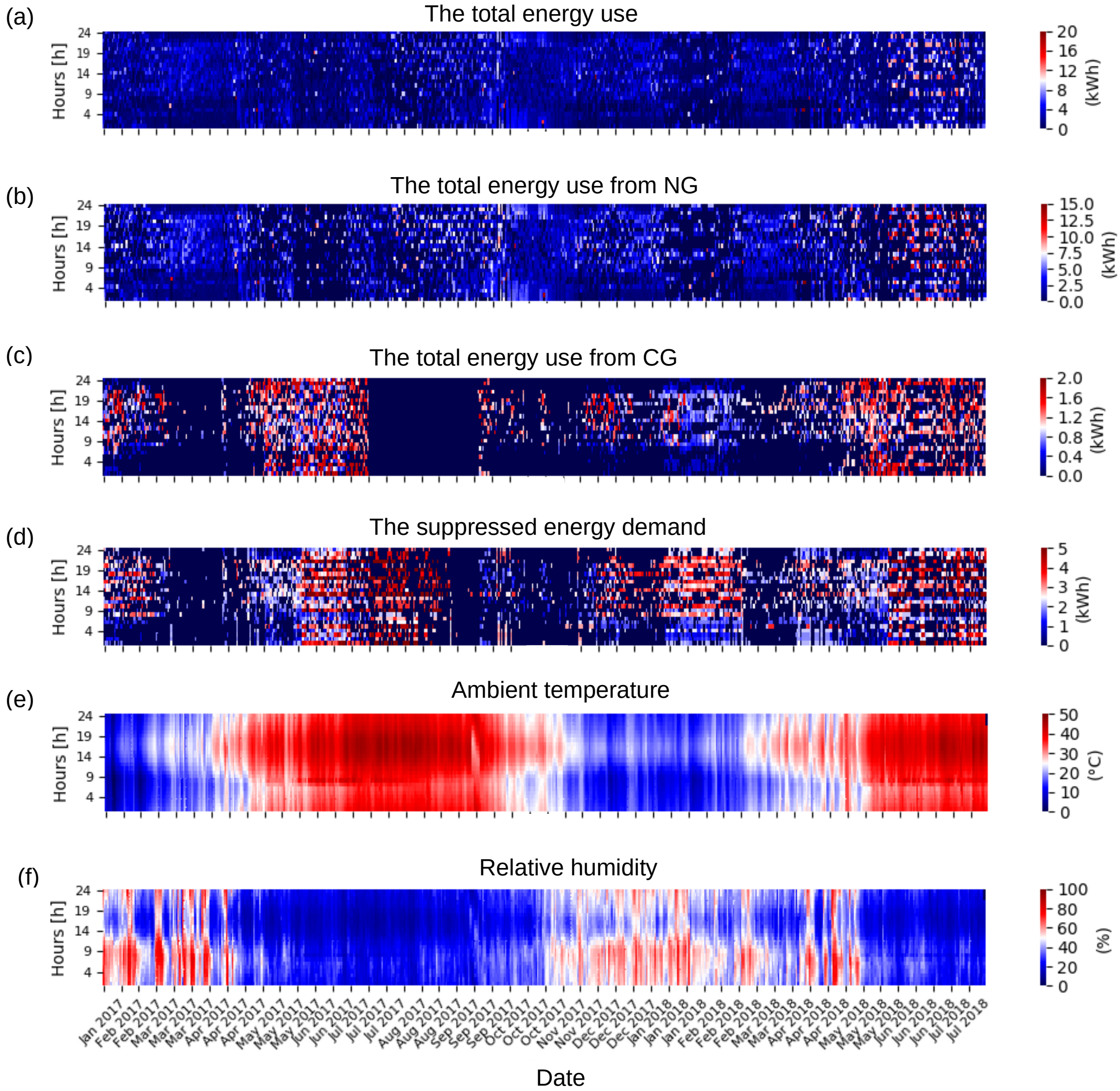


Figure 7-11. Carpet plots of the hourly monitored parameters of H1 case study between January 2017 and June 2018. (a) the total energy use, (b) energy use from NG, (c) energy use from SG, (d) suppressed energy demand, (e) Ambient Temperature, and outdoor Relative Humidity.

Table 7-10. Statistical summary of parameters in the monitored spaces for different seasons. (a) Pearson correlation of energy use from NG vs indoor DBT. (b) Pearson correlation of energy use from CG vs indoor DBT in H1, H2, and H3 case studies.

Category	**Sub Category**	**Case**								
		H1			**H2**			**H3**		
		LR [1]	KS	BR	LR	KS	BR	LR	KS	BR
(a) Energy use from NG vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.004	.000	.594	.000	.000	.000	.273	.271	.000
	R [2]	.054**	.086**	-.010	.130**	.192**	.163**	.020	.020	.079**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.158	.000	.000	.000	.005	.156
	R	-.094**	-.106**	-.077**	-.021	-.131**	-.254**	-.119**	-.043**	-.021
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.000	.000	.048	.001	.000	.000	.000
	R	.087**	.082**	.173**	.146**	-.033*	-.053**	-.067**	-.070**	-.134**
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.000	.031	.000	.000	.000	.000	.000	.000
	R	.119**	.141**	.046*	-.143**	-.162**	.078**	.272**	.339**	.349**
(b) Energy use from CG vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.340	.000	.401	.000	.000	.280	.044	.000
	R	-.152**	-.018	-.124**	-.015	-.229**	-.252**	-.020	-.037*	-.112**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.556	.000	.000	.000
	R	.339**	.437**	.305**	.114**	.074**	-.009	.346**	.364**	.371**
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	-.087**	-.106**	-.108**	-.234**	-.065**	-.158**	-.130**	-.162**	-.117**
Autumn (Sep–Nov)	Sig. (2-tailed)	.556	.016	.055	.000	.000	.000	.011	.000	.000
	R	-.013	-.052*	-.041	.313**	.329**	-.078**	.054*	.211**	.226**

Note: [1]LR: Living Room, KS: Kitchen space, and BR: Bedroom. [2]**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 7-11. Statistical summary of parameters in the monitored spaces for different seasons. (a) Pearson correlation of energy use from NG vs indoor DBT. (b) Pearson correlation of energy use from CG vs indoor DBT in H4, H5, and H7 case studies.

Category	**Sub Category**	**Case**								
		H4			**H5**			**H7**		
		LR [1]	KS	BR	LR	KS	BR	LR	KS	BR
(a) Energy use from NG vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.000	.085	.000	.000	.000	.000	.000
	R [2]	.241**	.138**	-.111**	-.032	-.086**	-.127**	.190**	-.104**	.082**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.004
	R	-.222**	-.247**	-.232**	-.281**	-.297**	-.315**	-.148**	-.201**	-.053**
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.000	.402	.964	.071	.000	.001	.180
	R	-.095**	.081**	.188**	.014	.001	.030	.086**	.073**	.029
Autumn (Sep–Nov)	Sig. (2-tailed)	.005	.000	.080	.000	.000	.000	.252	.877	.041
	R	-.061**	-.107**	-.037	-.114**	-.127**	-.146**	.025	-.003	-.044*
(b) Energy use from CG vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.008	.022	.001	.596	.000	.000	.000
	R	-.344**	-.302**	-.052**	-.043*	.063**	.010	-.081**	.105**	-.077**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.007	.088	.986
	R	-.084**	-.063**	-.063**	.255**	.264**	.269**	.050**	.032	.000
Summer (June–Aug)	Sig. (2-tailed)	.001	.000	.000	.423	.004	.244	.727	.673	.435
	R	.056**	-.080**	-.123**	.013	-.047**	.019	.007	.009	.017
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.026	.007	.017
	R	.153**	.092**	.109**	.118**	.213**	.278**	.048*	.057**	.051*

Note: [1]LR: Living Room, KS: Kitchen space, and BR: Bedroom. [2]**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 7-12. Statistical summary of parameters in the monitored spaces for different seasons. (a) Pearson correlation of the total energy use vs indoor DBT. (b) Pearson correlation of suppressed energy demand vs indoor DBT in H1, H2, and H3 case studies.

Category	**Sub Category**	**Case**								
		H1			**H2**			**H3**		
		LR [1]	KS	BR	LR	KS	BR	LR	KS	BR
(a) The total energy use vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.221	.000	.027	.000	.000	.000	.398	.562	.005
	R [2]	.023	.091**	-.041*	.138**	.157**	.121**	.015	.011	.051**
Spring (Mar–May)	Sig. (2-tailed)	.401	.994	.824	.828	.000	.000	.034	.001	.000
	R	-.013	.000	-.003	-.003	-.122**	-.262**	-.032*	.052**	.075**
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.000	.001	.000	.000	.000	.000	.000
	R	.074**	.064**	.161**	.056**	-.066**	-.131**	-.095**	-.104**	-.162**
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.000	.051	.694	.815	.027	.000	.000	.000
	R	.122**	.139**	.042	.008	-.005	.047*	.286**	.376**	.388**
(b) The estimated suppressed energy demand vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.002	.011	.201	.000	.000	.000	.000	.482
	R	-.065**	.056**	.047*	.024	-.176**	-.293**	.098**	.120**	-.013
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000
	R	.308**	.324**	.209**	.068**	.382**	.524**	.209**	.138**	.063**
Summer (June–Aug)	Sig. (2-tailed)	0.038	0.154	-.010	.000	.000	.000	.000	.000	.000
	R	.034*	-.024	.554	.162**	.198**	.132**	.072**	.131**	.233**
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.042	.026	.005	.091	.003	.000	.000	.000
	R	-.076**	-.043*	-.048*	.060**	.036	-.063**	-.160**	-.260**	-.249**

Note: [1]LR: Living Room, KS: Kitchen space, and BR: Bedroom. [2]**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

Table 7-13. Statistical summary of parameters in the monitored spaces for different seasons. (a) Pearson correlation of the total energy use vs indoor DBT. (b) Pearson correlation of suppressed energy demand vs indoor DBT in H4, H5, and H7 case studies.

Category	**Sub Category**	**Case**								
		H4			**H5**			**H7**		
		LR [1]	KS	BR	LR	KS	BR	LR	KS	BR
(a) The total energy use vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.000	.048	.000	.000	.000	.000	.000
	R [2]	.190**	.091**	-.123**	-.037*	-.081**	-.127**	.174**	-.084**	.068**
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.011
	R	-.237**	-.258**	-.243**	-.156**	-.168**	-.184**	-.106**	-.162**	-.047*
Summer (June–Aug)	Sig. (2-tailed)	.000	.009	.000	.054	.003	.000	.000	.001	.144
	R	-.069**	.043**	.129**	.032	-.049**	.059**	.087**	.074**	.031
Autumn (Sep–Nov)	Sig. (2-tailed)	.058	.000	.281	.009	.641	.633	.156	.864	.080
	R	-.041	-.096**	-.023	-.056**	-.010	.010	.030	.004	-.037
(b) The estimated suppressed energy demand vs indoor DBT										
Winter (Dec–Feb)	Sig. (2-tailed)	.000	.000	.000	.031	.861	.000	.000	.000	.019
	R	-.155**	-.126**	.142**	-.041*	-.003	.146**	-.110**	.161**	-.043*
Spring (Mar–May)	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.234
	R	.378**	.409**	.368**	.106**	.224**	.255**	.196**	.316**	.022
Summer (June–Aug)	Sig. (2-tailed)	.000	.000	.000	.286	.000	.000	.005	.433	.624
	R	-.076**	-.174**	-.315**	.018	.060**	.108**	-.060**	-.017	.010
Autumn (Sep–Nov)	Sig. (2-tailed)	.000	.000	.000	.043	.013	.001	.015	.002	.000
	R	.204**	.327**	.295**	.043*	.053*	.071**	.052*	.065**	.115**

Note: [1]LR: Living Room, KS: Kitchen space, and BR: Bedroom. [2]**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

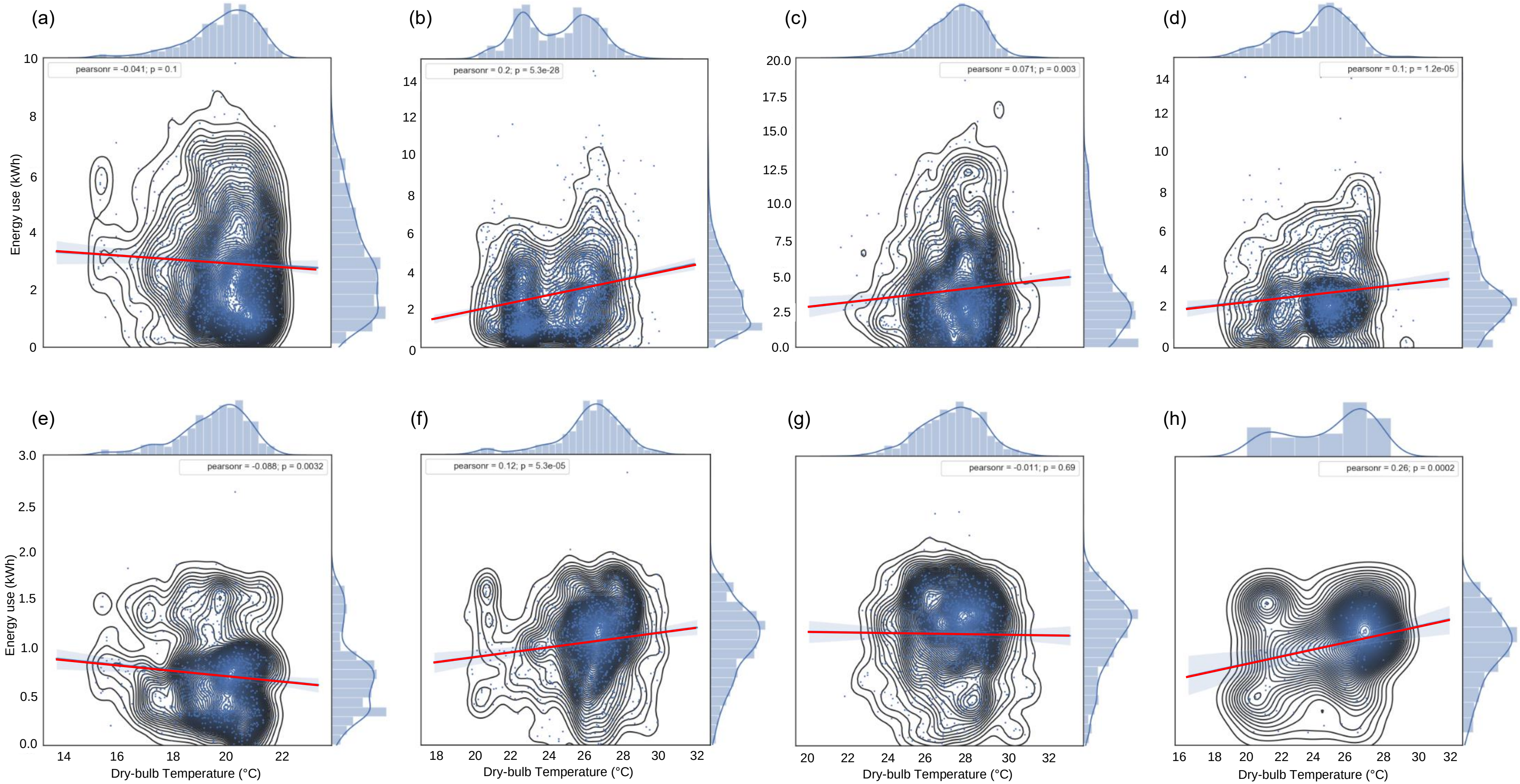


Figure 7-12. Pearson correlation of energy use from NG and CG vs DBT in living room in different seasons of H1 case study: (a-d) the correlation of energy use from NG vs DBT in living room in different seasons of H1, (e-h) the correlation of energy use from CG vs DBT in living room in different seasons of H1.

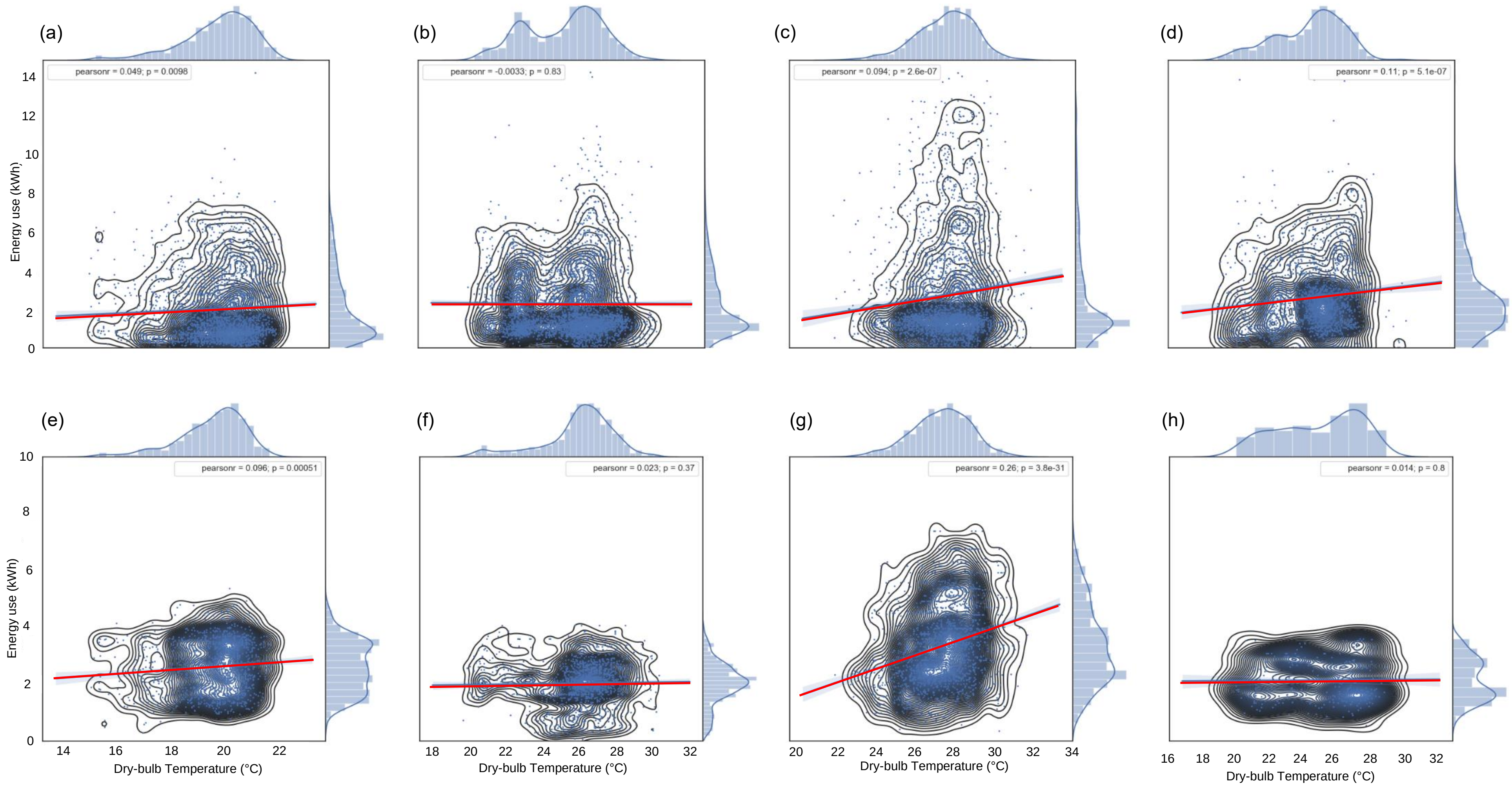


Figure 7-13. Pearson correlation of the total energy use and suppressed demand vs DBT in living room in different seasons of H1 case study: (a-d) the correlation of the total energy use vs DBT in living room in different seasons of H1, (e-h) the correlation of suppressed energy demand vs DBT in living room in different seasons of H1.

The energy use pattern of the NG was linked negatively to the indoor temperature in the monitored spaces in all case studies, where in the living room of H1 in winter, the *R*-value -0.04, while in summer the *R*-value was 0.07. However, in the intermediate seasons (spring and autumn), the relationship remained weak with a slight increase, where *R*-values were 0.2 and 0.1, respectively. This may be attributed to a slight improvement in the energy supply during these seasons coupled with the occurrence of indoor temperature data within the comfort zone, where less was the energy required. Meanwhile, in both winter and summer, more heating and cooling loads were required to provide a satisfactory level of the comfortable indoor thermal environment. Similarly, the energy consumed from CG showed almost the same relationship with the indoor temperature of the living room in H1, where the *R*-values were negative in both winter and summer. Spring and autumn days observed an increase in *R*-values, where they were 0.12 and 0.26, respectively. Moreover, the seasonal relationship between the hourly indoor temperature in living room of H1 with estimated hourly suppressed energy demand was also examined and the findings revealed that there was a strong correlation between these parameters in summer when compared to other seasons, with *R*-value 0.26, while in winter, spring, and autumn (*R*) values were 0.09, 0.02 and 0.01, respectively. The weak response of the energy use to the AT over the seasons of the year adversely reflected on the contribution to keeping the indoor temperature within an acceptable level, which strongly interacts with the seasonal change of outside temperature (as discussed in subsection 7.4.1).

7.5 Summary

This chapter analysed the outdoor weather conditions, indoor environment conditions, the relationship between these parameters, and the calculated energy use and the estimated suppressed energy demand. Hourly real-time data between January 2017 to August 2018 were used for the analyses and to affirm the results from prior research. Descriptive statistics and correlation analyses were employed to analyse the data. The independent parameter studied in this study was outside temperature. The dependent parameters included indoor environment conditions and energy use. The key findings include the following:

1. The results of the outdoor weather conditions (AT and RH) matched the prior studies that were reviewed in subsection 2.4.1, which revealed that Iraq's climate is characterised by an extremely hot and dry summer with maximum daily temperatures between 46–50°C in July and August, with a large diurnal temperature variation. In winter, the weather is moderate; and the temperature only reaches freezing on some nights.

2. Analysing the indoor thermal environment showed an inability to achieve an acceptable level of comfortable thermal environment for the occupants in most of the year, especially in summer followed by winter, although the rising use of energy during this period.

3. A weak response to the local weather conditions coupled with the negative impact of suppressed energy demand was revealed when investigating the indoor thermal environment. There was a strong relationship between changes in the AT and indoor DBT.

4. There was a poor relationship between changes in the AT and energy use over the seasons. Based on the findings, it can be concluded that energy use weakly and sometimes adversely changes in response to a change in the mean hourly AT.

5. The analysis found no correlation between indoor DBT and energy use for all six case studies. This could be a reflection of design weaknesses in terms of the physical characteristics that contribute to hinder the maintenance of the indoor thermal environment within comfort bounds. In addition, the poor correlation was caused by the inability of the energy supply to cover the actual energy demand.

Chapter 8: **Conclusion**

This chapter concludes the study by first outlining the background of the study and the reasons for its development. Next, it seeks to address the research questions that were stated at the start of this research, thereby demonstrating all questions had been answered and the objectives fulfilled. The contributions of this study to the body of knowledge on this subject are then outlined and the limitations of this study detailed and discussed. Finally, this study closes with recommendations for future research, detailing directions to further the work performed in this study.

8.1 Background

Suppressed electricity demand is seen as one of the key challenges facing developing countries. This challenge, particularly for domestic buildings, is responsible for the high misestimation of the actual energy demand and the occupants' dissatisfaction with the comfortable indoor thermal environment, especially in regions characterised by a hot-arid climate, such as where the case studies are located. The previous literature has indicated that providing an actual estimation of the suppressed energy demand could play a promising role in determining and then reducing energy use and demand for domestic buildings. Several studies have provided empirical evidence of the influence of suppressed electricity demand on the total energy demand in buildings. However, this research area requires further investigation to reveal the impact of suppressed electricity demand on sustaining the comfortable indoor thermal environment. This contradiction requires clarification. Therefore, the main aim of this research was to find ways to provide a better understanding of this challenge and its implications, including the indoor thermal environment of buildings in a hot-arid climatic region. The research questions were established and presented in the introduction chapter, which helped to guide the researcher to meet the research objectives.

8.2 Research conclusion

The first point to make is that the research has successfully met the main aims proposed for the study. The approach of this research was to estimate the suppressed energy demand in Baghdad homes, which impacts both the estimation of the actual energy demand and the indoor thermal environment in these buildings. The current energy use and the local extreme hot-arid climate conditions of the city, together with the dwellings' physical characteristics, the occupants' behaviour in terms of energy use and the economic factors were taken into account. Chapter 4 detailed the key social, economic features of Iraqi households, including their physical and environmental characteristics. Chapter 6 detailed the estimated energy suppressed demand and the estimated actual energy demand based on the real data of energy use. Furthermore, Chapter 7 detailed the potential of the suppressed demand influence on the indoor thermal environment in Baghdad homes. This contribution to the knowledge of the energy use with suppressing demand and indoor thermal environment of the studied sample of Baghdad's dwellings could be appropriate for all Iraq's homes and may also be applicable throughout the other developing countries as long as the same characteristics are applied. The rest of this section will discuss the conclusions of the research in reference to each of the research questions.

8.2.1 Research questions one

How is energy, especially electricity used in Iraqi dwellings? and how does it vary temporally and compare regionally?

This question was answered in detail in Chapter 6 by: (i) investigating the energy use of existing representative homes in Baghdad city separately. To do that the energy supply sources and the resulted daily scenarios of energy supply were investigated. (ii) evaluating the domestic energy use for different seasons by using different evaluation scales such as (hourly, daily, per capita, per square meter) and per year. Regarding the first point, the results of the total annual energy supplied showed that NG represents the main supply source of energy for households—its contribution was 51% of the total annual energy supplied. While the share of both the energy supplied from CG and the blackout duration in the total annual energy supplied were 22% and 27%, respectively. Moreover, the reliance on two different energy supply sources, coupled with outages hours that occur during the day contributed to four main daily energy supply scenarios. The proportion of the first scenario, which refers to getting 24 hours of energy from the national grid (NG), within the total energy supply over the year was the lowest compared with just 12%. Getting 24 hours from NG and CG was the second scenario with 32% of the annual energy supply. The proportion of the third scenario, which describes a situation where the energy provided by both the NG and CG failed to keep pace with the required demand for the whole day. This scenario accounted for the largest part of the total energy supply compared to other scenarios, with 46% over the year. The fourth scenario is the worst in terms of suppressing the energy actual demand for households, with 9% of the total annual energy supply. Regarding the energy use, the summer season was the highest season in terms of energy supply with 1,473 kWh compared to 1,457 kWh, 1,259 kWh and 932 kWh for the autumn, winter, and spring. The calculated energy use (in kWh/capita·year, kWh/m2·year) were then used to conduct a comparison against the domestic energy use in other countries with a similar hot-arid climate where Iraq was the lowest.

8.2.2 Research question two

Does the existing supply meet the occupants' demand for electricity and if not, how can the unmet demand be estimated?

This question was answered in detail in Chapter 6 by: (i) estimating the suppressed energy demand and then the actual energy demand in the selected homes, and (ii) defining the range of energy use levels (before and after adding the suppressed demand amount of electricity) in the homes in kWh for different scales (hourly, daily, seasonally, per capita, per square meter). A comparison between the real energy use calculated in the research question one and the estimated suppressed demand for each case study and in total has indicated that the annual estimated suppressed demand exceeded the amount of the annual energy use in two of seven case studies, which are H3, and H6, with ~181%, and 174%. However, the values of the total energy estimated suppressed demand of H1, H2, H4, H5, and H7 case studies were constituted is equal to 41%, 29%, 65%, 47%, and 86% of their total energy use per annum. The total average of the annual estimated suppressed demand for all case studies was equal to ~77% of their total annual energy use rate. Seasonally, the energy estimated suppressed demand for different seasons revealed that the highest suppressing demand occurred in the summer season with 3,860 kWh, followed by spring with just 1,553 kWh. In addition, the estimated total energy demand after adding suppressed demand to the supplied energy for the annual time step showed that the estimated actual demand rate for all case studies was higher than the actual use by more three-fourths.

Furthermore, one of the key objectives of the present study was to identify the level of energy use (in kWh/m^2·year, kWh/capita·year) of Iraqi domestic buildings and then compare them against regional domestic buildings to determine if this use is deemed to be low, or very low, based on the comparison's results. The total average of the estimated energy actual demand (in kWh/m^2·year) after adding suppressed demand was 78 kWh/m^2 (in the range of 27–121 kWh/m^2) for the case studies. The total average of the estimated energy actual demand (in kWh/capita·year) after adding suppressed demand was 3,094 kWh/capita (in the range of 728–4,223 kWh/capita) for the case studies. Comparing these results to other countries with similar hot-arid climate, Iraq was the lowest, which reflects the significant impact of suppressed demand on the deficit of Iraqi households to meet their actual demand.

8.2.3 Research question three

How do the socio-economic and physical characteristics of dwellings influence energy use?

This question was answered in Chapter 4 by discussing the findings of the comprehensive questionnaire conducted in Baghdad city with 210 respondents. The key finding was that living in extended families (i.e. more than one family live in the same house) means an increase in the total number of people living in the housing unit, which in turn results in an increase in energy use. Moreover, analysing the economic impacts of residential energy use in Iraq showed a high dependency on CGs, given the increase of frequent blackout hours in electricity supply from the NG. This dependency has imposed more economic burdens on these households, especially in the extreme summer periods where the demand reaches its peak, resulting in more electricity outages. This is why most of the participants showed a high degree of dissatisfaction regarding the energy cost for cooling in summer.

In terms of the physical characteristics that might influence the energy use, the results showed that the majority of surveyed families live in single-family housing, while 73% of them live in townhouses (i.e. terraced) with two storeys. The key results of this part that could link to the energy use in domestic buildings in Iraq are the evolution of the construction system and materials that are used. The conventional construction method and the type of materials have not experienced a notable change over the last 75 years or more. In the same context, the results regarding this aspect showed that there is low use of insulation solutions within the house envelope or its components over the same period. Consequently, the prevailing physical characteristics of the houses play a key role in increasing energy use, especially for cooling in the summer months. In addition, these results confirm that there is a lack of awareness concerning energy issues. One of the key implications for these inadequate physical characteristics is that the thermal performance of the dwellings during summer is perceived by the occupants as being the worst, especially in a hot summer. This can be attributed to the following reasons: inefficient thermal behaviour of domestic buildings against the ambient temperature a lack of energy supply from the NG, and an insufficient and expensive energy supply from the CGs. These factors have all inversely influenced the indoor thermal environment.

8.2.4 Research question four

How do occupants interact with the building and its environmental systems to maintain a comfortable indoor environment?

Chapter 4 and 5 investigated the main energy sources used for daily activities and end-use as well as the environmental systems used to cool and heat spaces in Iraqi dwellings. Chapter 7 examined the outdoor weather conditions (AT and RH). The findings revealed that Iraq's climate is characterised by a cold winter. Although 78% of the captured readings in all case studies ranged within the thresholds of radiation requirement, more radiation should be provided to move the data up for weather comfort to be provided. In spring, about 53% of events have the potential for entering the comfort zone, while 34% required radiation to be in the "comfort zone". In the summer season, just 8% were located within "comfort zone", while around 87% of the bioclimatic measurements were in zones 5 and 6, where more air movement and humidity are required to move the data down to the comfort zone boundaries. Meanwhile, 4% of data in summer were located within the "severe dry" zone, where the ambient temperature value is higher than 45°C, while the relative humidity value is less than 20% with large diurnal temperature variation. Plotting the bioclimatic measurements for autumn revealed that 52% were described as comfortable, and 46% were described as within "radiation requirement" and "windy-humidity requirement" zones.

Moreover, analysing the indoor thermal environment showed an inability to achieve an acceptable level of the comfortable indoor environment for occupants in most of the year, especially in summer and winter. In the winter months, even though heating systems were used, 43% of hourly measurements in living rooms of all case studies were considered as comfortable, while 68% were located within zones' boundaries where more heating was required to achieve an acceptable comfortable thermal environment for the occupants. In the kitchen spaces, the monitored data located within comfort zone bands was 57%, while 43% of the captured readings in these spaces for all of the case studies were distributed within the thresholds of heating strategy. However, in the same season, more than 70% of bedroom readings required more heating, and just 28% were referred to as comfortable. In the spring season, 53%, 44% and 40% of the time in this season were quite comfortable in living rooms, kitchen, and bedrooms, respectively. However, during these months, 33%, 45% and 43% of the measurements in living rooms, kitchens, and bedrooms, respectively, needed evaporative and mechanical cooling to maintain the environment in these spaces within comfortable thermal environment limits.

For the summer season, where the ambient temperature is high, and its diurnal difference is significant and the using of cooling systems is more than 20 hours/day. However, the majority of the hourly indoor measurements of living rooms, kitchens, and bedrooms located within bioclimatic zones where evaporative and air conditioning were necessary, with 86%, 99%, and 96% respectively. In the autumn, about 44%, 24%, and 38% of the average data in living rooms, kitchens, and bedrooms were referred to as comfortable, while 49%, 75%, and 57% of monitoring data in living rooms, kitchens, and bedrooms located within bioclimatic zones where evaporative and air conditioning are required to achieve the acceptable indoor comfortable thermal environment. These results could be a reflection of a thermally weak response to the local climate conditions under the status quo of energy use, as revealed by the indoor thermal environment investigation. There was a strong relationship between changes in the outside temperature and the indoor temperature.

8.2.5 Research question five

How do ambient conditions and suppressed energy demand affect the indoor thermal environment?

This question was answered in Chapter 7, where the relationship was investigated between the energy use, suppressed demand, the ambient conditions for each case study. The findings show that there was a poor relationship between these parameters over the seasons of the year. Based on the findings, it can be concluded that energy use weakly and sometimes adversely changes in response to a change in the mean hourly AT. Moreover, the results showed that the poor relationship between energy use and the ambient conditions negatively affected the indoor environment conditions in all each case study. These findings could be a reflection, first, of the design weaknesses in terms of the physical characteristics, which hinder the maintenance of the indoor environment within comfortable thermal environment bounds. Second, this poor correlation is due to the inability of the energy supply to cover the actual energy demand as the outside and indoor temperatures increase.

8.3 Research limitations

This research has examined existing residential energy use and indoor environment conditions in Baghdad city. However, several limitations were encountered by the researcher during the research process. These limitations are summarised as follows:

1. Major challenges reside in the determination and selection of the cases. There were in total of seven case studies. Unfortunately, it was not possible to increase this number because the choices were limited based on the house locations and willing householders who permitted the researcher to conduct the physical measurements without any conditions. Another added limitation of conducting monitoring on a large set of houses was the limited number of available instruments for monitoring.

2. Conducting the fieldwork and data monitoring created many challenges, including the transmission and storage of the measurements. It was also necessary to sustain the wireless connection and network stability to reduce the probability of data loss. However, for the current research, the lack of a continuous internet connection was another added limitation.

3. Monitoring the energy use from the CG in case study H7 had to be stopped due to the inability of the household to receive electricity from the CG for technical reasons, which is considered one of the key limitations of this study. In addition, technical problems while monitoring the weather and environment conditions in case study H6 also caused this case to be excluded in the part of the analysis related to climatic conditions.

4. The topic was explored within the time constraints of a PhD study and, consequently, the sample was constrained by time and resource limitations. Therefore, with greater resources and more time, a larger sample size could have been used. This would have provided a better representation of energy use with suppressed demand faced by households in Iraq.

5. DBT and RH were used in this study. However, these parameters are not the only parameters that could refer to the indoor comfortable thermal environment that could be affected by the energy use pattern. Therefore, it is recommended that future studies should also take into consideration factors such as wind speed and solar radiation.

8.4 Research recommendations

The following general recommendations are made to suit both future and existing domestic buildings in Iraq, and to meet the requirement to achieve both efficient energy use and sufficient indoor comfortable thermal environment. These recommendations were formulated based on the study's outcomes and are intended for those who are interested in developing sustainable energy and environmental systems in Iraq and other developing countries, these may include future researchers, decision-makers, developers, clients, and consumers.

8.4.1 Recommendations for researchers

The key recommendations for researchers are as follows:

1. In the present study, the monitoring process was only conducted in a small set of houses. Therefore, it is important to assess the impact of applying this monitoring on a large number of houses to improve the accuracy of the results;
2. Data were only recorded for two cool and one hot season, thus a study of two whole-years of data would be preferable;
3. In-site renewable energy sources as a replacement of CGs may help to reduce energy use in residential buildings and may relieve the negative impacts of using CGs in Iraq's residential buildings; and
4. It would be useful to study the homes of low-income people to find how suppressing the energy demand is influenced by the social and economic aspects in these homes and what behaviours these people use to meet their actual demand for electricity.

8.4.2 Recommendations for decision-makers

The key recommendations for construction industry workers are as follows:

1. The regulations and policies that are used in the housing construction industry need to be revised to build low energy homes in Iraq, and ensure economic and environmental benefits;
2. For future domestic buildings, given the current energy situation, it is necessary to establish energy use standards for Iraq to control energy use;
3. For existing domestic housing stock, it is necessary to promote simple solutions for energy retrofitting and efficiency such as smart appliances, building

management system;

4. The use of in-site renewable energy resources such as PV to generate electricity from natural resources, and to reduce energy use from the grid and stop using CGs should be investigated further in the residential sector; and

5. Public awareness of the level of personal energy use in the domestic sector needs to be raised and the public should be educated about the importance of efficient energy use for both the environment and the economy.

8.5 Directions for future research

It is well-known that new studies are built on the foundations of former studies, and so it is useful to highlight the potential of this research to stimulate future studies:

1. Concerning the findings of this research and the current energy use situation in Iraq's residential sector, a paradigm shift is required to lead improve the present situation by minimising the negative impacts of suppressing the electricity demand in residential buildings. This process requires a timescale and roadmap to increase awareness. Moreover, it requires an in-depth study and analysis of the policies and regulations of property managers in the construction and energy sectors. Hence, because the researcher is an architect in the Iraqi Ministry of Construction, Housing and Public Municipalities, the aim is to achieve collaboration between the organisations associated with the construction and energy industry and management in Iraq, including the Ministry of Construction and Housing and Public Municipalities, and the Ministry of Electricity. The focus should be on designing strategies for the housing sector to develop both the current policies on electricity use and efficient energy housing design regulations in both authorities.

2. This study provides a calculation method to estimate the hourly electricity suppressed and actual demand based on real data of a sample of monitored houses. Therefore, the hope here is that the expansion of the study sample would create a large database for Iraqi researchers to explore the issues of energy efficiency and comfortable indoor thermal environment in more depth. Furthermore, future work could focus on researching and investigating new and creative architectural interventions that could improve a building's energy performance, while taking into consideration local climates, weather patterns, and efficient architectural designs. Furthermore, collaboration with different disciplines would also enhance and enrich the knowledge of these aspects.

3. Finally, future studies could focus on estimating the energy demand of all of the domestic buildings in Baghdad and develop a framework to conserve energy use in this sector. The output of this future study will help those in the other regions of Iraq to plan and establish a roadmap to achieve sustainability in the residential sector in Iraq.

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APPENDICES

Appendix A – Research method

A.1 Ethical approval forms of Cardiff University

Cardiff School of Engineering

Ethical Approval Application for Non-Clinical Research Involving Human Participants, Data or Materials

Tick one box: ☐ **Staff project** ☒ **PG Research project** ☐ **UG or PG Taught Project**
Title of project: Domestic energy use and suppressed energy demand in hot-arid climate
Name of researchers: Balsam Alwan Shallal
Name of Supervisor (student research projects): Prof. Monjur Mourshed Project Start Date: 1st /Oct./2015

Is this research:

a) Non-clinical ☒ Please complete sections A-J.

b) Clinical ☐ Your project may be beyond the remit of the School Ethics Committee.

(Involving NHS patients, data, facilities or staff)

Please see the "Ethical Review Options Map" in Appendix C of the School Ethical Procedures. If appropriate, seek approval from the appropriate Local Research Ethics Committee.

A. PARTICIPANTS

		Yes	No	N/A
1	Does your project include children or young people up to 18 years of age?	☐	☒	☐
2	Does your project include people of any age with learning or communication difficulties?	☐	☒	☐
3	Does your project include people of any age belonging to a vulnerable group?	☐	☒	☐

If you have answered "Yes" to any of the above, please confirm that you have gained all necessary authorisation, that ethical issues have been addressed and that you have read CU's Interim Guidance for Researchers Working with Children and Young People (Appendix E of ENGIN Policy). It is your responsibility to check the existence of and comply with any legal requirements, such as vetting procedures. ☐

B. CONSENT AND PARTICIPATION

		Yes	No	N/A
4	Will you tell participants that their participation is voluntary?	☒	☐	☐
5	Will you obtain written consent for participation?	☒	☐	☐
6	If the research is observational, will you ask participants for their consent to being observed?	☒	☐	☐
7	Will you tell participants that they may withdraw from the research at any time and for any reasons?	☒	☐	☐

8	Will you give potential participants a significant period of time to consider participation?	☒	☐	☐
9	Will you give participants the option of omitting questions they may not wish to answer?	☒	☐	☐
10	Will you explain the main experimental procedures to participants in advance so that they are informed as to what to expect?	☒	☐	☐
11	Will you tell participants that their data will be treated with full confidentiality and that, if published, it will not be identifiable as theirs?	☒	☐	☐
12	Will you debrief participants at the end of their participation (i.e. give them a brief explanation of the study)?	☒	☐	☐

If you have answered "No" to any questions in this section, please provide an explanation in Section F.

C. RISKS OF HARM TO PARTICIPANTS

		Yes	No	N/A
13	Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?	☐	☒	☐
14	Is there any realistic risk of any participants experiencing a detriment to their interests as a result of participation?	☐	☒	☐
15	Will your project involve deliberately misleading participants in any way?	☐	☒	☐

If you have answered "Yes" to any questions in this section, please explain in section F how you propose to minimise these risks.

D. DATA PROTECTION

		Yes	No	N/A
16	Will any non-anonymised and/or personalised data be generated and/or stored?	☒	☐	☐
	If "Yes" will you gain the consent of the individuals concerned?	☒	☐	☐
17	Will you have access to documents containing sensitive* data about living individuals?	☐	☒	☐
	If "Yes" will you gain the consent of the individuals concerned?	☐	☐	☐

If "No" please give details in Section F.

* Sensitive data are *inter alia* data that relates to racial or ethnic origin, political opinions, religious beliefs, trade union membership, physical or mental health, sexual life, actual and alleged offences.

E. RESEARCH GOVERNANCE/ HUMAN MATERIALS

		Yes	No	N/A
18	**Does your study include the use of a drug?** *If yes, , please contact Research Governance before submission (resgov@cf.ac.uk)*	☐	☒	☐
18	Does the study involve the collection or use of Human Tissue (including, but	☐	☒	☐

	not limited to, blood, saliva and bodily waste fluids)? *If yes, a copy of the submitted application form and any supporting documentation must be e-mailed to the Human Tissue Act Compliance Team (HTA@cf.ac.uk).* *A decision will only be made once these documents have been received.*	☐	☐	☐

If "No" please give details in Section F.

F. Please use this space to provide further information/explanation in relation to your responses above:
The participation will be voluntary, and the participants will be asked for their written consent before staring answering this questionnaire. Also, they will be told that the data is undertaken exclusively for academic purposes. Therefore, their individual privacy and the confidentiality of the information provided will be maintained in all published and written data analysis resulting from this study.
Continue on a separate sheet as necessary.

G. OTHER ETHICAL CONSIDERATIONS

Please note in the space provided any additional ethical issues that you think the Committee should consider. It is your obligation to bring to the attention of the Committee any ethical issues not already covered on this form.

Continue on a separate sheet as necessary.

Prevent Duty	**YES**	**NO**	**N/A**
Has due regard be given to the 'Prevent duty', in particular to prevent anyone being drawn into terrorism? https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/445916/Prevent_Duty_Guidance_For_Higher_Education__England__Wales_.pdf http://www.cardiff.ac.uk/public-information/policies-and-procedures/freedom-of-speech	☐	☐	☒

H. Please give a brief description of the project, or attach copy of funding application:

In Iraq, the housing sector occupies the highest fraction in energy consumption compared to any other sector; which is projected to increase in coming decades. A considerable amount of such energy consumed is used for cooling (predominantly) and heating purposes. Heat and gas emissions represent one of the main environmental implications of this escalating energy demand and use. Therefore, adopting a high climate-responsive housing design with less energy-consumption, constitutes one of the key goals of Iraq's National Housing Policy; which was prepared in 2010 by the Iraqi Ministry of Construction and Housing and Public Municipalities, supported by the UN-HABITAT Program.

