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Energy performance in Kuwaiti villas: understanding the social and physical factors that drive energy use

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Declaration

I, Badria Nabil Jaffar, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

In Kuwait almost 60% of electrical energy is used in residential buildings and this is predicted to grow with the rapid increase in population and demand for housing. Despite the magnitude of residential energy demand, there is limited data and research reported about the Kuwaiti housing stock and its energy use. To assess the potential for efficiency improvements and demand reduction in this sector, an understanding of the factors that drive household energy use is crucial.

This thesis utilizes a mixed-method research approach to identify key physical and social drivers of energy use in Kuwaiti villas. A quantitative household survey, of 250 villas geographically stratified throughout Kuwait, was undertaken to better understand household socio-demographic characteristics, building form and fabric, space conditioning, lighting, appliances, and energy use. This was followed by a 12-month longitudinal investigation of four case study villas whose energy and internal temperatures were monitored and occupant behaviour, building fabric and appliances surveyed. This empirical data was then used in the development of energy models for each villa to help better understand energy use.

Key drivers found to impact energy use are air-conditioning thermostat set points, building size and number of occupants. While the impact of insulation and double glazing on energy use could not be determined, monitoring suggests these technologies create more uniform internal temperatures. Models grounded with empirical data suggest that space cooling accounts for 50% to 75% of total energy use, and that drivers of cooling energy demand can vary significantly between villas. The research concludes with recommendations that could potentially save considerable energy in Kuwait, such as increasing air-conditioning thermostat settings during periods of summer travel.

This thesis has collected valuable household-level energy, building and occupant data, about which little has been published, and has laid the groundwork for future evidence-based energy policy in Kuwait.

Impact Statement

This research has generated a number of findings that benefit academia and other stakeholders in the energy and residential building sector.

The thesis has shown academic impact via two peer-reviewed academic journal papers and a presentation at a conference (listed at the end of this statement). These demonstrate a novel and integrated approach towards a more empirically based examination of energy use in residential villas. In particular, the research's quantitative household survey provided a comprehensive information base about the physical and social characteristics of Kuwaiti villas on a national level, of which published data is virtually non-existent. Similarly, while many studies only collect temperature data in one or two rooms of a dwelling, the mixed-method multi-case study collected longitudinal indoor temperature data, at 20-minute intervals, in almost every room, providing greater insight into the cooling and heating of households. Another unique aspect of the multi-case study is the interactive feedback between monitoring data and occupant interview data, demonstrating the value of longitudinal studies of energy use that also incorporate a longitudinal social element.

In addition, research findings are of relevance to the Kuwaiti government that is seeking to meet the residential energy demands of a growing population while reducing carbon emissions and capital infrastructure costs for power generation. Impact on government is especially important in Kuwait as all developments in the country's energy sector are owned and controlled by government, including production, supply, and distribution of energy. Primarily findings highlight the value of an evidence-based approach to policy evaluation, particularly in the development and validation of energy models commonly used as tools to inform interventions. Findings have also supported the development of policy recommendations that could potentially save considerable energy in Kuwait, particularly at times of peak demand. These include policies that encourage higher air-conditioning thermostat settings during the summer travel period, more efficient appliances, a reduction in villa size, air-conditioning maintenance schemes, electricity tariff redesigns, and endorsement of robust national databases with empirically measured energy, building and occupant data. Such recommendations are relevant to a number of government organizations, including the Ministry of Electricity and Water, Kuwait Institute for Scientific Research, Kuwait Municipality, and the Public Authority for Housing welfare.

Research findings and recommendations are also likely to impact decisions and actions of other stakeholders including designers, engineers, contractors, material and equipment suppliers and homeowners.

A list of academic publications developed from this thesis:

Refereed Journals

- Jaffar, B., Oreszczyn, T., Raslan, R., Summerfield, A., 2018. Understanding energy demand in Kuwaiti villas: findings from a quantitative household survey. *Energy and Buildings*. 165: 379-389
- Jaffar, B., Oreszczyn, T., Raslan, R., 2019. Empirical and modelled energy performance in Kuwaiti villas: understanding the social and physical factors that influence energy use. *Energy and Buildings*. 188-189: 252-268

Refereed Conference

- Jaffar, B., Oreszczyn, T., Raslan, R., 2014. A framework to evaluate the energy efficiency potential of Kuwaiti homes. In Energy and Sustainability V conference - WIT Transactions on Ecology and The Environment. 186: 25-38

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A special thanks to my family, the source of love and strength in my life. My dear parents, thank you for inspiring in me the belief that knowledge and its pursuit has no end. My husband Ahmed, who has lived every stage of this journey with me, thank you for your endless support and encouragement.

Finally, I would like to dedicate this PhD to my beautiful children who have been my true motivation throughout these years, my key drivers: Mohammed, Nabil, Mubarak, Abdulrahman and our princess Muneerah.

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Definitions

Building energy modelling is the computerized simulation of a building to explore, predict and quantitatively assess its energy consumption and performance.

Building energy performance is the amount of energy consumed or estimated as necessary to meet the various needs associated with a standard use of a building.

Building simulation is the use of a computer to build a virtual reproduction of a building.

Coefficient of performance (COP) in Simergy (the energy modelling program used in this research) is the ratio of the gross total cooling capacity to electrical power input (in watts) of the DX cooling coil unit at rated conditions. Simergy assumes a varied COP with external temperature based on inbuilt performance curves.

Cross-sectional refers to data obtained at one point in time.

Energy Conservation Code of Practice for Buildings is a mandatory energy conservation code applicable to all new and renovated buildings in Kuwait. The code was developed by the Kuwait Institute for Scientific Research for the Ministry of Electricity and Water in 1983 (updated in 2010 and 2014).

Energy Efficiency is the use of less energy to achieve the same level of output (of performance, service, goods or energy).

Energy Security is the ability to ensure adequate, affordable and continuous energy resources to meet national energy requirements.

Glazing ratio is the window-to-wall ratio measured by dividing a buildings total glazed area by the exterior envelope wall area.

Government villas in Kuwait are detached two floor houses designed and built by the Public Authority for Housing Welfare (the agency responsible for setting and implementing national housing policies).

Longitudinal refers to data obtained over a period of time.

Modelling is the process of developing a model that closely represents a complex system.

One-way ANOVA is a one-way analysis of variance used to determine statistically significant differences between the means of two or more groups.

Pearson's R is a correlation coefficient measuring the linear correlation between two continuous (numeric) variables.

Pre-1983 code villas are villas in Kuwait built before enforcement of the 1983 Energy Conservation Code of Practice for Buildings.

Post-1983 code villas are villas in Kuwait built after enforcement of the 1983 Energy Conservation Code of Practice for Buildings.

Private villas in Kuwait are detached two to three floor houses (with or without a basement) designed and built by the homeowner. Such villas are often partly financed by the Public Authority for Housing Welfare.

Regression analysis is a statistical method for examining the relationship between a dependent variable and one or more independent variables.

Simergy is a building energy modelling program that incorporates detailed information about building systems, internal loads and schedules, building site and climate.

Spearman's Rho is a correlation coefficient measuring the monotonic relationship between two continuous (numeric) and ordinal (categorical rank order) variables.

Abbreviations and Symbols

Abbreviations

AC	Air-conditioning
CO-OP	Cooperative society complexes in Kuwait
COP	Coefficient of performance of AC units
CPDP	Co-generation Power Desalinating Plant
EFUS	Energy Follow Up Survey. This is a UK Survey collecting data on household and dwelling energy use, prepared by the Building Research Establishment (BRE) and published by the Department of Energy & Climate Change, now the Department for Business, Energy and Industrial Strategy
EIA	Energy Information Administration
GDP at PPP	Gross domestic product at purchasing power parity rate (an exchange-rate-adjusted unit of money to show the comparative value of money in different countries)
INDC	Intended Nationally Determined Contributions
KCBS	Kuwait Central Statistical Bureau
KEO	Kuwait Energy Outlook
KIA	Kuwait International Airport weather station
KISR	Kuwait Institute for Scientific Research
KM	Kuwait Municipality
KMC	Kuwait Meteorological Center
MEW	Ministry of Electricity and Water (Kuwait)
OBG	Oxford Business Group
OAPEC	The Organization of Arab Petroleum Exporting Countries
PACI	Public Authority for Civil Information (Kuwait)
PAHW	Public Authority for Housing Welfare (Kuwait)
WHO	World Health Organization
1983 code	The 1983 Energy Conservation Code of Practice for Building (Kuwait)

Statistical Symbols

R^2	A statistical measure indicating the proportion of variance for a dependent variable that is explained by independent variables in a regression model. Values range between 0 to 1 and are often stated as a percentage between 0-100%.
Adjusted R^2	A modified version of R^2 that has been adjusted for the number of predictors (independent variables) in a regression model. It is always lower than the R^2.
n	The sample size
z	Standard error with the chosen level of confidence
p	Estimated percent in the population
e	Acceptable sample error
+ T	The difference between external and internal temperatures at a given time, degrees C

Currency Symbols

KWD	Kuwait Dinar (one KWD is subdivided into 1,000 fils)
$	United States Dollar
£	United Kingdom Pound Sterling

Chapter 1: Introduction

This chapter provides an introduction to a study that seeks to identify and understand the key physical and social drivers of energy use in Kuwaiti villas. It begins by presenting the rational for the study, before defining the research aim, question, and objectives. The limitations and boundaries of the research are then noted, and the main structure of the thesis is outlined.

1.1 Background & rational

Residential energy use in Kuwait accounts for almost 60% of national electrical power generated (MEW 2018). This presents a major challenge for security of the electricity supply, especially with Kuwait's population and demand for housing growing (Alotaibi 2011; Alshalfan 2013; Wood & Alsayegh 2014). Over the next 20 years, the Kuwaiti government plans to construct 250,000 new residential units, largely in the form of detached single-family villas (KEO 2019). This is almost double the number of villas built over the past 70 years (PAHW 2018). While such plans are necessary to meet the housing demands of a rapidly growing population, they will require substantial electricity production. This is particularly challenging as power generation is largely oil-based and rising electricity demand will increasingly undermine the country's hydrocarbon export capacity and national income (Wood & Alsayegh 2014).

Kuwait is one of the world's top ten oil producers and relies almost entirely on oil for its economy; the oil sector alone accounts for 90% of the country's export revenues and 90% of government income (KEO 2019). Today, in addition to rising electricity demand, the country is facing an increasingly challenging energy world characterised by oil-price volatility and a global transition towards decarbonisation and renewable energy resources (Shehabi 2020). Since 2014, Kuwait has seen growing annul budgetary deficits as oil export revenues have fallen while government spending, a large share of which is allocated towards welfare benefits including subsidised energy and housing, has increased (Shehabi 2020). In particular, the energy subsidy programme currently endorses about 95% of the cost of electricity to residential consumers, with heavily subsidised tariffs (that have remained unchanged for over 55 years) leading to unconstrained energy practices and an intrinsic demand for large, centrally air-conditioned homes (Wood & Alsayegh 2014; Krane 2013; Al-

Mumin 2003). In light of a more uncertain economic and energy future however, reducing residential electricity use in Kuwait is essential and can potentially reduce expenditure for new power generation, energy subsidy costs, fossil fuel usage and carbon emissions.

To effectively plan and implement energy efficiency policy interventions to control residential consumption a thorough understanding of the factors that drive household energy use is needed (Howden-Chapman et al. 2009; Kavousian et al. 2013; Huebner et al. 2015). In Kuwait however, very limited data and research is available about the housing stock, its fabric, energy consuming equipment, the disaggregation of energy use, and occupants demand for services. Residential energy demand research has largely been based on energy modelling which has had little empirical grounding; estimating changes in energy consumption through simulating the impact of different interventions (Al-Ragom 2003; Sadek et al. 2006; Al-ajmi & Hanby 2008; Assem & Al-Ragom 2009; Krarti & Hajiah 2011; Cerezo et al. 2015; Krarti 2015; Ameer & Krarti 2016; De Wolf et al. 2017). To date, there does not appear to be a published study collecting and examining empirical household-level building and energy use data, and no larger survey describing the composition of the national housing stock, dwelling sizes, fabric characteristics, building services, appliances and energy use. Similarly, although a mandatory Energy Conservation Code of Practice for Buildings has been enforced in Kuwait since 1983 there is very little evidence of its impact in practice (Maheshwari et al. 2009; Wood & Alsayegh 2014).

To better assess the potential for efficiency improvements and demand reduction in Kuwait's residential sector, this research investigated both the physical and social related aspects of energy use in Kuwaiti villas. It focused on villas as they are the main housing type for Kuwaiti nationals and constitute the bulk of previous and future government housing projects (KCSB 2013; OBG 2015). Research was carried out in three stages: 1) cross-sectional quantitative household survey, 2) longitudinal mixed-method multi-case study and 3) building energy modelling. A cross-sectional household survey, of 250 villas geographically stratified throughout the six districts of Kuwait, was first undertaken to gather information about household socio-demographic characteristics, building form and fabric characteristics, space conditioning, lighting, appliances, and energy use. This was followed by a 12-month longitudinal investigation of four different case study villas that included monitoring of energy and internal temperature as well as surveying of occupant behaviours, building fabric and systems. Empirical monitored and surveyed data was then combined and used to support the development of energy models of each case study villa to better understand energy use and inform policy.

Throughout this thesis, the term 'energy' is used to refer to metered energy (i.e. electricity). This is because energy use for cooling, heating, lighting, appliances and hot water in Kuwaiti villas is in the form of electricity. For cooking, while many properties traditionally use gas (in the form of propane 12kg cylinders), use of electric ovens and stoves is increasing (Jaffar et al. 2018).

1.2 Research aim, question and objectives

The research aims to determine the importance of social and physical drivers of energy use in Kuwaiti villas to enable more informed analysis of the potential for different energy efficiency interventions. The research question is as follows:

"What are the key physical and social drivers of energy use in Kuwaiti villas?"

Sub-research questions to address underlying elements of this question are:

- How does energy use vary across seasons in different villas?
- Do better insulated villas consume less energy and are they more uniform in their internal temperatures?
- Do villas with a larger internal floor area consume more energy than smaller villas?
- Do villas with more occupants consume more energy than villas with fewer occupants?
- Do households with a higher income consume more energy than those with a lower income?
- What occupant behaviours affect energy use in villas and how?
- Why do occupants control their energy using systems and appliances in the ways they do?
- Are there variations between actual and reported occupant behaviors and perceptions?

The objectives of the study are to:

1. Develop a comprehensive understanding of the physical and social characteristics of Kuwaiti villas on a national level.
2. Monitor energy use and internal temperature and survey social and physical building components in a number of case study villas over a period of one year.
3. Develop energy models grounded with empirical monitored and surveyed data.
4. Determine the relative importance of different physical and social drivers identified and provide recommendations to inform energy and buildings policy.

1.3 Limitations and boundaries of the study

The limitations of a study are aspects that influence a research design or methodology that a researcher cannot control (Simon 2011). Such aspects pose restrictions on the interpretation of results and the extent to which they can be generalized.

Limitations of this study include:

- Difficulty in finding a large number of villas and households willing to participate and collaborate as part of the longitudinal multi-case study due to the sensitive socio-cultural environment and concern associated with monitoring private residences in the region.
- Risk of inappropriate handling of monitoring devices by some household occupants (i.e. kids, household staff)
- A tragedy or occurrence (death, injury, prolonged travel) within a household that negatively effects the progression of monitoring.

Boundaries (or delimitations) of a study are those set by a researcher to control the scope of an investigation. Such boundaries are established based on the intentional inclusion and exclusion of certain characteristics in a study made while developing a research proposal and undertaking the literature review (Simon 2011).In this research the following boundaries were defined:

- Considering both published and grey literature, the dwelling type selected for examination is the single family villa (government and private). While there may be a greater number of flats (as a unit mainly housing the expatriate population), villas account for about 82% of residential electricity use (MEW 2014) , are the main housing type for Kuwaiti nationals (housing 80% of Kuwaitis - KCBS 2013), and constitute the bulk of current and future PAHW (Public Authority for Housing Welfare) housing projects as detailed in section 2.4.
- Given the novelty of the research approach in the region as well as cultural restrictions regarding assess to homes and willingness to share data, a decision was taken to administer survey questionnaires (for the quantitative household survey) at residential cooperative society complexes (co-op's) within different residential neighborhoods throughout Kuwait rather than at individual villa addresses. The rational for this decision is discussed in Section 5.1.2.
- In defining the number of case study villas to examine, the physical size of the building was considered. This is because Kuwaiti villas are large with multiple rooms, which required the sourcing of an adequate number of monitoring devices (to be available for a period of one year).