I am conducting a questionnaire in regard to the status quo of housing design as well as social and energy consumption patterns in Iraq, as a part of my study. The main purpose of gathering data within this questionnaire is to determine: -

- How well does existing residential buildings in Iraq respond to local climatic conditions.
- The influential physical characteristics of prevalent housing prototypes in Iraq that would affect energy efficiency and environmental performance; in respect to each prototype.
- Occupants' behaviour's stimulus, social requirements and occupancy peculiarity in Iraq.
- The features of existing houses that are linked to the cooling and heating systems, which consumes the bulk of the energy (electricity, oil and gas).
- The amount of public consciousness on energy issues.

Continue on a separate sheet as necessary.

I. Health and Safety/Risk Assessment

Principal Investigator/Supervisor: please sign to confirm that the relevant health and safety measures, in accordance with University policy and School requirements, have been taken into account for the proposed research.

Signature:

J. UG/PGT Student Project Authorisation

To the student: please submit this form to your project supervisor.

To the supervisor: please sign in Section I. Health and Safety/Risk Assessment and then submit this form to the Research Office for consideration by the School Ethics officer.

Approval by School Ethics Officer

I confirm that I believe that all research ethical issues have been dealt with in accordance with University policy and the research ethics guidelines of any relevant professional bodies.

Name: **Prof P N T Wells** Signature: _____ Date: _____

The School Ethics Officer's signature indicates the project is approved and may commence.

K. PGR/Staff Project Authorisation

Principal Investigator/ PGR Supervisor: please sign below to confirm that you believe all research ethical issues have been dealt with in accordance with University policy and the research ethics guidelines of any relevant professional bodies.

Name: _____ Signature: _____ Date: _____

Please submit this form to the Research Office. The application will be considered by the School Ethics Officer, the Lay Member and the Internal Member of the School Ethics Committee, and a recommendation on approval made to the next meeting of Research Committee, after which you will be informed of the decision of the Committee. Please note the project may not commence until you have received approval from the Committee.

Recommendation by Lay Member of School Ethics Committee

I recommend☐ / do not recommend☐ that this project should be approved by Research Committee

If not recommended for approval, please note reason (or attach separately):

....

Name: **Dr W Evans** (Cardiff and Vale University Health Board (UHB) Signature: _____ Date: _____

Recommendation by Internal Member of School Ethics Committee

I recommend☐ / do not recommend☐ that this project should be approved by Research Committee

If not recommended for approval, please note reason (or attach separately):

....

Name: **Dr Paul Brown (SOHCS)** Signature: _____ Date: _____

Recommendation by School Ethics Officer to Research Committee

I recommend☐ / do not recommend☐ that this project should be approved by Research Committee

If not recommended for approval, please note reason (or attach separately):

....

Name: **Prof P N T Wells** Signature: _____ Date: _____

Date reviewed at Research Committee : Outcome: Approved ☐ Not Approved ☐

Date reported to School Board :

A.2 The Original version of the general questionnaire and the transverse survey

CONSENT FORM

نموذج الموافقة

Title: Energy consumption in Iraqi houses **العنوان: استهلاك الطاقة لقطاع السكن في العراق**

Researcher: Balsam Alwan Shallal الباحث: بلســــم علـــوان شـــلال

Please check

1. I confirm that I have read and understand the information sheet dated .... ☐
for the above study and have had the opportunity to ask questions.
أؤكد أنني قد قرأت وفهمت الاستبيان المؤرخ .... للدراسة المذكورة أعلاه، وأتيحت لي الفرصة لطرح الأسئلة.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. ☐
أنا أفهم أن مشاركتي طوعية وأنا حر في الانسحاب في أي وقت، بدون اعطاء اي سبب.

3. I agree to take part in the above study. أنا أوافق على المشاركة في الدراسة المذكورة أعلاه. ☐

____________________ __________________________

Name or email of Participant	Date	Signature
اسم او البريد الالكتروني للمشارك	التاريخ	التوقيع

☐ Check box if the participant wishes to remain anonymous. تأشير المربع إذا رغب المشارك عدم الكشف عن هويته.

____________________ ______________________________

Name of Person taking consent (If different from researcher)	Date	Signature
اسم الشخص الذي استحصل الموافقة إذا كان غير الباحث	التاريخ	التوقيع

____________________ _____________ _________________

Researcher	Date	Signature
الباحث	التاريخ	التوقيع

Person conducted questionnaire　　　　　　الشخص الذي أجرى الاستبيان

Please type your demographic information　　　　　　الرجاء كتابة البيانات الشخصية قبل البدء بتقييم الاستبيان

Name	الاسم	
Company/ or organization	جهة العمل	
Subject field	مجال التخصص	
Position	المنصب	
Job title	الدرجة الوظيفية	
Years of experience	سنوات الخبرة	
Email address	البريد الالكتروني	
Place of residence	مكان الاقامة	

Energy consumption in Iraqi housing stock

Introduction: In Iraq, the housing sector accounts for 40% of the total energy consumption. International Energy Agency projects such energy demand to increase in the coming decades. Energy consumed is used predominantly for space cooling and heating purposes. Adopting climate-responsive housing design with reduced energy-consumption is, therefore, one of the key goals of Iraq's National Housing Policy, developed in 2010 by the Iraqi Ministry of Construction and Housing and Public Municipalities, supported by the UN-HABITAT Program.

I am a PhD researcher at Cardiff University's School of Engineering, United Kingdom, where I am investigating ways to reduce energy consumption from Iraqi houses, ultimately contributing to the development of new housing standards and policies.

Aim of this survey: this survey is designed to: -

- Identify the physical characteristics of Iraqi houses that affect energy efficiency and environmental performance.
- Investigate occupants' behaviour, social requirements and occupancy profiles result consuming the bulk of the energy.

Your participation is essential to identify a better solution for greater energy efficiency while not affecting comfort and lifestyle.

The data collected through this questionnaire will be made exclusively for academic purposes. Your privacy and the confidentiality of the information provided will be maintained in all published and written documents resulting from the study.

Your cooperation, effort and time are highly appreciated.

الاستهلاك السكني للطاقة في العراق

المقدمة:- إن النسبة التي يستهلكها قطاع السكن من مجموع الطاقة الكلية المستهلكة سنوياً في العراق هي (40%) والتي تشكل النسبة الاعلى مقارنةً مع باقي القطاعات, ومن المتوقع إزدياد هذه النسبة خلال العقود القادمة حسب تقرير المنظمة الدولية للطاقة. ومن المثير للاهتمام هنا هو أن الجزء الاكبر من هذه الطاقة يستخدم لأغراض التدفئة والتبريد حصراً. بناءاً على ذلك، فإن وزارة الاعمار والاسكان والبلديات العامة قد تبنت في سياستها الوطنية للاسكان والصادرة عام 2010 بالتعاون مع برنامج االمستوطنات البشرية في الامم المتحدة التصميم السكني المستدام الذي يحقق أعلى اداء بيئي مع اقل استهلاك للطاقة كأحد اهدافها الرئيسية.

أُفيدكم بأني طالبة دكتوراة تخصص هندسة معماري في كلية الهندسة- جامعة كارديف- المملكة المتحدة البريطانية. موضوع دراستي يتعلق بالبحث عن الوسائل الفعالة لتقليل استهلاك الطاقة ضمن قطاع السكن في العراق، والتي من شأنها ان تساهم بشكل أساسي في تطوير السياسات والمعايير السكنية المعتمدة هناك.

هدف الاستبيان:- تم أعداد هذا الاستبيان لتحقيق الاهداف التالية:-

- تحديد الخصائص المعمارية والانشائية المؤثرة على كفاءة الطاقة والاداء البيئي للمساكن في العراق.
- تقصي تأثير سلوك الأفراد، المتطلبات الاجتماعية، وخصوصية الاشغال المؤدية الى هذا الاستهلاك العالي للطاقة.

إن مشاركتم القيّمة وإجابتكم الدقيقة سوف تعكس المساهمة الفعالة للمواطن العراقي في مساعدة المؤسسات ذات الصلة لتقديم الحلول المُثلى لتصميم المساكن في العراق بما يوفر الراحة الحرارية مع زيادة كفاءة استخدام الطاقة ، كما أود أن أُؤكد هنا ان البيانات التي يتم جمعها في هذا الاستبيان هي تحت السرية التامة ولن تستخدم إلا لأغراض البحث العلمي .

تعاونكم، جهدكم، ووقتكم في الاجابة محل التقدير العالي والفائدة العلمية

Balsam Alwan Shallal
Ministry of Construction, Housing, and Public municipalities
Baghdad- Iraq.

بلســـم علـــوان شـــــلال
وزارة الاعمار والاسكان والبلديات العامة
بغداد / العراق

House questionnaire No مسلسل المنزل في الاستبيان		Date التاريخ	.... dd/ .... mon/ .... yr اليوم الشهر السنة

SECTION 1: Location Please put (√) in the appropriate box الجزء الأول: الموقع الرجاء وضع علامة (√) في مربع الاجابة الصحيحة

1	Municipality البلدية					
		Al-Rusafa الرصافة 1 ☐	Al-karkh الكرخ 2 ☐	Karrada الكرادة 3 ☐	Al-Ghadir الغدير 4 ☐	Al-Shaab الشعب 5 ☐	Baghdad Jedidah بغداد الجديدة 6 ☐
		Al-Kadhimiya الكاظمية 7 ☐	Al-Adhamiya الأعظمية 8 ☐	Mansur المنصور 9 ☐	Sader/1 الصدر الأولى 10 ☐	other / specify الرجاء التحديد	
		Al-Rasheed الرشيد 11 ☐	Dora الدورة 12 ☐	Al-Shualla الشعلة 13 ☐	Sader/2 الصدر الثانية 14 ☐		

Zone Please put (√) in the appropriate box البيئة الحضرية الرجاء وضع علامة (√) في مربع الاجابة الصحيحة

2	Urban حضر 1 ☐	Sub-urban الضواحي 2 ☐	Rural الريف 3 ☐
3	District الحي .... / Quarters المحلة	4 Village اسم القرية	5 Village اسم القرية ....

SECTION 2: Head of household الجزء الثاني: معلومات عن رب الاسرة

Please put (√) in the appropriate box الرجاء وضع علامة (√) في مربع الاجابة الصحيحة

6	Gender الجنس	Male ذكر 1 ☐	Female أنثى 2 ☐

7	Occupation المهنة	Government employee موظف حكومي 1 ☐	Non-government employee موظف غير حكومي 2 ☐	Self-employed أعمال حرة 3 ☐	Other / specify مهنة أخرى/ الرجاء التحديد .... 4 ☐

8	Age (please state your age) يرجى كتابة العمر
	.... year (سنة)

9	Educational attainment (please select your highest qualification) التحصيل العلمي (يرجى اختيار اعلى شهادة حاصل عليها)	
	Post- graduate degree (Msc, PhD ,etc) شهادة عليا (ماجستير، دكتوراة ..الخ) 1 ☐	Under- graduate degree شهادة جامعية او شهادة معهد 2 ☐
	High school certificate حاصل على الشهادة الإعدادية 3 ☐	Primary school حاصل على الشهادة الإبتدائية 4 ☐
	No qualification بدون مؤهل علمي 5 ☐	

SECTION 3: Background on household الجزء 3: معلومات عن الاسرة

Please put (√) in the appropriate box الرجاء وضع علامة (√) في مربع الاجابة الصحيحة

10	How many households live in the dwelling? ماهو عدد الاسر التي تعيش في المنزل؟	One أسرة واحدة 1 ☐	Two أسرتان 2 ☐	Three ثلاث أسر 3 ☐	Four أربع أسر 4 ☐	More than four أكثر من اربع أسر 5 ☐

11	Household size (persons) عدد افراد الاسرة	
	1st Household عدد افراد الاسرة الاولى	
	2nd Household عدد افراد الاسرة الثانية	
	3rd Household عدد افراد الاسرة الثالثة	
	4th Household عدد افراد الاسرة الرابعة	
12	What is the total number of persons live in the dwelling? ماهو العدد الكلي للافراد الذين يسكنون في المنزل؟	

13	How long have you lived at this address? (yr) (السنة)........................ كم مضى على الاسرة وهي تعيش في هذا المسكن؟		
14	Does your household own this accommodation or are you a tenant? Please put (√) in the appropriate box. ملكية الدار؟ الرجاء وضع علامة (√) في مربع الاجابة الصحيحة		
	Owner ملك 1 ☐	Rented–private ايجار - قطاع خاص 2 ☐	Rented-state ايجار - قطاع حكومي 3 ☐
	Provided by the employer سكن متوفر عن طريق رب العمل 4 ☐	Other / specify أخرى/ الرجاء التحديد .... 5 ☐	

SECTION 4: Household members					الجزء 4: افراد الاسرة
	15		16	17	18
Person No. تسلسل الفرد	Gender Please put (√) in the appropriate box. جنس الفرد الرجاء وضع علامة (√) في مكان الاجابة الصحيحة.		Age (yr) العمر (سنة)	Relation to the head of the household (Please select the number for the appropriate answer) درجة قرابة الفرد مع رب الاسرة (يرجى الاجابة من خلال اختيار رقم الاجابة المناسبة لكل فرد)	Employment status (Please select the number for the appropriate answer) مهنة الفرد (يرجى الاجابة من خلال كتابة رقم الاجابة المناسبة لكل فرد)
	Male ذكر	Female أنثى		Wife/ husband زوج / زوجة 2	Employed يعمل 1
				Daughter / son بنت / ابن 3	Unemployed عاطل عن العمل 2
				Mother or father أم / أب 4	Homemaker ربة منزل 3
				Sister or brother الأخ او الأخت 5	Student طالب 4
				Nephew / niece ابن/ بنت الأخ او الأخت 6	Retired متقاعد 5
				Sister / brother -in-law زوجة الأخ / زوج الاخت 7	Preschool مرحلة ما قبل المدرسة 6
				Grandchild الحفيد 8	
				Other relatives الاقارب 9	
				Daughter / son -in-law زوجة الابن / زوج البنت 10	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

SECTION 5 : Background on dwelling					الجزء 5: معلومات عن المسكن
A.	Characteristics of the dwelling Please put (√) in the appropriate box				خصائص المسكن الرجاء وضع علامة (√) في مربع (مربعات) الاجابة الصحيحة
19	In what year was the dwelling built? (Year).........................				تاريخ تشييد المنزل (السنة)
20	Type of dwelling نوع الوحدة السكنية	House منزل 1 ☐ →	Please go to Q. 21 & 22 الرجاء الذهاب الى السؤال 21 و22	Flat شقة 2 ☐ →	Please go to Q. 23 الرجاء الذهاب الى السؤال 23
21	Type of the house نوع المنزل	Detached غير ملاصق للجيران 1 ☐	Semi-detached ملاصق لـ 1 او 2 من الجيران ☐	Townhouse/ terraced (attached) ملاصق لـ 3 من الجيران ☐	Other / specify اختيار اخر / يرجى التحديد 4 ☐ ....
22	How many floors? عدد طوابق المنزل	One طابق واحد 1 ☐	Two طابقين 2 ☐	Three ثلاث طوابق 3 ☐	Other / specify اختيار اخر / يرجى التحديد 4 ☐ ....
23	On what floor is your flat located? في أي طابق تقع الشقة ؟	Ground floor الطابق الأرضي ☐	1st floor الطابق الأول 2 ☐	2nd floor الطابق الثاني 3 ☐	Other / specif اختيار اخر / يرجى التحديد 4 ☐ ....
24	What is the total area? ماهي المساحة الكلية لـــــ	Land (m^2) قطعة الأرض	Built area of the dwelling (m^2) المساحة المبنية	25 The dimensions of the land area ابعاد قطعة الأرض	Length ....(m) الواجهة Width .... (m) العمق

26 How many rooms are there in the dwelling? ما هو عدد الغرف (حسب نوع الفضاء) المتوفرة في المنزل؟

No التسلسل	Space نوع الفضاء	How many? العدد	In use الغرف قيد الاستخدام		Floor موقع الغرفة في أي طابق				Notes الملاحظات
			In use عدد الغرف قيد الاستخدام	Not in use عدد الغرف خارج الاستخدام	Ground الطابق الأرضي	First الطابق الأول	Second الطابق الثاني	Other طوابق أخرى	
1	Bedroom(s) غرفة النوم								
2	Family room(s) (Hall) غرفة المعيشة (هول)								
3	Guests' Room غرفة الضيوف								
4	Dining Room غرفة الطعام								
5	Kitchen المطبخ								
6	Hot kitchen and dining space مطبخ حار وفضاء الطعام								
7	Bathroom حمام								
8	Bathroom with toilet حمام مع خدمات صحية (تواليت)								
9	Separate toilet خدمات صحية داخلية منفصلة (تواليت)								
10	Outer toilet خدمات صحية خارجية (تواليت)								
11	Storage مخزن								
12	Balcony/ veranda شرفة (بالكونه)								
13	Stairwell بيت الدرج (بيتونه)								
14	Garage كراج								
15	Garden حديقة								
16	Patio متور								
17	Other rooms (specify) type: غرف أخرى / الرجاء التحديد --								

27 Structural materials (select as many as appropriate) **المواد الانشائية** (بالإمكان اختيار اكثر من إجابة)

Walls الجدران	Concrete readymade / pre-cast كونكريت مسبق الصب [1] ☐	Brick الطابوق [2] ☐	Cement blocks بلوك سمنتي [3] ☐	Thermo stone الثرمستون [4] ☐	Other / specify مواد أخرى / يرجى تحديدها [5] ☐ ....
Ceilings السقوف	Reinforced concrete casting صب الخرسانة المسلحة [1] ☐	Jack arching عقادة [2] ☐	Steel حديد [3] ☐	Wood خشب [4] ☐	Other / specify مواد أخرى / يرجى تحديدها [5] ☐ ....

28 Finishing materials (select as many as appropriate) **مواد الانهاءات** (بالإمكان اختيار اكثر من إجابة)

External walls الجدران الخارجية	Cement rendering نثر [1] ☐	Stone حجر [2] ☐	Ceramic/ marble tiles سيراميك / مرمر [3] ☐	Brick الطابوق [4] ☐	Other / specify مواد أخرى / يرجى تحديدها [5] ☐ ....
Internal walls الجدران الداخلية	Plaster بياض [1] ☐	Ceramic tiles سيراميك [2] ☐	Brick الطابوق [3] ☐	Stone حجر [4] ☐	Other / specify مواد أخرى / يرجى تحديدها [5] ☐ ....
Floors الأرضيات	Mosaic cement tiles موزائيك كاشي [1] ☐	Ceramic tiles سيراميك [2] ☐	Concrete casting صبة الكونكريت [3] ☐	Floor (flat) Bricks طابوق فرشي [4] ☐	Other / specify مواد أخرى / يرجى تحديدها [5] ☐ ....

29	Windows & doors materials (select as many as appropriate) مواد الابواب والشبابيك (بالإمكان اختيار اكثر من إجابة)				
Window frame إطارات الشبابيك	Steel حديد 1 ☐	Aluminium الألمنيوم 2 ☐	PVC بي في سي 3 ☐	Wood خشب 4 ☐	Other / specify مواد أخرى / يرجى تحديدها 5 ☐ ....
Doors الابواب	Steel حديد 1 ☐	Aluminium الألمنيوم 2 ☐	PVC بي في سي 3 ☐	Wood خشب 4 ☐	Other / specify مواد أخرى / يرجى تحديدها 5 ☐ ....

30	Number of glazing layers used in the dwelling's windows and glass doors عدد طبقات الزجاج المستخدمة في شبابيك وابواب المنزل Please put (√) in the appropriate box الرجاء وضع علامة (√) في مربع الاجابة الصحيحة		
Single طبقة مفردة 1 ☐	Double طبقتين 2 ☐	Triple ثلاث طبقات 3 ☐	Other / specify مواد أخرى / يرجى تحديدها 4 ☐ ....

31	Which of the following does the dwelling have? أي العناصر التالية متوفرة في المسكن؟ Please put (√) in the appropriate box(es) الرجاء وضع علامة (√) في الحقول المتوفرة			
Low energy light bulbs مصابيح انارة اقتصادية 1 ☐	False ceilings سقوف ثانوية 2 ☐	Cavity walls جدران مجوفة 3 ☐	Automatic temperature controls (room thermostat) أجهزة تحكم اتوماتيكية بدرجات الحرارة (ثرموستات) 4 ☐	Insulation material مواد عازلة 5 ☐ ***(If YES, GO TO Q 32)*** ***(إذا كان الجواب نعم يرجى الانتقال الى س 32)***

32	Which of the following elements have insulation materials? (select as many as appropriate) في أي جزء من المنزل تم استخدام المواد العازلة (بالإمكان اختيار اكثر من إجابة)			
Roofs السطوح 1 ☐	Walls الجدران 2 ☐	Floors الأرضيات 3 ☐	Ceilings السقوف 4 ☐	Other / specify مواد أخرى / يرجى تحديدها 5 ☐ ....

33	Which direction the front elevation is facing towards? ماهو توجيه الواجهة الامامية للمسكن؟ Please put (√) in the appropriate box الرجاء وضع علامة (√) في مربع الاجابة الصحيحة		
North شمال 1 ☐	South جنوب 2 ☐	East شرق 3 ☐	West غرب 4 ☐
North-east شمال- شرق 5 ☐	South-east جنوب- شرق 6 ☐	North-west شمال- غرب 7 ☐	South-west جنوب- غرب 8 ☐

B. Sources of energy مصادر الطاقة

34 Rank the sources of energy according to their use for the following Activities?
رتب مصادر الطاقة حسب درجة استخدامها للفعاليات المنزلية التالية؟

First source (1) كمصدر اول — Second source (2) كمصدر ثاني — Third source (3) كمصدر ثالث — Fourth source (4) كمصدر رابع — Fifth source (5) كمصدر خامس

Activity الفعالية	Electricity from national grid شبكة الكهرباء الوطنية	Electricity from neighbourhood generator الطاقة الكهربائية من المولدات الاهلية	Electricity from generator in the house الطاقة الكهربائية من المولدات المنزلية	Liquid gas cylinder (propane) قناني الغاز السائل	Kerosene (heating oil) النفط (نفط التدفئة)	Other /specify مصادر اخرى/ الرجاء تحديدها
Cooking الطبخ						
Lighting الانارة						
Cooling التبريد						
Heating التدفئة						
Hot water تسخين الماء						

C. The peak period of usage of cooling and heating systems فترات ذروة الاستخدام لأنظمة التدفئة والتبريد خلال السنة

35 **Using the scale below, from 1-5, please select during which month(s) do you use cooling and heating systems in your dwelling and for how long do you use it for.**

من خلال استخدام المقياس التالي من (1) الى (5)، الرجاء تحديد عدد الساعات التي يتم فيها استخدام انظمة التبريد والتدفئة في منزلك خلال اشهر السنة.

=< 5 hours /day (1) (أقل او يساوي خمس يوميا) | 5-10 hours /day (2) (من خمس الى عشر ساعة يوميا) | 11-15 hours /day (3) (من عشرة الى خمسة عشرة ساعة يوميا) | 16-20 hours /day (4) (من ستة عشر الى عشرين ساعة يوميا) | => 20 hours > /day (5) (يساوي او اكثر من عشرين ساعة يوميا)

	1	2	3	4	5	6	7	8	9	10	11	12
	January كانون الثاني	February شباط	March آذار	April نيسان	May أيار	June حزيران	July تموز	August آب	September أيلول	October تشرين الأول	November تشرين الثاني	December كانون الأول
Cooling system نظام التبريد												
Heating system نظام التدفئة												

36 **According to your answer in question 35, What is the peak schedule of cooling / heating systems used per day in summer / winter?** Please put (√) in the appropriate box(s)

بناءا على اجابتكم للسؤال 35. ماهي فترة الذروة في استخدام نظام التبريد/ التدفئة خلال اليوم صيفا/ شتاءا. الرجاء وضع علامة (√) في مربع (المربعات) الاجابة الصحيحة

	1 am to 12 pm من 1 ليلاً حتى 12 ظهراً												From 1pm to 12am من 1 ظهراً حتى 12 ليلاً											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Cooling system نظام التبريد																								
Heating system نظام التدفئة																								

37 **What is the main method(s) of cooling the dwelling?** (select as many as appropriate)

ماهي اهم الطرق المستخدمة للتبريد في منزلك؟ (بالإمكان اختيار اكثر من إجابة)

Air-conditioner, split unit etc. المكيفات او السبلت يونت .... الخ [1] ☐	Evaporative Cooler المبردات [2] ☐	Ceiling / Standing fan المراوح السقفية / الأرضية [3] ☐	Natural Ventilation تهوية طبيعية [4] ☐	Other / specify طرق أخرى / يرجى تحديدها .... [5] ☐

38 **What is the main method(s) of heating the dwelling?** (select as many as appropriate)

ماهي اهم الطرق المستخدمة للتدفئة في منزلك (بالإمكان اختيار اكثر من إجابة)

Air-conditioner, split unit etc. المكيفات او السبلت يونت .... الخ [1] ☐	Oil heater مدفأة نفطية [2] ☐	Electric Heater مدفأة كهربائية [3] ☐	Gas heater مدفأة غازية [4] ☐	Other / specify طرق أخرى / يرجى تحديدها .... [5] ☐

39 **Based on your experience in your accommodation, please indicate your point of view on the following aspects of cooling and heating systems used in your accommodation.** Please put (√) in the appropriate box.

استنادا" الى تجربتك الشخصية، ضع وجهة نظرك حول الجوانب التالية المتعلقة بمنزلك. الرجاء وضع علامة (√) في مربع الاجابة الصحيحة.

		Strongly disagree أعارض جداً	Disagree أعارض	Neither agree nor disagree لا أوافق ولا أعارض	Agree أوافق	Strongly agree أوافق جداً
The cooling system is نظام التبريد المستخدم في منزلك هل هو	Safe آمن					
	healthy صحي					
	easy to use سهل الأستخدام					
The heating system is نظام التدفئة المستخدم في منزلك هل هو	Safe آمن					
	healthy صحي					
	easy to use سهل الأستخدام					

D. Expenses on energy مقدار الانفاق لاستهلاك الطاقة

40 (a)	(b)		(c)	(d)	
Type نوع الانفاق المنزلي على مصادر الطاقة	**How much was the last payment?** ما هو مقدار المبلغ المالي الذي قامت الاسرة بانفاقه مؤخرا على مصادر الطاقة المذكورة في الفقرة (a)		**How many months did this last payment cover?** ماهي الفترة الزمنية التي غطاها الانفاق في (b)	**Only for neighbourhood generators** هذا الحقل يخص فقط الاشتراك في المولدات الاهلية **Maximum current (ampere) allowed in summer and winter?** ما هو عدد الامبيرات التي يتضمنها الاشتراك في المولدات الاهلية صيفاً و شتاءاً	
	In ID (Iraqi dinars) بالدينار العراقي		months عدد الأشهر	Ampere امبير Summer صيفا	Winter شتاءا
Electricity from the national grid bill قوائم الكهرباء من الشبكة الوطنية				X	X
Bill for electricity bought from a neighbourhood generator قوائم الكهرباء من المولدات الاهلية	Summer صيفا	Winter شتاءا			
Electricity from a private network مقدار الانفاق على المولدات المنزلية				X	X
Liquid gas cylinder قناني الغاز السائل				X	X
Kerosene النفط				X	X
Other /specify مصادر اخرى/ الرجاء تحديدها				X	X

41 According to your present needs, how satisfied are you with each of the following aspects of your accommodation?
Please put (√) in the appropriate box.
كيف تقيم الجوانب التالية لمنزلك، استنادا" الى احتياجاتكم الحالية؟ الرجاء وضع علامة (√) في مربع الاجابة الصحيحة .

		Very dissatisfied غير راض جداً	Dissatisfied غير راض	Neither satisfied nor dissatisfied لا راض ولا غير راض	Satisfied راض	Very satisfied راض جداً
Physical aspects الجوانب الفيزيائية للمنزل	Total area of the dwelling المساحة الكلية للمنزل					
	Total built area المساحة المبنية الكلية					
	Total open area (garden, garage) المساحة المفتوحة (حديقة، كراج...الخ)					
	Total number of rooms عدد الكلي للغرف					
	Average size of rooms متوسط حجم الغرف					
Environmental features الخصائص البيئية للمنزل	Thermal comfort during summer الراحة الحرارية لمنزلك خلال الصيف					
	Thermal comfort during winter الراحة الحرارية لمنزلك خلال الشتاء					
	Daylight in rooms الإنارة الطبيعية للغرف					
Cost of energy consumption تكلفة استهلاك الطاقة في المنزل	Total cost of energy consumption إجمالي الطاقة المستهلكة في المنزل					
	Total cost of energy consumption for cooling إجمالي تكلفة الطاقة المستهلكة في المنزل لأغراض التبريد					
	Total cost of energy consumption For heating إجمالي تكلفة الطاقة المستهلكة في المنزل لأغراض التدفئة					

42	What percentage of the total monthly household income is spent on buying energy (electricity, gas, Kerosene and other)? Please put (√) in the appropriate box. ما هي النسبة التقديرية للانفاق على مصادر الطاقة (كهرباء، غاز، نفط، والمصادر الاخرى) من مجموع الدخل الإجمالي الشهري للاسرة؟ الرجاء وضع علامة (√) في مربع الاجابة الصحيحة .									
	0-5% [1]		6-10% [2]		11-15% [3]		16-20% [4]		21-25% [5]	
	26-30% [6]		31-35% [7]		36-40% [8]		41-45% [9]		>45% [10]	

E. Appliances and their energy sources الاجهزة المنزلية ومصادر الطاقة المستخدمة لتشغيلها

43 **Here is a list of appliances which a household might have. Which of the things listed your household has?**
هنا مجموعة من الأجهزة التي ربما تملكها الاسرة، الرجاء إعطاء المعلومات حول كل جهاز تملكه الاسرة حسب متطلبات الجدول.

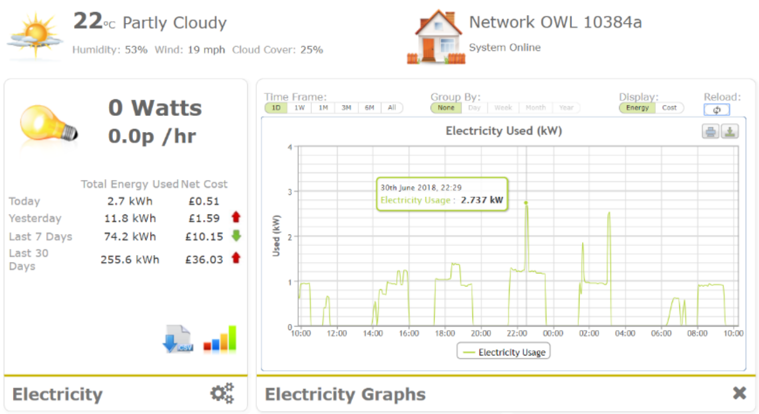
	Appliances انواع الأجهزة	**How many** العدد	**Energy source** مصدر الطاقة المستخدم في تشغيل الجهاز **Electricity** 1 كهرباء **Gas** 2 غاز **Kerosene** 3 نفط **Other / specify** 4 مصادر اخرى/ يرجى تحديدها **Please select the number for the appropriate answer** (يرجى كتابة رقم الاجابة المناسبة)	**Notes** الملاحظات
1	Evaporative Cooler مبردة			
2	Fridge ثلاجة			
3	TV تلفزيون			
4	Cooker+ oven طباخ+ فرن			
5	Hot water boiler سخان ماء			
6	Water cooler براد ماء			
7	Fan مروحة			
8	Air conditioner (window type) مكيف			
9	Air conditioner (split unit) سبلت يونت			
10	Extractor fan مروحة سحب (ساحبه)			
11	Chest frozen مجمدة			
12	washing machine غسالة			
13	vacuum cleaner مكنسة كهربائية			
14	Personal computer كمبيوتر شخصي			
15	Router/modem شبكة انترنت			
16	Game console (play station, X box, العاب البلي ستيشن، أكس بوكس			
17	Satellite ستلايت			
18	Tablet (iPad, tab) ايباد			
19	Iron مكوي			
20	Microwave مايكرويف			
21	Telephone (whether fixed or mobile) هواتف بأنواعها (ثابتة او محمولة)			
22	Oven فرن			
23	Grill شواية			
24	Tandoori oven تنور غازي			
25	Sewing machine ماكنة خياطة			
26	Water filter مرشح مياه (فلتر)			
27	Water pumping مضخة ماء (ماطور)			
28	Mill مطحنة			
29	Juicer معصارة			
30	Mixers خلاط			
31	Mincer ماكنة فرم اللحم			
32	Toaster محمصه			
33	Other/ specify أجهزة أخرى / يرجى التحديد ………………………………………………			

THIS IS THE END OF THE QUESTIONNAIRE

THANK YOU FOR TAKING THE TIME TO COMPLETE IT

A.3 Energy use monitoring system

(a)



(b)

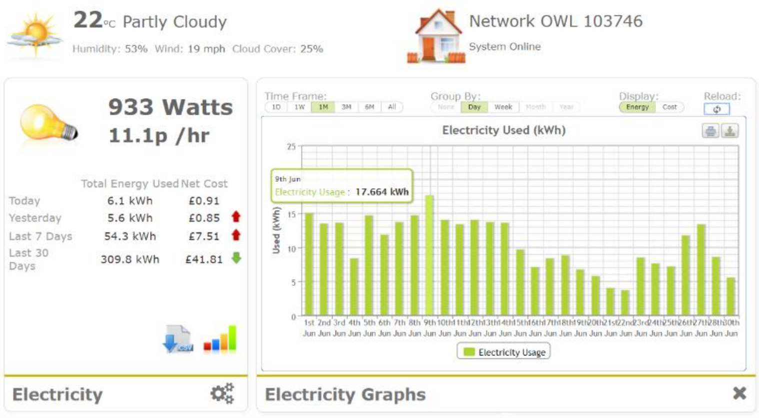


Figure A-1. The interface of the energy use monitoring program from which data can be exported as a .csv file, the data can then be illustrated in graphs in Excel. (a) the interface of the hourly energy use, (b) the interface of the daily energy use.

Table A-1. CSV file of electricity monitoring data with description.

	A	B	C	D	E
1	timestamp	curr_property	curr_property_cost	day_property	day_property_cost
2	29/06/2018 22:21	9788	116	78675	963
3	29/06/2018 22:21	9579	114	78675	963
4	29/06/2018 22:21	9595	114	78675	964
5	29/06/2018 22:21	9659	115	78836	964
6	29/06/2018 22:21	9627	114	78836	965
7	29/06/2018 22:22	9659	115	78836	965
8	29/06/2018 22:22	9836	117	78836	965
9	29/06/2018 22:22	9997	119	78836	966
10	29/06/2018 22:22	10013	119	78999	966
11	29/06/2018 22:22	10158	120	78999	967
12	29/06/2018 22:23	10029	119	78999	967
13	29/06/2018 22:23	10206	121	78999	967
14	29/06/2018 22:23	10126	120	78999	968
15	29/06/2018 22:23	10077	120	79168	968
16	29/06/2018 22:23	10174	121	79168	969

Column Heading	Description	Format / Units
timestamp	Date and Time	yyyy-mm-dd hh:mm:ss
curr_property	Live Electricity Consumption Power (Aggregated for all consumption channels)	Watt
curr_property_cost	Live Electricity Consumption Cost (Aggregated for all consumption channels)	Monetary sub units, e. g, Pence or Cents
day_property	Accumulated Electricity Consumption Power since midnight (Aggregated for all consumption channels)	Watt/hour
day_property_cost	Accumulated Electricity Consumption Cost since midnight (Aggregated for all consumption channels)	Monetary sub units, e. g, Pence or Cents

The steps of calculating the minutely and hourly energy use:-

- Step 1: The raw data of (day_property) column was used to calculate the energy use since it represents the cumulative readings of electricity use.
- Step 2: python code used to get one reading for each minute which is the last reading as a maximum reading.
- Step 3: python code used to calculate the minutely energy use by subtracting the previous reading from the reading after.
- Step 4: python code used to get the hourly energy use in both Wh and kWh by aggregating the minutely energy use for each hour.

By applying the above steps, the hourly energy use was calculated for both NG and SG for each case study separately which used later to calculate the suppressed demand.

Appendix B – Energy use and Suppressed energy demand

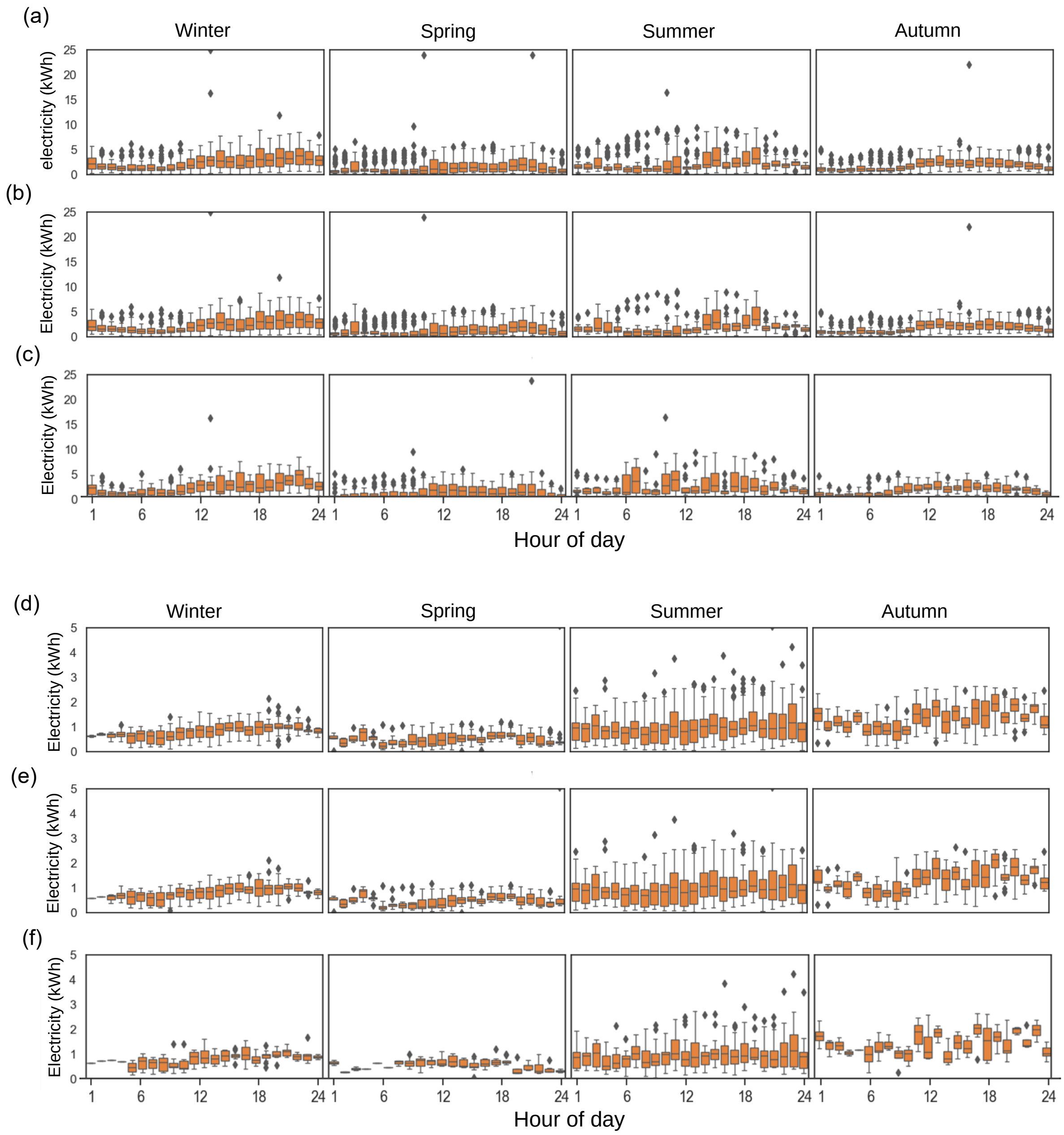


Figure B-1. The hourly energy use for different seasons in H2 case study: (a-c) the hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the hourly energy use from CG during all days of week, weekdays, weekends.

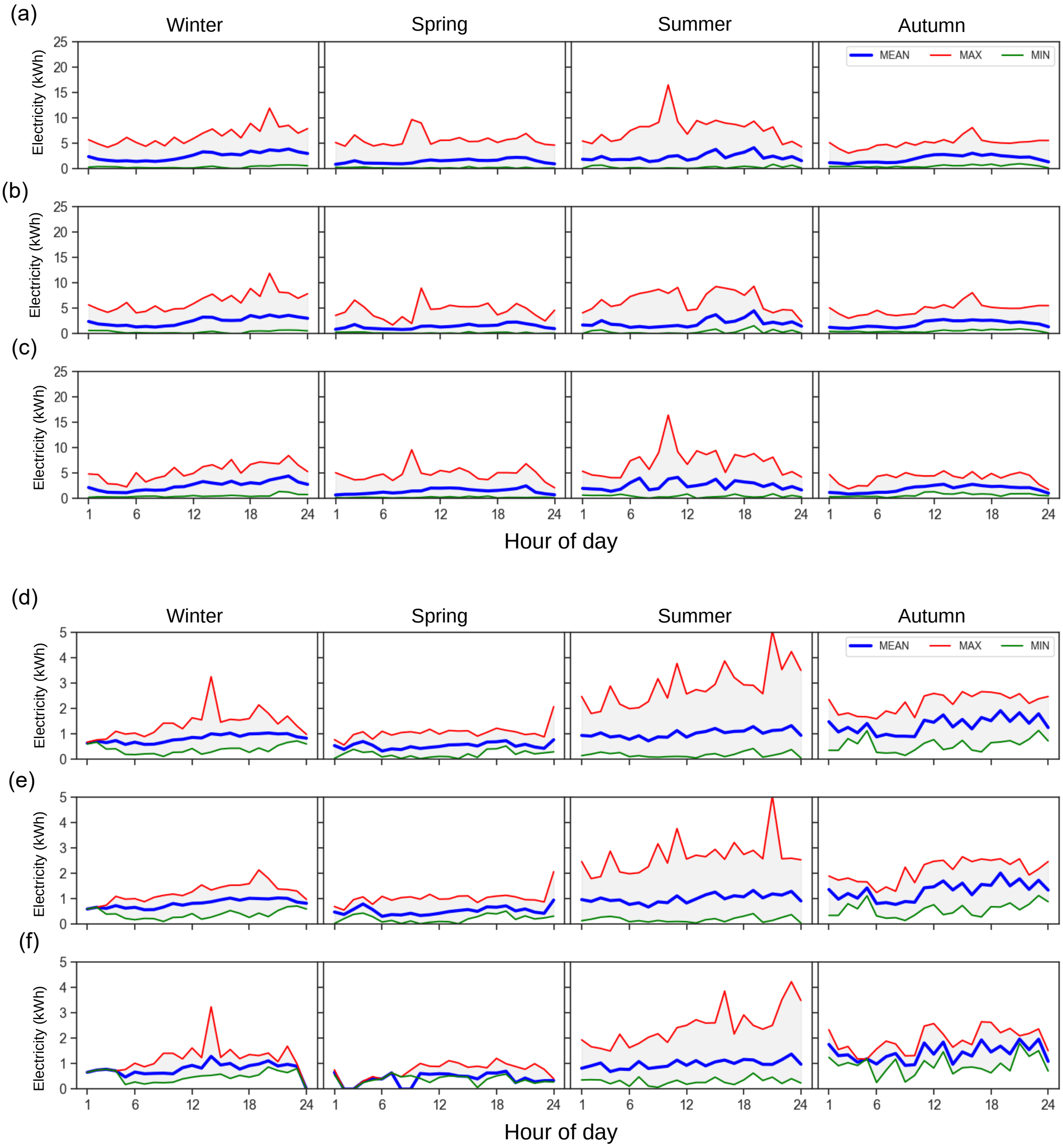


Figure B-2. The maximum, minimum and mean hourly energy use for different seasons in H2 case study: (a-c) the maximum, minimum and mean hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the maximum, minimum and mean hourly energy use from CG during all days of week, weekdays, weekends.

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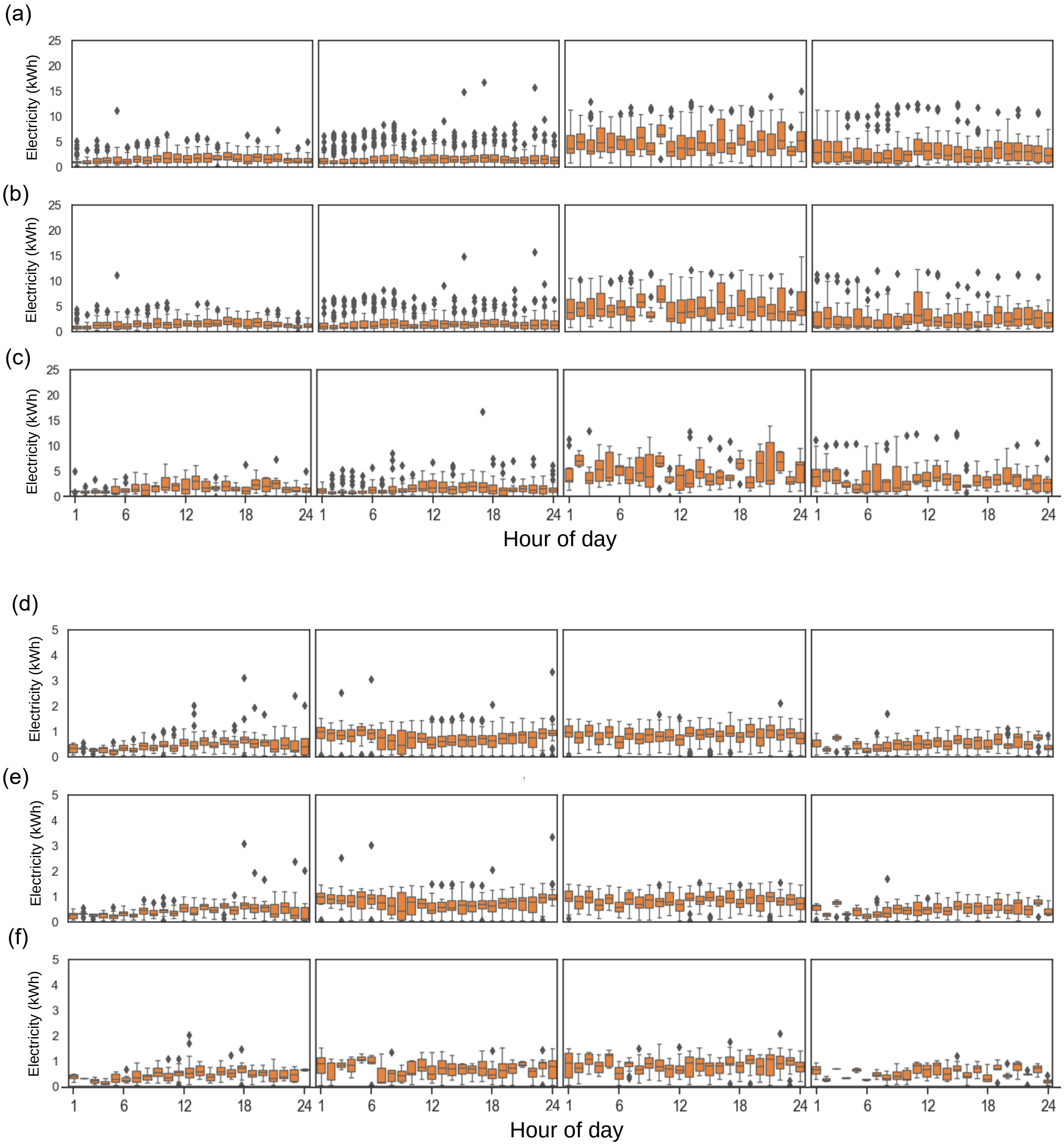

Figure B-3. The hourly energy use for different seasons in H3 case study: (a-c) the hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the hourly energy use from CG during all days of week, weekdays, weekends.

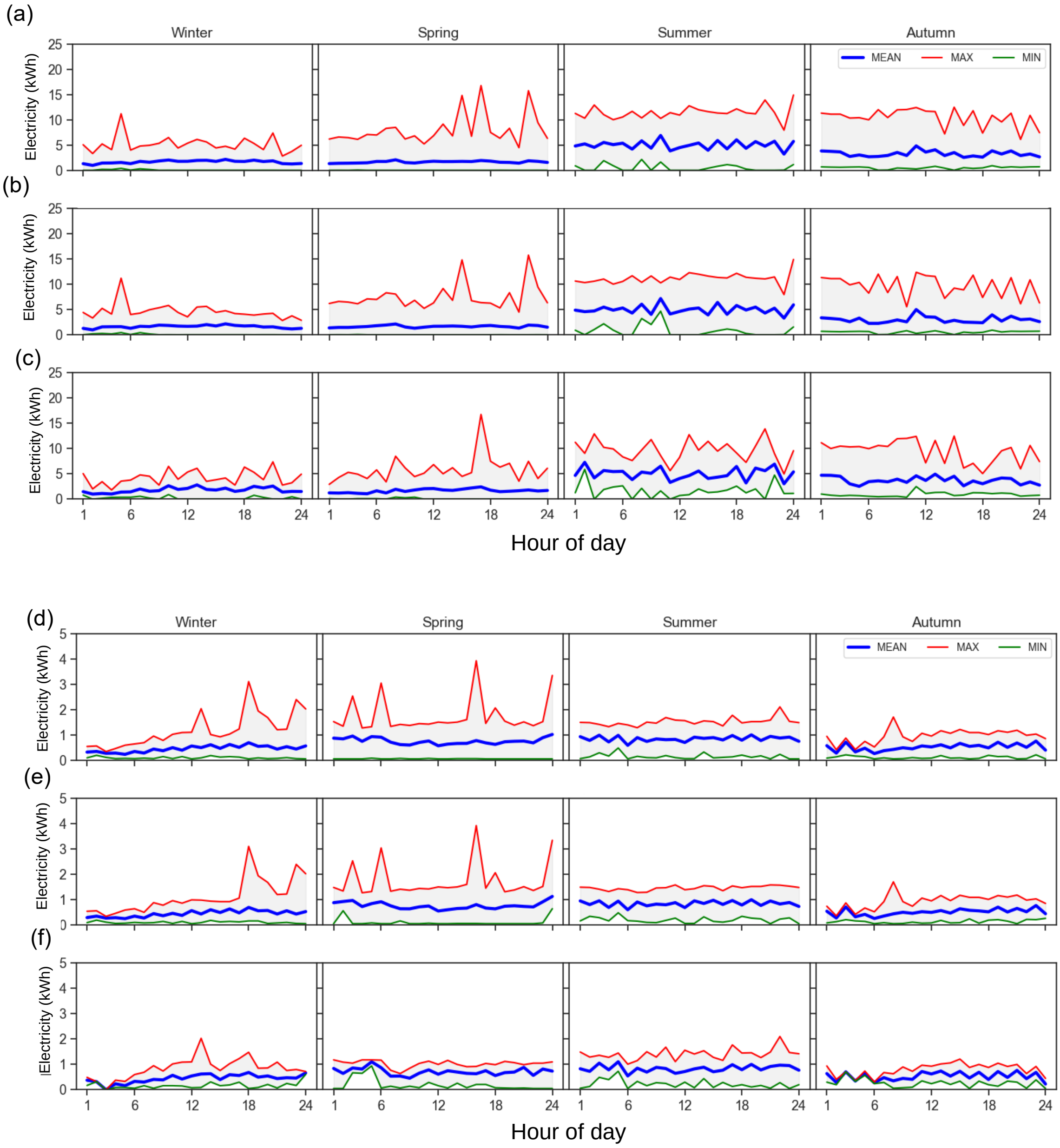

Figure B-4. The maximum, minimum and mean hourly energy use for different seasons in H3 case study: (a-c) the maximum, minimum and mean hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the maximum, minimum and mean hourly energy use from CG during all days of week, weekdays, weekends.

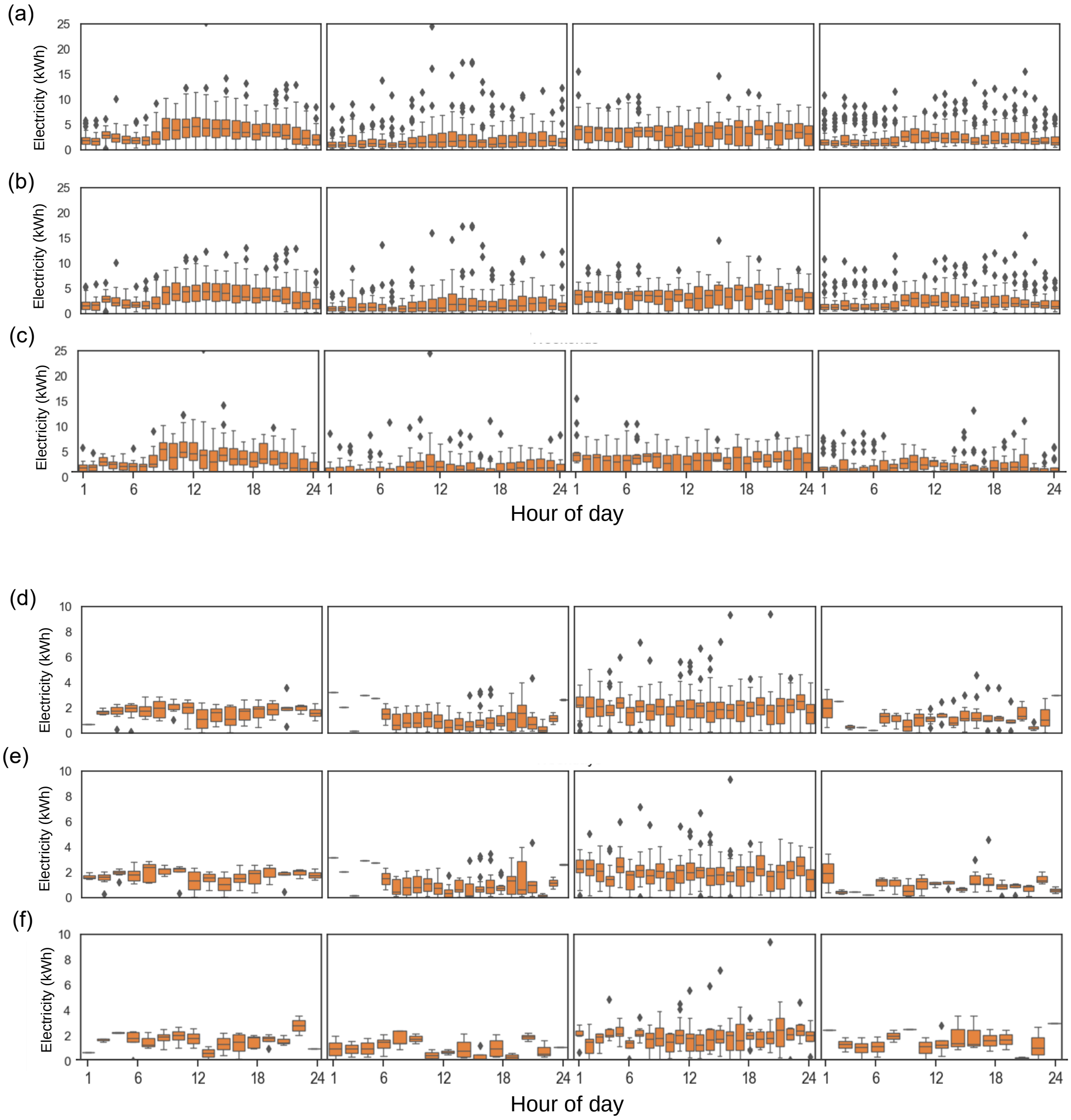

Figure B-5. The hourly energy use for different seasons in H4 case study: (a-c) the hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the hourly energy use from CG during all days of week, weekdays, weekends.

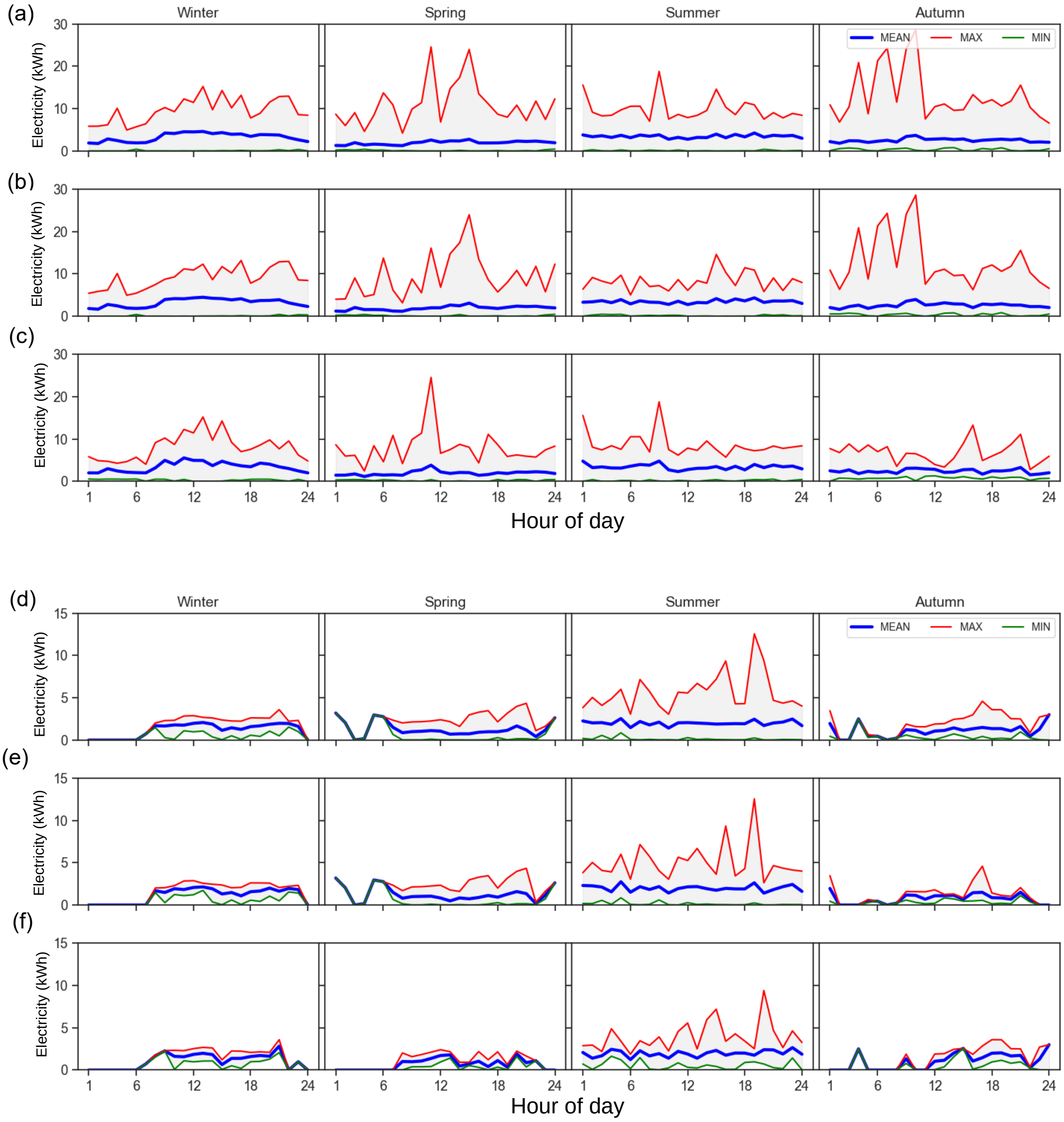

Figure B-6. The maximum, minimum and mean hourly energy use for different seasons in H4 case study: (a-c) the maximum, minimum and mean hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the maximum, minimum and mean hourly energy use from CG during all days of week, weekdays, weekends.

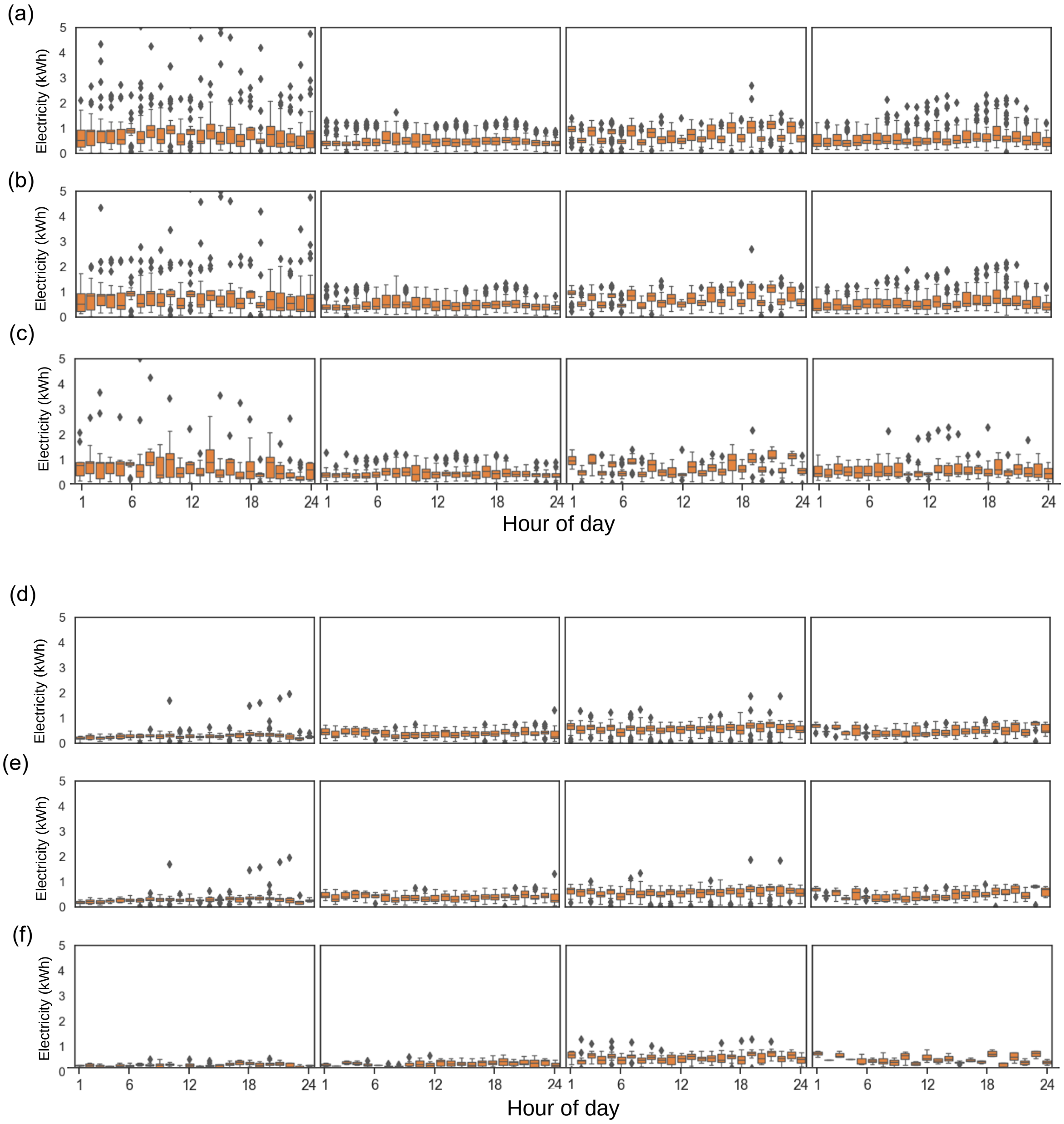

Figure B-7. The hourly energy use for different seasons in H5 case study: (a-c) the hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the hourly energy use from CG during all days of week, weekdays, weekends.

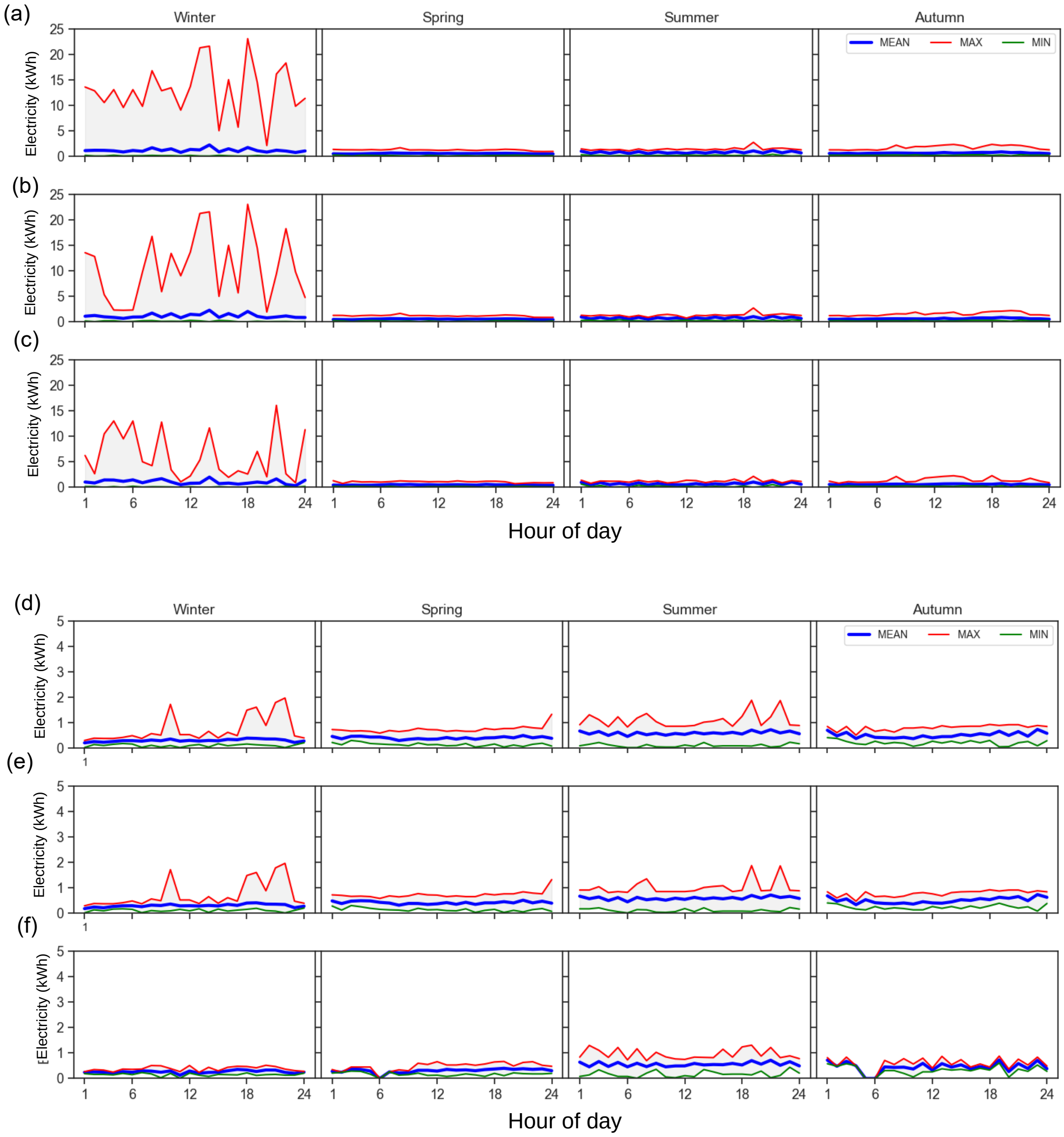

Figure B-8. The maximum, minimum and mean hourly energy use for different seasons in H5 case study: (a-c) the maximum, minimum and mean hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the maximum, minimum and mean hourly energy use from CG during all days of week, weekdays, weekends.

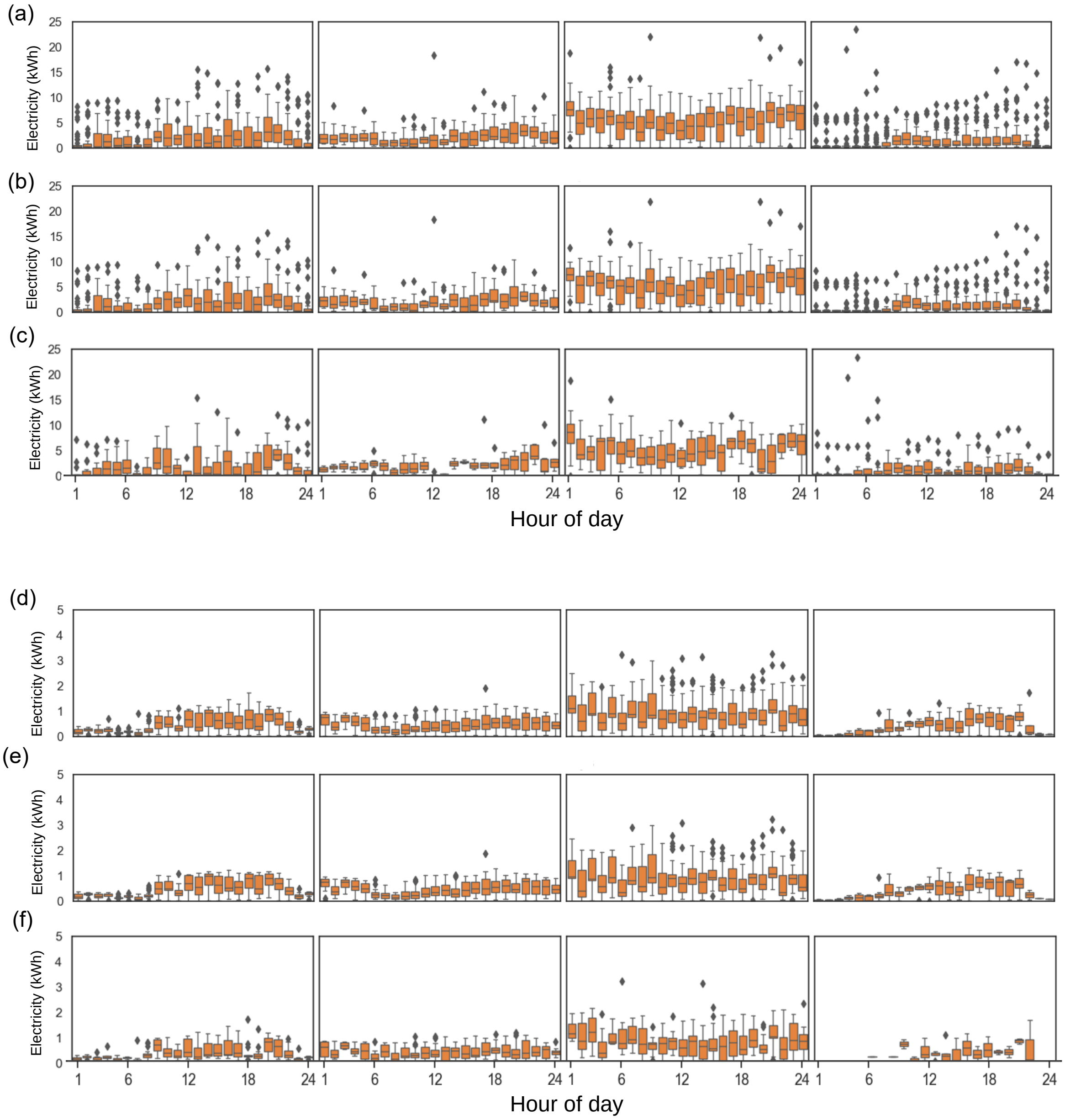

Figure B-9. The hourly energy use for different seasons in H6 case study: (a-c) the hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the hourly energy use from CG during all days of week, weekdays, weekends.

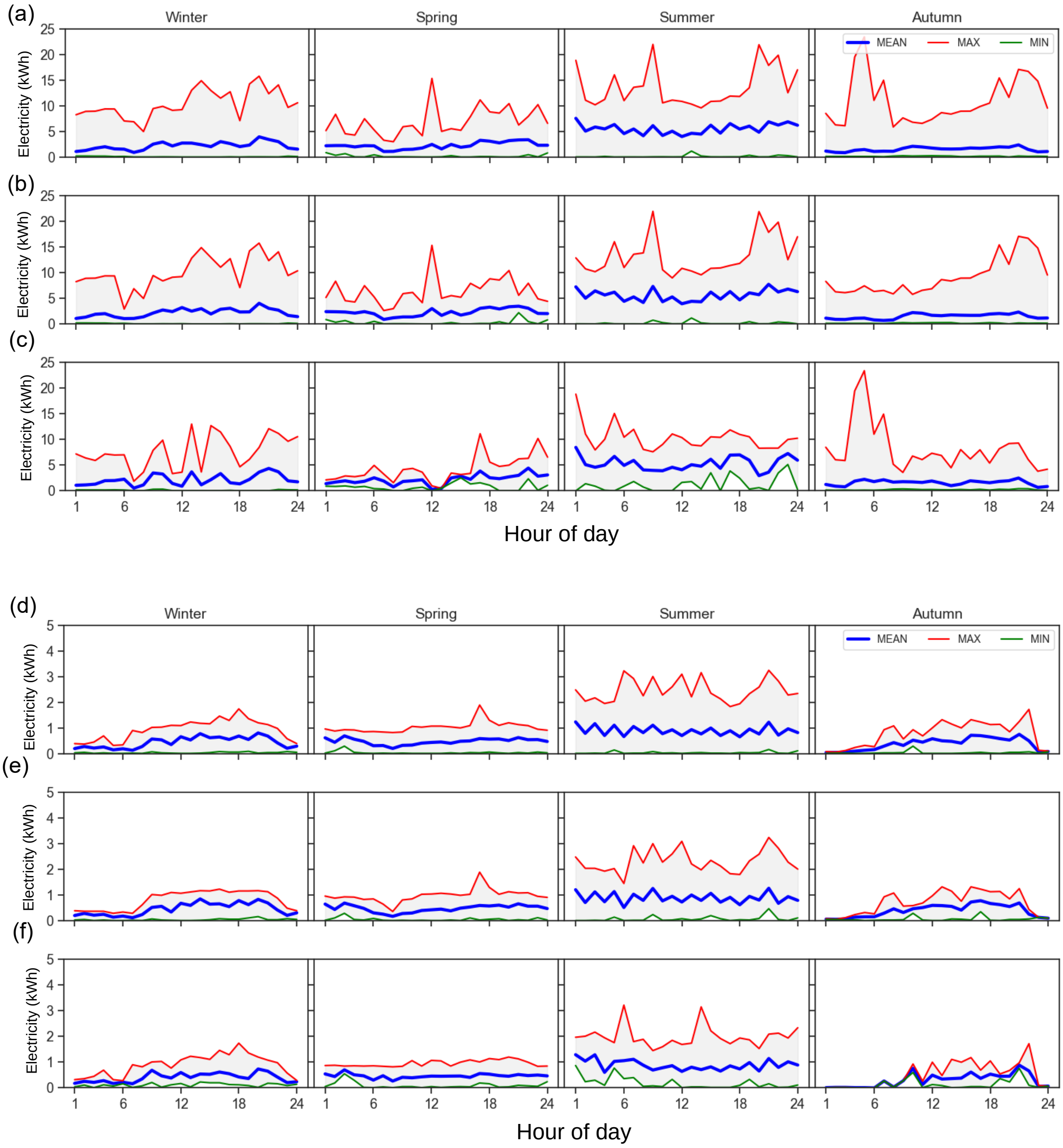

Figure B-10. The maximum, minimum and mean hourly energy use for different seasons in H6 case study: (a-c) the maximum, minimum and mean hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the maximum, minimum and mean hourly energy use from CG during all days of week, weekdays, weekends.

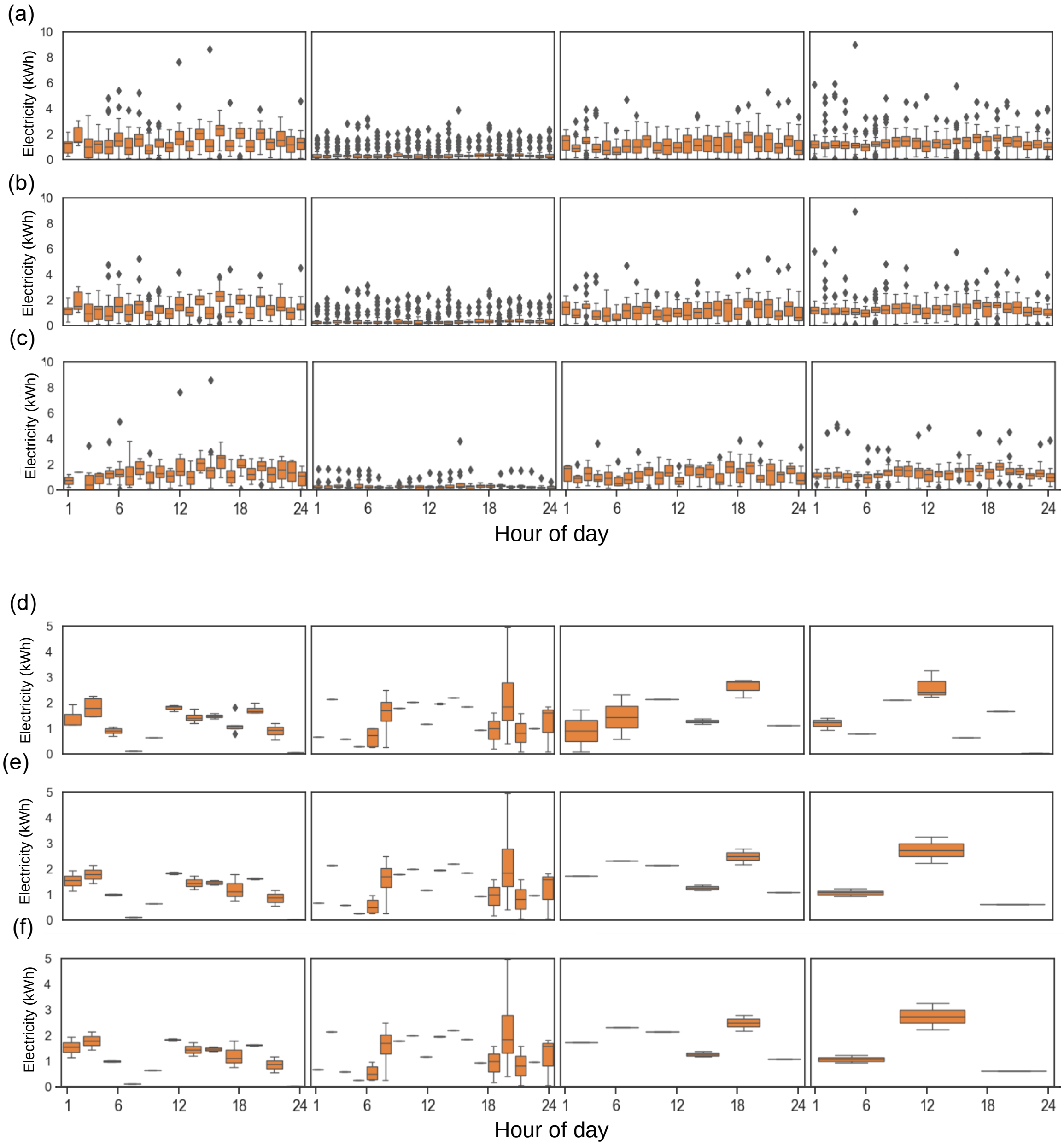

Figure B-11. The hourly energy use for different seasons in H7 case study: (a-c) the hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the hourly energy use from CG during all days of week, weekdays, weekends.

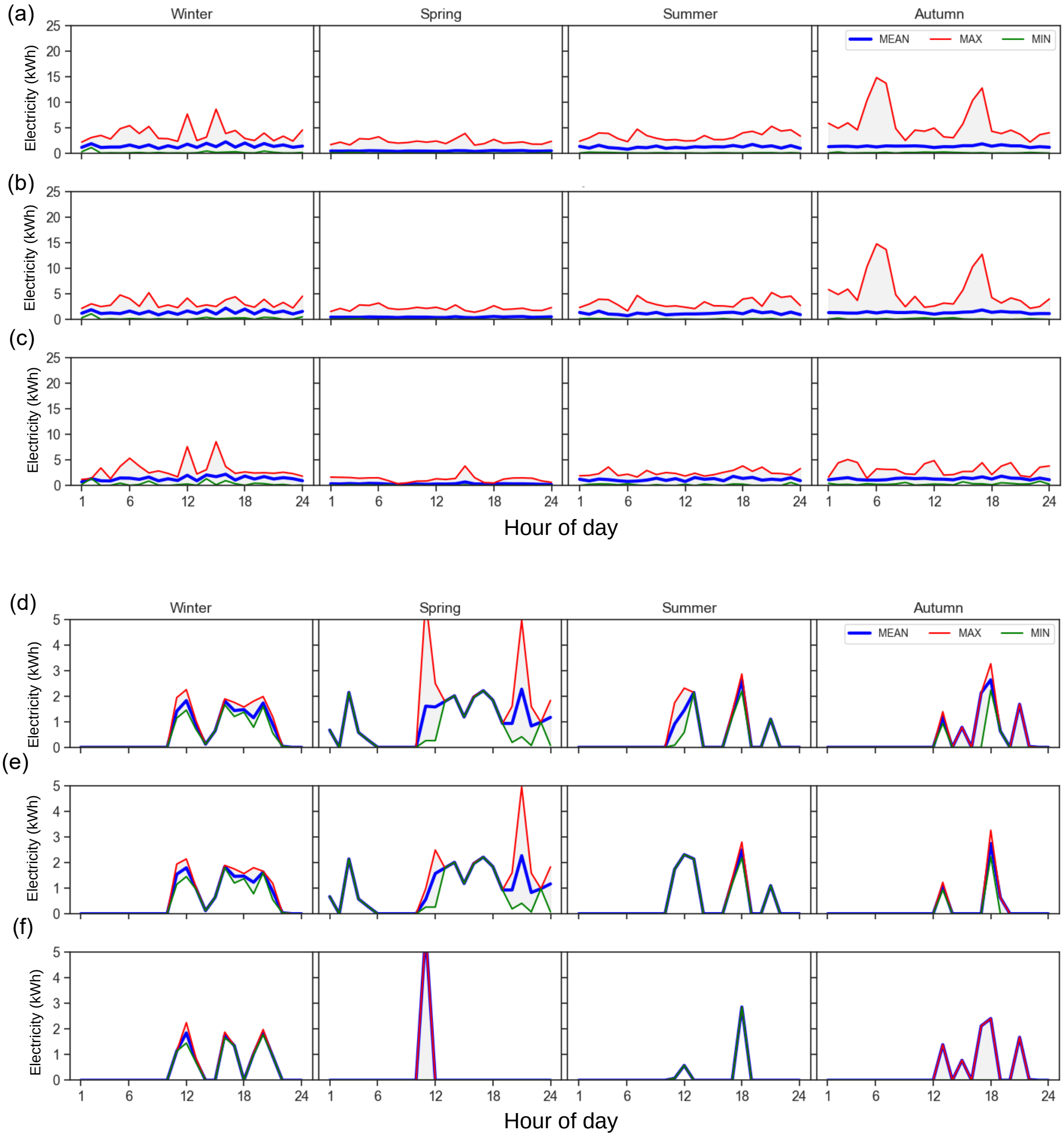

Figure B-12. The maximum, minimum and mean hourly energy use for different seasons in H7 case study: (a-c) the maximum, minimum and mean hourly energy use from NG during all days of week, weekdays, weekends, (d-f) the maximum, minimum and mean hourly energy use from CG during all days of week, weekdays, weekends.

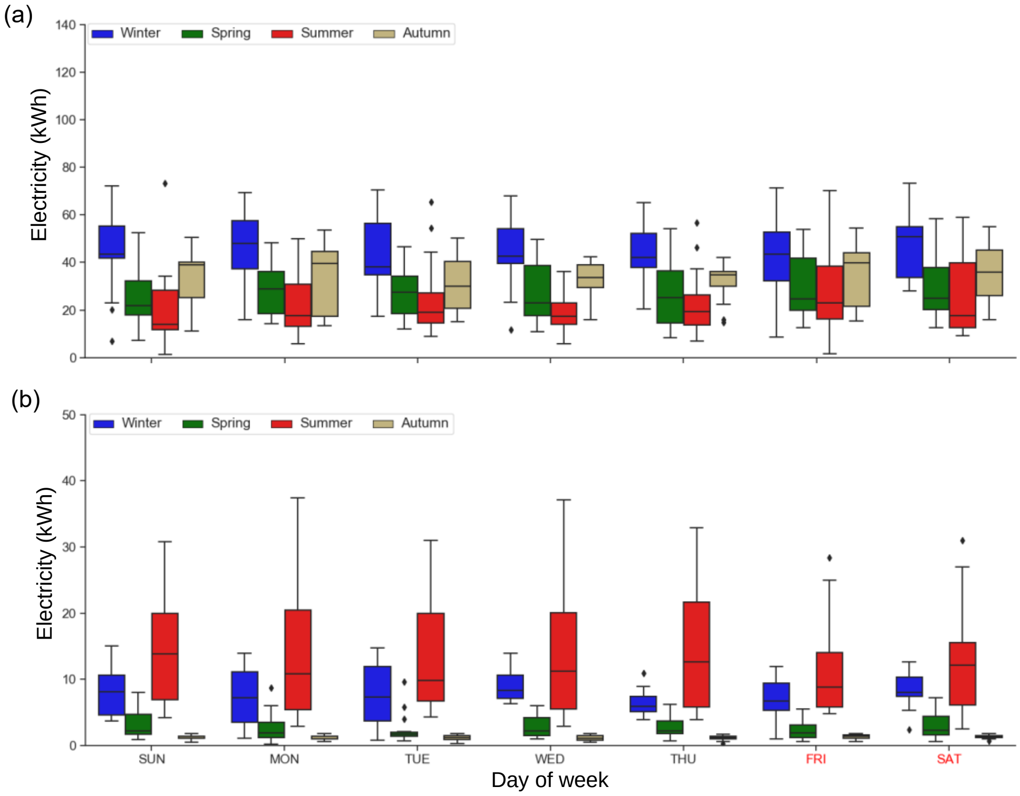

Figure B-13. The daily energy use from NG and CG (kWh) for different seasons in H2 case study: (a) the daily energy use from NG, and (b) the daily energy use from CG.

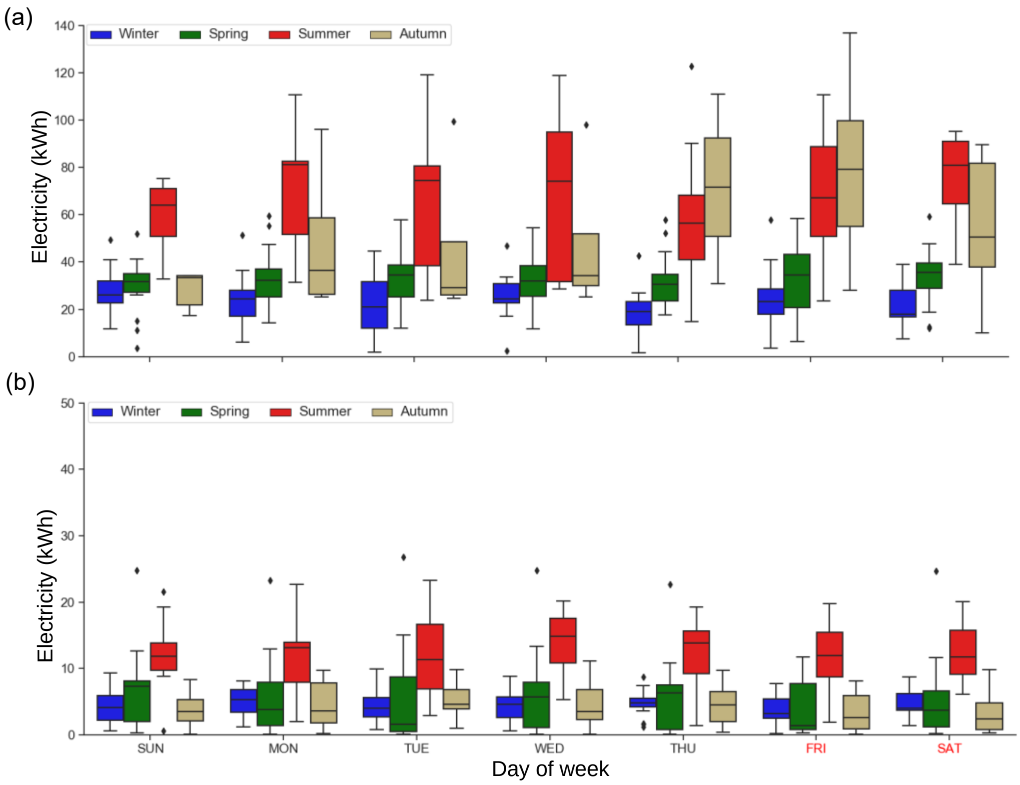

Figure B-14. The daily energy use from NG and CG (kWh) for different seasons in H3 case study: (a) the daily energy use from NG, and (b) the daily energy use from CG.