1.4 Research structure

Chapter 1 - Introduction

Chapter 1 discusses the background to the research and rational for the study. The research aim, question and objectives are identified, along with an overview of the research chapters.

Chapter 2 – Residential energy consumption in Kuwait

Chapter 2 provides a background about Kuwait, its geographical context, population, and energy production and consumption profile. It begins by describing the magnitude of energy use by the country's residential building sector. Causes and concerns of rising residential energy demand are then discussed, and current policy interventions designed to control demand are reviewed. Finally, the chapter highlights the lack of data and research into the Kuwaiti housing stock, and the need for empirical data to better understand energy use and inform policy in this field.

Chapter 3 – Drivers of residential energy use

Chapter 3 provides an overview of residential energy demand research undertaken worldwide that has sought to understand the sector's energy use profile and the determinants that influence this. It begins by describing the characteristics of the residential building sector before discussing key drivers of energy use reported by various residential energy demand researchers. Implications of the prevalent positivist experimental approach adopted within the field are noted, and the recent interest in human-centered aspects of energy and evidence-based empirical data are highlighted.

Chapter 4 – Research Methodology

Chapter 4 presents the methodological framework of this research and the methods of data collection used. The research follows the philosophical foundations of pragmatism in which mixed methods are combined to link judgment and analysis, and provide multiple perspectives to address the research question and objectives. Data is collected using three different strategies: 1) cross-sectional quantitative household survey, and 2) longitudinal mixed method multi-case study, and 3) building energy modelling. Each is described briefly including what elements were measured and how, and the data analysis procedures used. The chapter also presents the process of piloting the methods and describes the ethical and cultural concerns addressed prior to data collection.

Chapter 5- Cross-sectional household survey

Chapter 5 begins by describing the survey methodology, including the survey questionnaire, the sample selection process, and the data analysis methods used. Survey results are then analysed, both descriptively and through multiple linear regression, and key findings are drawn.

Chapter 6- Longitudinal case study monitoring and surveying

Chapter 6 begins by presenting the monitoring and surveying data collection framework, the case study sampling strategy and the data analysis process used. Quantitative and qualitative data collected from each case study villa is then examined and compared and key findings are drawn.

Chapter 7- Building energy modelling

Chapter 7 begins by describing the methodology adopted in the development of energy models for each case study villa. Modelling results are then analysed by comparing simulated and measured energy consumption, examining modelled end-use energy breakdowns, and through a differential sensitivity analysis to assess the impact of various factors on energy use.

Chapter 8: Discussion

Chapter 8 provides a discussion of results from the quantitative household survey, longitudinal mixed method multi-case study and energy modelling (reported in Chapters 5,6 and 7). Results are discussed through the use of the triangulation method and findings are examined in light of other studies including those mentioned in the literature review in Chapters 2 and 3. Implications of the research findings for policy are also discussed.

Chapter 9- Conclusions, recommendations and future research

Chapter 9 highlights the main conclusions of this research and presents its original contributions to knowledge. The chapter also presents research recommendations and suggestions for further research.

Chapter 2: Residential Energy Consumption in Kuwait

This chapter provides an overview of residential energy demand in Kuwait. It begins with background information about Kuwait's climate, population and energy production and consumption dynamics. The magnitude of residential energy demand is then described and key factors contributing to this are discussed. The chapter highlights the significant lack of empirical data available about the country's housing stock and its energy use, and presents some grey, unpublished literature accessed by the researcher to better understand the sector.

2.1 The context of Kuwait

The state of Kuwait is located in the north east corner of the Arabian Peninsula. It has a total land area of 17,818 km², of which only 8% is inhabited (KEO 2019) - Figure 2.1. The country has a subtropical hot and dry desert climate, with long summers and short winters (Figure 2.2). The current population is 4.5 million (m); 1.3m (32%) are Kuwaiti nationals and 3.2m (68%) expatriates (PACI 2018), of which 21% are domestic staff in Kuwaiti households. Primary natural resources in Kuwait include crude oil and natural gas, which account for about 6% (101 billion barrels) and 0.9% (63trn cu ft) of the world's proven reserves (EIA, 2016). The country has a gross domestic product (GDP) at purchasing power parity (PPP) per capita of $67,000 in 2018, among the highest in the world (IMF 2019).

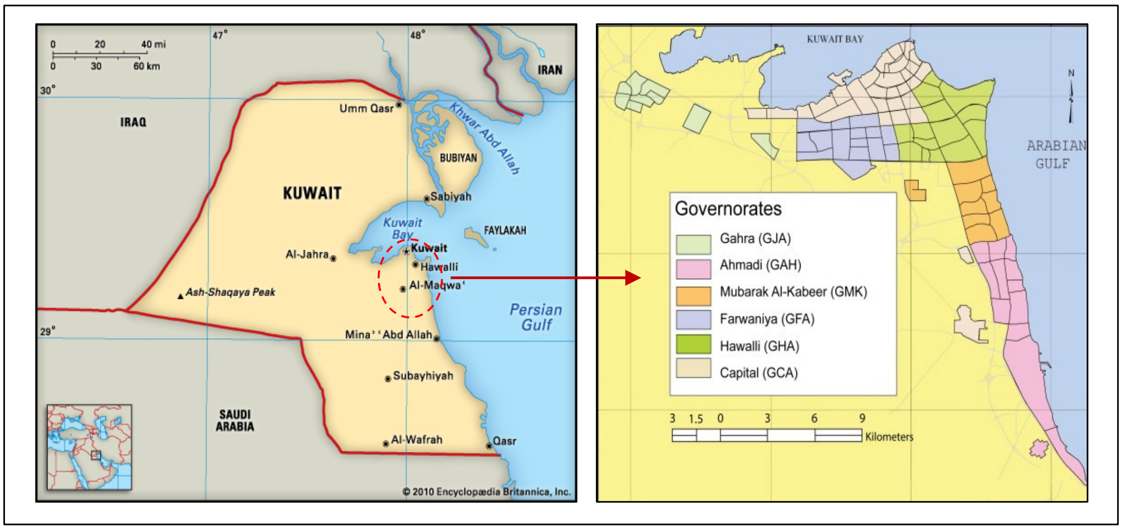


Figure 2.1: Map of Kuwait

Source: Encyclopedia Britannica, 2010

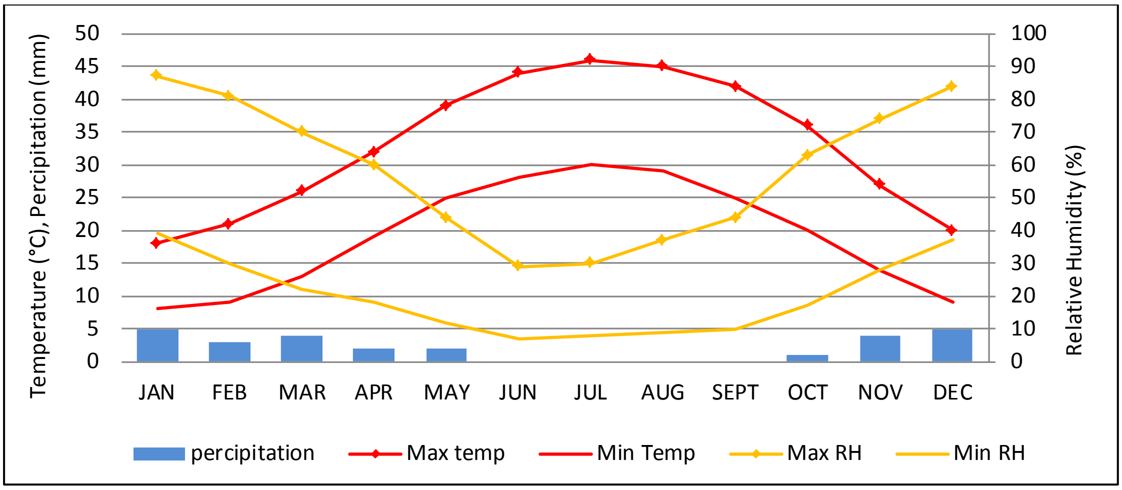


Figure 2.2: Kuwait climate information

Source: Average daily data collected from Kuwait Metrological Center covering the period between 1962-2014 (KMC n.d)

Today Kuwait depends on its abundant hydrocarbon resources both as a source of national income and for its domestic energy requirements (Alotaibi 2011). The oil sector alone accounts for up to 90% of the country's export revenues and 90% of government income (KEO 2019). In 2017, primary energy consumption accounted for nearly 25% of the country's total oil and gas production (OAPEC 2017), and per capita, primary energy consumption is amongst the highest in the world (Figure 2.3). Per capita carbon dioxide (CO_2) emissions are also amongst the highest in the world amounting to 25.2 Mt of CO_2 in 2014 (World Bank 2014). Although Kuwait has ratified the Paris Climate Agreement in April 2018, no explicit carbon emission reduction targets were submitted as part of its Intended Nationally Determined Contributions (INDC) (INDC – Kuwait, 2015), indicating, in part, the country's strong dependence and reliance on high-carbon fossil fuels (Tobin et al. 2018).