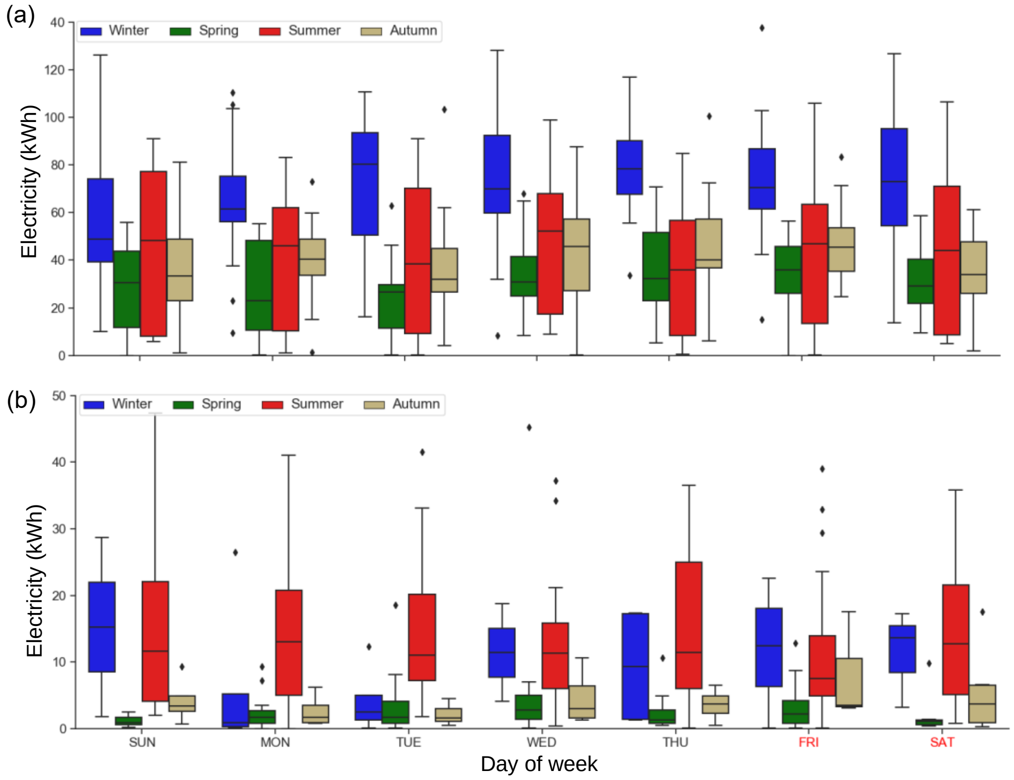

Figure B-15. The daily energy use from NG and CG (kWh) for different seasons in H4 case study: (a) the daily energy use from NG, and (b) the daily energy use from CG.

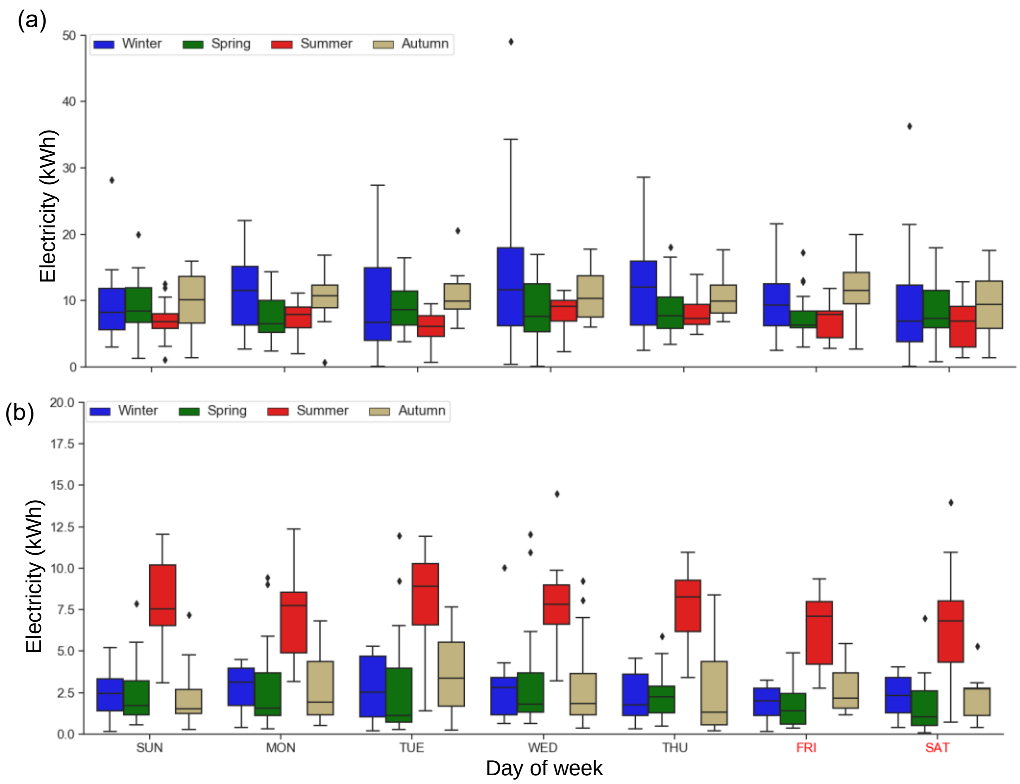

Figure B-16. The daily energy use from NG and CG (kWh) for different seasons in H5 case study: (a) the daily energy use from NG, and (b) the daily energy use from CG.

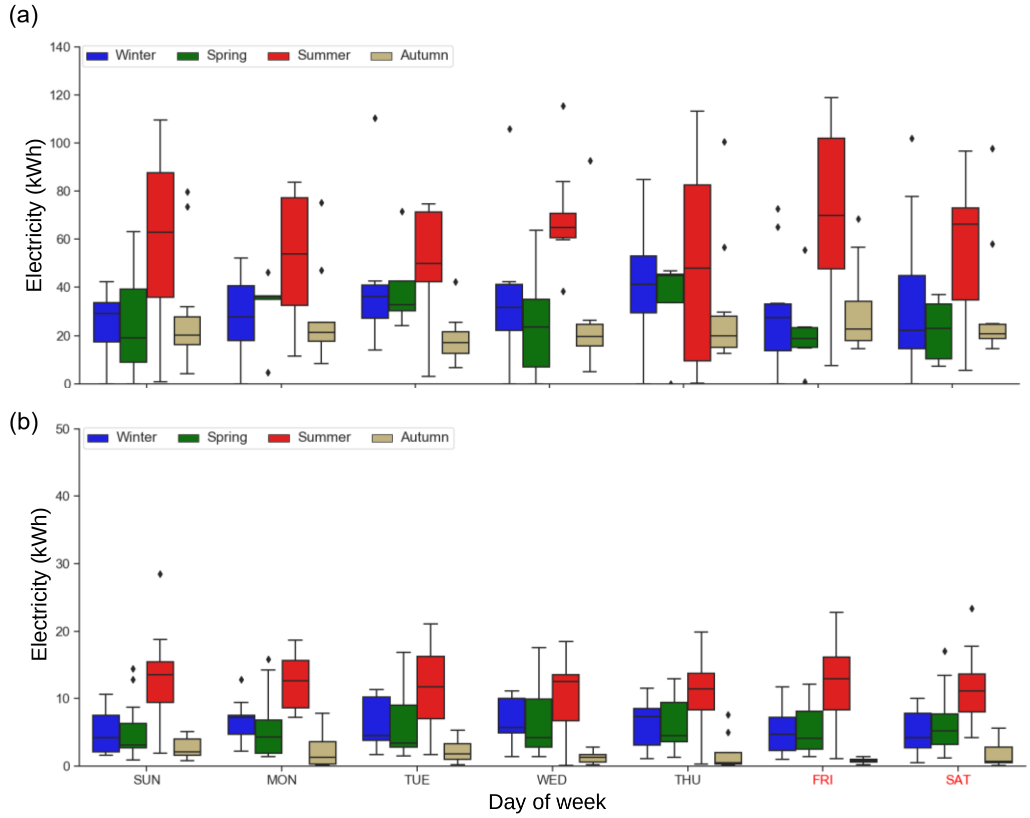

Figure B-17. The daily energy use from NG and CG (kWh) for different seasons in H6 case study: (a) the daily energy use from NG, and (b) the daily energy use from CG.

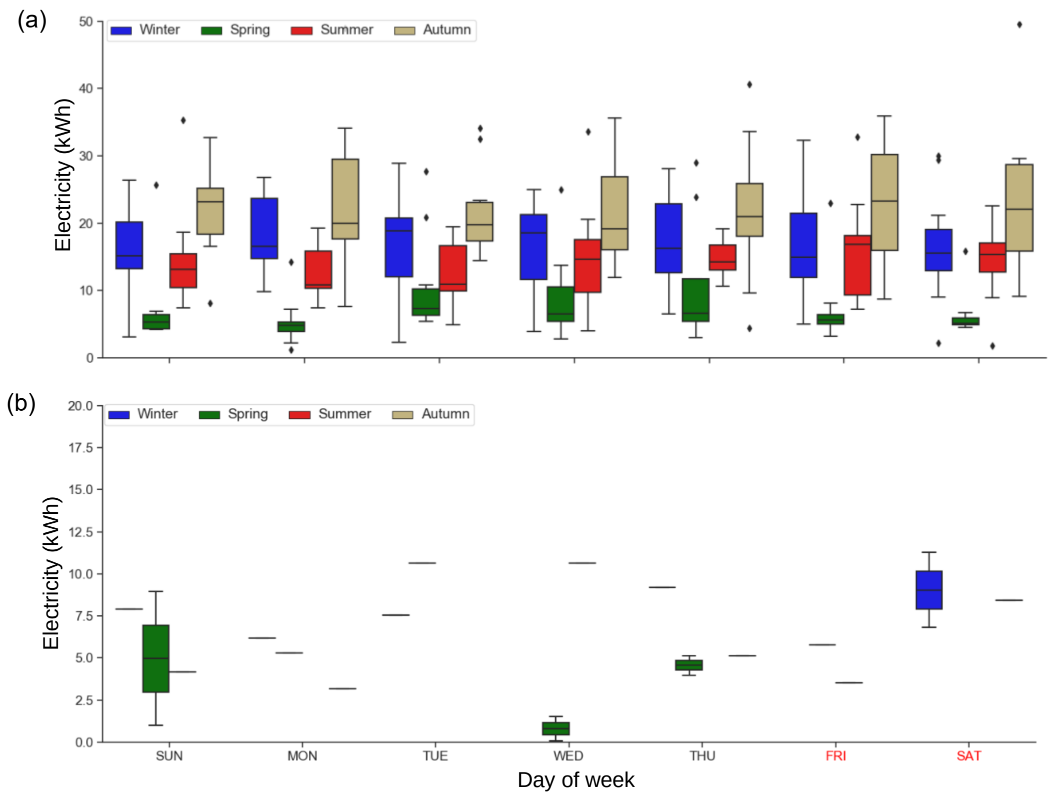

Figure B-18. The daily energy use from NG and CG (kWh) for different seasons in H7 case study: (a) the daily energy use from NG, and (b) the daily energy use from CG.

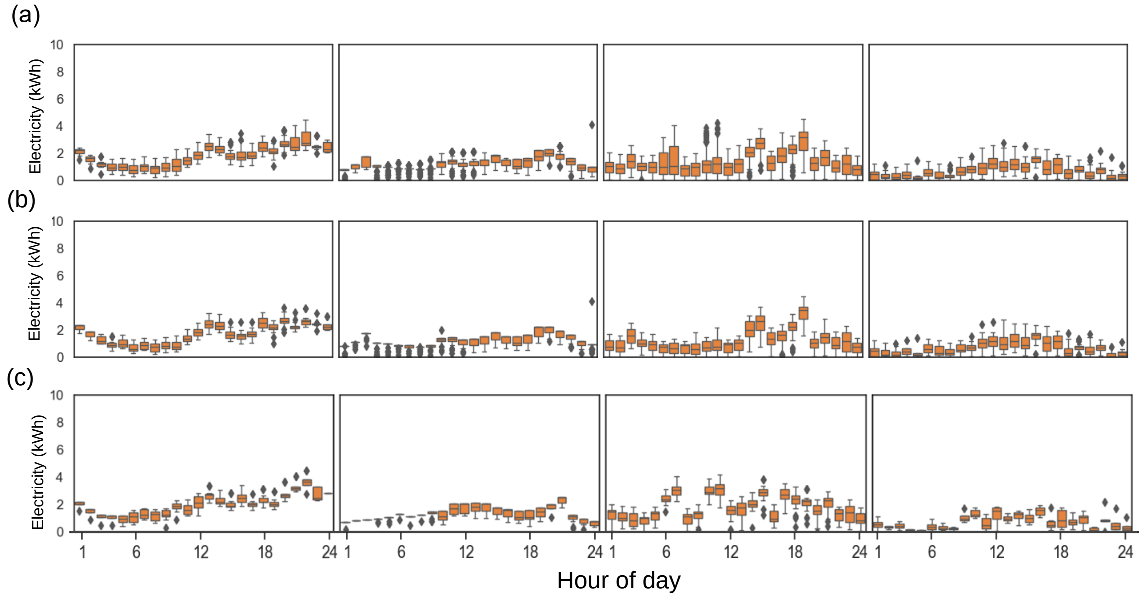

Figure B-19. The hourly suppressed energy demand for different seasons in H2 case study: (a-c) hourly suppressed energy demand during all days of week, weekdays, weekends.

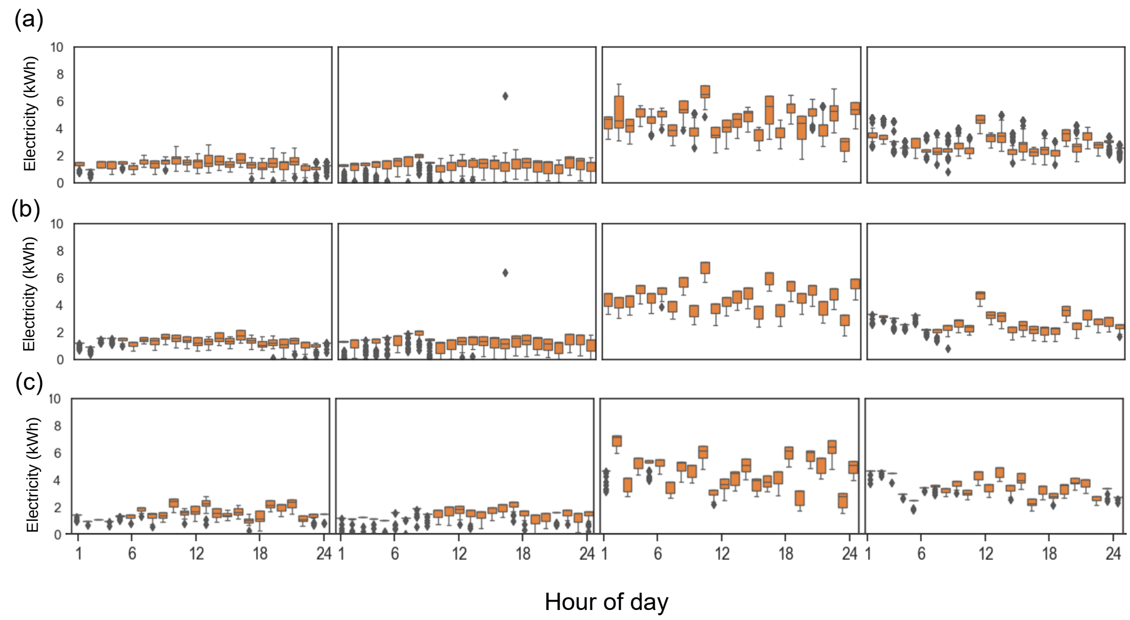

Figure B-20. The hourly suppressed energy demand for different seasons in H3 case study: (a-c) hourly suppressed energy demand during all days of week, weekdays, weekends.

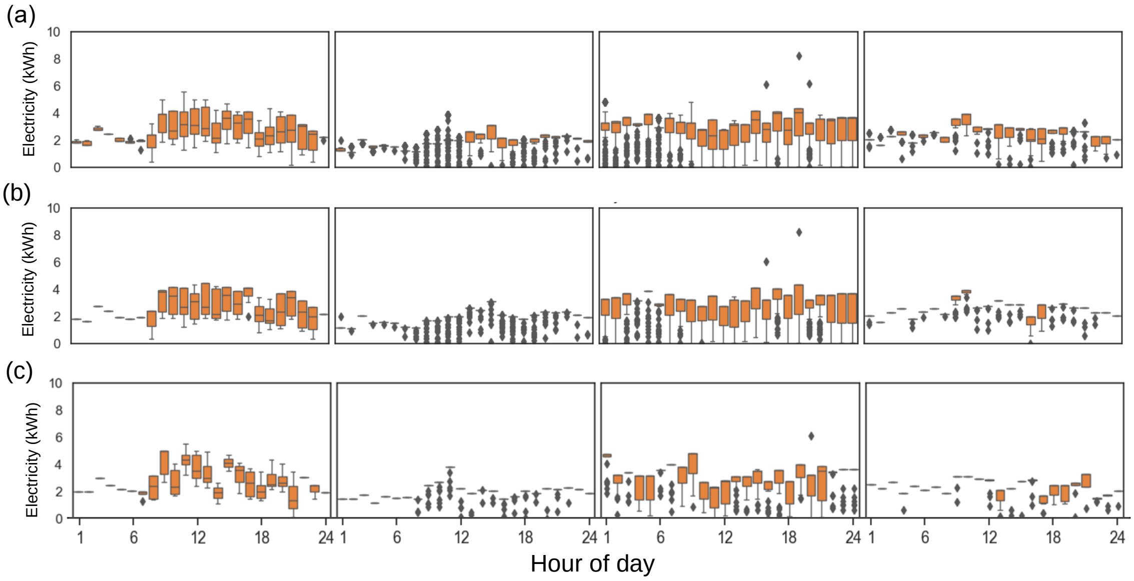

Figure B-21. The hourly suppressed energy demand for different seasons in H4 case study: (a-c) hourly suppressed energy demand during all days of week, weekdays, weekends.

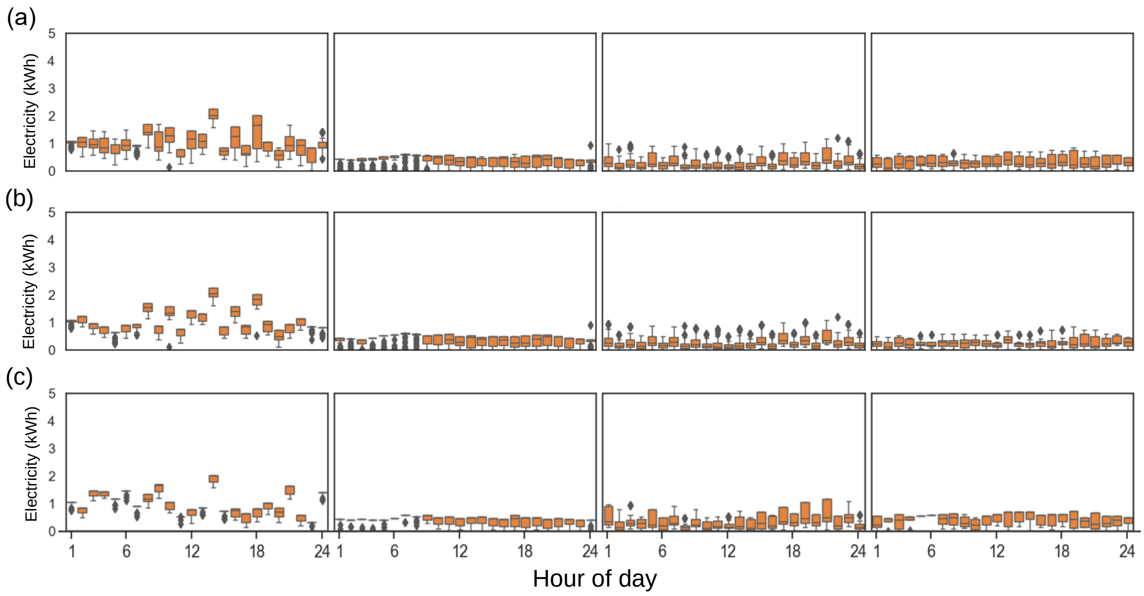

Figure B-22. The hourly suppressed energy demand for different seasons in H5 case study: (a-c) hourly suppressed energy demand during all days of week, weekdays, weekends.

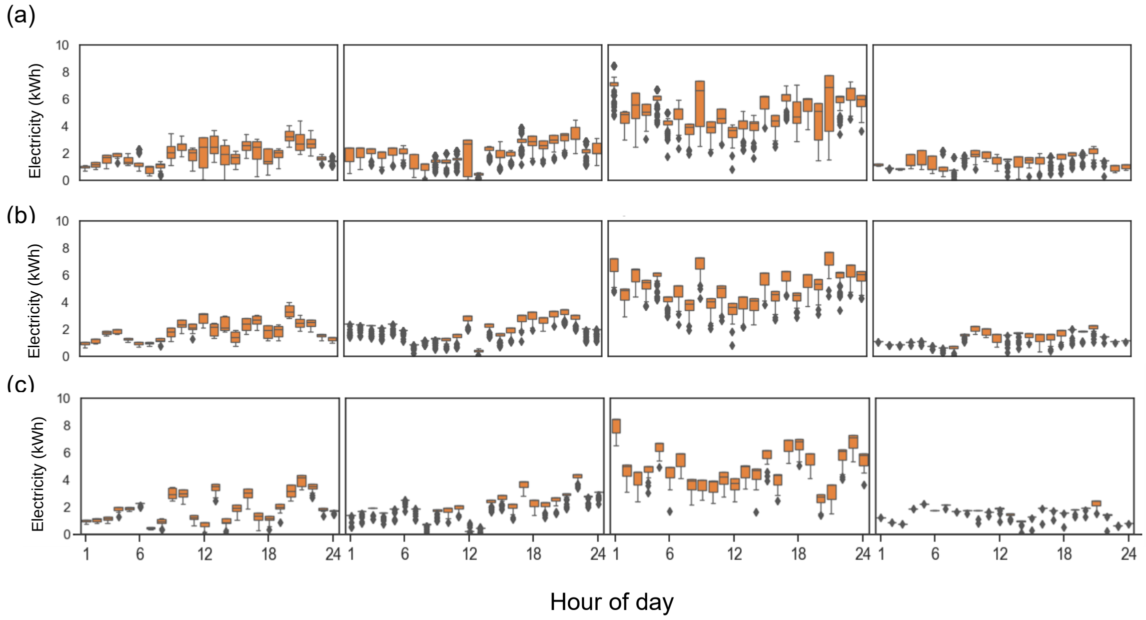

Figure B-23. The hourly suppressed energy demand for different seasons in H6 case study: (a-c) hourly suppressed energy demand during all days of week, weekdays, weekends.

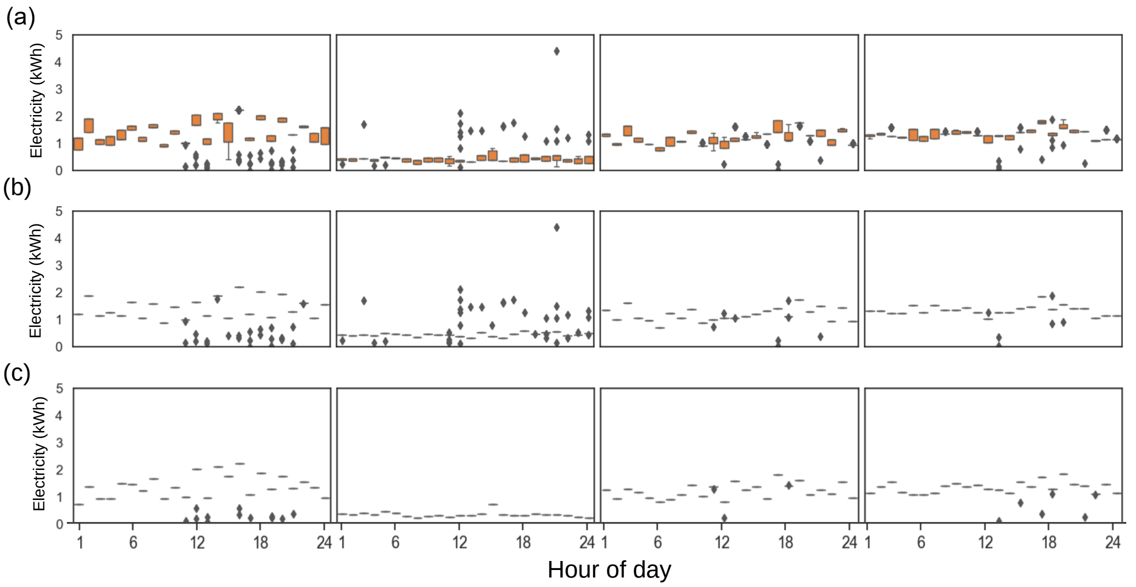

Figure B-24. The hourly suppressed energy demand for different seasons in H7 case study: (a-c) hourly suppressed energy demand during all days of week, weekdays, weekends.

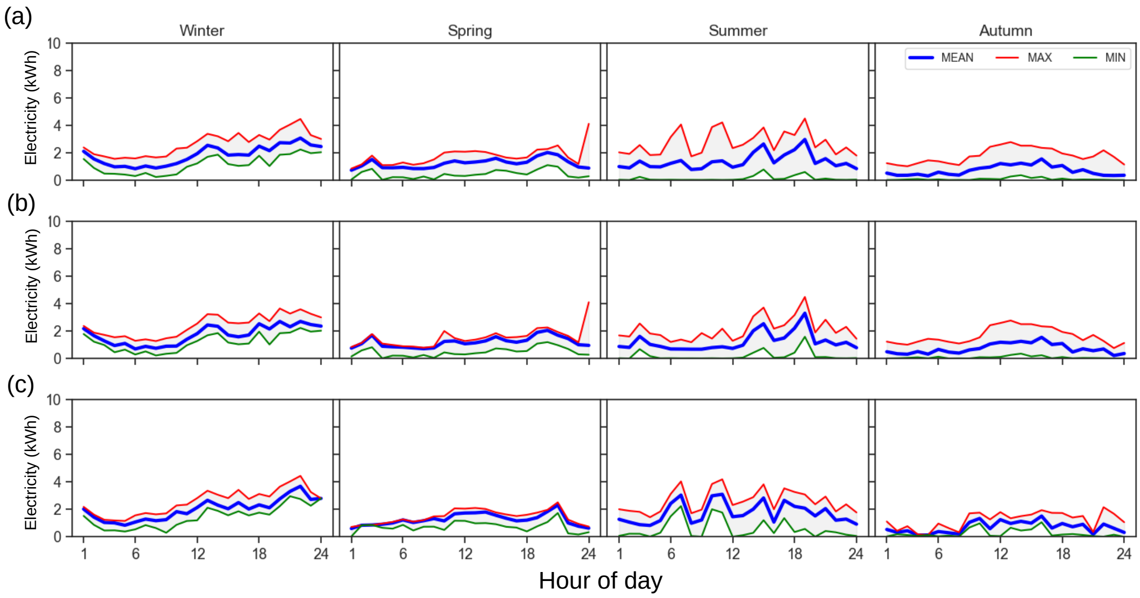

Figure B-25. The maximum, minimum and mean hourly suppressed energy demand for different seasons in H2 case study: (a-c) the maximum, minimum and mean hourly suppressed energy demand during all days of week, weekdays, weekends.

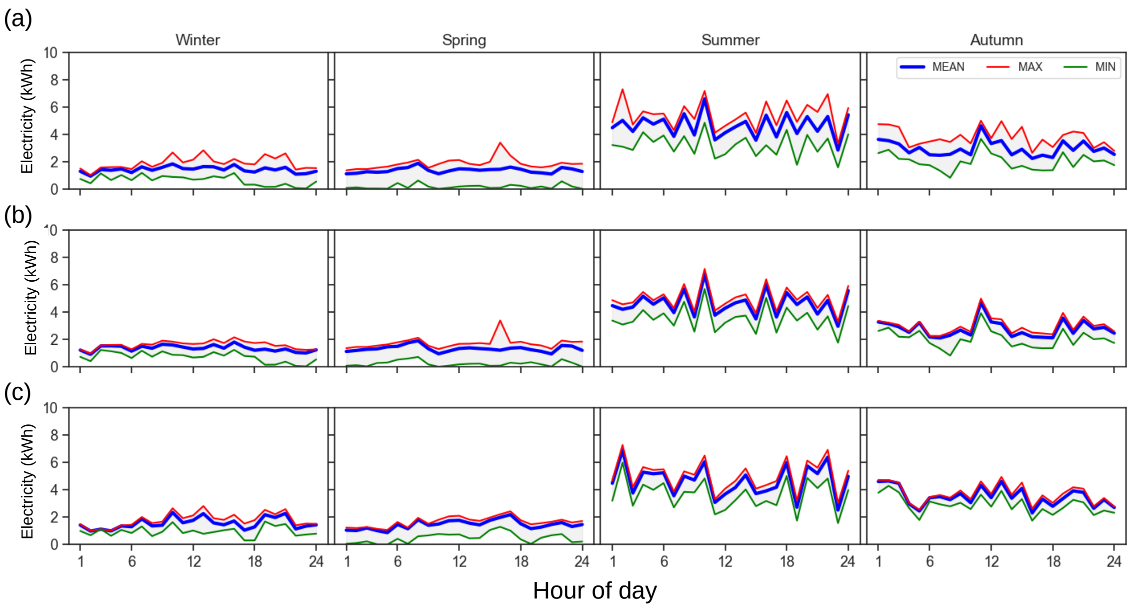

Figure B-26. The maximum, minimum and mean hourly suppressed energy demand for different seasons in H3 case study: (a-c) the maximum, minimum and mean hourly suppressed energy demand during all days of week, weekdays, weekends.

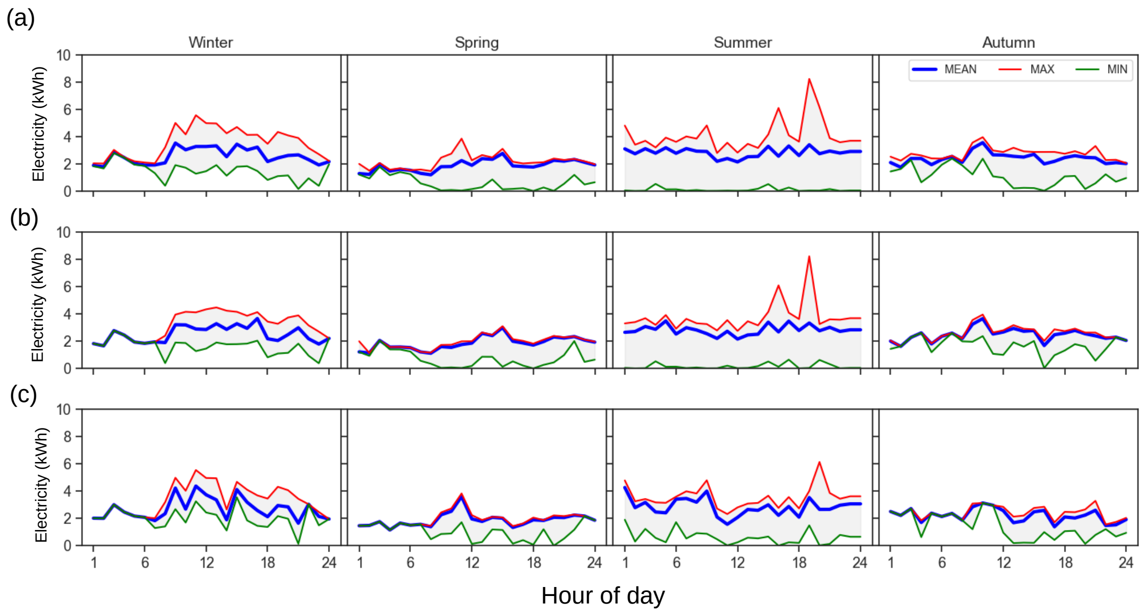

Figure B-27. The maximum, minimum and mean hourly suppressed energy demand for different seasons in H4 case study: (a-c) the maximum, minimum and mean hourly suppressed energy demand during all days of week, weekdays, weekends.

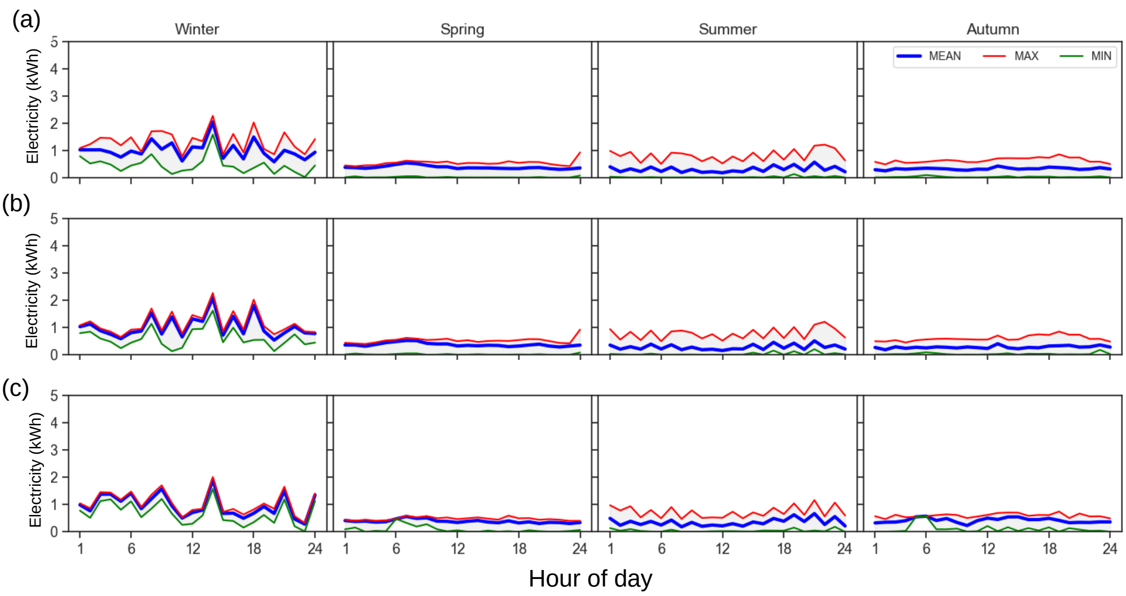

Figure B-28. The maximum, minimum and mean hourly suppressed energy demand for different seasons in H5 case study: (a-c) the maximum, minimum and mean hourly suppressed energy demand during all days of week, weekdays, weekends.

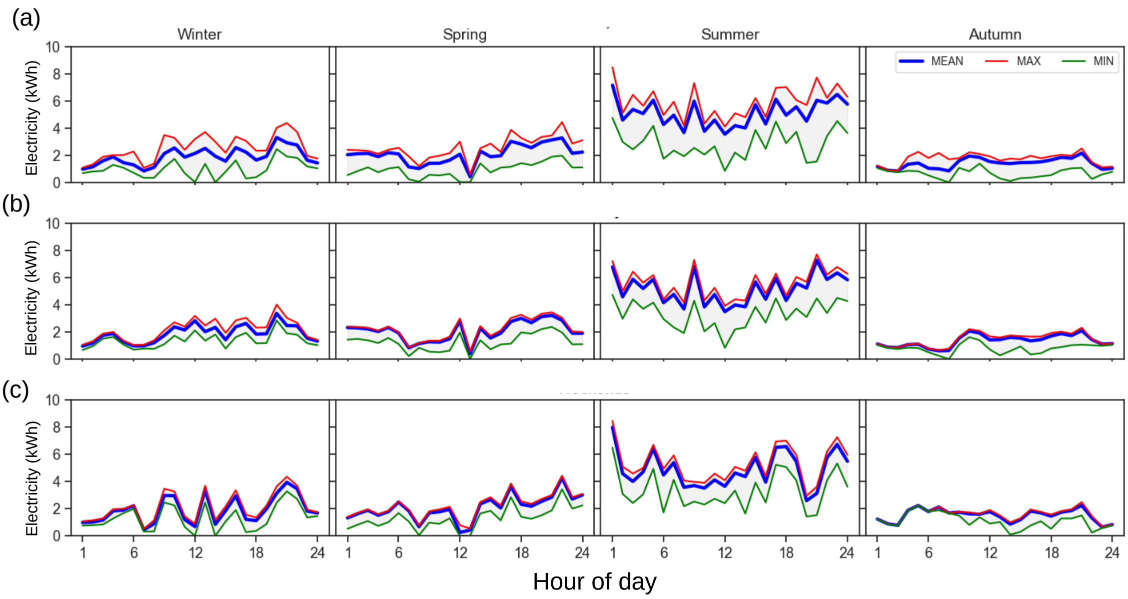

Figure B-29. The maximum, minimum and mean hourly suppressed energy demand for different seasons in H6 case study: (a-c) the maximum, minimum and mean hourly suppressed energy demand during all days of week, weekdays, weekends.

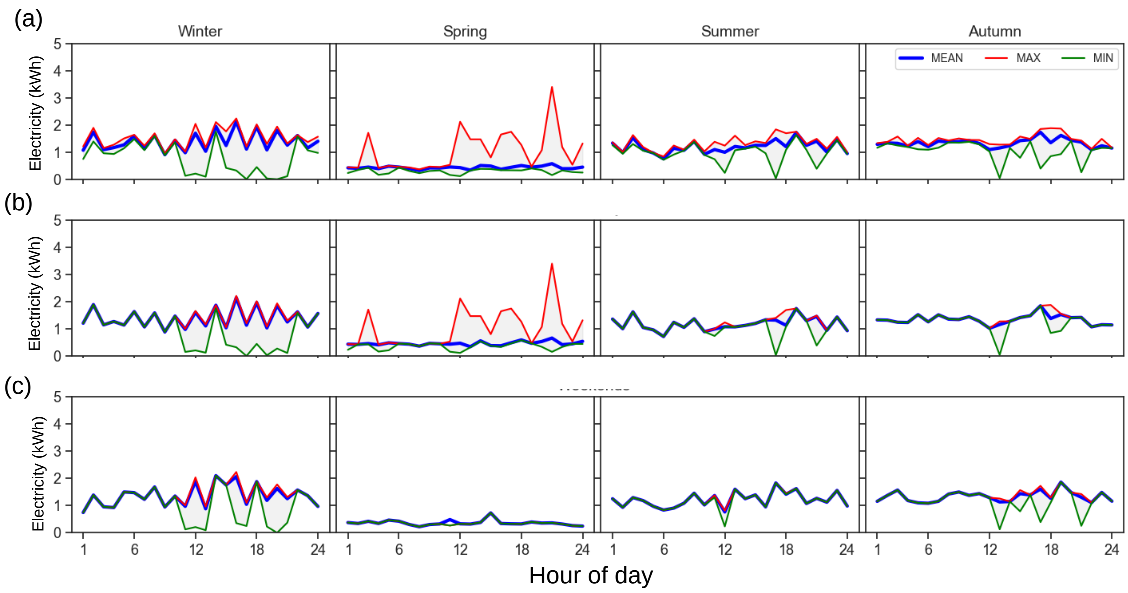

Figure B-30. The maximum, minimum and mean hourly suppressed energy demand for different seasons in H7 case study: (a-c) the maximum, minimum and mean hourly suppressed energy demand during all days of week, weekdays, weekends.

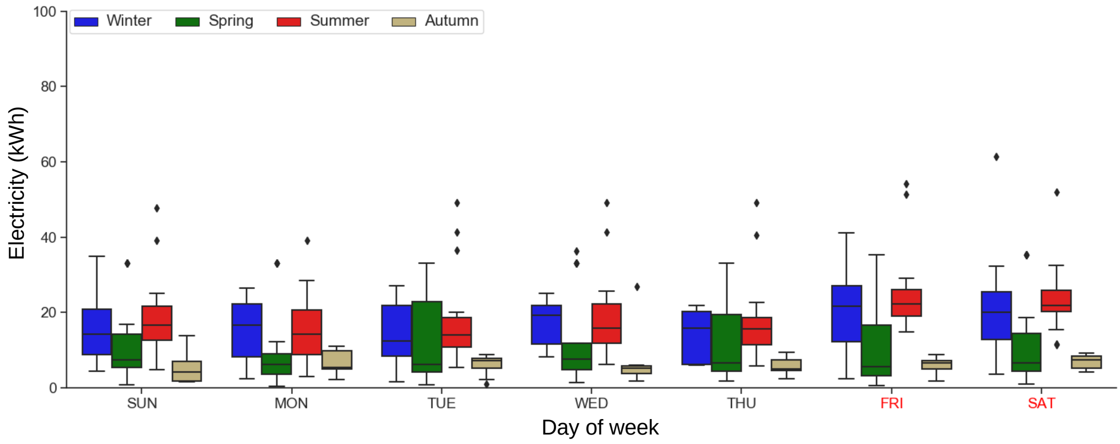

Figure B-31. The daily suppressed energy demand for different seasons in H2 case study.

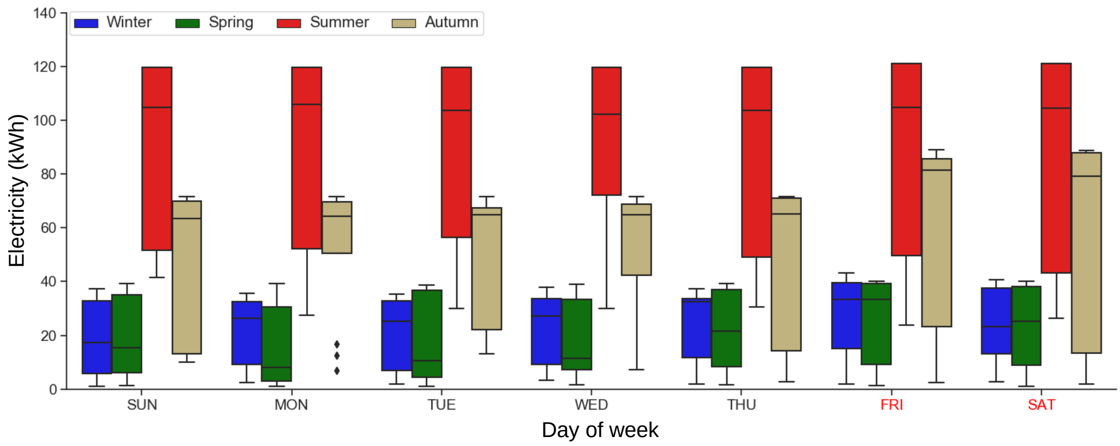

Figure B-32. The daily suppressed energy demand for different seasons in H3 case study.

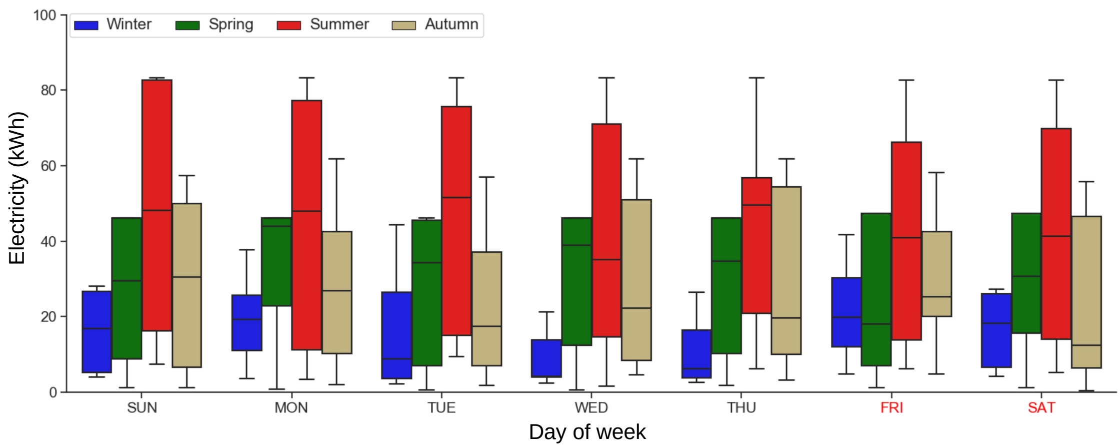

Figure B-33. The daily suppressed energy demand for different seasons in H4 case study.

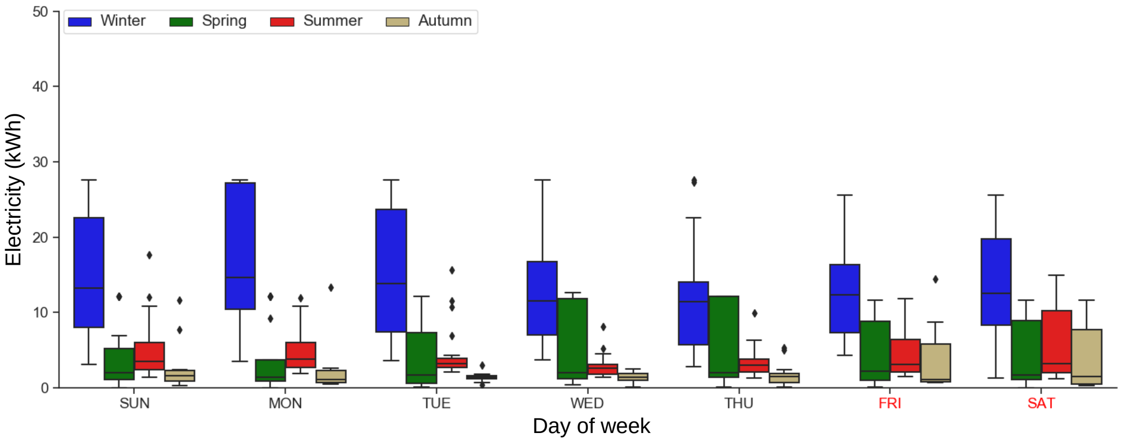

Figure B-34. The daily suppressed energy demand for different seasons in H5 case study.

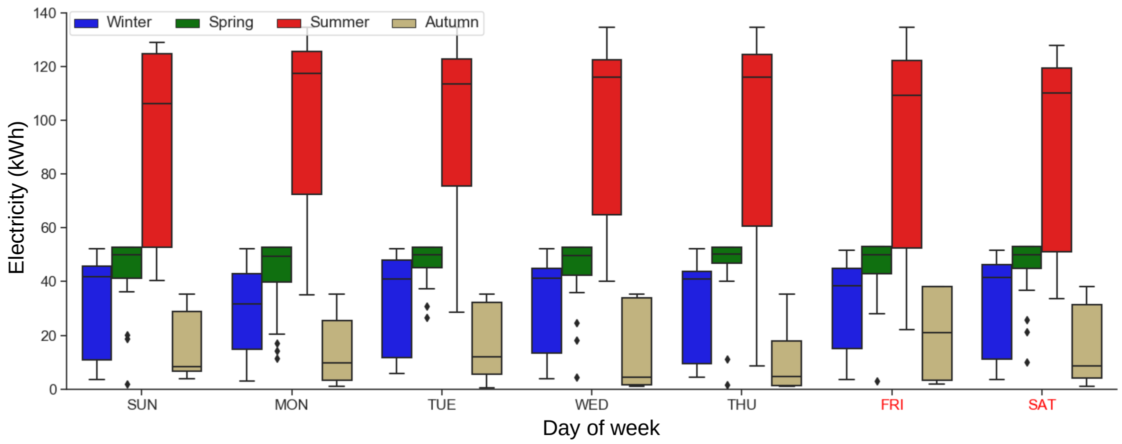

Figure B-35. The daily suppressed energy demand for different seasons in H6 case study.

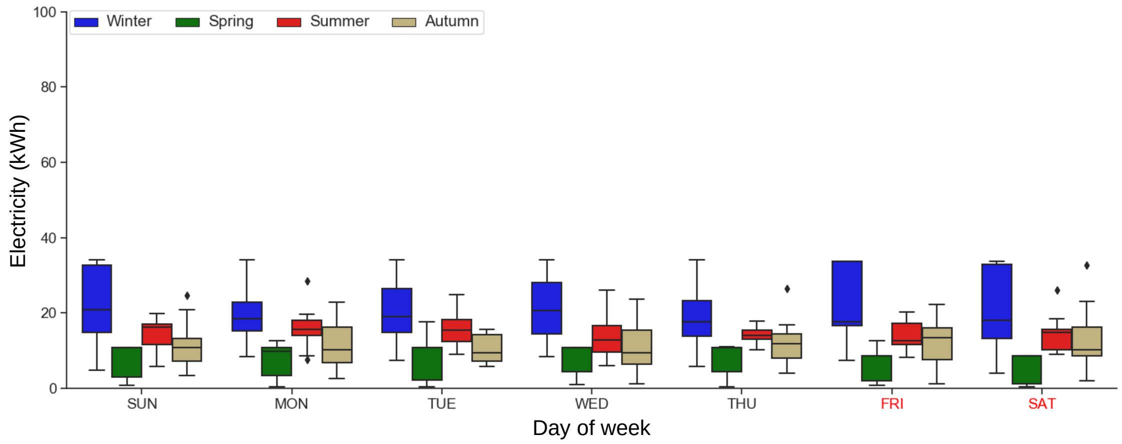

Figure B-36. The daily suppressed energy demand for different seasons in H7 case study.

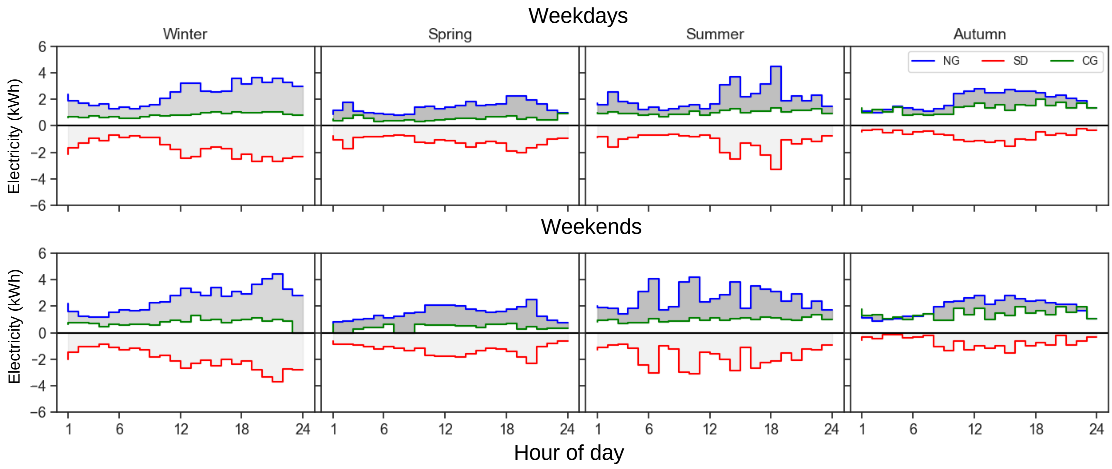

Figure B-37. The hourly average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H2 case study.

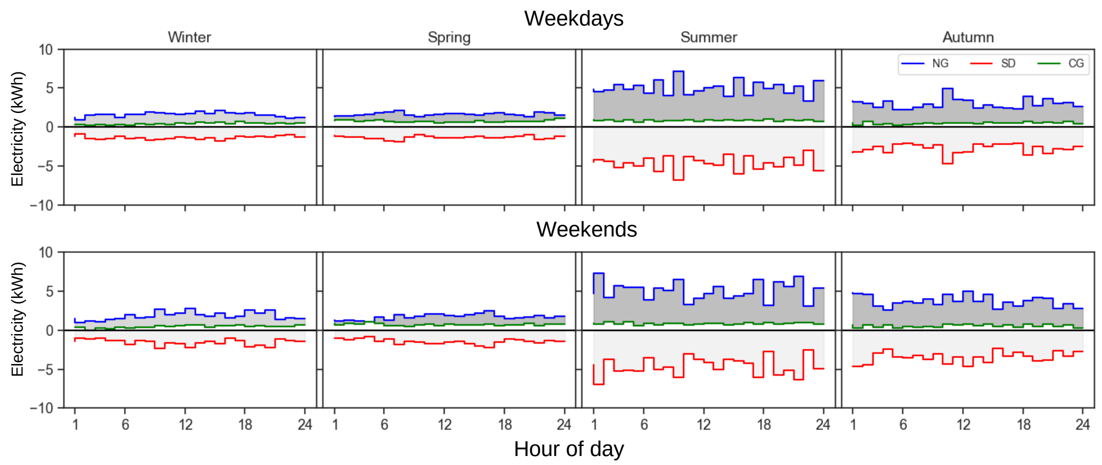

Figure B-38. The hourly average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H3 case study.

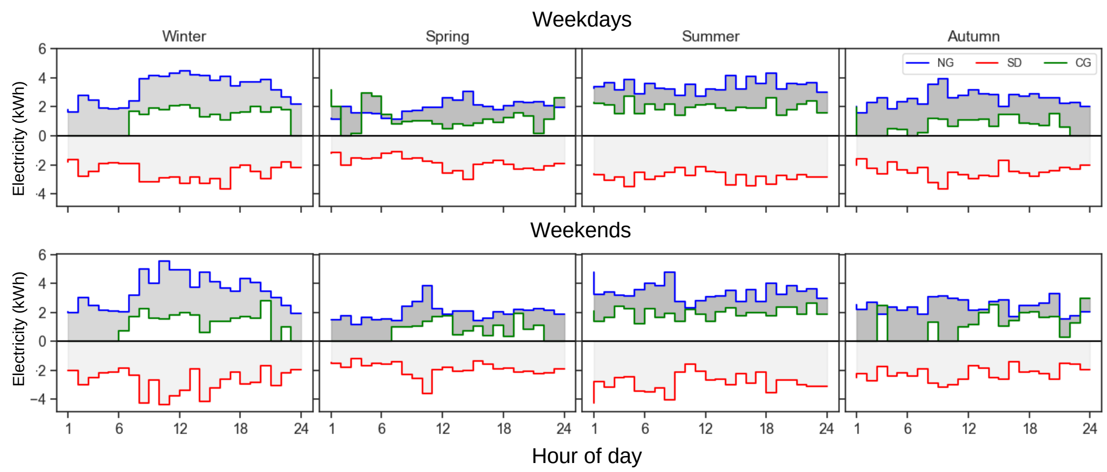

Figure B-39. The hourly average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H4 case study.

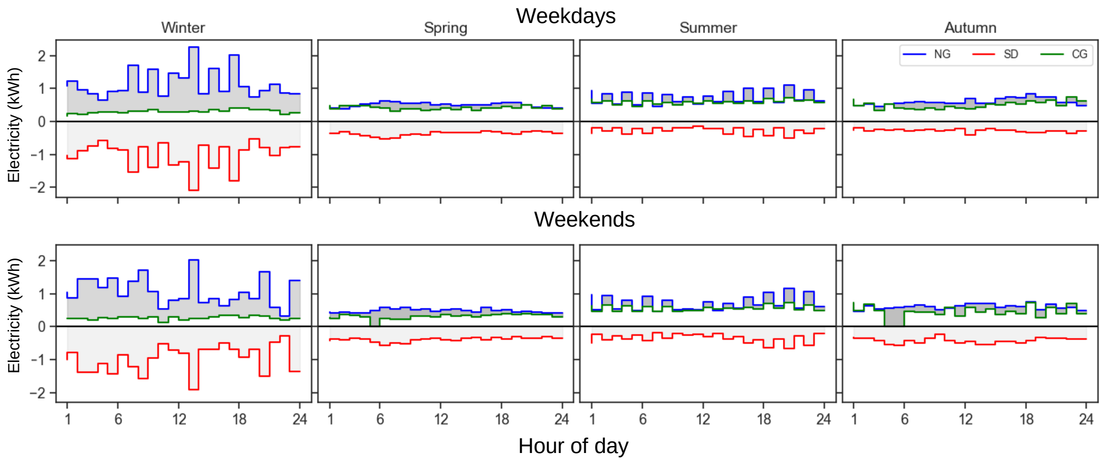

Figure B-40. The hourly average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H5 case study.

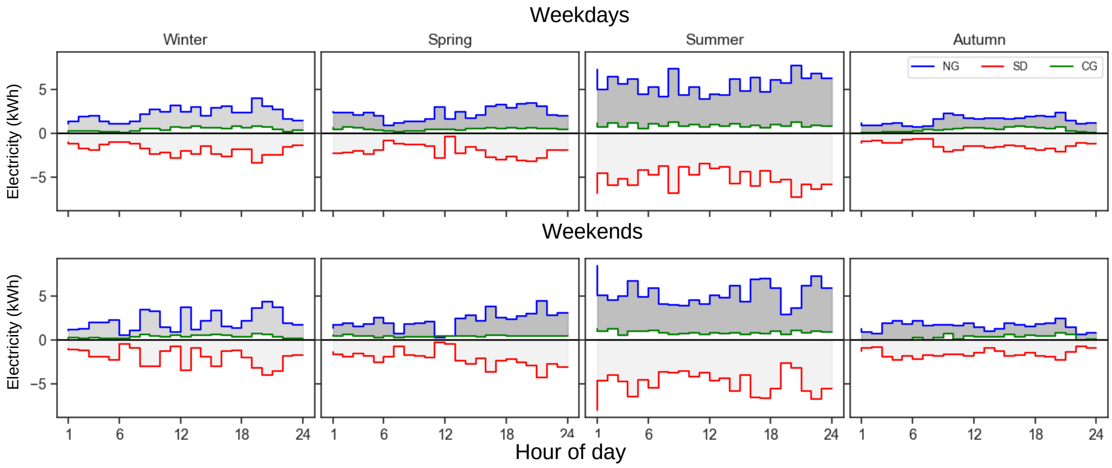

Figure B-41. The hourly average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H6 case study.

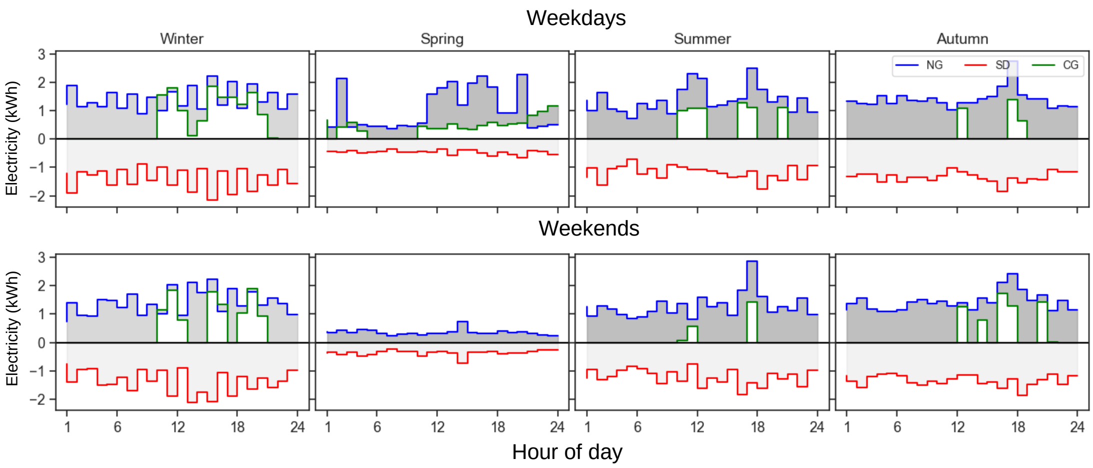

Figure B-42. The hourly average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H7 case study.

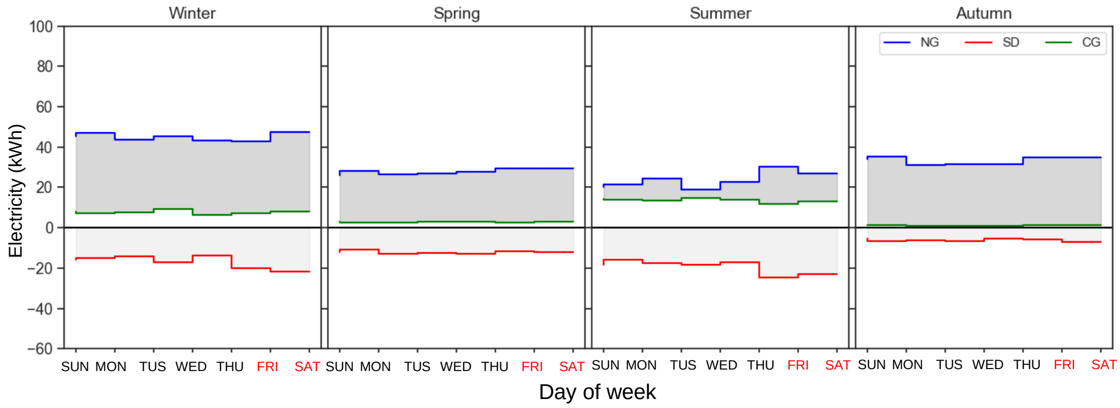

Figure B-43. The daily average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H2 case study.

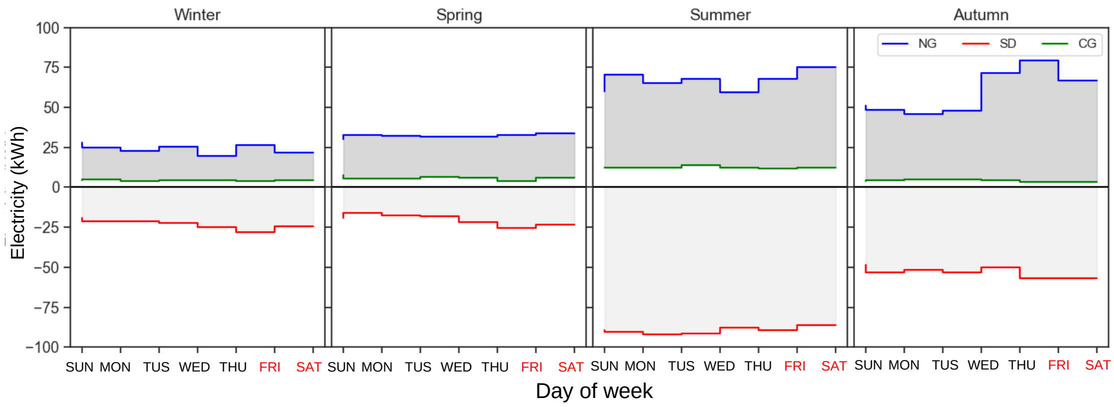

Figure B-44. The daily average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H3 case study.

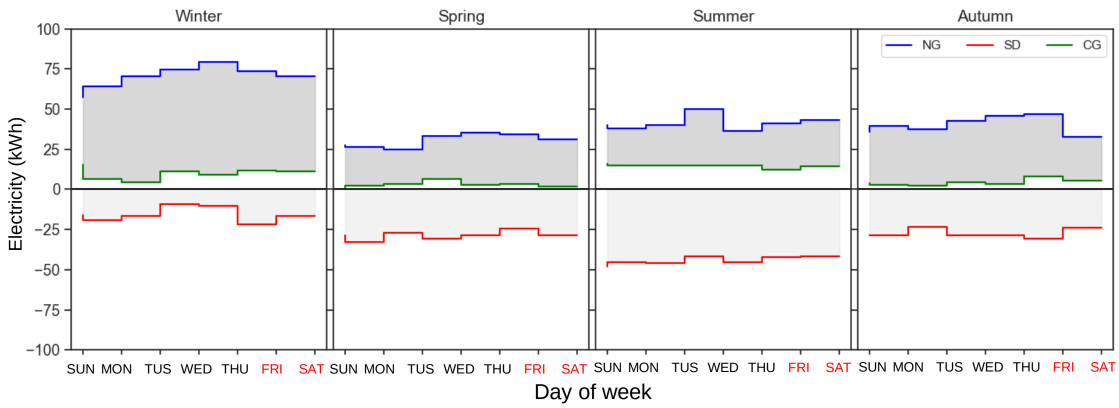

Figure B-45. The daily average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H4 case study.

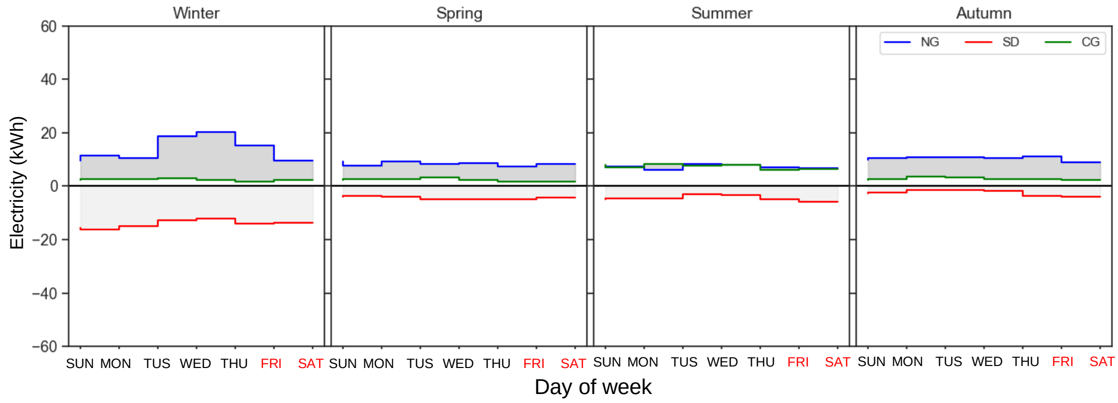

Figure B-46. The daily average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H5 case study.

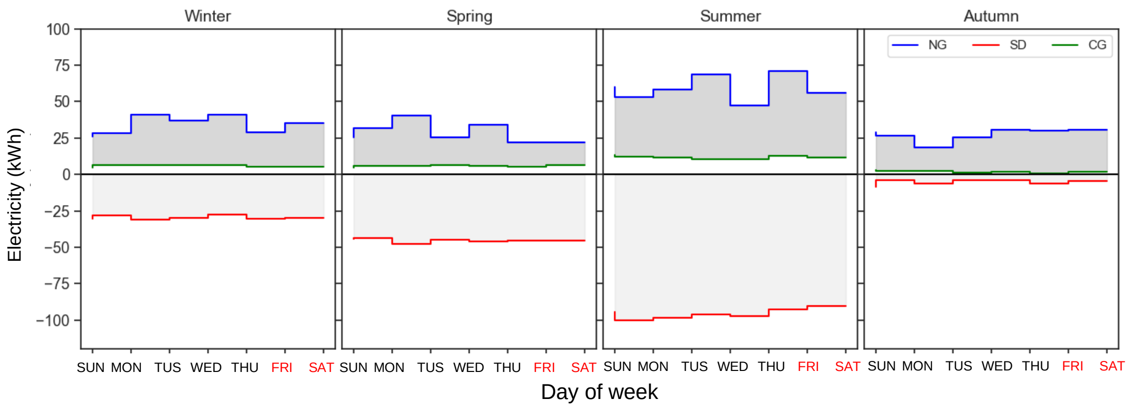

Figure B-47. The daily average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H6 case study.

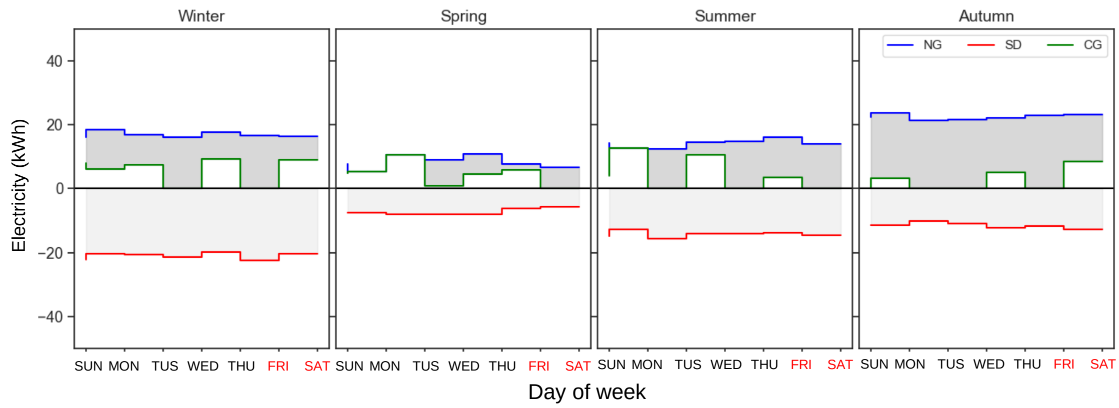

Figure B-48. The daily average of energy use from NG, CG and the suppressed energy demand during weekdays and weekends for different seasons in H7 case study.

Appendix C – Suppressed energy demand vs indoor thermal environment

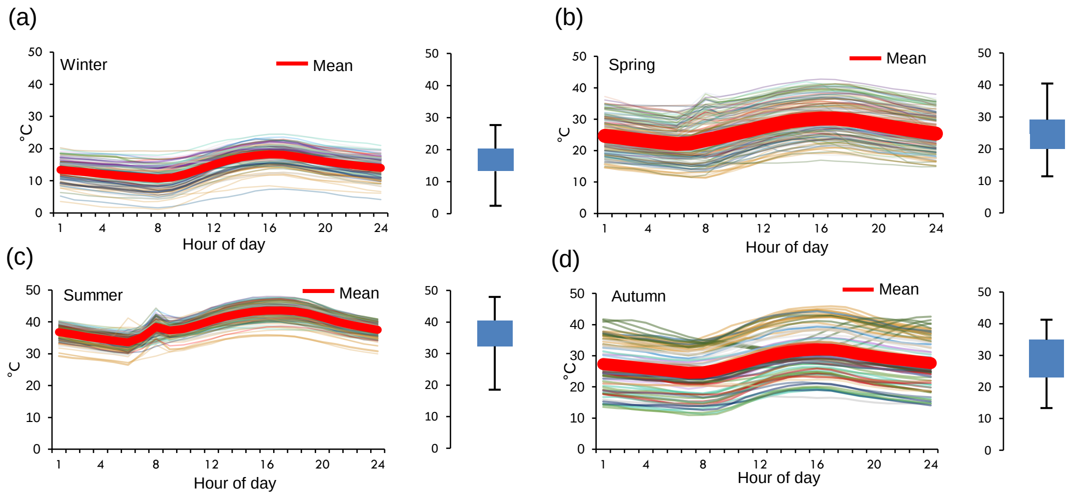

Figure C-1. Hourly ambient temperature for H2 case study during the target monitoring period. (a)-(d) Hourly ambient temperature over the seasons.

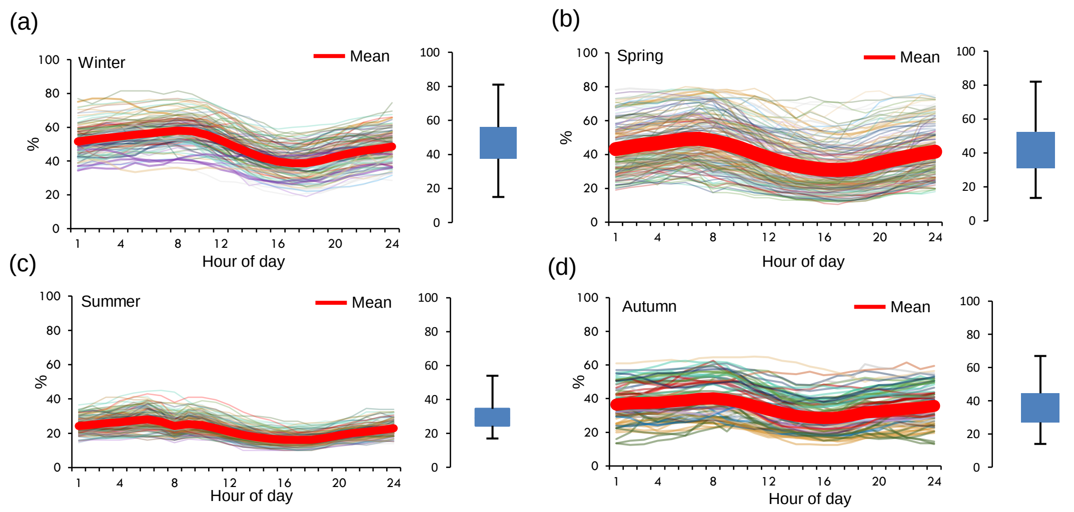

Figure C-2. Outdoor hourly RH for H2 case study during the target monitoring period. (a)-(d) Hourly RH over the seasons.

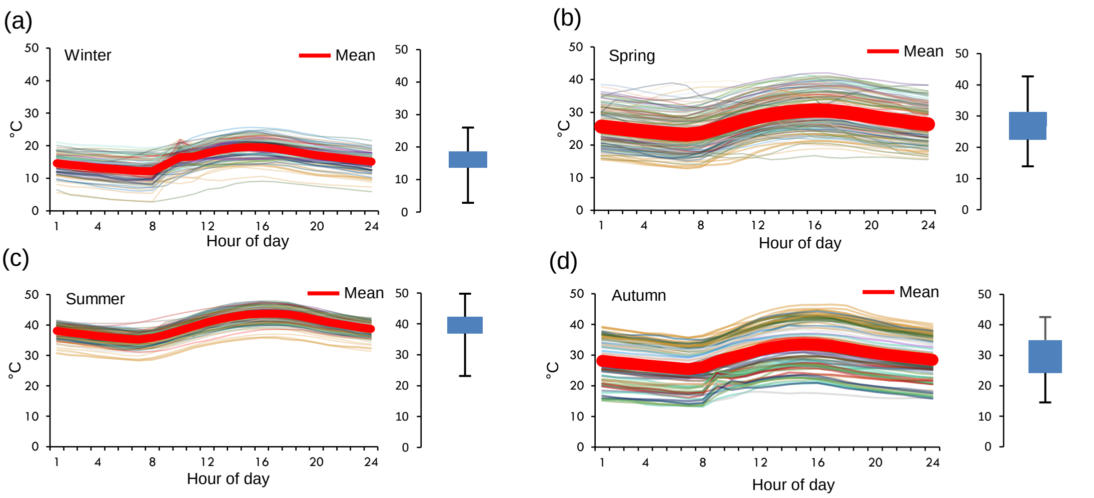

Figure C-3. Hourly ambient temperature (C°) for H3 case study during the target monitoring period. (a)-(d) hourly ambient temperature over the seasons.

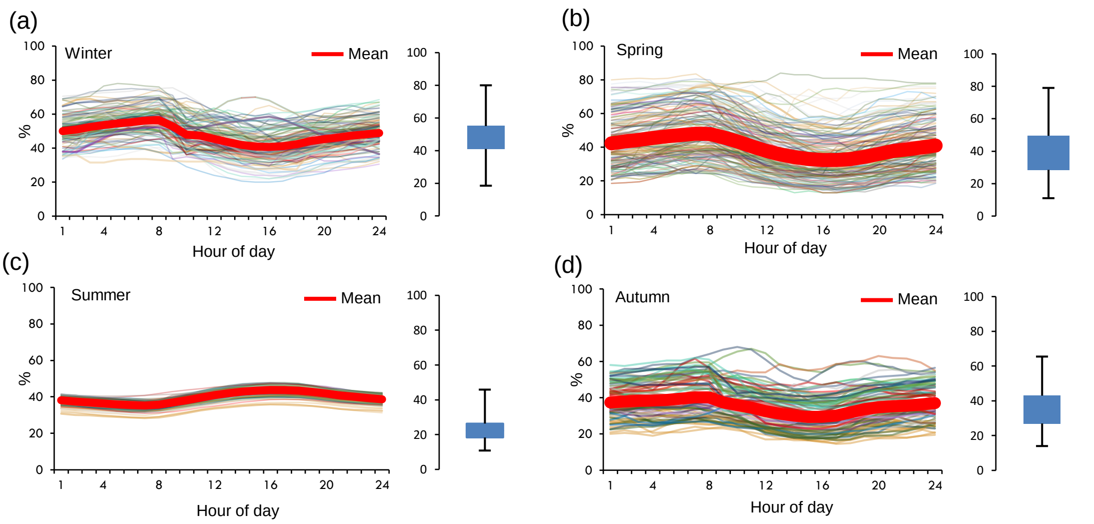

Figure C-4. Outdoor hourly RH for H3 case study during the target monitoring period. (a)-(d) Hourly RH over the seasons.

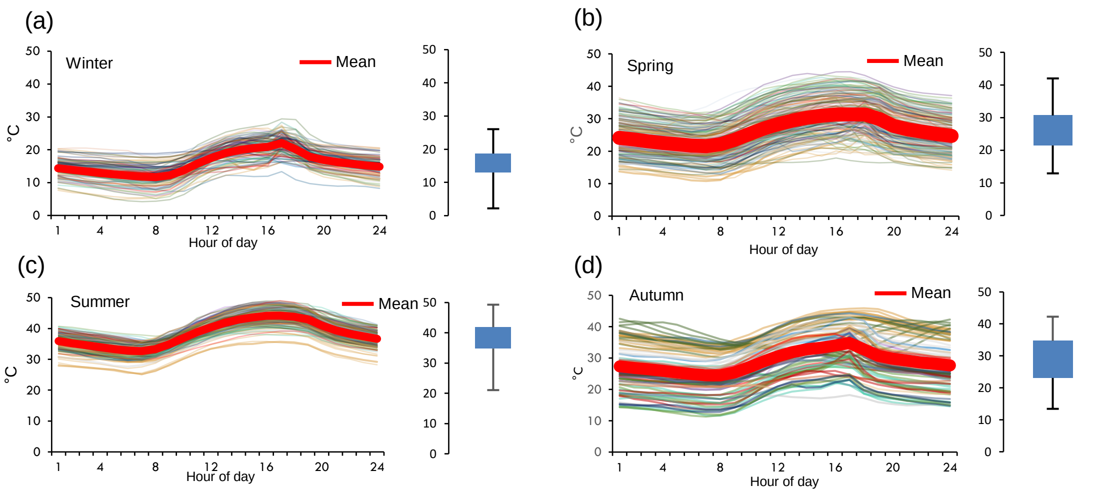

Figure C-5. Hourly ambient temperature for H4 case study during the target monitoring period. (a)-(d) hourly ambient temperature over the seasons.

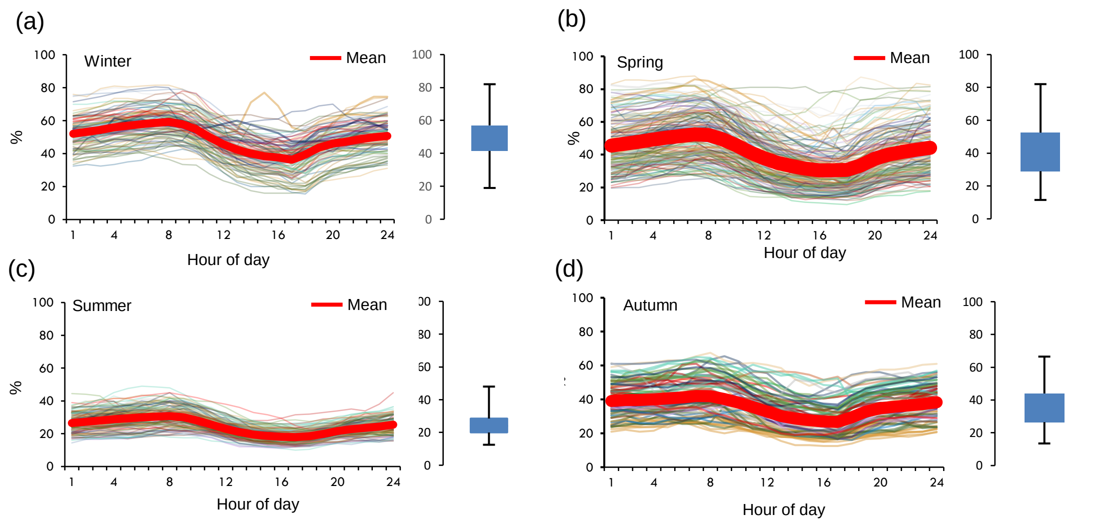

Figure C-6. Outdoor hourly RH for H4 case study during the target monitoring period. (a)-(d) hourly RH over the seasons.

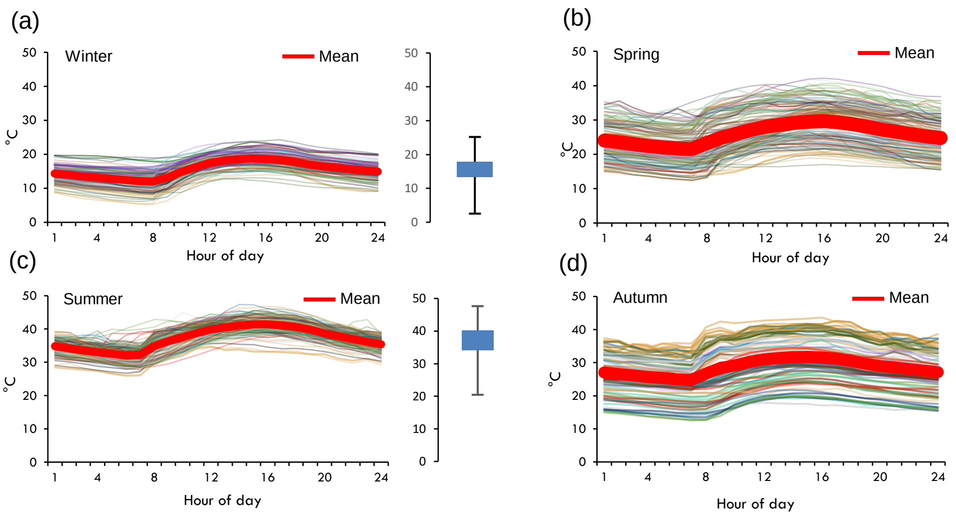

Figure C-7. Hourly ambient temperature for H5 case study during the target monitoring period. (a)-(d) hourly ambient temperature over the seasons.

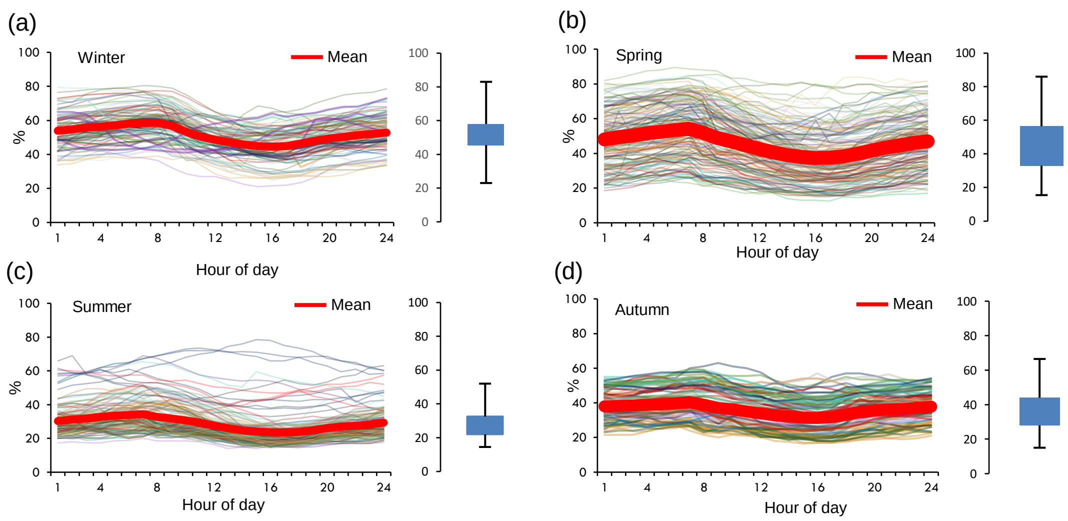

Figure C-8. Outdoor hourly RH for H5 case study during the target monitoring period. (a)-(d) hourly RH over the seasons.

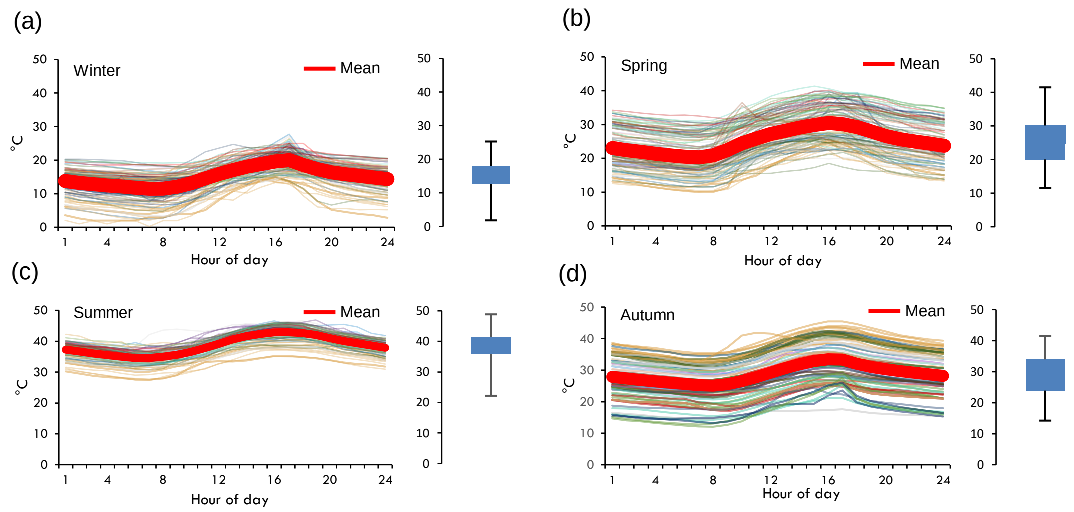

Figure C-9. Hourly ambient temperature for H7 case study during the target monitoring period. (a)-(d) hourly ambient temperature over the seasons.

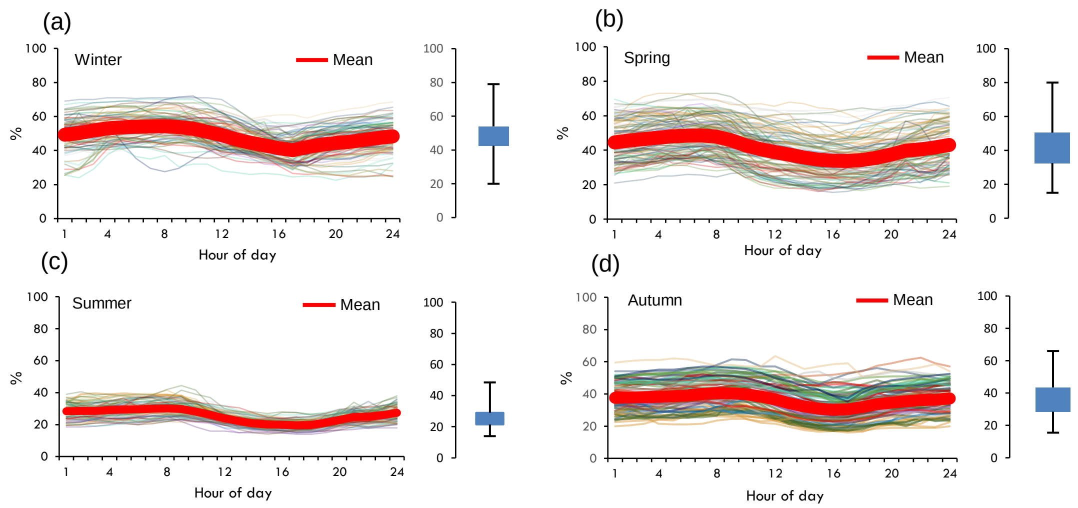

Figure C-10. Outdoor hourly RH for H7 case study during the target monitoring period. (a)-(d) hourly RH over the seasons.