Rising energy consumption is increasingly undermining the country's export capacity and presenting complex energy security challenges (Alotaibi 2011; Wood & Alsayegh 2014; Alsayegh et al. 2018). This is alarming as some concerns about Kuwait's physical oil production capacity (oil fields are over 60 years old and aging) and increasing volatility in international oil prices (due, in part, to increases in hydrocarbon production from unconventional shale resources in North America) have been raised in recent years (Krane 2013; Alotaibi 2011; OBG 2017). Brent crude prices for example, fell from an average of $100 per barrel in 2011-2014 to as low as $28 in January 2016, significantly reducing the country's oil export revenue from $119 billion in 2012 to $40 billion in 2015 (OBG 2017).

Figure 2.4 presents the flow of energy produced, exported and consumed in Kuwait. The power generation sector accounts for the bulk of domestic fuel consumption (55%), and the residential building sector consumed the highest share of national electricity generated (60%). Electricity is the main fuel used for residential energy end-uses including space cooling and heating, water heating, lighting and appliances. Although no published empirical data exists on electricity use in residential buildings disaggregated by end use, modelled and anecdotal data estimate that 60% to 70% of total annual electricity use is due to AC cooling (Al-Qudsi 1989; Almutairi 2012).

Until very recently, the electricity system in Kuwait was fully owned and operated by the Ministry of Electricity and Water (MEW) as the sole body responsible for planning, generating, transmitting and distributing electric power (Al-Shalabi et al. 2013). To support the rapidly growing demand for electricity and water, opportunities for private sector involvement emerged through public-private partnerships (PPP), with the Al-Zour North One being the country's first PPP plant that began operating in December 2016 (KEO 2019). Under this PPP model, the government transfers its responsibility for building and operating generation facilities but retains responsibility for regulation, and purchasing electricity generated from the PPP plant for 40 years (KEO 2019).

Today there are nine co-generation power desalting (CPDP) plants providing both electricity and freshwater, with an installed capacity of 18,743 MW (MEW 2018). Peak demand, which occurs during the summer months where daily average temperatures often exceed 40°C, was 13,800MW in 2017 (MEW 2018). Over the past 10 years, peak demand increased by an average annual rate of 4.3% (Table 2.1). The government expects current installed capacity (18.7 GW) to reach 32.0 GW by 2035, with 70% of this attributed to new residential construction (KEO 2019, Soares et al. 2017).This is particularly problematic and challenging, requiring both the building of more power plants and the sourcing of ample quantities of fuel to operate them - especially as power generation is primarily oil-based (Oxford Business Group 2012).

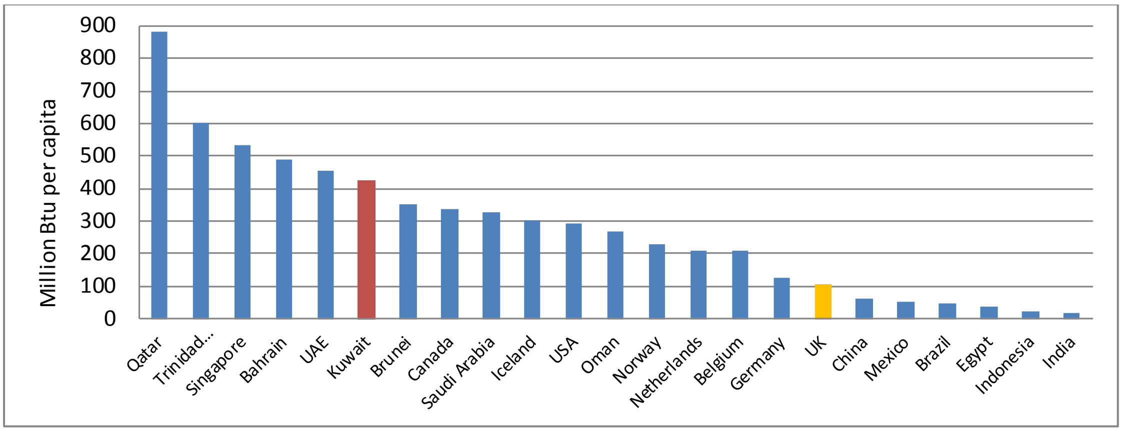


Figure 2.3: Primary energy consumption per capita, 2014

Source: EIA, 2015

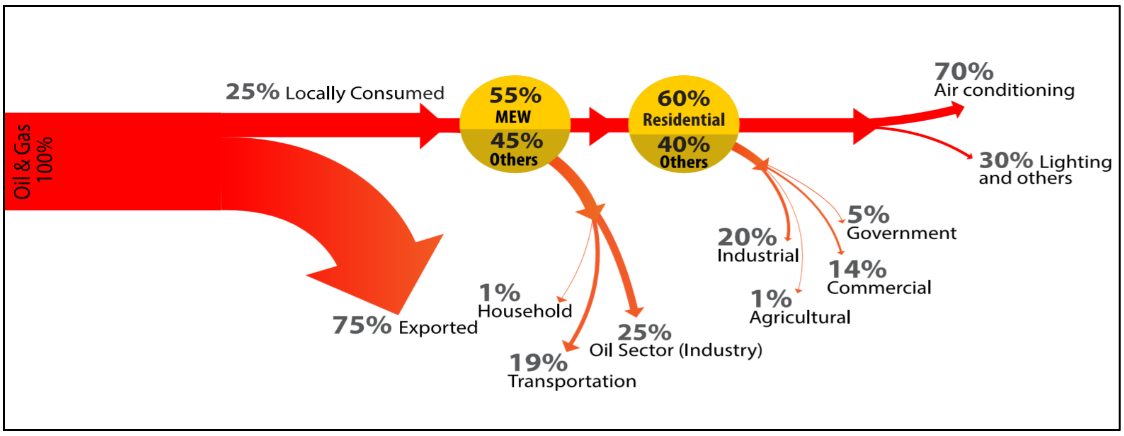


Figure 2.4: The flow of energy produced, exported and consumed in Kuwait, 2012
Source: Author generated based on data from (MOO 2012; MEW 2012; OAPEC 2017; MEW 2018; Al-Qudsi 1989; Almutairi 2012)

Table 2.1: Increase in peak electricity demand and per capita electricity consumption relative to installed capacity (1987-2017)

	Installed capacity (MW)	Peak demand (MW)	Annual rate of growth in peak demand (10 year average)	Electricity consumption per capita (kWh/person)	Annual rate of growth in per capita consumption (10 year average)
1987	6696	3740	-	8054	-
1997	6898	5360	5.2%	12442	4.4%
2007	10481	9070	5.4%	12527	0.3%
2017	18743	13800	4.3%	14413	1.5%

Source: MEW, 2018

2.2 Factors contributing to rising residential electricity demand in Kuwait

Following the discovery of oil in Kuwait in 1938, the state entered an exceptional period of economic development and wealth that significantly impacted the residential building sector and its energy use (Alotaibi 2011). According to the Public Authority for Civil Information's (PACI) Housing and Building Statistics, there are a total of 202,377 buildings across Kuwait, of which residential buildings represent a significant portion, about 70% (PACI 2018).

High and rising residential electricity demand in Kuwait is due to a combination of factors including the government's generous welfare and energy subsidy program, a rapid growth in the population – with an average annual growth rate of 3.1% over the past 10 years (PACI 2018) - municipality building codes progressively allowing for increases in villa sizes (in 1996, 2002, and 2012), and the country's harsh summer climatic conditions with average temperatures of 38°C, and maximum temperatures in excess of 50°C (Al-Munim et al. 2003; Hertog & Luciani 2009; Alotaibi 2011; Wood & Alsayegh 2014). The energy subsidy programme facilitates high energy-use consumer behaviour and the air conditioning of large homes designed with little consideration of energy efficiency (Al-Munim et al. 2003; Hertog & Luciani 2009; Krane 2013). First set up in 1962, this programme currently subsidises 95% of the cost of energy to the final consumer. Residential consumers are charged a rate of KWD 0.002/kWh (equivalent to $0.01 at the time of writing) of the electricity generation cost of KWD 0.047/kWh (equivalent to $0.16), and this rate (charged to consumers) has remained unchanged for over 50 years (Wood & Alsayegh 2014). Negative impacts of recent oil price volatility on the country's revenue however have driven the government to initiate some reform of energy subsidies; in May 2017 a new law was enacted that reduced subsidies for expatriates to KWD 0.015 /kWh, but excluded locals and villas (Alsayegh et al 2018).

Similarly, Kuwait's high annual population growth rate has resulted in an increased demand for housing, which has translated directly into an increased demand for energy (Wood & Alsayegh 2014). In 2016 a total of 103,000 Kuwaiti families were on the government waiting list for housing (OBG 2017) and consequently, in its latest National Development Plan (2015-2020) the government set out its goal to establish six new residential cities providing more than 45,000 new housing units by 2020 (OBG 2017). Although such projects are essential to meet the demands of a rapidly growing population, they will require significant additional production of electricity.

2.3 Energy related interventions undertaken in Kuwait

To ensure long term reliability and security of any nation's energy supply, governments can adopt measures that broadly fall under two categories: Supply-side management measures and demand-side management measures (Alotaibi 2011; Al-Shalabi et al. 2013). Examples of the former include the use of renewable energy sources, while examples of the latter include energy efficiency codes, energy tariff reforms, and other initiatives that modify end-users demand for energy.

With regards to renewable energy sources, the Kuwaiti government announced in 2011 its aim to produce 15% of national electricity from solar and wind by 2030. While no roadmap or framework has been published to indicate how this would be achieved, it is estimated that 4.32GW capacity is required to meet the 2030 target (OBG 2017). Although progress has been made in recent years, current renewable installed capacity does not exceed 70MW (OBG 2017). There are currently no plans for Kuwait to generate nuclear power as its programme was abruptly cancelled in 2011 following the Fukushima Daiichi nuclear accident in Japan in March 2011 (Al-Shalabi et al., 2013). In the near and mid-term future oil and gas continue to be the major primary energy sources in Kuwait, with focus largely being placed on expansion and development of conventional production (OBG 2017).

With regards to demand-side management, the Kuwaiti government has largely focused on initiatives with lower political impact such as building code development and awareness campaigns, rather than electricity tariff reform (Hertog and Luciani 2009; Al-Shalabi et al. 2013; Krane 2013). In 1983 a mandatory Energy Conservation Code of Practice (hereafter referred to as the 1983 code), applicable to all new and renovated buildings was developed by the Kuwait Institute for Scientific Research (KISR) for the MEW. KISR is a government funded institution concerned with oil, energy, water and environment research. The 1983 code stipulates minimum thermal insulation requirements for walls, roof, columns and glazing as well as peak power guidelines for air-conditioning units (MEW 1983). While researchers at KISR estimate that a building constructed in full compliance with the 1983 code requires 40% less cooling (Maheshwari et al. 2009), in practice, little evidence of the code's impact exists (Maheshwari et al. 2009; Wood & Alsayegh 2014). The 1983 code was updated in 2010, and again in 2014, to allow for more stringent guidelines (refer to Appendix A for a comparative summary of the features of the 1983 code and its revisions).

2.4 The residential building stock in Kuwait

The Kuwaiti residential building stock consists primarily of large villas and smaller flats in mid to high-rise apartment buildings (Table 2.2). More than 80% of Kuwaiti nationals live in villas (KCBS 2013) of which there are two main types: government and private. In Kuwait, villas are detached, two to three floor single-family houses. Government villas are designed and built by the Public Authority for Housing Welfare (PAHW – the agency responsible for setting and implementing national housing policies), while private villas are often partly financed by the PHAW but commissioned by the homeowner. A description of typical villa building characteristics including sizes is presented in Table 2.5. Mid-high rise apartment buildings largely house the expatriate population, which reside in Kuwait on a temporary basis and are not normally allowed to own property.

To illustrate the development and evolution of the housing stock, the number of different dwellings based on year of build and various events that have impacted the built environment were mapped on a timeline (Appendix B). Such events include modifications in Kuwait Municipality building codes (1996, 2000 and 2002 to increase floor area), the MEW's energy conservation code and its revisions (1983, 2010 and 2014) and changes to the national housing welfare scheme by the Public Authority for Housing Welfare.

Table 2.2: Number of residential dwellings by type in Kuwait

<table>
<tr><th colspan="2">Villas</th><th rowspan="2">Apartment blocks</th><th colspan="2">Flats within apartment blocks</th><th rowspan="2">courtyard houses</th><th rowspan="2">Palaces</th></tr>
<tr><th>Government</th><th>Private</th><th>Government</th><th>Private</th></tr>
<tr><td>56,536</td><td>49,228</td><td rowspan="2">10669</td><td>1088</td><td>169,727</td><td rowspan="2">20,984</td><td rowspan="2">47</td></tr>
<tr><td colspan="2">105,764</td><td colspan="2">170,815</td></tr>
</table>

Source: (PACI 2013)

Note: Table 2.2 presents data collected by the researcher from PACI in 2014, which was subsequently used in the sampling of the household survey undertaken as part of this research fieldwork in March 2015.

2.4.1 Building codes

Building codes are a set of regulations adopted to regulate the design and construction of buildings (Mahgoub 2002). Such regulations govern elements such as a building’s size, layout, structure, fire protection, energy use, acoustics and construction. In Kuwait different elements of a building’s design and construction are governed by different agencies, and no one unified building code currently exists (Al-Khait 2012).

Kuwait Municipality (KM), established in 1930, is responsible for building regulations that control the size and volume of buildings including guidelines for setbacks, floor areas, height, zoning and layout. The first set of consistent regulations by KM was issued in 1962, following independence of Kuwait in 1961. In 1985, more cohesive and integral building regulations in the form of a set of specifications were made official for all types of buildings including residential dwellings. This code was later modified in 1996 and again in 2000 and 2002 primarily to enlarge villa volumes and floor areas to allow for the accommodation of larger family sizes (Mahgoub 2002).

With regards to the structural design of residential buildings, a unified code for the design and construction of concrete structures was only recently (in 2012) adopted as an official code (Al-Khait 2012). Prior to this, the structural engineer was responsible for selecting any approved foreign code for specifying loads and designing structural members (Sadek et al. 2006; Al-Khait 2012)

Energy conservation measures were introduced into the built environment in 1983, through the 1983 energy code developed by KISR for the MEW (MEW 2010). As noted in Section 2.3 (and detailed further in Appendix A), this code requires all new or older properties undergoing renovation to incorporate minimum thermal insulation requirements for walls and roofs, and sets guidelines for the size and quality of glazing, fresh air requirements, and maximum allowable power limits for air-conditioning systems and lighting systems.

2.4.2 Housing stock characteristics and data collection challenges

With regards to specific characteristics of the Kuwaiti housing stock and its energy use, a review of the literature found there is little organised and coherent empirical data available. No detailed household survey describing characteristics of the national housing stock including dwelling sizes, building services, number and type of appliances, thermal performance, and energy use, has been undertaken. Building census data from various government agencies such as PACI and building archival records from Kuwait's Central Statistical Bureau (KCSB) provide only limited information about dwelling type, count and year of build.