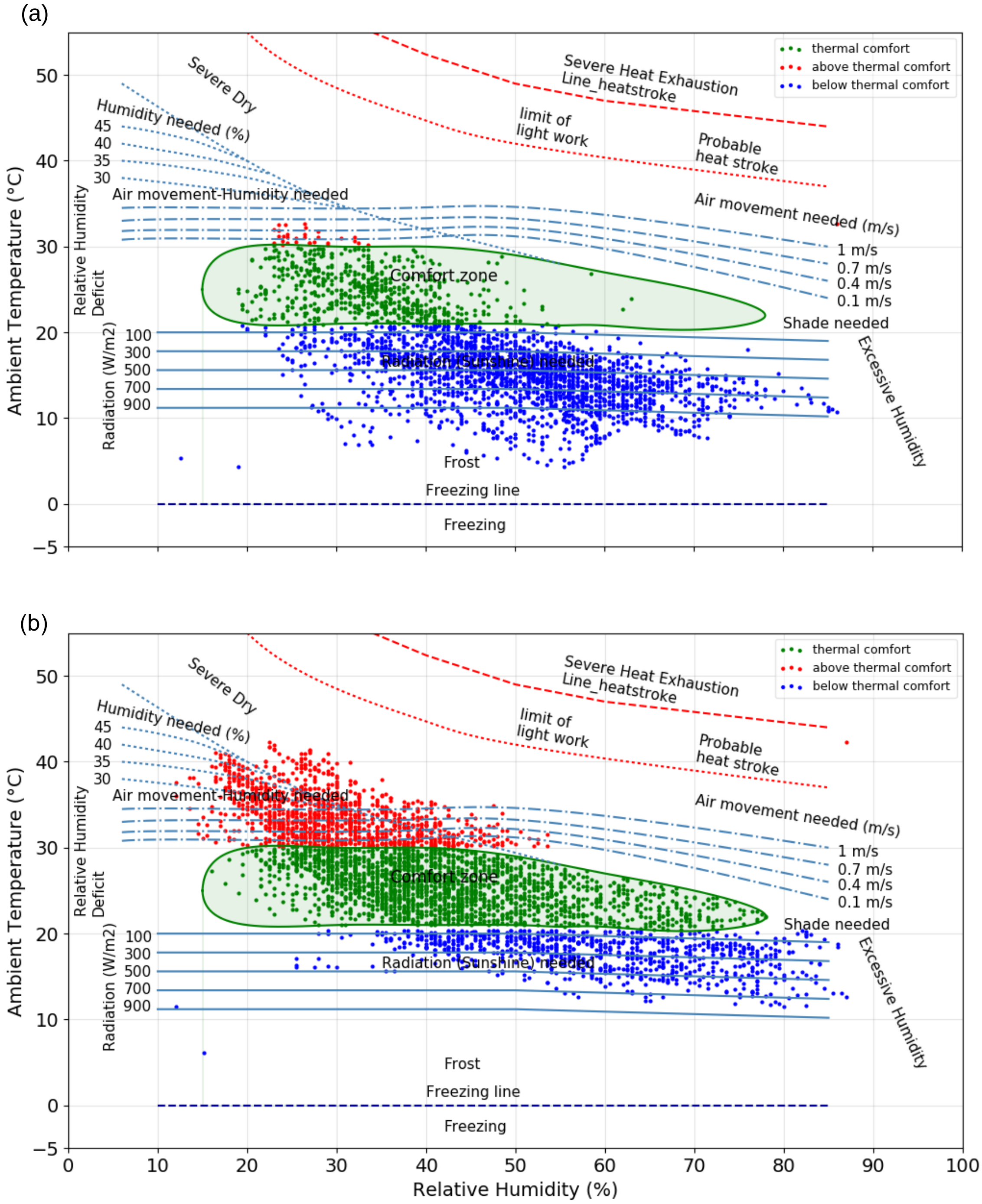

Figure C-11. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H2 case study during the target monitoring period. (a) winter, (b) spring.

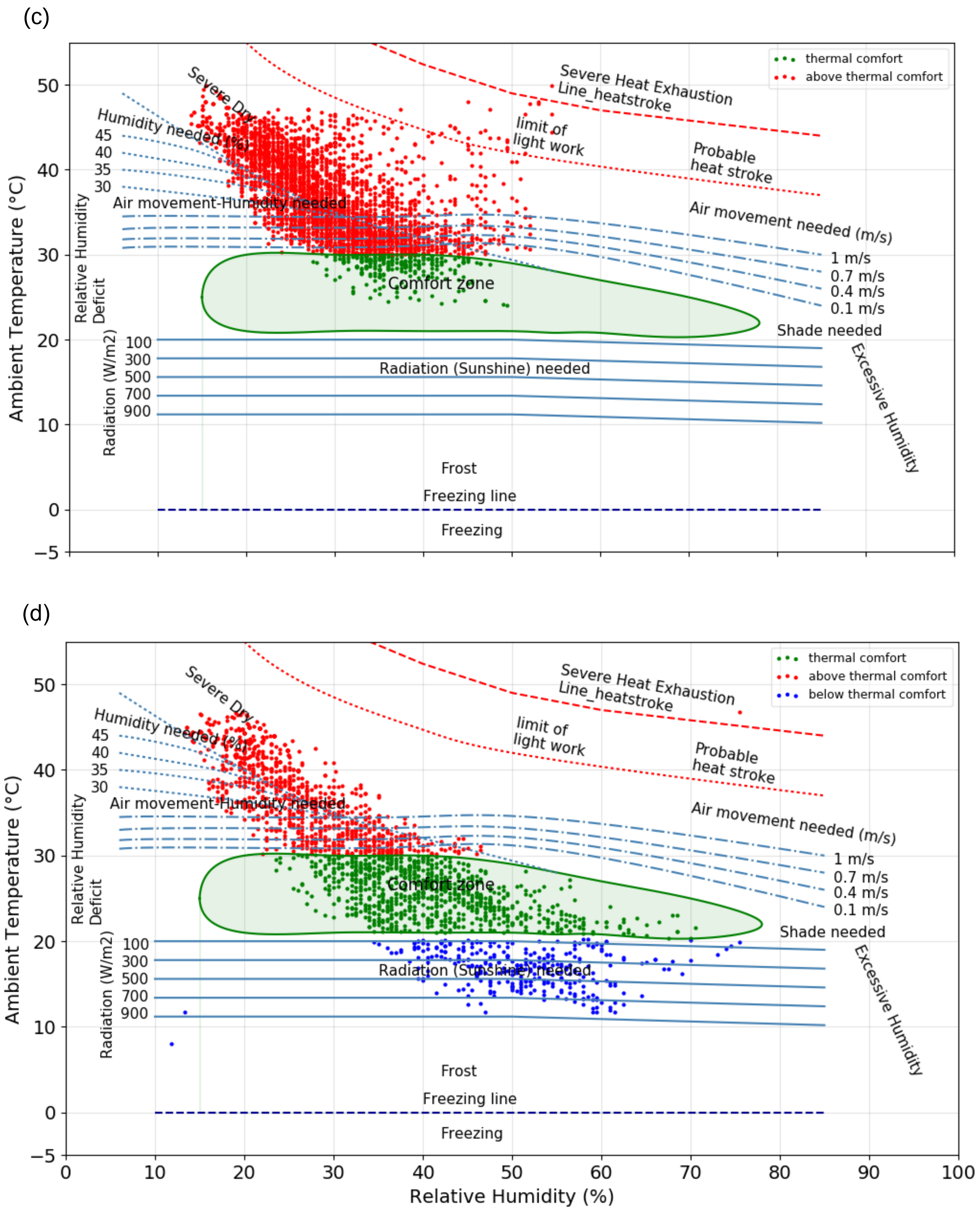

Figure C-12. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H2 case study during the target monitoring period. (c) summer, and (d) autumn.

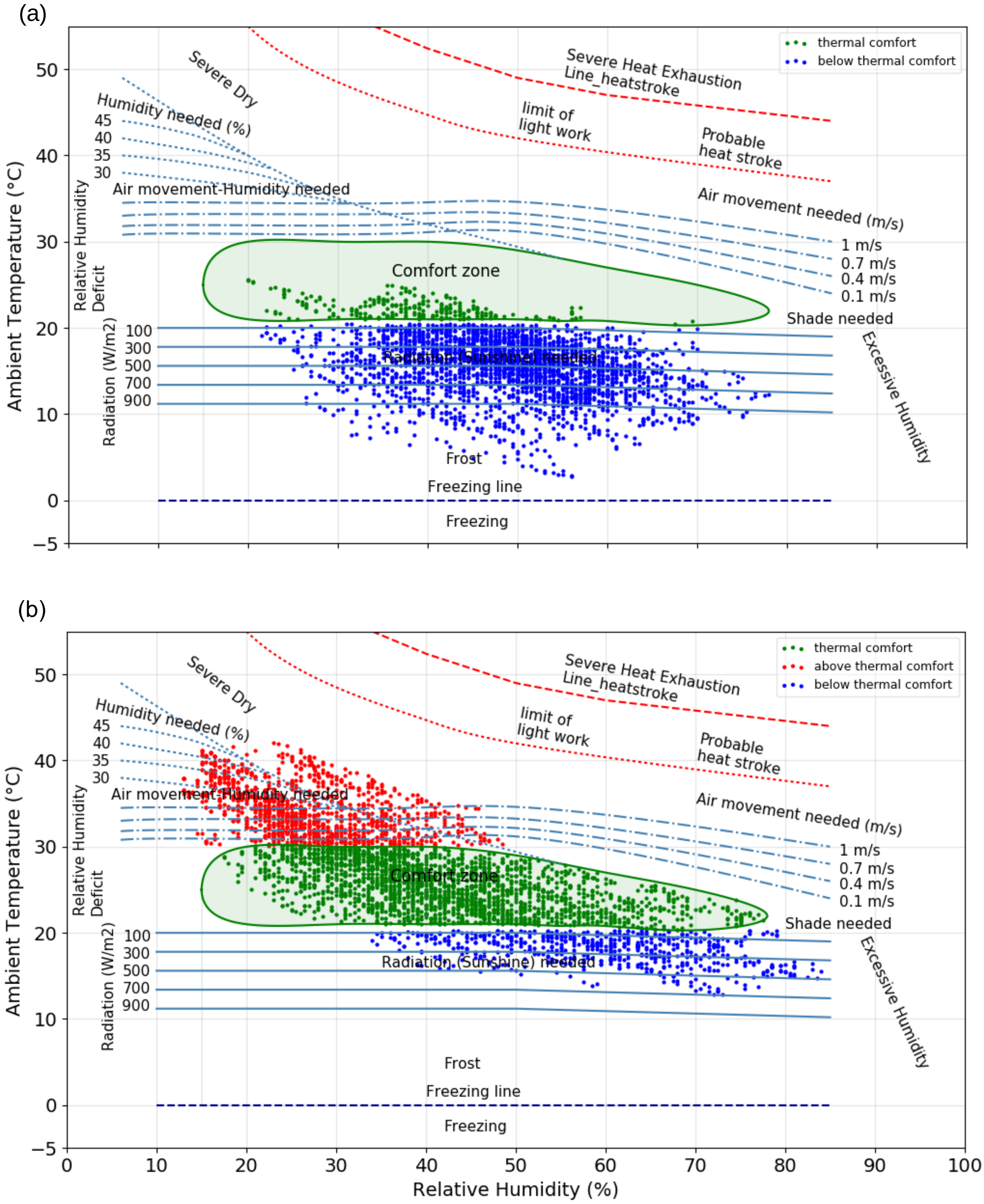

Figure C-13. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H3 case study during the target monitoring period. (a) winter, (b) spring.

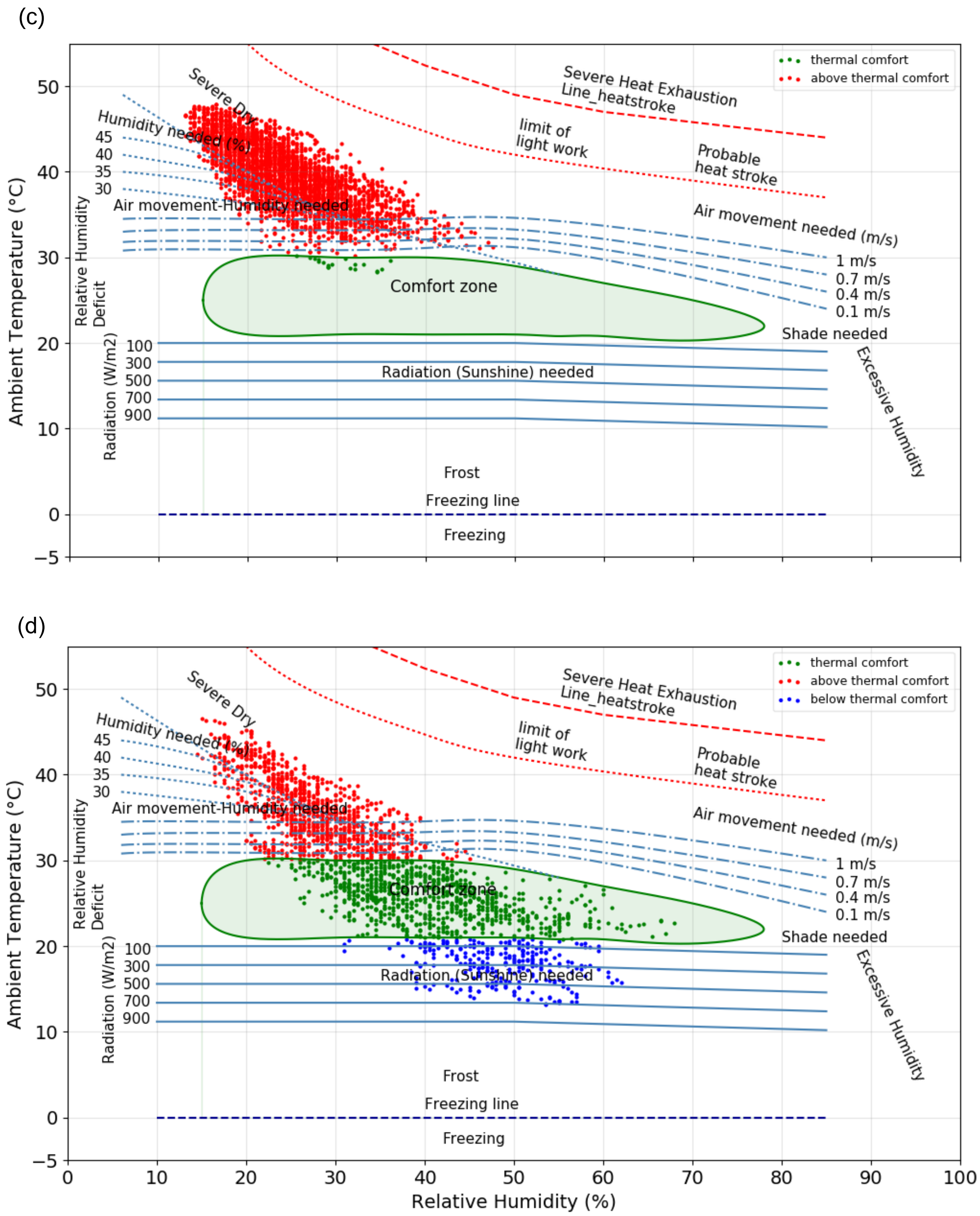

Figure C-14. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H3 case study during the target monitoring period. (c) summer, and (d) autumn.

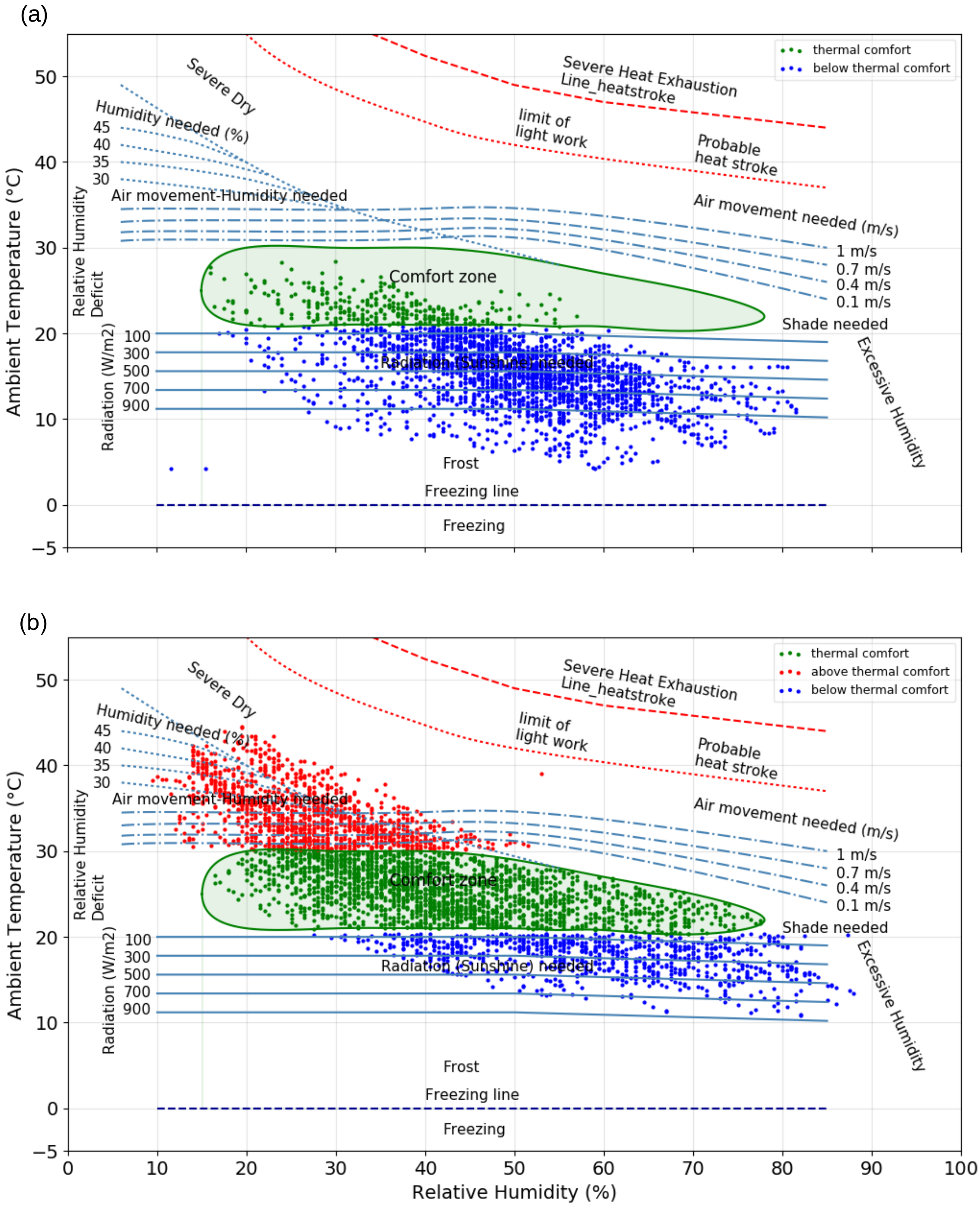

Figure C-15. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H4 case study during the target monitoring period. (a) winter, (b) spring.

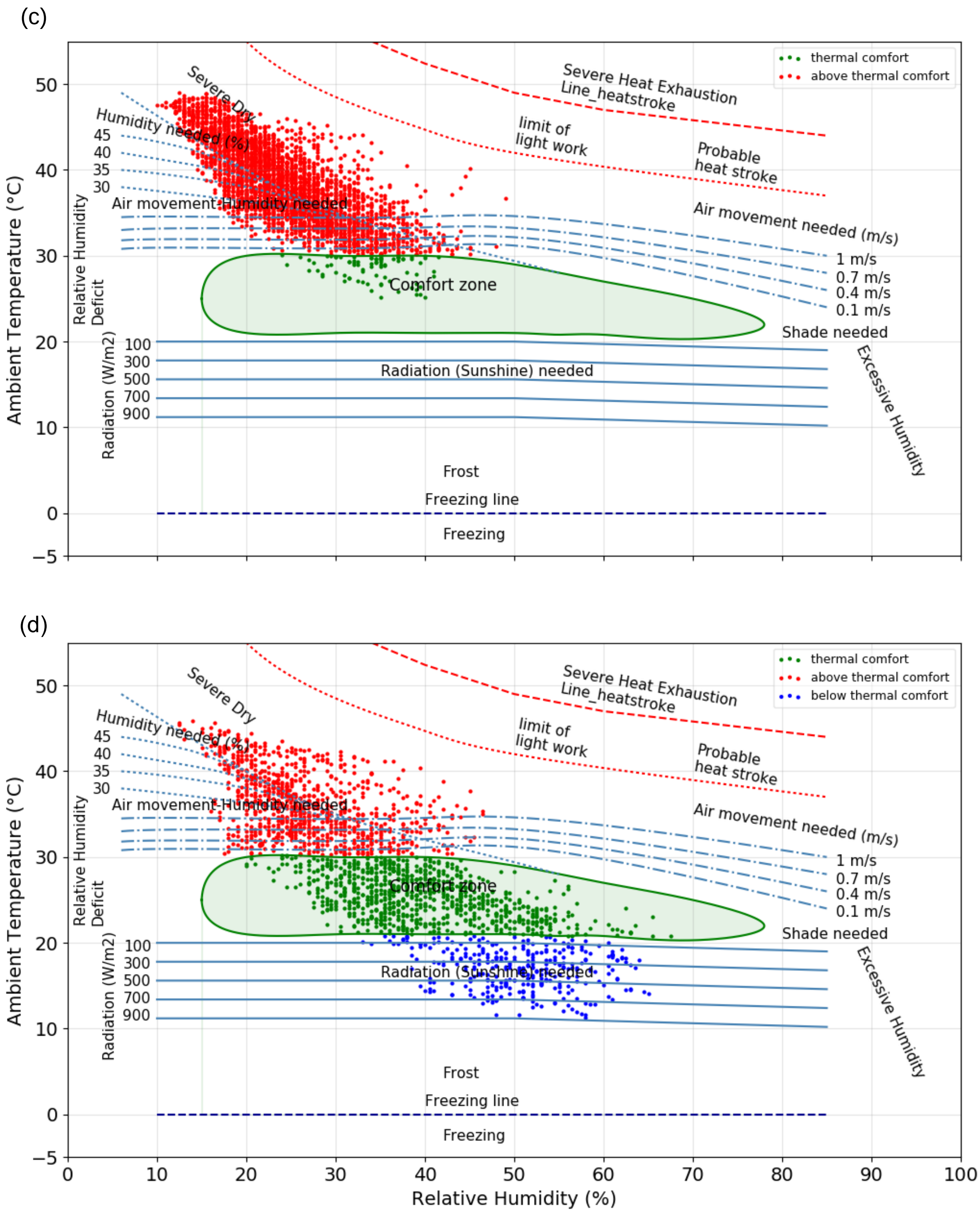

Figure C-16. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H4 case study during the target monitoring period. (c) summer, and (d) autumn.

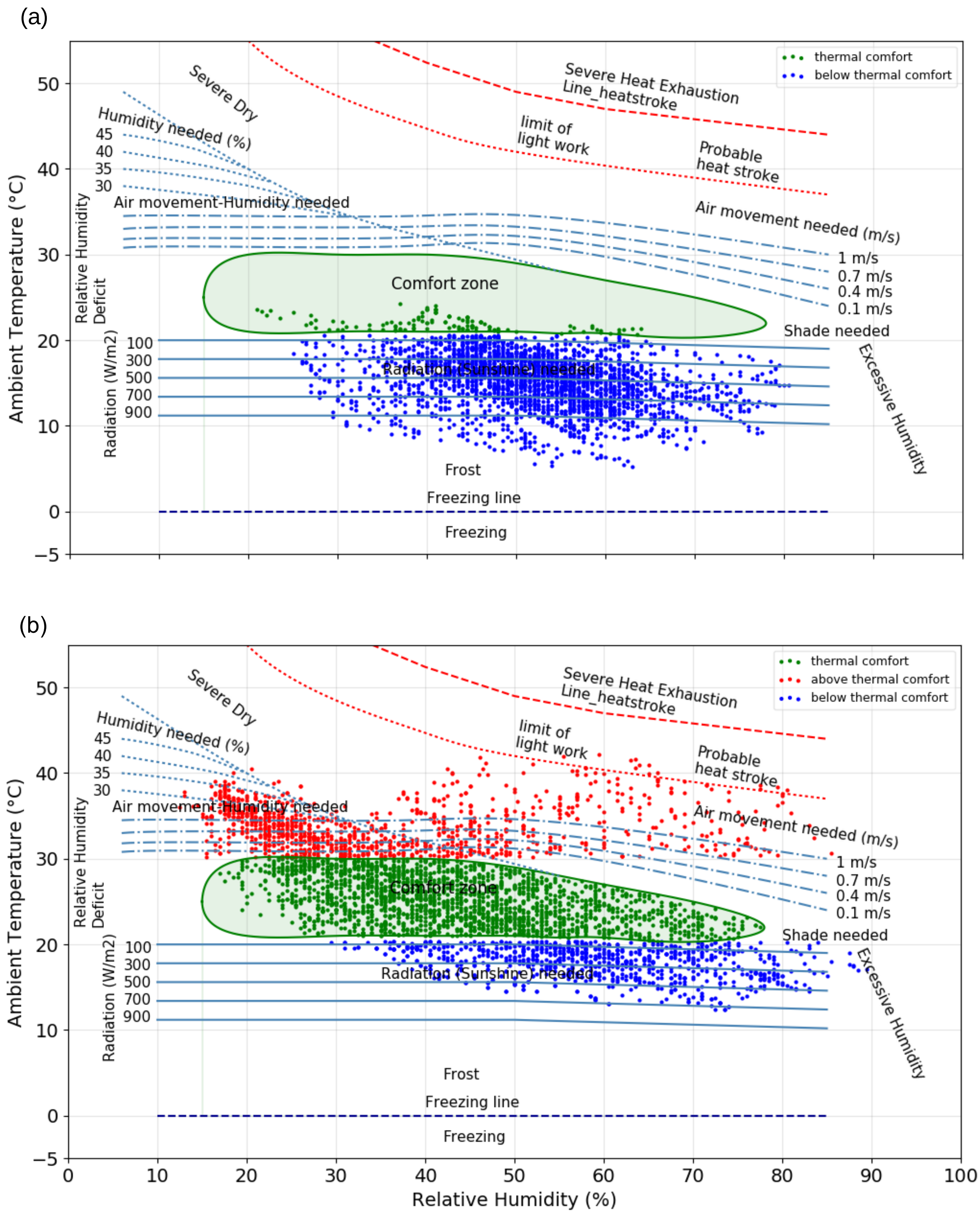

Figure C-17. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H5 case study during the target monitoring period. (a) winter, (b) spring.

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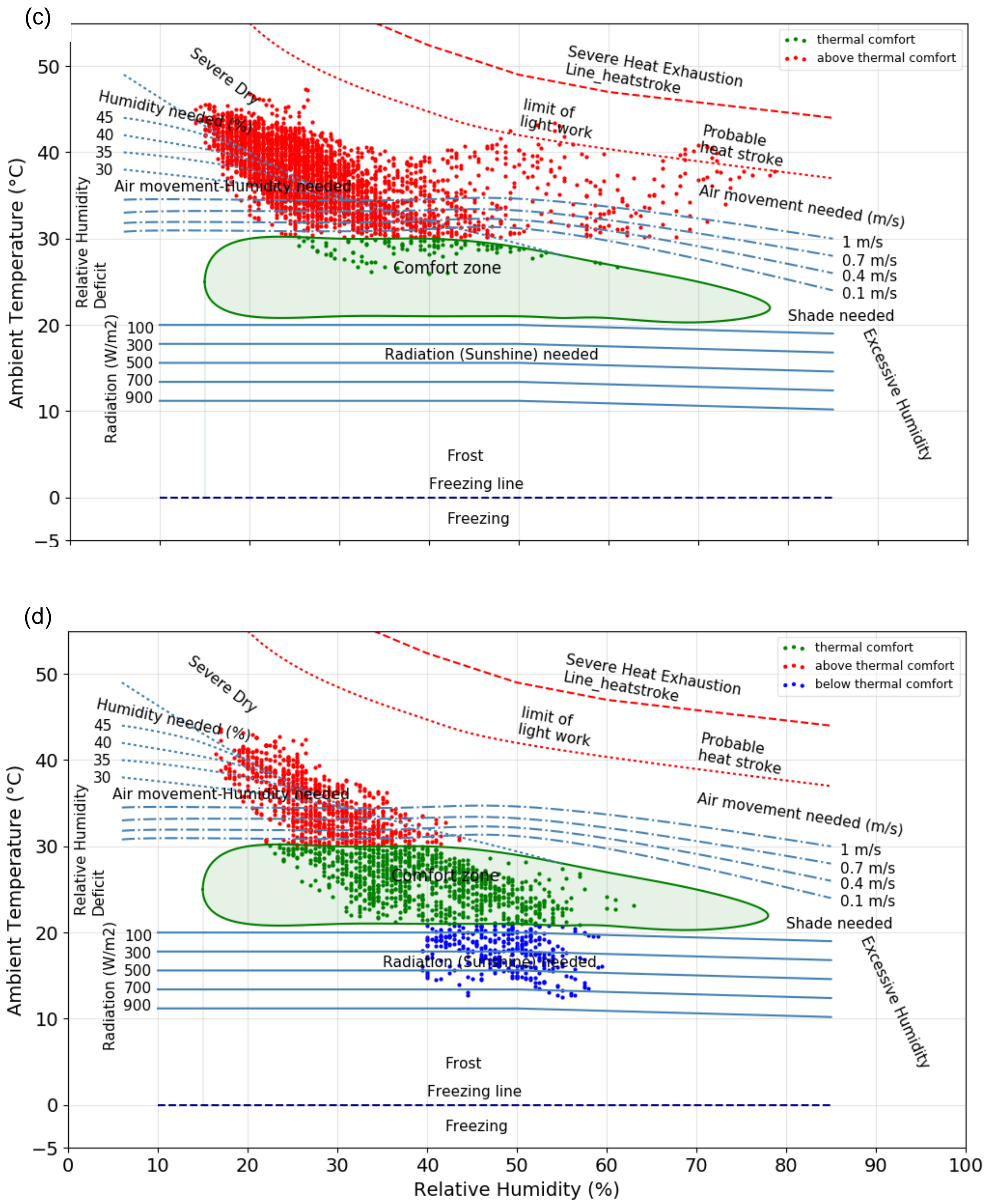

Figure C-18. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H5 case study during the target monitoring period. (c) summer, and (d) autumn.

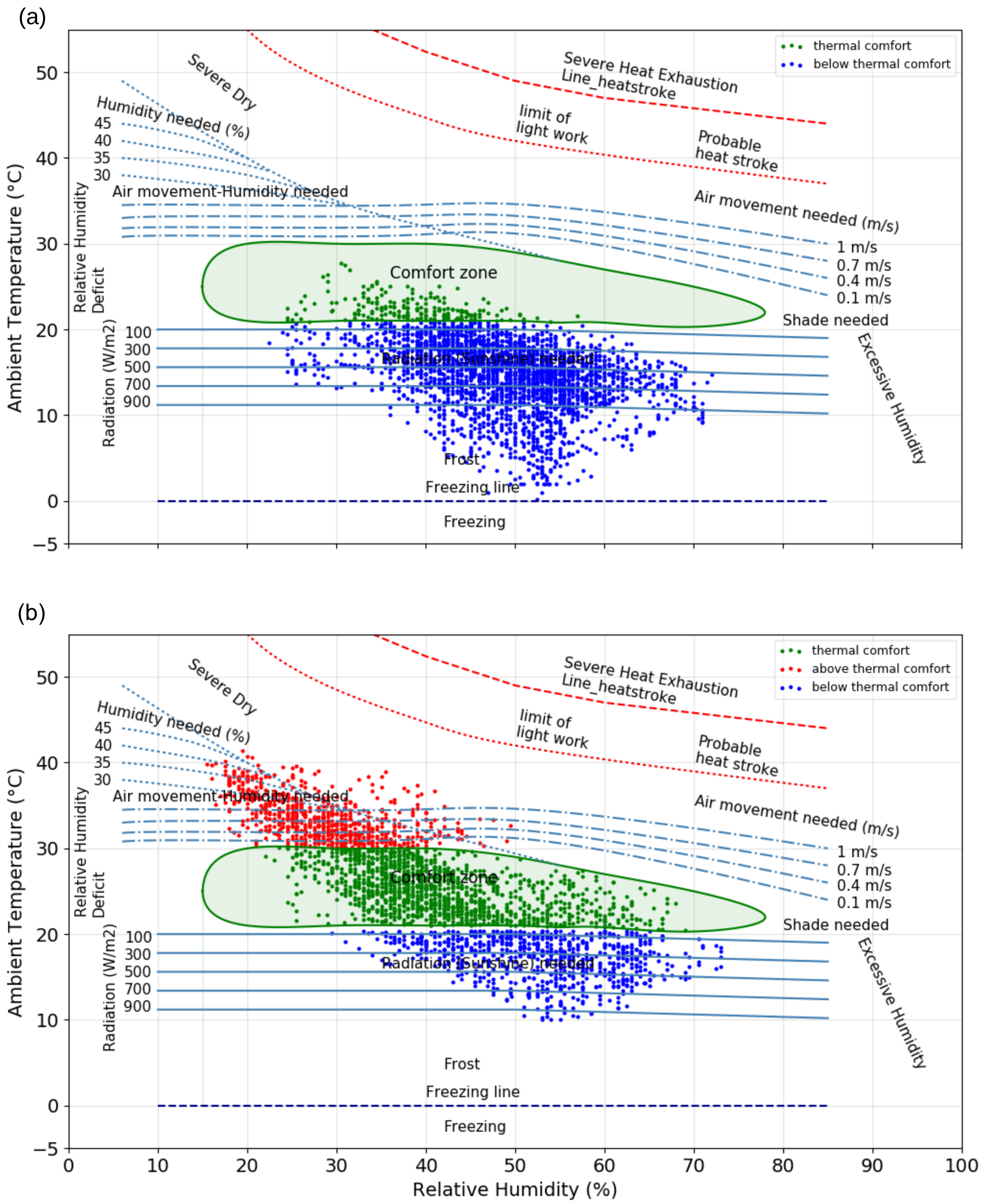

Figure C-19. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H7 case study during the target monitoring period. (a) winter, (b) spring.

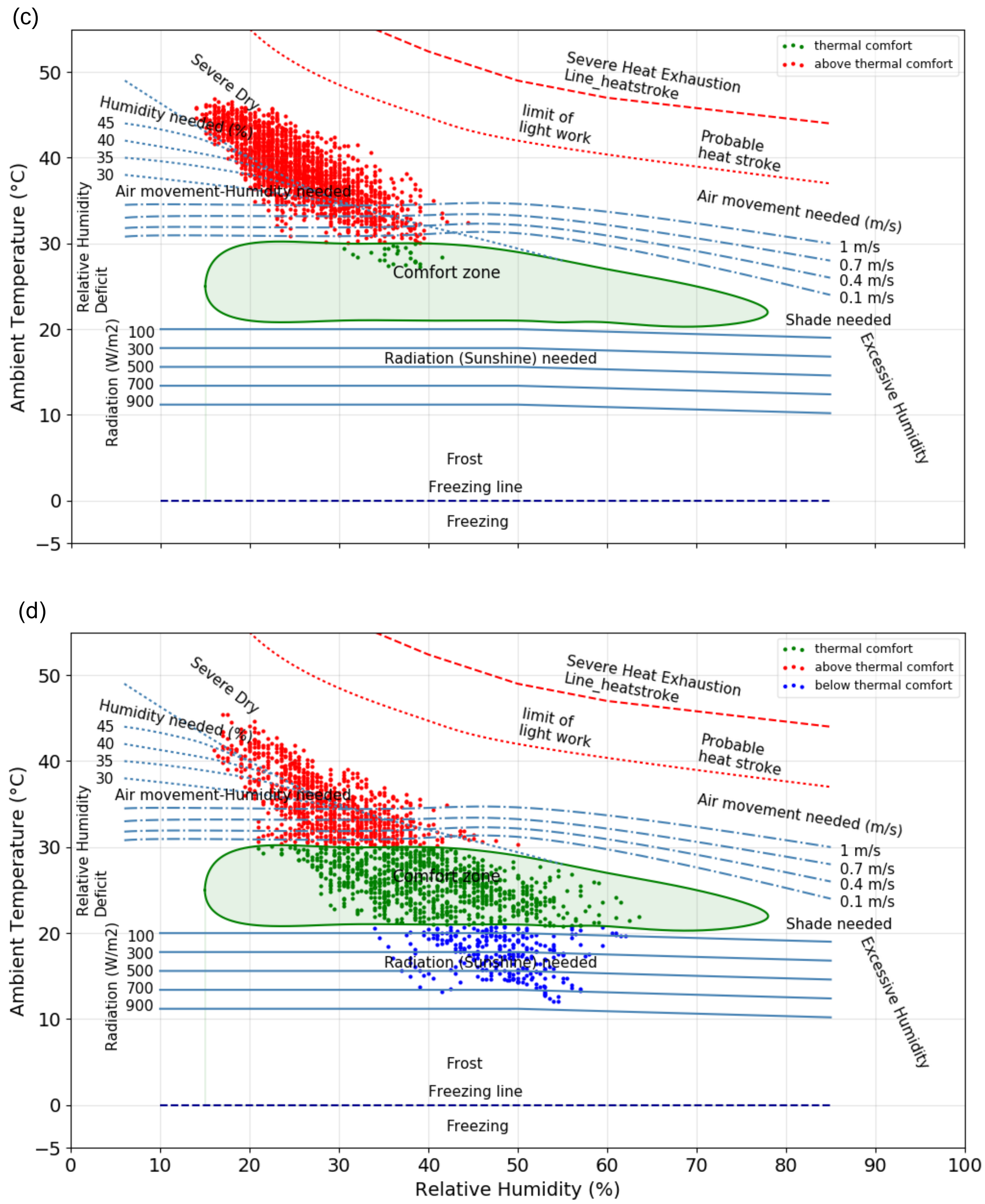

Figure C-20. Distribution of hourly ambient conditions (AT and RH) for winter and spring seasons of H7 case study during the target monitoring period. (c) summer, and (d) autumn.

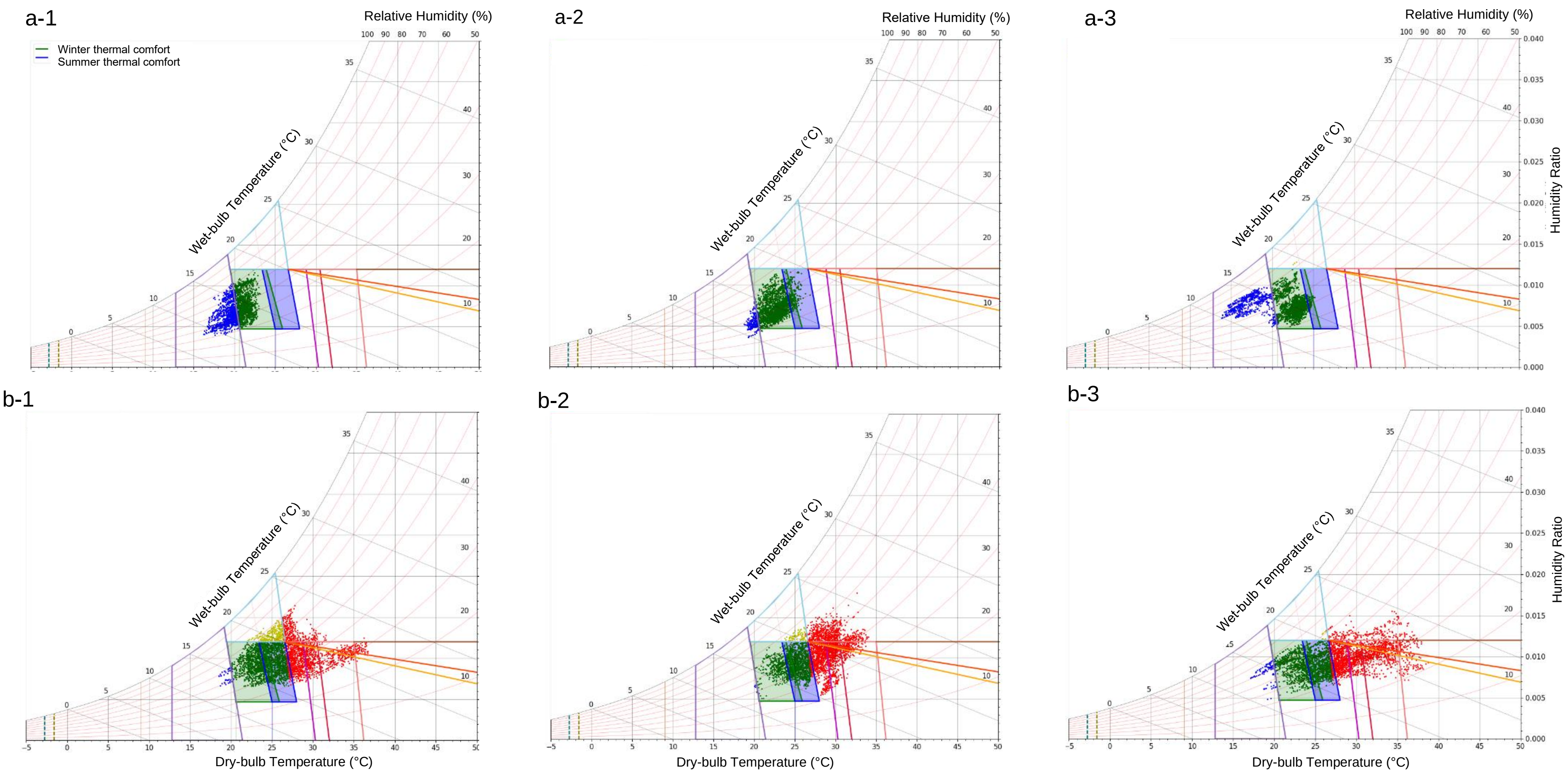

Figure C-21. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H2 case study for winter and spring. (a1, a2, a3) the indoor DBT and RH recorded in living room, kitchen and bedroom for winter, (b1, b2, b3) the indoor DBT and RH recorded in living room, kitchen and bedroom for spring.