Similarly, while there have been many important studies undertaken about the performance of residential villas in Kuwait and their energy efficiency potential (Al-Ragom 2003; Sadek et al. 2006; Al-ajmi & Hanby 2008; Assem & Al-Ragom 2009; Krarti & Hajiah 2011; Cerezo et al. 2015; Krarti 2015; Ameer & Krarti 2016; De Wolf et al. 2017) this research has largely been based on energy modelling with limited empirical grounding. A recent study by Ameer and Krarti (2016) for example develops a base case energy model for a prototypical Kuwaiti villa and undertakes a series of analyses to determine the impact of energy efficiency measures. Al Ragom (2013) also uses energy modelling to develop various retrofitting cases that represent potential retrofitting scenarios, concluding that substantial energy savings can be achieved at the national level when implementation costs are supported by the government. Published studies based on empirical data about residential buildings and their occupants however are limited (Al-Mumin et al. 2003; Al-ajmi & Loveday 2010). A study by Al-Mumin et al. (2003), provides occupancy, appliance and lighting use data collected from a sample of 30 villas, but does not measure energy use or describe physical features of surveyed villas. Similarly, a field study by Alajmi and Loveday (2010) while collecting useful information about indoor environmental conditions and occupants' thermal comfort provides no energy, building or occupant behaviour data.

To better understand the housing stock and its energy use and better define the area of focus for this study the researcher sought to access grey unpublished literature sources. This included raw energy data from the MEW, conference proceedings, technical reports from KISR, and key informant interviews. Key informant interviews were particularly useful and were undertaken with three experts in the energy and housing sector. Table 2.3 summarizes the type of data collected from each expert, and Figure 2.5 and Tables 2.4-2.5 present this information. An expert is largely defined as an individual with a high level of skill, experience and knowledge of a particular field, system or process, and generally has exclusive access to information (Bogner et al. 2009). The purpose of the interviews was exploratory, to gather information that was unavailable or outdated in the published literature.

For example, as no data regarding the housing stock's overall energy consumption was available, the researcher met a key professional at the MEW to obtain and tabulate such data; this included annual energy data from a sample of 53,000 villas and 96,000 flats in 2009, about half the stock of villas and flats at the time. From this data, it was found that villas account for a significantly greater share of residential energy use (about 82%) compared to flats (MEW 2014), and that the average villa consumes about 7 times more energy than the average flat per year (Figure 2.5). Surprisingly, Figure 2.5 also indicates that Kuwaiti villas have a similar energy use per unit of floor area to the UK but much higher energy use. This suggests that the high energy consumption in Kuwaiti villas compared to the UK is mainly a function of the size of villas (about 6 times larger than the average UK home) and not their efficiency or the extreme climate. While this may at first seem surprising, the average temperature difference between outside and inside during heating season in the UK is about 16°C (assuming an internal of 20°C and an external of 4°C) and the average cooling season difference in Kuwait is about 17°C (assuming an internal temperature of 21°C and an external of 38°C). Although the fabric efficiency in Kuwait may be poor compared to the UK, the cooling system efficiency is likely to be much higher (200% to 400% efficiency) as AC coefficient of performances typically range from 2 to 4 compared to typical gas boilers in the UK (80% to 90% efficiency).

Table 2.3: A summary of the main purpose of the expert interviews

	Interviewee 1	**Interviewee 2**	**Interviewee 3**
Area of expertise	MEW	PAHW	Building technology
Purpose of interview	To obtain measured energy consumption data of villas and flats (Figure 2.5)	To obtain data about the number and size of government and private dwellings since 1960 (Table 2.4)	To obtain background data about building construction and materials (Table 2.5)

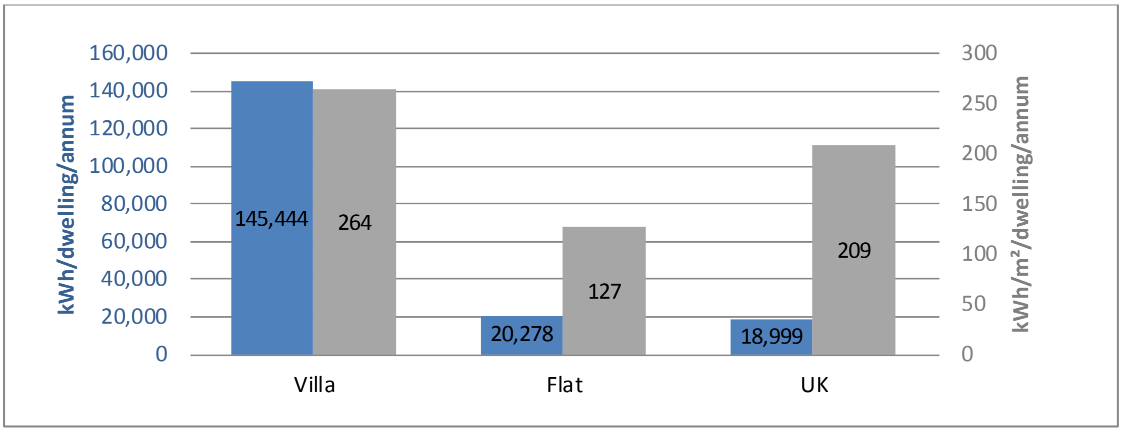


Figure 2.5: Average energy consumption by flats and villas in Kuwait, 2009

Source: Author generated based on data obtained from the MEW in 2014 (sample of 53,000 villas and 96,000 flats) and UK DECC 2013 & 2014

Note: Average kWh/m²/dwelling for villas is calculated based on an approximate floor area of 550m², and for flats 160m² (MEW 2014). Average kWh/m²/dwelling in the UK has been calculated based on an average dwelling size of 91m² (DECC 2013)

Table 2.4: Typical plot and internal floor area sizes of dwellings in Kuwait

House Type	Number of units	Approx. plot size (m²)	Approx. floor area/dwelling (m²)
Villas	**105,764**		
Government Low income housing 1967-1984	27,626	250-750	350
Government - Middle income housing 1967-1984	4,000	400-750	500
Government housing 1984 – present	24,910	400-600	400-500
Private villas	49,228	350-1,000	350-1,400
Flats	**170,815**		
Government flats 1980's	1,088	large with many flats/floor	350
Government flats - future plans	Planning stage	Low-rise with 1 flat/floor	400
Other residential flats	169,727	In excess of 400	70-250
Pre-1940s courtyard houses	**20,984**		
	-	100-150	100-150
Palaces	**47**		
	-	In excess of 1,000	> 3,000

Source: Author generated based on a data from PAHW interview

Table 2.5: A summary of common occupancy and building characteristics in Kuwaiti villas

	Description
Occupancy	The average household size (numer of occupants) in Kuwaiti villas is eight. This typically includes six Kuwaiti household members and two (expat) domestic household staff. Extended family gatherings in homes are common in Kuwait (often weekly) and as such both government and private villas are designed to have separate and multiple living rooms to accomonate such gatherings.
Building design	Government villas consist of a standard size, shape and structure, and include a number of sleeping and living spaces, including domestic staff accommodation. They are two floors in height with living and kitchen spaces on the ground floor and four to five bedrooms on the first floor (without basements). Private villas vary in design and internal layout, are typically two to three floors in height, with or without basements, fully detached with a number of sleeping and living spaces. Many private villas also have indoor/outdoor pools.
Building size	All villas are designed and constructed according to KM building codes, which set guidelines for building size, height, interior layout, and construction. Today a villa's built up area can be 210% of its plot size - a rise of 40% from 1996. Government villas tend to be samller than privately built villas, ranging between 350-500m² while private villa are 350-1400m².
Structure	Skeleton frame construction using reinforced concrete.
Walls	Two main types of exterior walls are typically used: the autoclaved aerated concrete (AAC) wall and a classical concrete block wall. The classic wall, introduced in the 1950s, initially consisted of a concrete block and cement mortar, but was later developed to incorporate thermal insulation following the MEW 1983 code. The AAC wall is a cementitious matrix made by introducing air into prepared slurry, and started to be used in the 1980's due to its thermal properties.
Roof	Flat roofs of reinforced concrete and paving tiles. Insulation used in roofs built after the MEW 1983 code.
Glazing	Windows consist of a single or double pane of 6-8mm glass. Many have over the past 15 years incorporated shutters for protection from dust and heat.

Source: Author generated based on a data from PAHW interview and building technology expert interview

Based on the review of published and grey literature, a decision was made to focus on the single-family villa (government and private) as the key dwelling type for analysis as part of this thesis. Villas account for a significantly greater portion of residential energy use compared to flats, are the main housing type for Kuwaiti nationals (KCBS 2013), and constitute the bulk of current and future PAHW housing projects (Table 2.4).

2.5 Chapter summary

- The Kuwaiti power generation sector accounts for 55% of national fuel consumption, of which 60% is consumed as electricity by residential buildings. Rising residential energy demand is undermining the country's hydrocarbon export capacity,limiting national income, and presenting electricity security challenges for government.

- Effective energy efficiency policy interventions are essential to help tackle growing residential energy demands while reducing carbon emissions and capital infrastructure costs for power generation.
- In Kuwait there is a significant lack of empirical data and research available about the housing stock, its fabric, energy consuming equipment, the disaggregation of energy use, occupants demand for services and use of energy.
- A more holistic understanding of energy use within homes (including factors that drive household energy use and their relative importance) is essential to better inform research and policy.
- The key dwelling type to be considered in this study is the single-family villa
- The high energy consumption per Kuwaiti villa compared to a UK house is attributable to the large size of these villas rather than more severe climate or less efficiency.
- Potential drivers of energy consumption, derived from a review of the literature in this chapter (and examined in the fieldwork Chatpers 5-7) include:
  - Villa size
  - Villa age
  - Fabric efficiency
  - Villa type (government and private)

Chapter 3: Drivers of Residential Energy Use

This chapter describes the main characteristics of the residential building sector and the key determinants of residential energy use on an international level. It begins by presenting the sector's energy use profile and the current state of energy efficiency policy in the field. Key physical and social drivers of residential energy use, reported by researchers worldwide, are then outlined. Finally, the need for better research to inform more effective policy and change in the sector is emphasized.

3.1 The residential building sector: energy profile and characteristics

Buildings are amongst the largest contributors to energy consumption worldwide. It is estimated that between 20% and 40% of total energy consumed globally is within the building sector including residential and commercial buildings (EIA 2018; Eurostat 2017). Residential buildings account for a large portion of this consumption: In the USA, EU and UK for example residential buildings consume approximately 20%, 26% and 28% of total final energy use compared with commercial buildings that consume 18%, 11%, and 15% respectively (EIA 2017; Eurostat 2017; BEIS 2018). Population growth, increasing demand for building services, and higher demand for comfort are among the key factors driving global residential energy consumption (Péres-Lombard et al. 2008).

Energy consumption in residential buildings is generally split into five end use groups which include: 1) space conditioning (heating and/or cooling), 2) water heating, 3) cooking, 4) lighting and 5) appliances (Swan & Ugursal 2009). Such end use groups utilise energy to satisfy household occupants' needs, which can be classified into two categories, physical and non-physical (Hong et al. 2015). Physical needs include thermal comfort (which is a combination of indoor air temperature, humidity, radiant temperature, indoor air velocity, activity level, and occupant clothing level), visual comfort (acceptable levels of glare, contrast, or brightness), acoustic comfort (acceptable range of background noise), and indoor environmental health (acceptable indoor air quality or humidity) (Hong et al. 2015). Non-physical needs include factors such as privacy or the need to maintain outside views.

From an energy perspective, researchers have noted a variety of characteristics associated specifically with the residential sector that make it particularly challenging to examine (Wei et al. 2011; Swan & Ugursal 2009; Isaac & Van Vuuren 2009; Pérez -Lombard et al. 2008; Wood & Newborough 2003; Lam 1997; Hass 1997). Wei et al. (2011) describes some of these characteristics as ‘time-variance, complexity, randomness, and regionalism’, explaining that the sector consists of dwellings designed and built in a variety of sizes, shapes, and materials, and are inhabited by occupants who behave in largely different and somewhat unpredictably ways. In describing the transient nature of residential energy consumption Wood and Newborough (2003) classify household electricity consumption as ‘predictable’, ‘moderately predictable’ and ‘unpredictable’. Predictable consumption (also referred to as base load) includes small cyclic loads or steady loads from appliances on standby, and occurs when a house is unoccupied or the occupants are asleep. Moderately predictable and unpredictable consumptions however are influenced by both occupancy and external factors such as daily and seasonal weather variations. Moderately predictable consumption is associated with occupants’ general routine behaviours (occupants in different households tend to switch off lights on weekday mornings before leaving for work), while unpredictable consumption is variable and random depending on the occupants’ own preferences (occupants may use washing machines at different times). Furthermore, another characteristic associated with the residential sector is occupant privacy and confidentiality concerns, which can frequently hinder sufficient examination of dwellings such as accessing energy data (Swan & Ugursal 2009).

3.2 The current state of energy efficiency policy in the residential building sector

The overarching aim of current energy policy is to achieve quick and profound reductions in carbon dioxide (CO_2) emissions and to ensure that the energy supply system is sustained (Oreszczyn & Lowe 2008). Energy efficiency in residential buildings has become a widely accepted element of overall energy policy ever since the first oil crisis in the 1970s (Delzendeh et al. 2017; Hong et al. 2015; Janssen 2008).. The EU Energy Efficiency Directive (2012/27/EU) broadly defines energy efficiency as “*the ratio of output of performance, service, goods or energy, to input of energy*” (page 10). When less energy is used to produce the same amount of output, energy efficiency can have wide ranging benefits including increasing energy security and reducing capital infrastructure costs for power generation at the national level, to reducing consumer bills at the individual level (Janssen 2008; Patterson 1996).

To promote an enabling environment for energy efficiency improvements in buildings and enhance motivation to adopt efficient technologies and practices a variety of policy instruments have been designed and implemented at both national and international levels (Koeppel et al. 2007; UNEP 2010). In the European Union for example, numerous directives have been created as a framework to promote building energy efficiency policies in individual member states. These include the 'Energy Performance of Buildings Directive' (2002), requiring that all buildings have an energy performance certificate, the 'Ecodesign Directive' (2005), on design requirements for energy products, and the 'Energy Efficiency Directive' (2012 and recent updates in 2016) which repealed the 'Energy Service Directive' (2006) on energy end-use efficiency requirements.

3.2.1 Energy modelling in building energy research and policy

Traditionally, energy demand research and the energy efficiency challenge have, on an international level, been defined in technical terms and studies have largely focused on a building physics approach examining the thermal performance of materials and the efficiency of heating and cooling systems (Hamilton et al. 2013 and 2017; Oreszczyn & Lowe, 2010; Wright 2008; Lutzenhiser 1992). Energy models, which consist of the computerized simulation of a building, have increasingly been used as tools in such studies, and in particular, to aid the design and evaluation of policies aimed at reducing building energy use (Summerfield et al. 2011, Kavgic et al 2010; Clarke et al 2004).

Broadly, models have been used to analyse building performance by quantifying energy consumption and providing a baseline from which to predict the impact of energy efficiency interventions (Kavgic et al. 2010). In situations where energy consumption data is missing or is not directly measured, models have also been used to provide insight into the disaggregation of energy use, quantifying where and how much energy is consumed (Al-ajmi and Hanby 2008; Hernandez et al. 2008; Duarte et al. 2018). Duarte et al. (2018) for example used energy models to provide detailed insights on end-use energy breakdowns in large commercial office buildings in Singapore that were difficult to obtain from direct building measurements. In recent years, studies have also used models to explore the impact of occupant behaviours on energy use, and especially occupant space heating behaviours including thermostat set-points and duration of heating (Love 2014; Wei et al. 2014; De Meester et al. 2013; Fabi et al. 2013; Karlsoon et al. 2007). Fabi et al. (2013) for example classified occupants into passive, medium and active users based on their frequency of adjusting thermostatic radiator valves in 13 Danish dwellings, and used energy models to investigate the impact of such behaviour on indoor environmental performance and energy consumption.

Despite their ability however, models are reliant, to varying degrees, on simplifications and assumptions that can considerably influence their output results (Summerfield et al. 2011; Kavgic et al 2010). In particular, models commonly assume standard occupant behaviour, overlooking the complex interaction between people and technology as disussed further in Section 3.2.2 below (Summerfield et al. 2011).