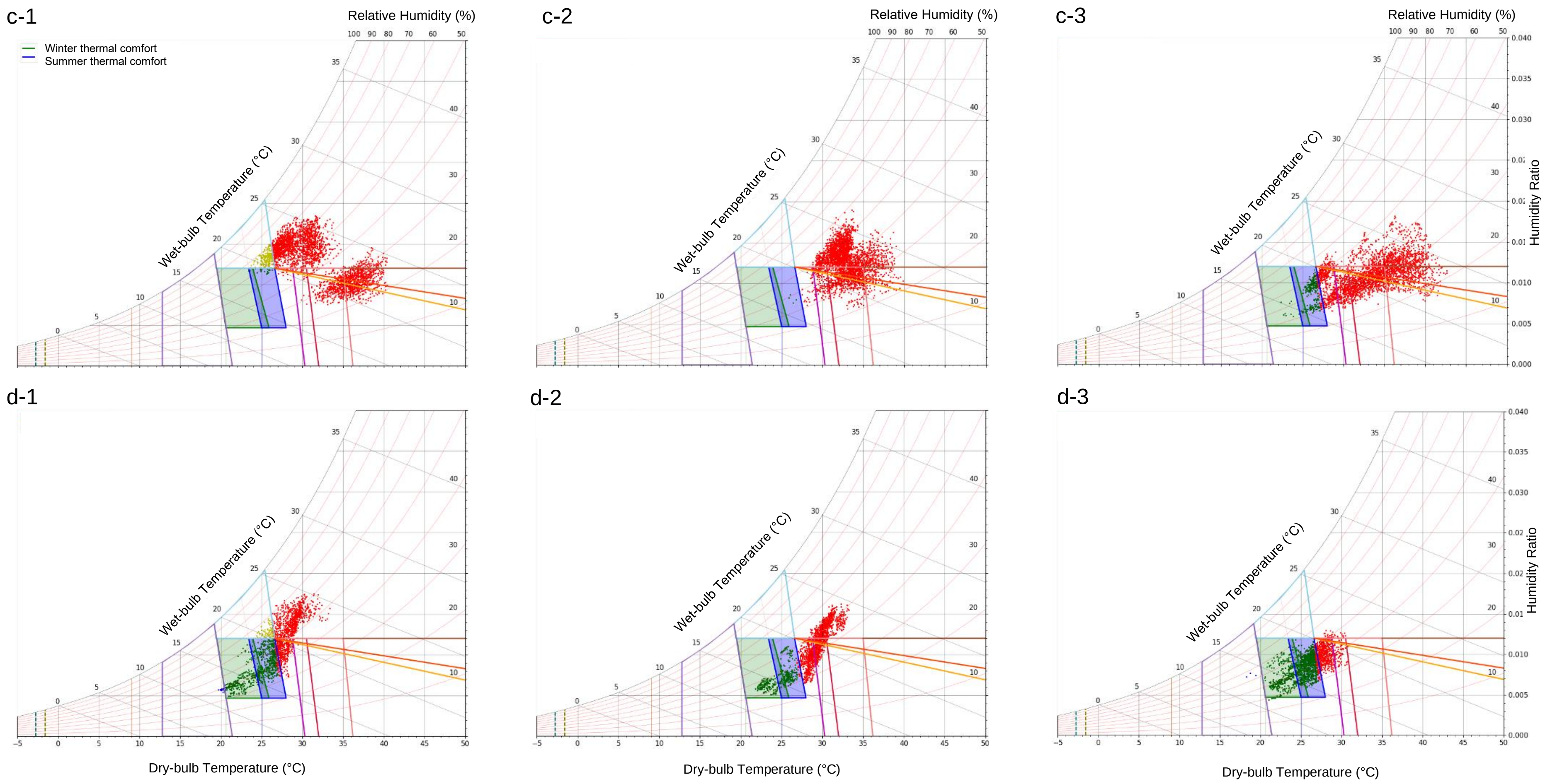

Figure C-22. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H2 case study for summer and autumn. (c1, c2, c3) the indoor DBT and RH recorded in living room, kitchen and bedroom for summer, (d1, d2, d3) the indoor DBT and RH recorded in living room, kitchen and bedroom for autumn.

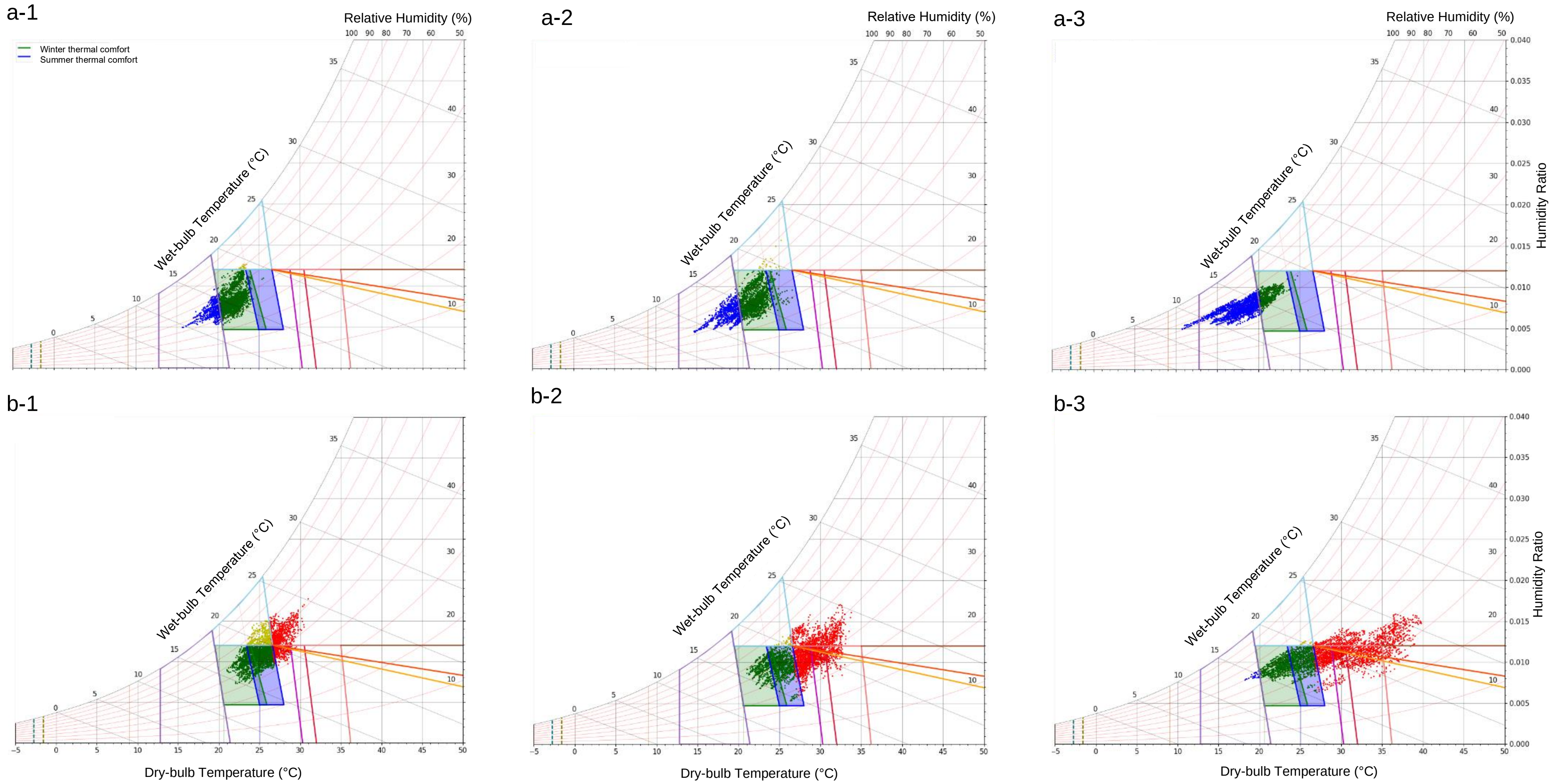

Figure C-23. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H3 case study for winter and spring. (a1, a2, a3) the indoor DBT and RH recorded in living room, kitchen and bedroom for winter, (b1, b2, b3) the indoor DBT and RH recorded in living room, kitchen and bedroom for spring.

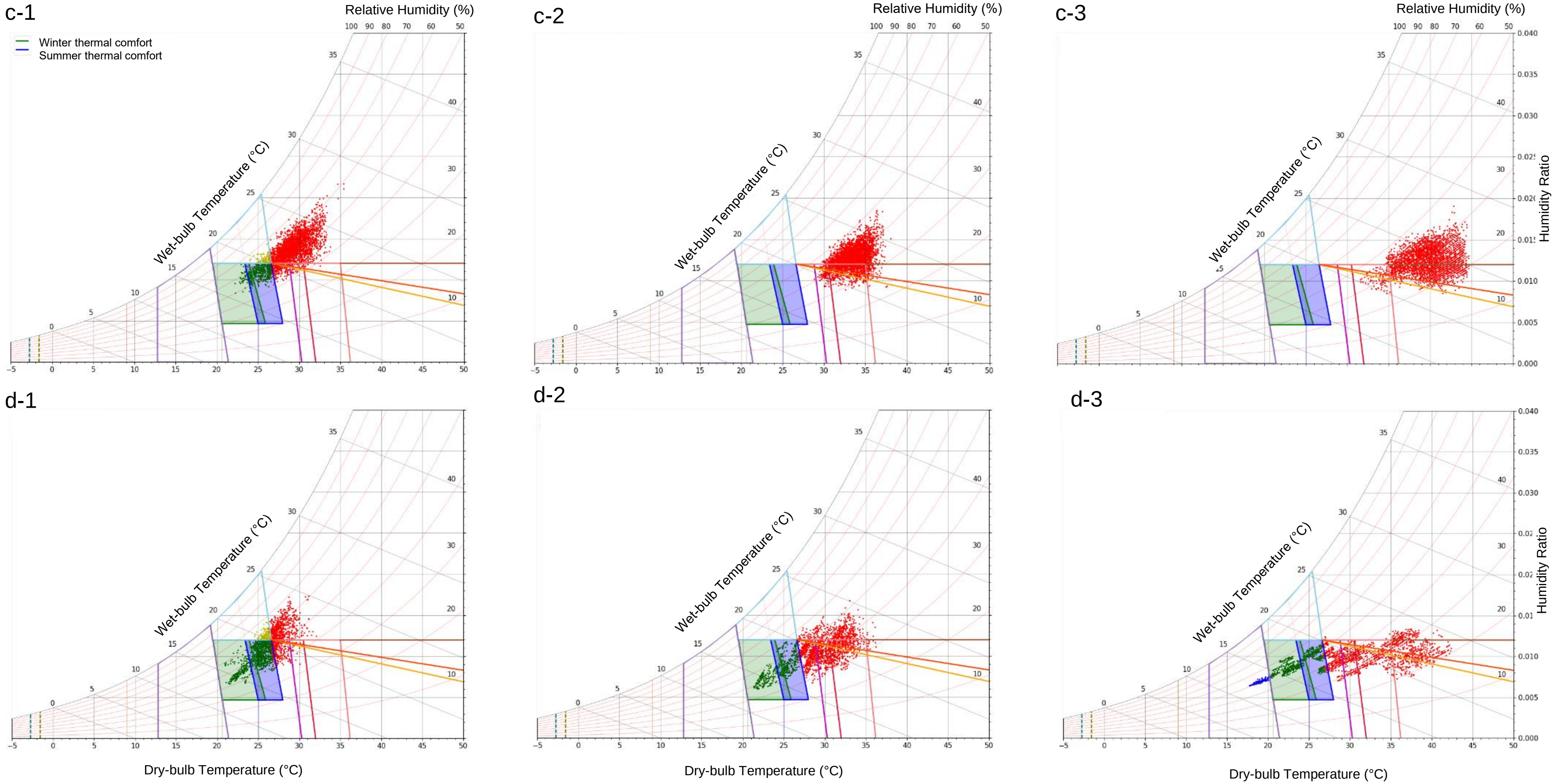

Figure C-24. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H3 case study for summer and autumn. (c1, c2, c3) the indoor DBT and RH recorded in living room, kitchen and bedroom for summer, (d1, d2, d3) the indoor DBT and RH recorded in living room, kitchen and bedroom for autumn.

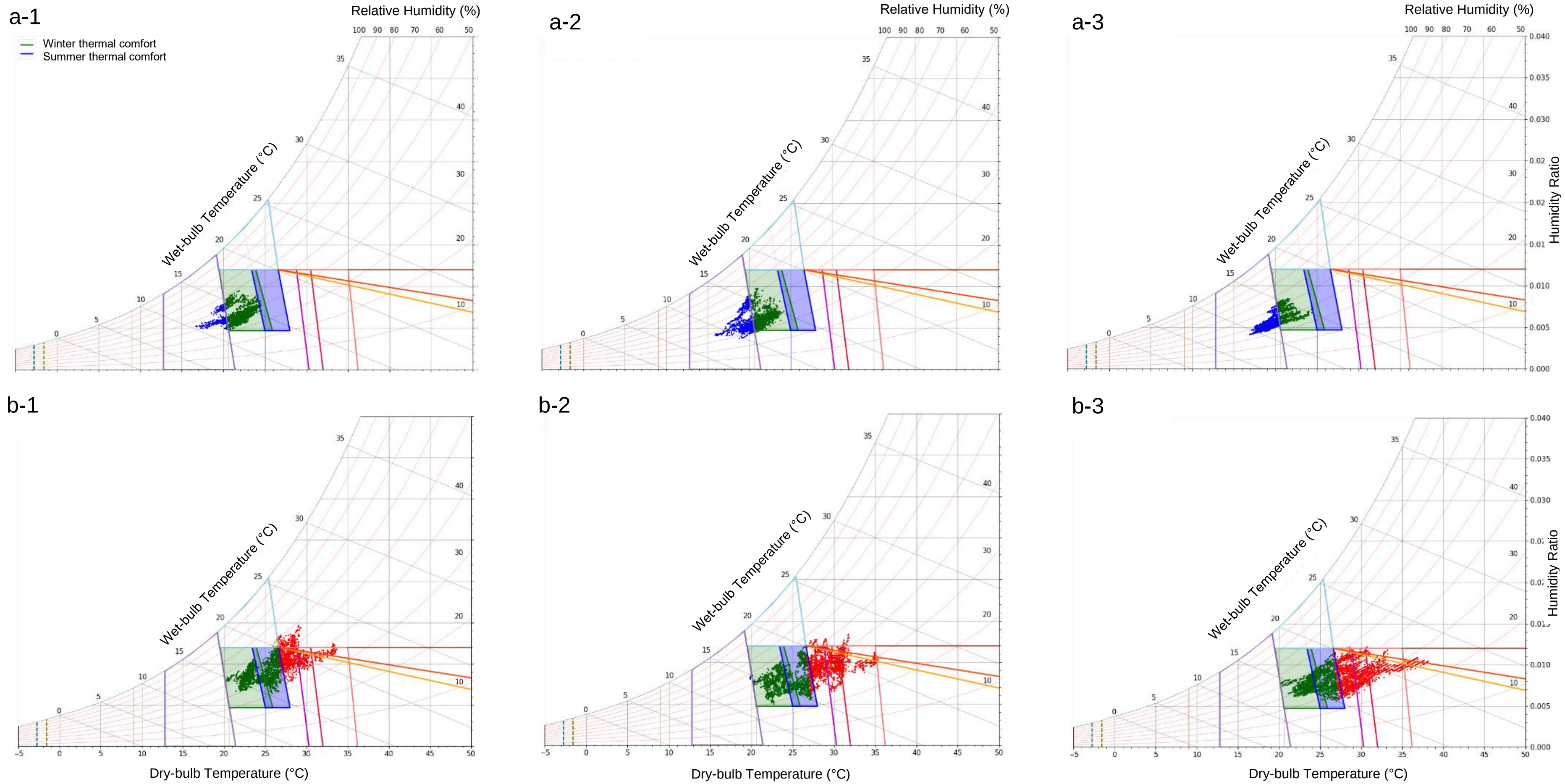

Figure C-25. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H4 case study for winter and spring. (a1, a2, a3) the indoor DBT and RH recorded in living room, kitchen and bedroom for winter, (b1, b2, b3) the indoor DBT and RH recorded in living room, kitchen and bedroom for spring.

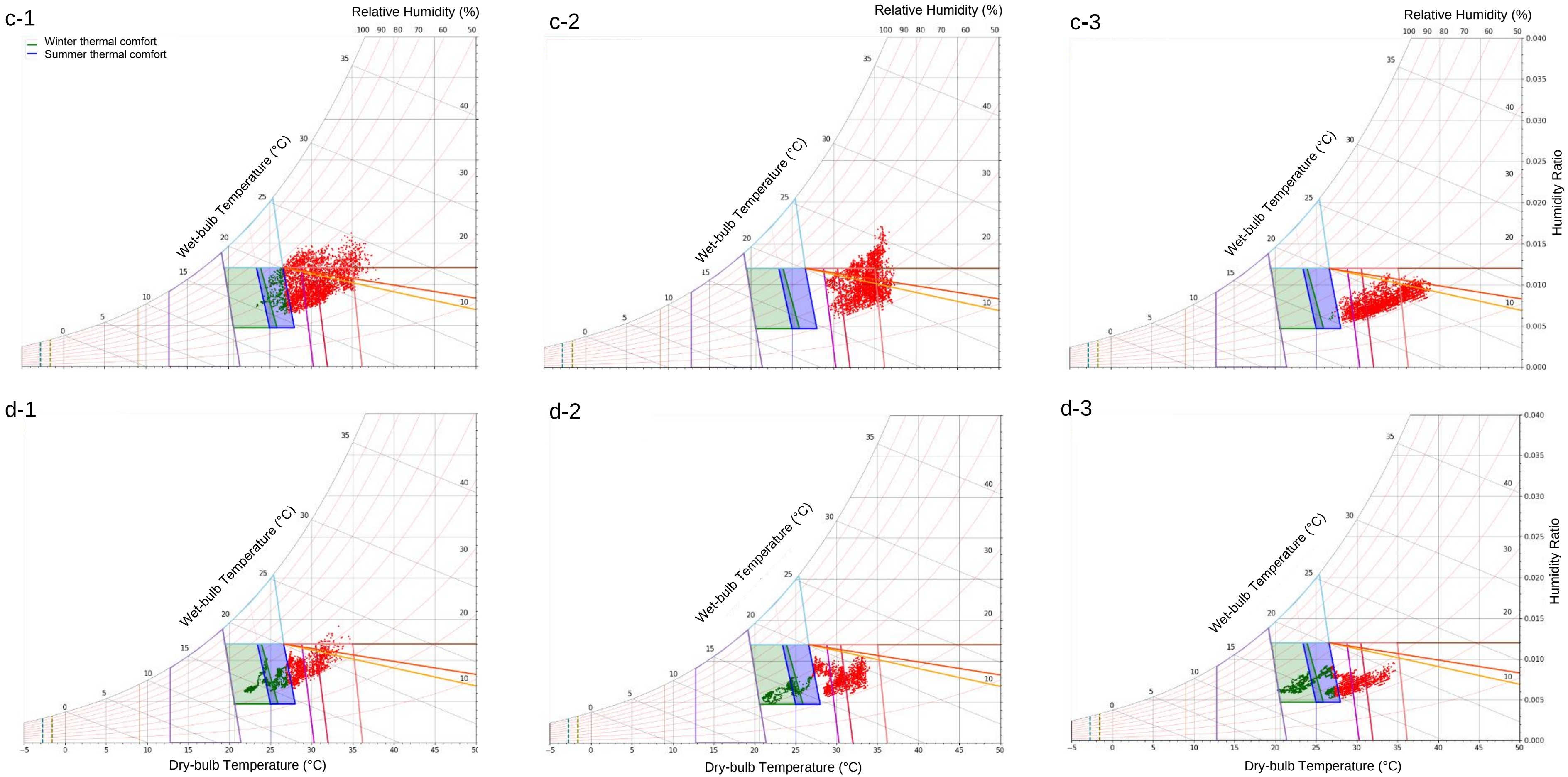

Figure C-26. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H4 case study for summer and autumn. (c1, c2, c3) the indoor DBT and RH recorded in living room, kitchen and bedroom for summer, (d1, d2, d3) the indoor DBT and RH recorded in living room, kitchen and bedroom for autumn.

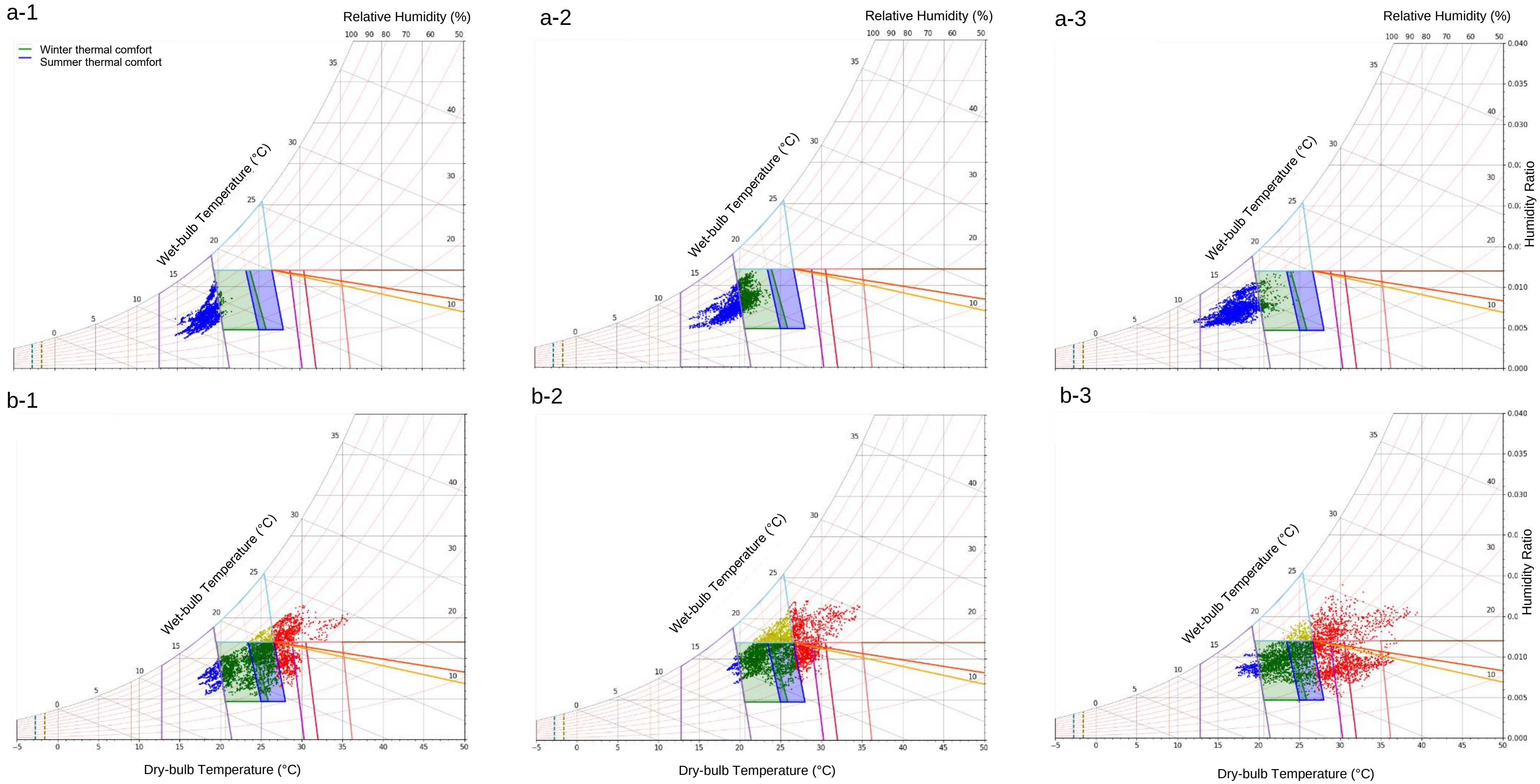

Figure C-27. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H5 case study for winter and spring. (a1, a2, a3) the indoor DBT and RH recorded in living room, kitchen and bedroom for winter, (b1, b2, b3) the indoor DBT and RH recorded in living room, kitchen and bedroom for spring.

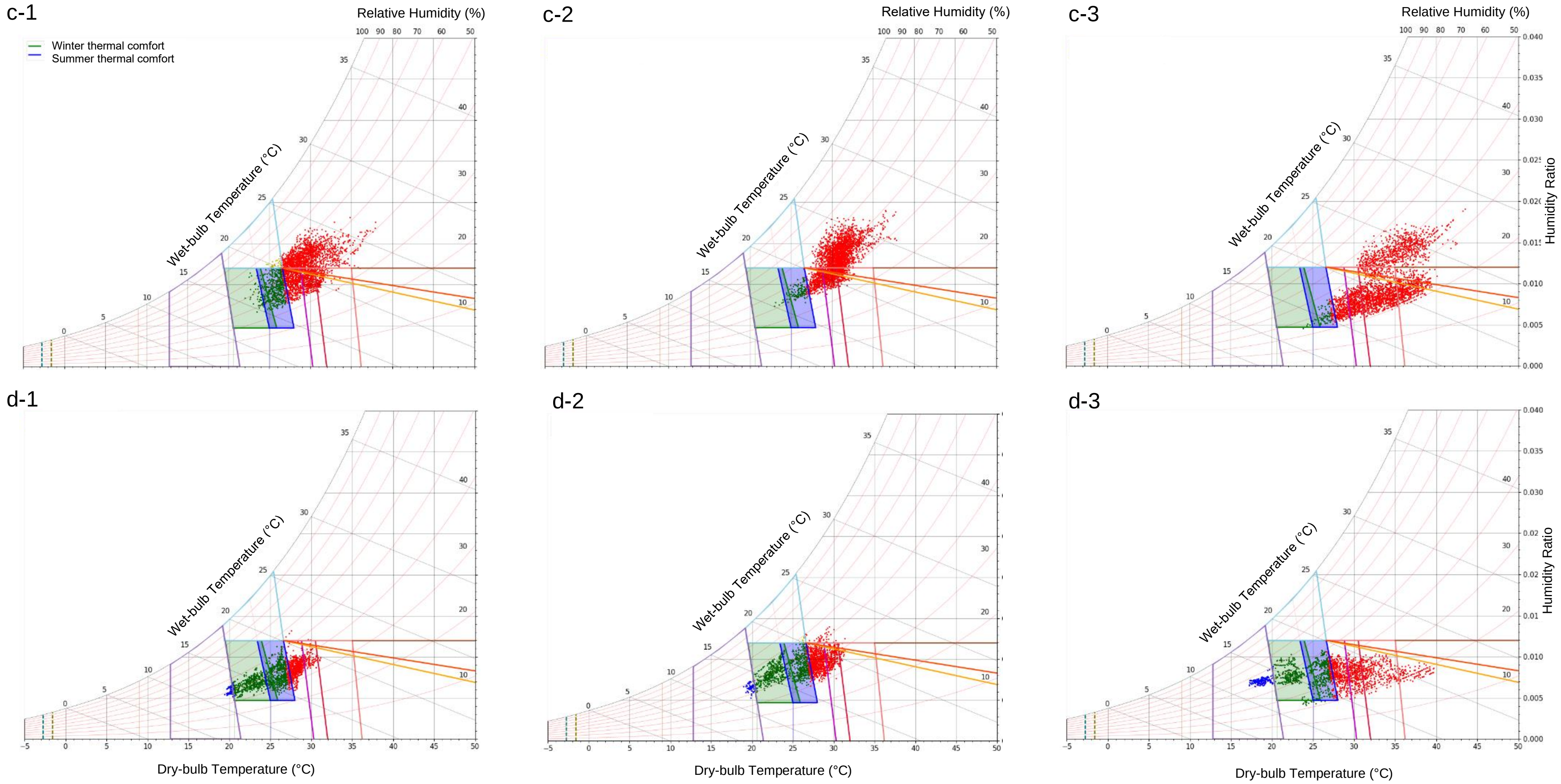

Figure C-28. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H5 case study for summer and autumn. (c1, c2, c3) the indoor DBT and RH recorded in living room, kitchen and bedroom for summer, (d1, d2, d3) the indoor DBT and RH recorded in living room, kitchen and bedroom for autumn.

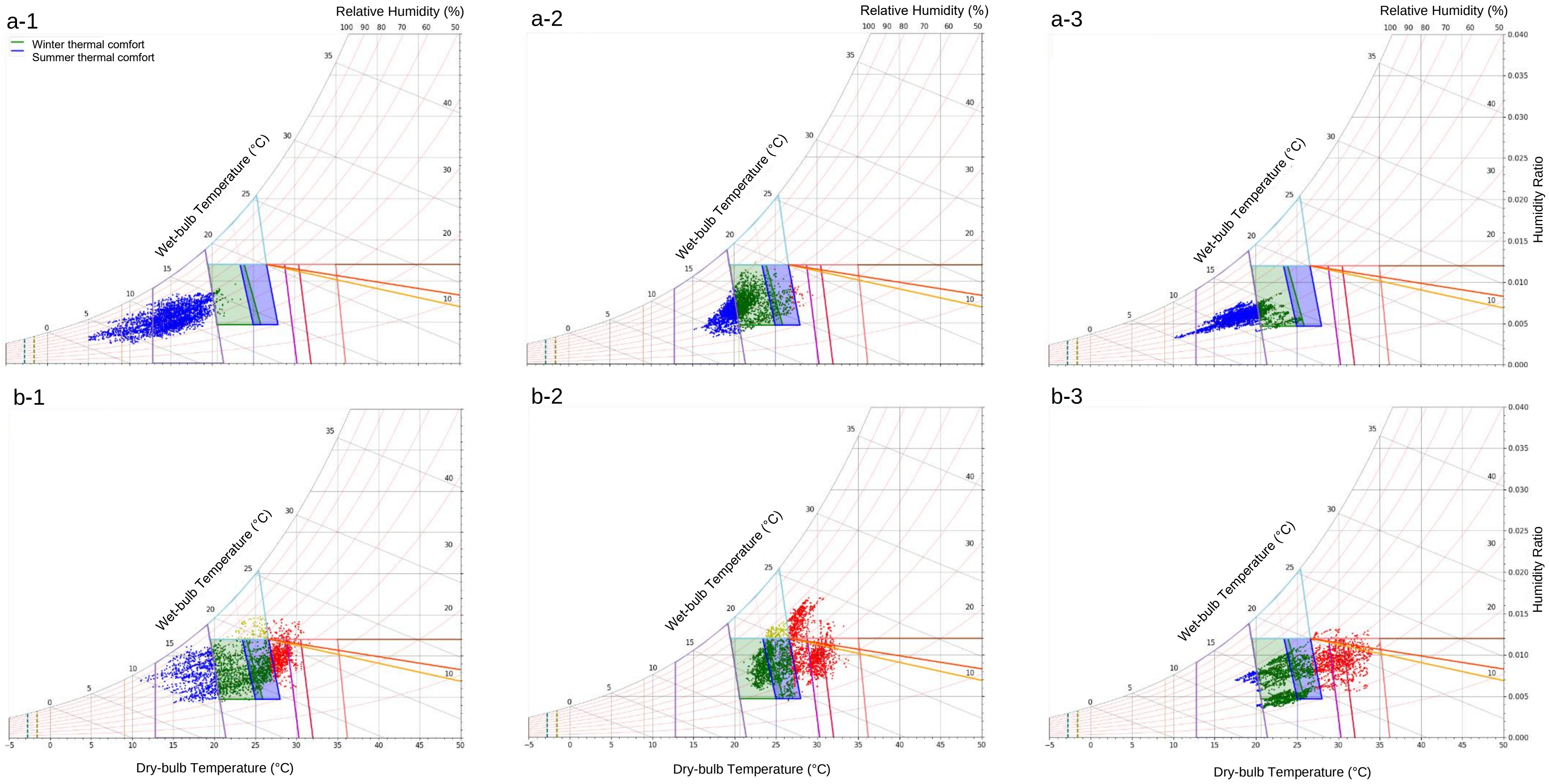

Figure C-29. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H7 case study for winter and spring. (a1, a2, a3) the indoor DBT and RH recorded in living room, kitchen and bedroom for winter, (b1, b2, b3) the indoor DBT and RH recorded in living room, kitchen and bedroom for spring.

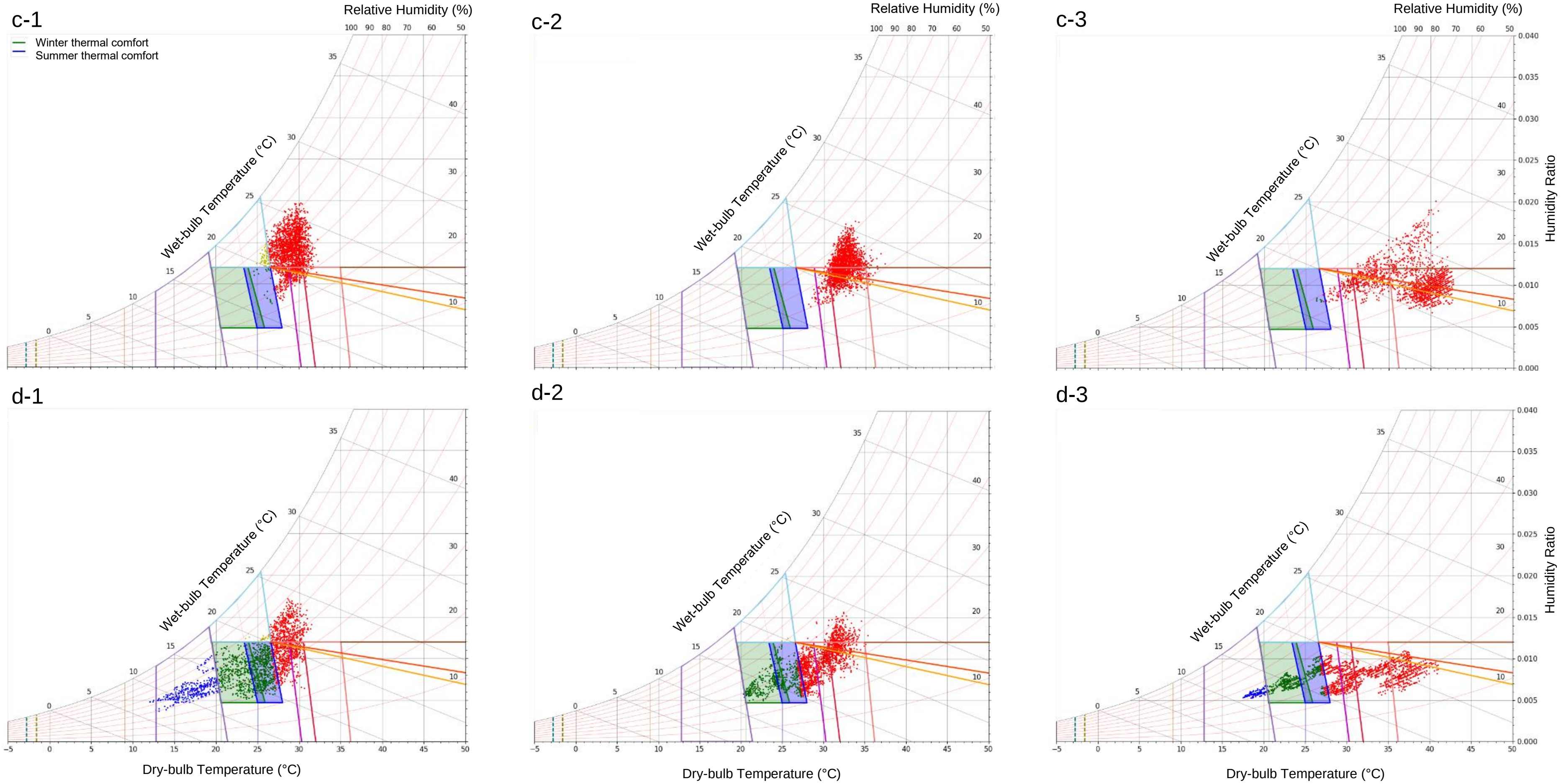

Figure C-30. Psychrometric chart of the indoor environment conditions (DBT and RH) recorded in living room, kitchen and bedroom of H7 case study for summer and autumn. (c1, c2, c3) the indoor DBT and RH recorded in living room, kitchen and bedroom for summer, (d1, d2, d3) the indoor DBT and RH recorded in living room, kitchen and bedroom for autumn.

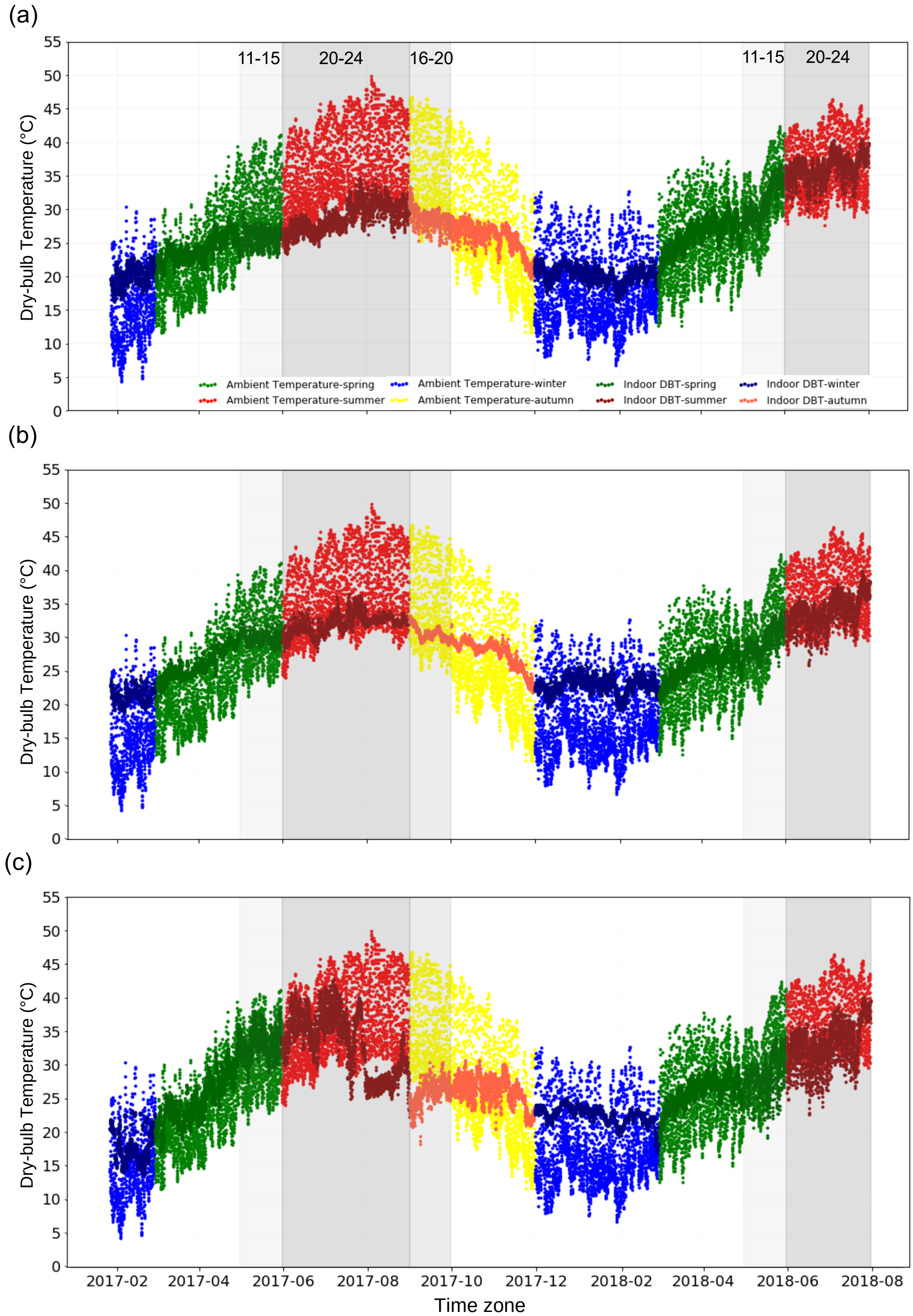

Figure C-31. Scatter plot of hourly AT and indoor hourly DBT in (a) living room, (b) kitchen, and (c) bedroom with the daily time scales of using cooling system of H2 case study for the target monitoring period.

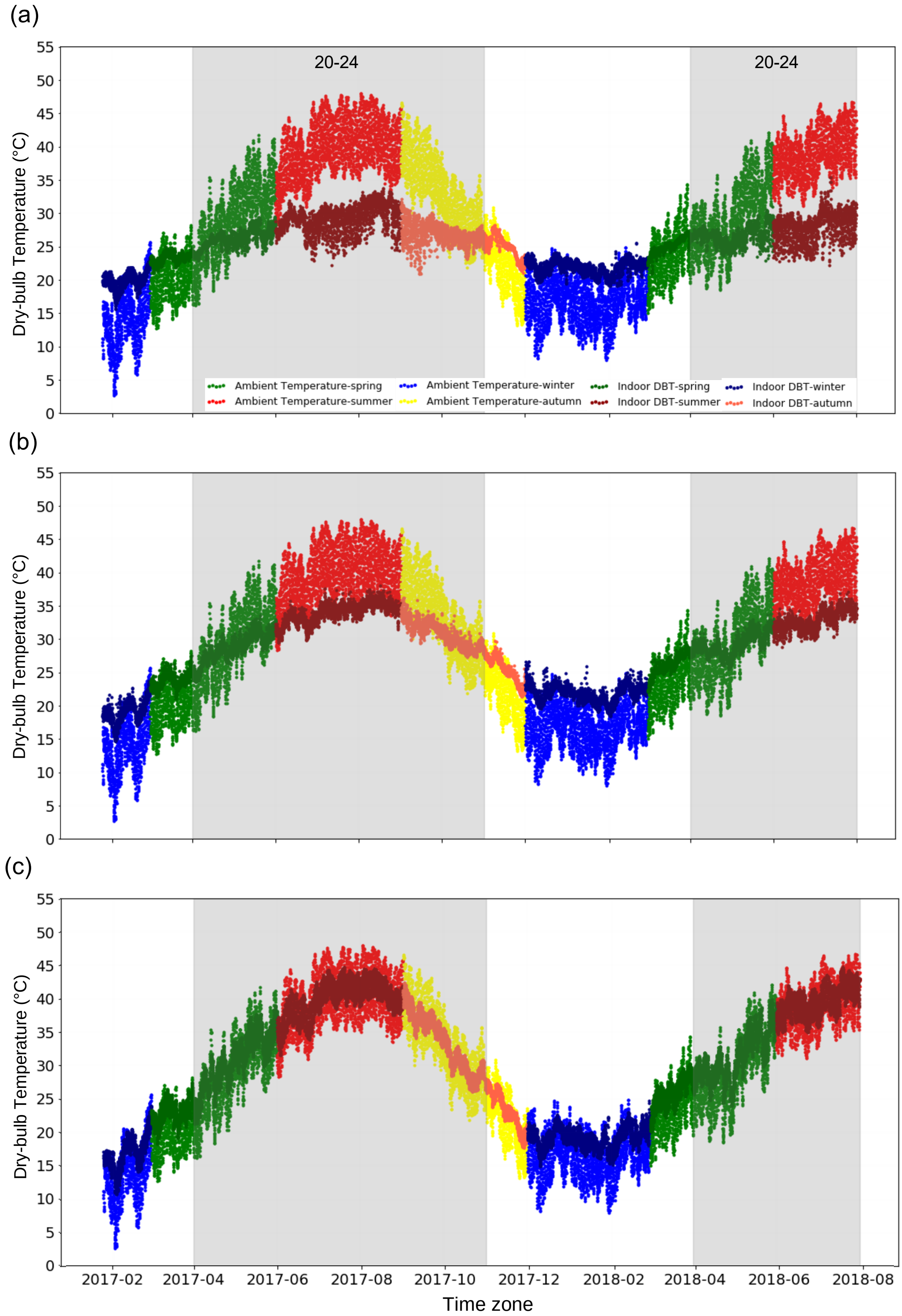

Figure C-32. Scatter plot of hourly AT and indoor hourly DBT in (a) living room, (b) kitchen, and (c) bedroom with the daily time scales of using cooling system of H3 case study for the target monitoring period.

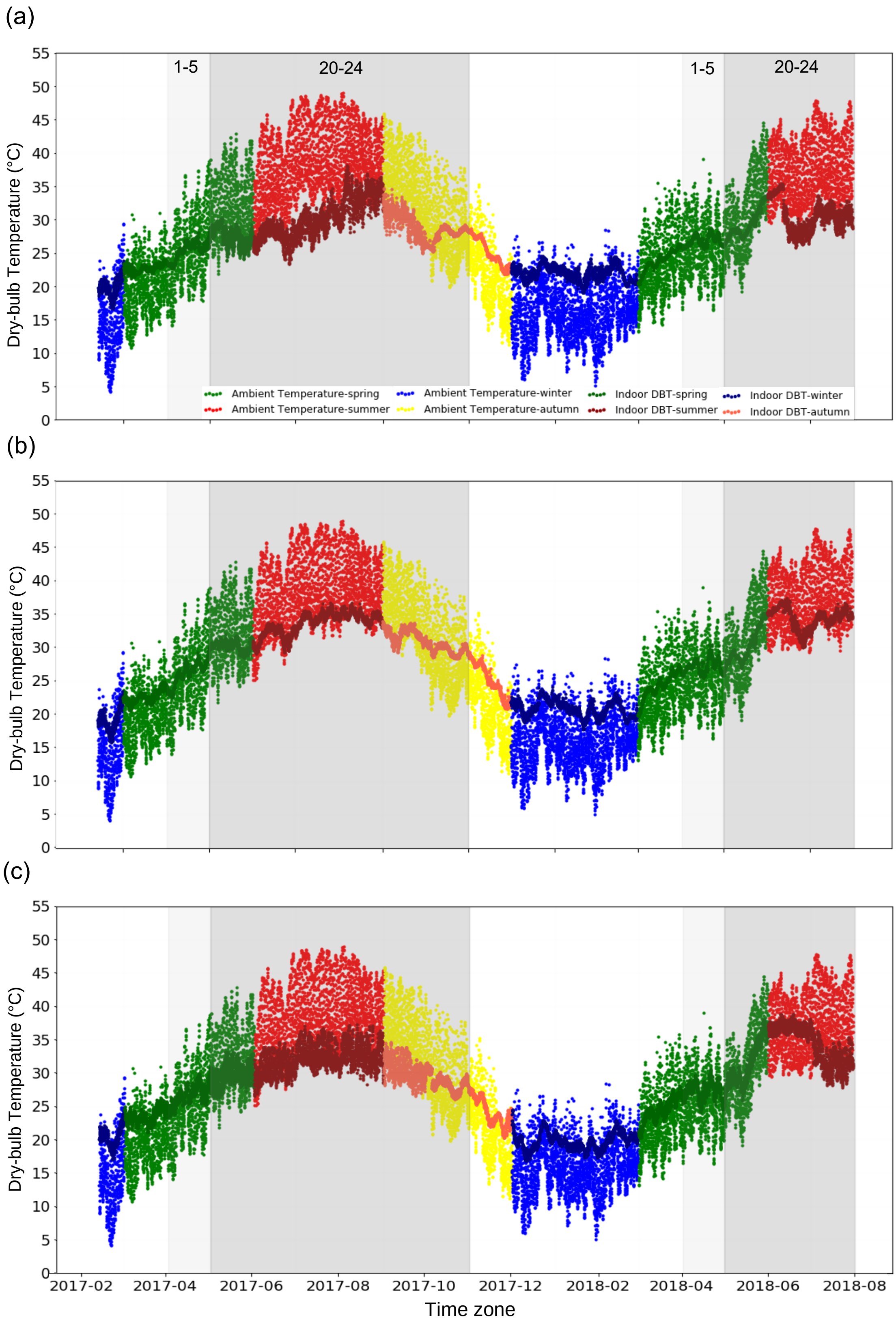

Figure C-33. Scatter plot of hourly AT and indoor hourly DBT in (a) living room, (b) kitchen, and (c) bedroom with the daily time scales of using cooling system of H4 case study for the target monitoring period.

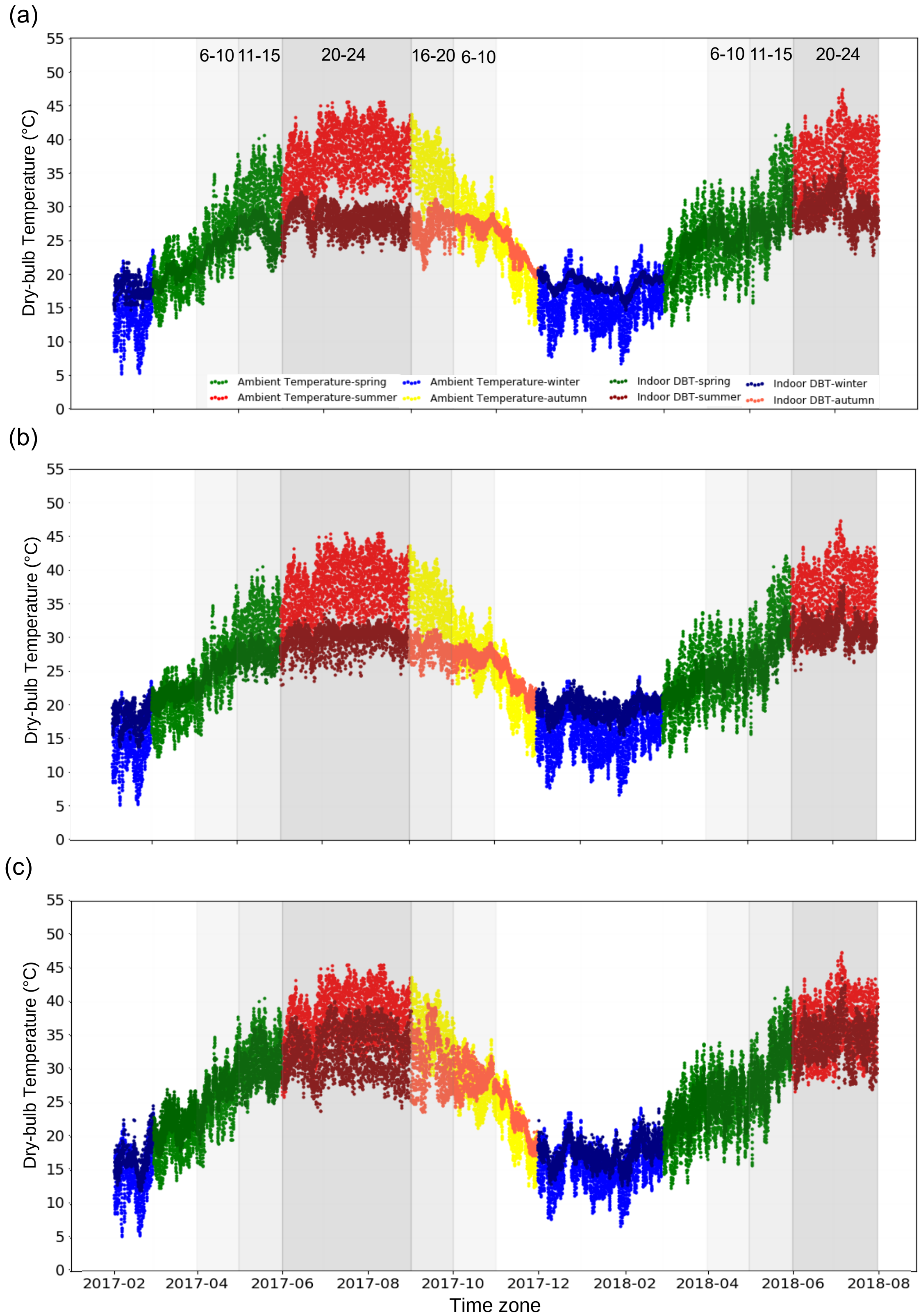

Figure C-34. Scatter plot of hourly AT and indoor hourly DBT in (a) living room, (b) kitchen, and (c) bedroom with the daily time scales of using cooling system of H5 case study for the target monitoring period.

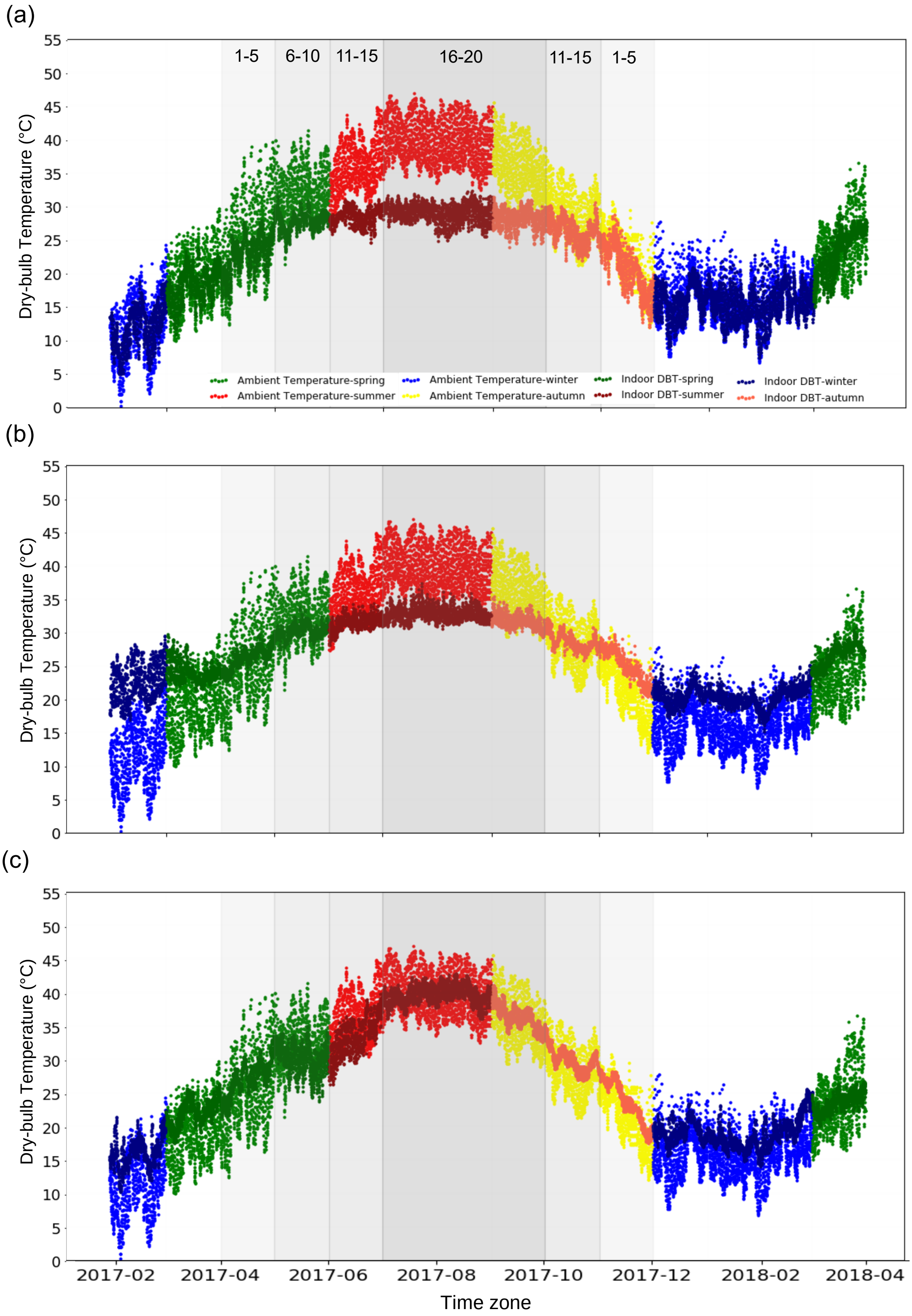

Figure C-35. Scatter plot of hourly AT and indoor hourly DBT in (a) living room, (b) kitchen, and (c) bedroom with the daily time scales of using cooling system of H7 case study for the target monitoring period.

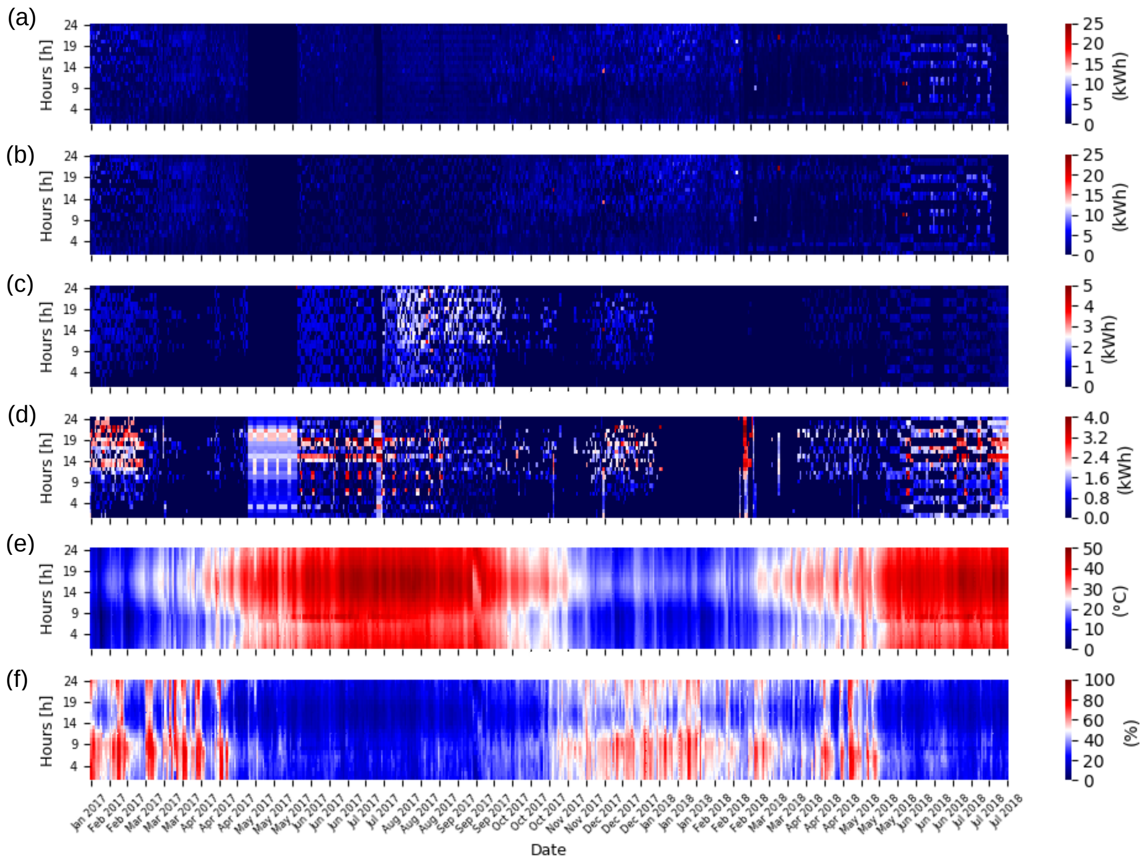

Figure C-36. Carpet plots of the hourly monitored parameters of H2 case study between January 2017 and June 2018. (a) the total energy use, (b) energy use from NG, (c) energy use from SG, (d) suppressed energy demand, (e) AT, and outdoor RH.

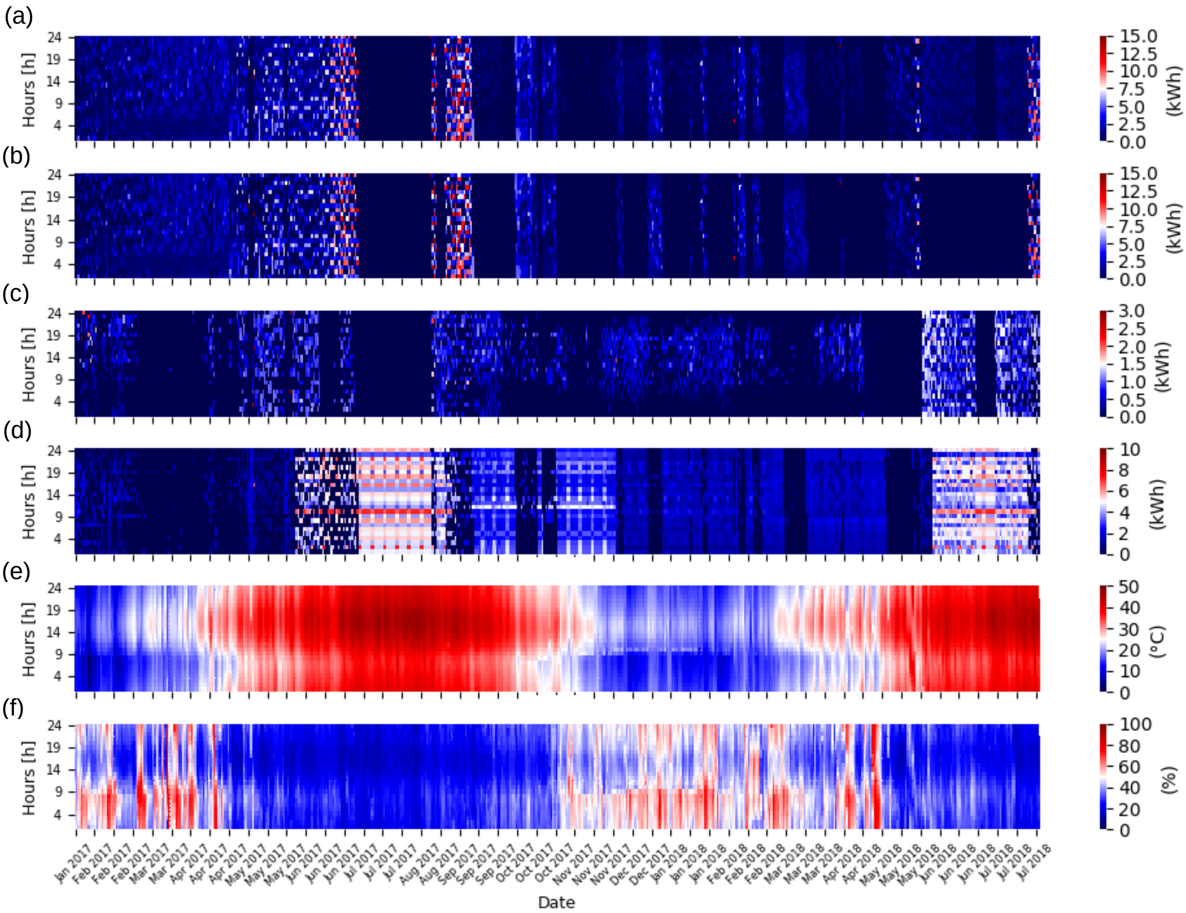

Figure C-37. Carpet plots of the hourly monitored parameters of H3 case study between January 2017 and June 2018. (a) the total energy use, (b) energy use from NG, (c) energy use from SG, (d) suppressed energy demand, (e) AT, and outdoor RH.

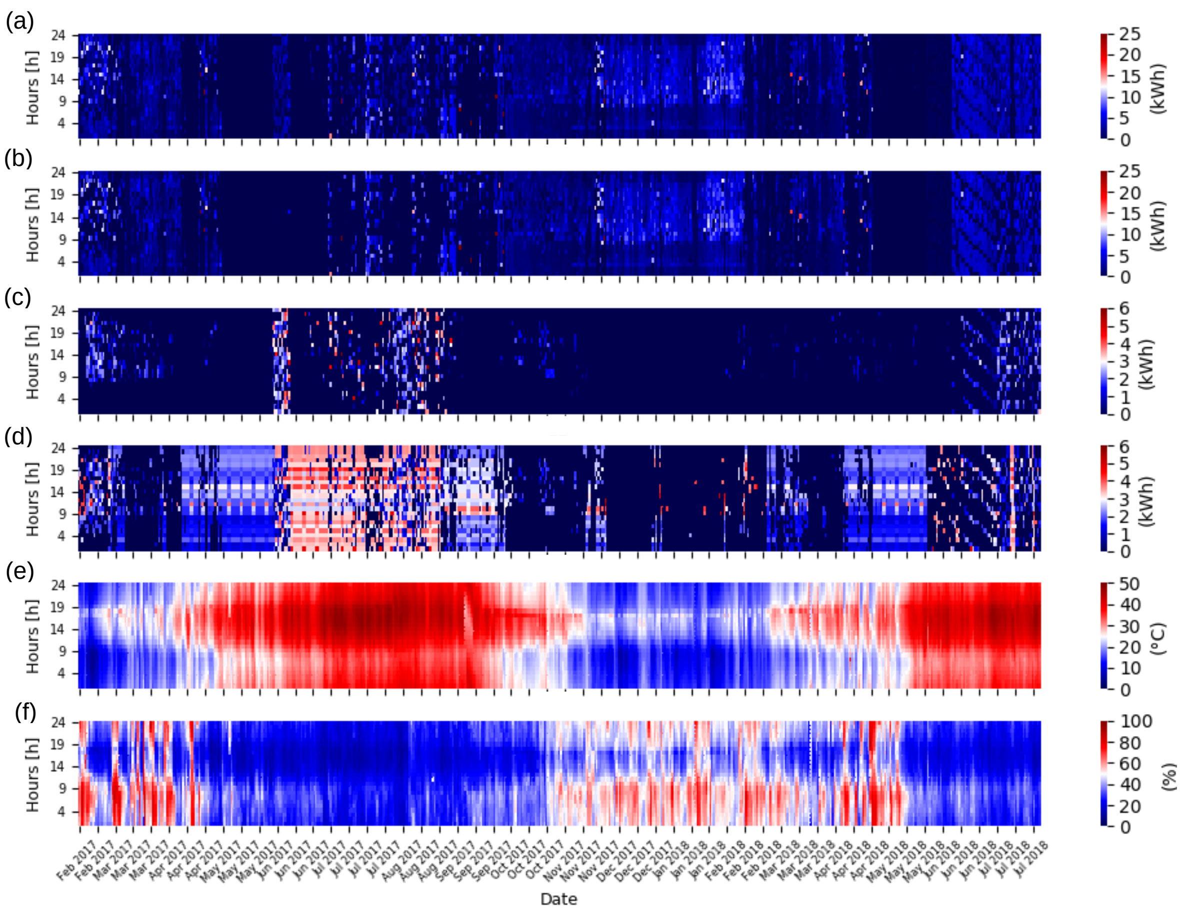

Figure C-38. Carpet plots of the hourly monitored parameters of H4 case study between January 2017 and June 2018. (a) the total energy use, (b) energy use from NG, (c) energy use from SG, (d) suppressed energy demand, (e) AT, and outdoor RH.

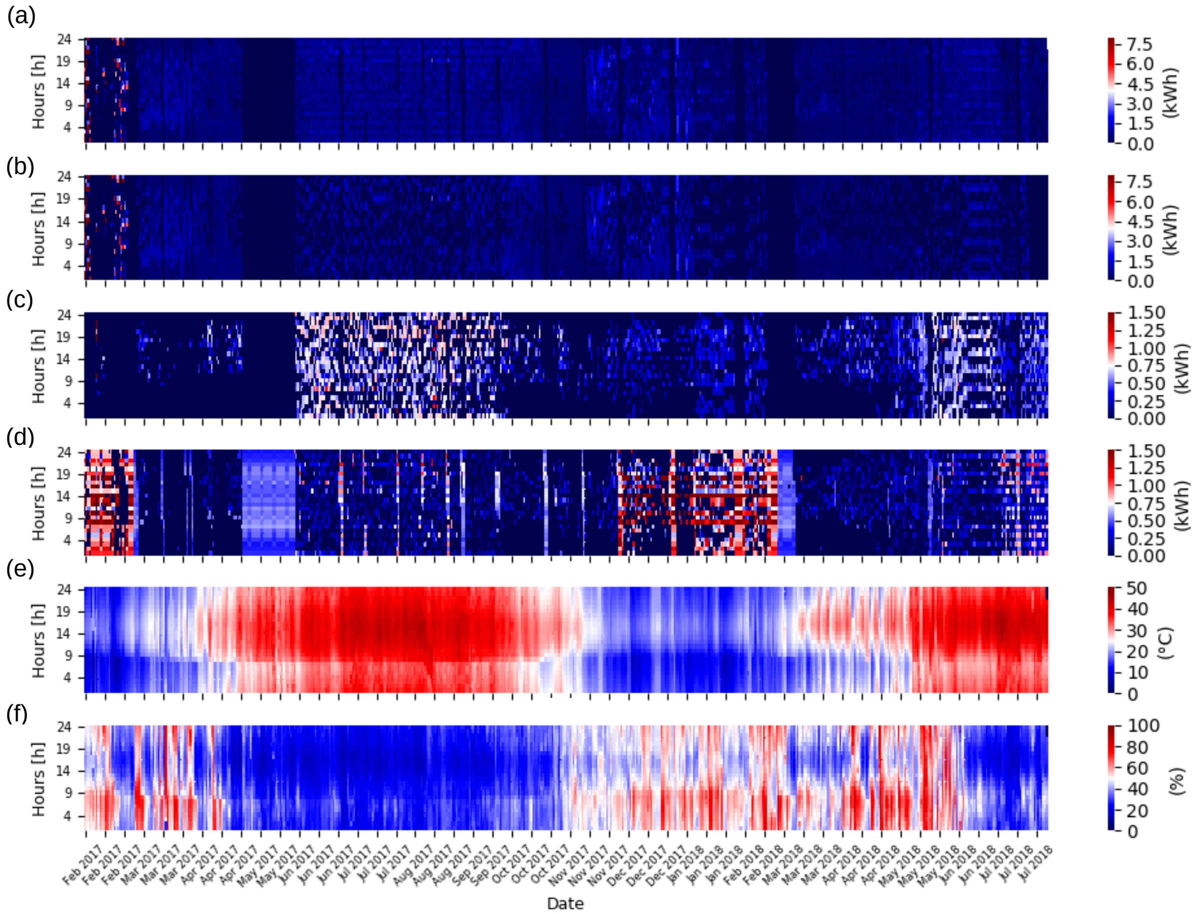

Figure C-39. Carpet plots of the hourly monitored parameters of H5 case study between January 2017 and June 2018. (a) the total energy use, (b) energy use from NG, (c) energy use from SG, (d) suppressed energy demand, (e) AT, and outdoor RH.

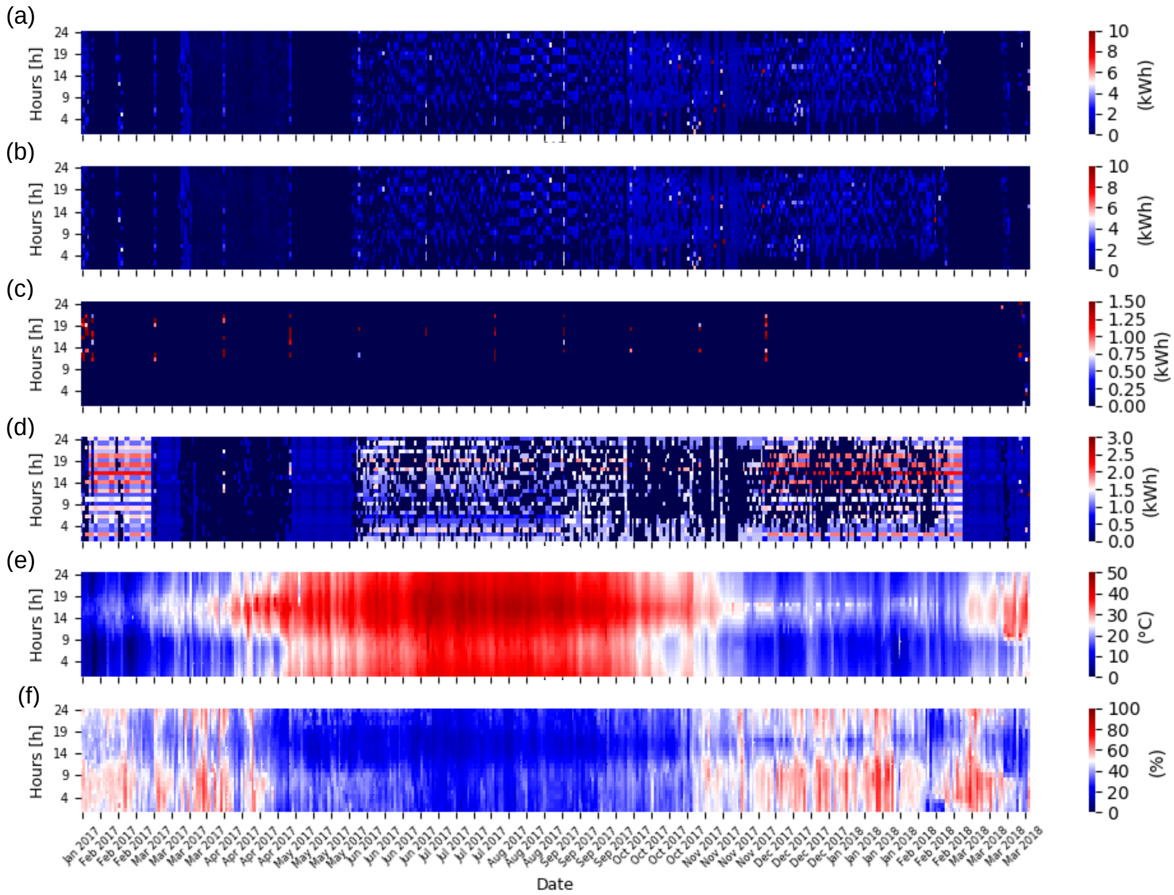

Figure C-40. Carpet plots of the hourly monitored parameters of H7 case study between January 2017 and June 2018. (a) the total energy use, (b) energy use from NG, (c) energy use from SG, (d) suppressed energy demand, (e) AT, and outdoor RH.

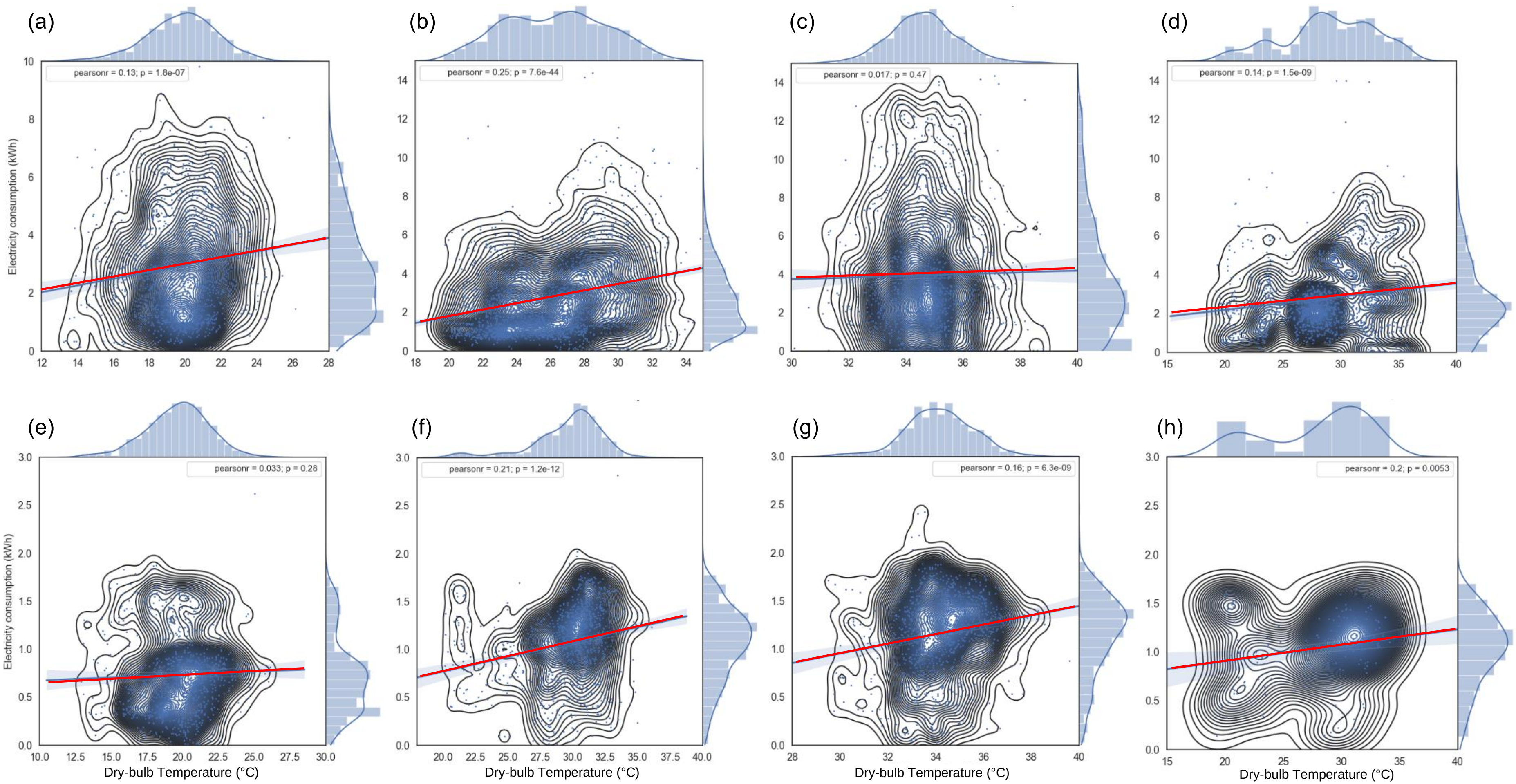

Figure C-41. Pearson correlation of energy use from NG and CG vs DBT in kitchen in different seasons of H1 case study: (a-d) the correlation of energy use from NG vs DBT in kitchen in different seasons of H1, (e-h) the correlation of energy use from CG vs DBT in kitchen in different seasons of H1.

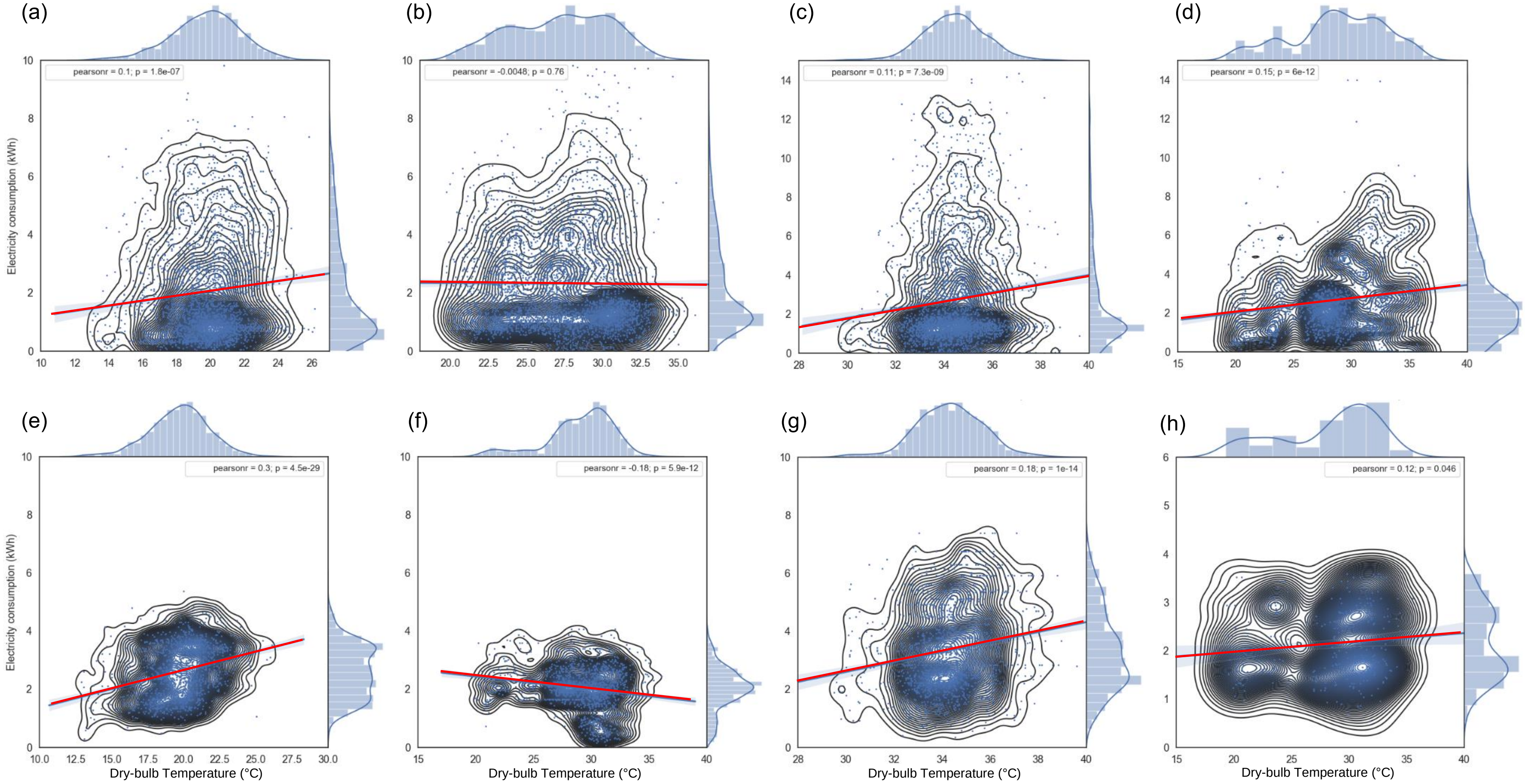

Figure C-42. Pearson correlation of the total energy use and suppressed demand vs DBT in kitchen in different seasons of H1 case study: (a-d) the correlation of the total energy use vs DBT in kitchen in different seasons of H1, (e-h) the correlation of suppressed energy demand vs DBT in kitchen in different seasons of H1.

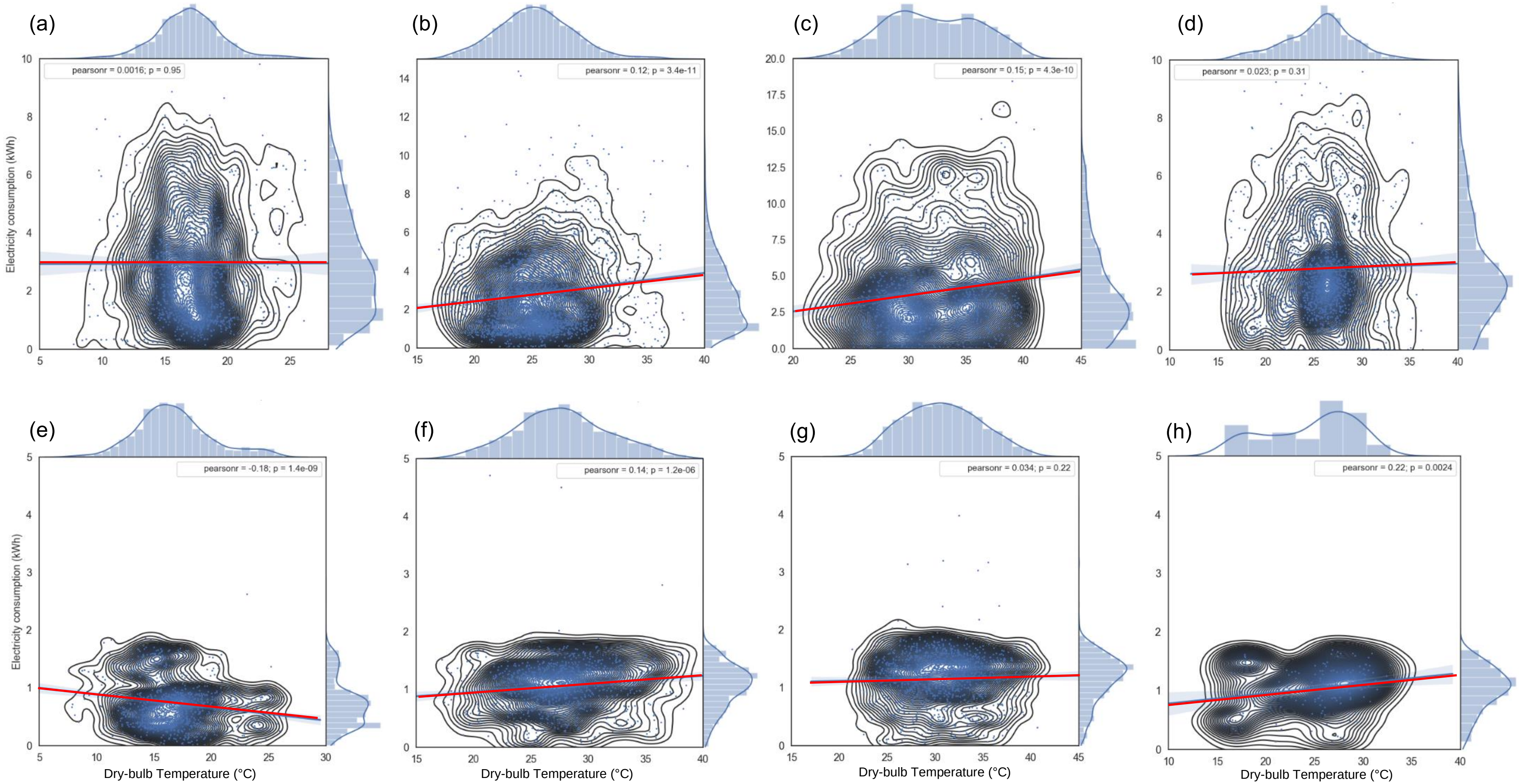

Figure C-43. Pearson correlation of energy use from NG and CG vs DBT in bedroom in different seasons of H1 case study: (a-d) the correlation of energy use from NG vs DBT in bedroom in different seasons of H1, (e-h) the correlation of energy use from CG vs DBT in bedroom in different seasons of H1.

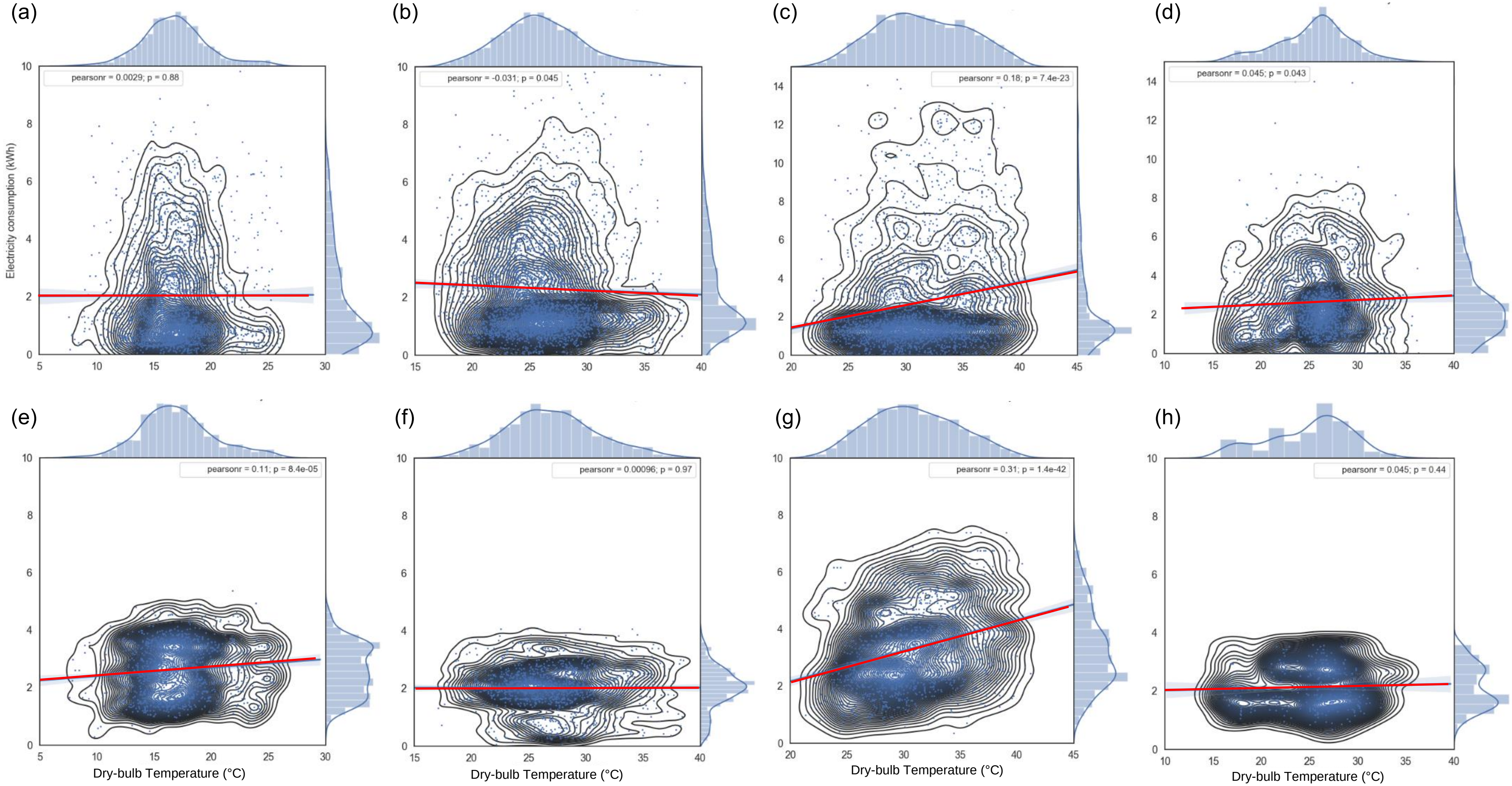

Figure C-44. Pearson correlation of the total energy use and suppressed demand vs DBT in bedroom in different seasons of H1 case study: (a-d) the correlation of the total energy use vs DBT in bedroom in different seasons of H1, (e-h) the correlation of suppressed energy demand vs DBT in bedroom in different seasons of H1.