3.2.2 The energy performance gap and rebound effect

Broadly, the expected benefits of current energy efficiency policies have been subject to a considerable level of uncertainty and have often failed to provide relevant solutions to real and practical matters (Hamilton et al. 2017; Chiu et al. 2014; Hamilton et al. 2013; Laurent et al. 2013; Oreszczyn & Lowe 2010). While for decades researchers have been able to demonstrate the energy saving potential of different technologies, in reality actual energy use has largely varied from design and modelled predictions with limited understanding of the reasons for this (Cali et al. 2016; Wilde 2014; Menezes et al. 2012). Such discrepancy between actual (measured) and predicted (simulated) performance is referred to as the 'performance gap' or the 'energy performance gap' (Van den Brom et al. 2018). Some important underlying causes of this gap, commonly reported in the literature, include uncertainty in building modelling (associated with model core calculation engines and mode input specifications) and uncertainty regarding occupant behaviour (Gram-Hanssen & Georg 2018; Van Dronkellar et al 2016; Laurent et al. 2013). Such uncertainties are, in part, due to the nature of research undertaken and the prevalent positivist experimental approach adopted within the field isolating individual factors and excluding the influence of people (Hamilton et al. 2017; Hamilton et al. 2013; Laurent et al. 2013; Oreszczyn and Lowe, 2010).

A number of studies for example have illustrated how some predicted energy savings do not eventuate following improved technical efficiency due to changes in occupant behaviour (Milne & Boardman 2000; Oreszczyn et al. 2006; Hong et al. 2009; Guerra Santin 2013). This is commonly recognized in literature as the 'rebound effect', which broadly refers to the increase in the demand for energy services for which improvements in energy efficiency reduce the costs (Sorrell et al. 2009). In residential buildings this effect is frequently described as 'temperature take-back', 'take-back' or 'comfort-taking', which interchangeably refer to the increase in internal temperature after an energy efficient retrofit, resulting in lower energy savings than expected (Sorrell et al. 2009). In other words, occupants take-back the benefits of energy savings due, for example, to a more efficient heating system, as improved thermal comfort by raising the set temperature or by heating more rooms. While occupant behaviour is widely accepted as a key determinant of take-back, many researchers recognize that a change in internal temperature is a result of an interaction between both behavioural and physical factors (Milne & Boardman 2000; Sorrell et al. 2009; Deurinck et al. 2012; Guerra Santin 2013; Love 2014). Understanding these interactions (between the building, its systems and occupants) is important in the process of evaluating energy efficiency initiatives (Lowe et al. 2017).

Today many countries lack robust databases with empirically measured energy and building data including metered data matched with building physical form, appliances, services and occupancy to support a sound understanding of how and why energy is used in building (Hamilton et al. 2017). While some countries have made progressive efforts to establish consistent platforms for data collection (such as the UK National Energy Efficiency Data Framework, the IEA's Annex 70 database, the US DOE's Building Energy Performance Database, and South Korea's Building Energy Integrated Database), energy and building stock data remains largely incomplete, unavailable, or inaccessible in most (Hamilton et al. 2017; Hamilton et al. 2013; Oreszczyn & Lowe 2010; Summerfield et al. 2011). Such data, although often costly and time-consuming to collect, can allow for a better understanding of energy use and the development of more representative energy models to better inform policy interventions in this field.

The section below will outline current literature about the physical and social drivers of residential energy use as reported by energy demand researchers worldwide.

3.3 Key physical and social drivers of residential energy use

Residential energy demand researchers have, through various methods, attempted to understand and establish the importance of key energy use drivers. Many studies have largely focused on building physical factors which have been noted to be easier to assess, more temporally stable and cheaper to measure than occupant-related factors (Gram-Hanssen 2011; Wright 2008; Lutzenhiser 1992).

Among building physical factors, **building size** and **building type** are frequently cited as the most important in driving energy demand (Yohanis et al. 2008; Guerra Santin et al. 2009; Kelly 2011; Theodoridou et al. 2011; Huebner et al. 2015). **Building age** however is found in the literature to have different effects on energy consumption; some studies report a negative association between building age and energy use due to improved efficiency standards (Lia and Chang 2002; Guerra Santin et al. 2009), while others report a positive relationship due to an increase in the penetration of high-consuming appliances (Theodoridou et al. 2011) or no significant effect (Kavousian et al. 2013). Huebner et al. 2015 explains that while building age is often perceived as a proxy for energy performance, variation in the reported effect of building age in different countries is possibly the result of modifications in building regulations or retrofitting programs applied at different times. Other physical factors associated with energy use include the **thermal performance** (insulation) of walls, floors and windows (Assimakopoulos 1992; Haas et al 1998; Lindén et al. 2006; Guerra Santin et al. 2009). Guerra Santin et al. (2009) explain that the respective impact of this tends to be lower than that of fixed physical factors like building size and type, which are harder to change through energy efficiency interventions.

In recent years, there has been a shift in interest towards human centered aspects of energy with studies seeking to better understand the role and impact of occupants on energy use (Papakosta & Sotiropoulos 1997; Haas et al. 1998; Al-Mumin et al 2003; Steemers & Young 2009; Guerra Santin et al. 2009; Abrahamse & Steg 2009; Wei et al 2014; Fabi et al. 2012; Chiu et al. 2014; Huebner et al. 2015). This has largely been in the form of examining the impact of occupant socio-demographic characteristics and/or occupant behaviour. Social and demographic factors commonly examined include **household income**, **household size**, **household age**, and **household education** level (Guerra Santin et al. 2009; Abrahamse & Steg, 2009; Huebner et al. 2015). Several studies suggest that household income is an important driver of energy use, with higher income households more likely to have higher energy consumption levels (Biesiot and Noorman 1999; Santamouris et al. 2007; Guerra Santin et al. 2009; Abrahamse & Steg, 2009). Santamouris et al (2007) further explains that although lower income households may use less energy than higher income groups, they are less able to reduce their energy use as they are more likely to be living in older buildings with poorer envelope conditions. Another noted driver is household size which is largely reported to be positively correlated with energy use (Brandon & Lewis 1999; Druckman & Jackson 2008; Huebner et al. 2015). In regards to household age however, the evidence is mixed; some studies have found older households tend to consume more energy than younger households (Liao & Chang 2002; Linden et al. 2006; Guerra Santin et al. 2009), while others have found the opposite effect (Gatersleben et al. 2002) or no effect at all (Abrahamse 2009).

The impact of occupant behaviour has also been examined by several researchers (Papakosta & Sotiropoulos 1997; Haas et al 1998; Al-Mumin et al. 2003; Linden et al. 2006; Steemers & Young 2009; Wei et al. 2014; Delzendeh et al. 2017). Occupant behaviour (in relation to environmental comfort) is generally defined as occupants' interaction with a building and its systems to control the indoor environment so as to achieve thermal, visual and acoustic comfort (Delzendeh et al. 2017). Studies exploring the impact of occupant behaviour have largely been addressed in terms of **occupant preferences for space heating/cooling** (including thermostat set points and number of rooms heated/cooled) (Al-Mumin et al. 2003; Steemers & Young 2009; Wei et al. 2014), **window opening behaviour** (Fabi et al. 2012) and **presence at home** (Al-Mumin et al. 2003; Fabi et al. 2012). A number of studies have also examined behaviours such as **appliance use** (Wang & Ding 2015; Yu et al. 2015; Gandhi & Brager 2016), **lighting use** (Crosbie & Wall 2009; Ouf et al. 2016) **use of fans** (Park & Kim 2012) and **hot water use** (Chen et al. 2015).

While the important effect of occupant behaviour has been documented by many researchers, the extent this impacts energy demand is less clear (Guerra Santin et al. 2009; Huebner et al. 2015; Godoy-Shimizu et al. 2014). This is partly due to the challenges associated with measuring energy-related behaviours, which broadly, has been undertaken by following two main approaches; an objective approach such as field monitoring and a more subjective approach such as self-reporting and questionnaires (Hong et al. 2015). Occupant behaviour however is complex and driven by several underlying factors including the thermal quality of a building, the type and performance of its technical systems, outdoor climate, energy tariffs, occupant age and income (Fabi et al. 2012; Wei et al. 2014; Gody-Shimizu et al. 2014; Huebner et al. 2015).

A number of researchers have also examined the extent to which both physical and occupant-related factors together determine variability in energy use, primarily through regression analysis. Huebner et al. (2015) using data from a sample of 924 English households, found that building variables alone explained 39% of the variability in energy use, while socio-demographics explained 24%, heating behaviour 14% and attitudes and other behaviours 5%. In a model that combined all variables, Huebner et al. (2015) found that only 44% of the variability in energy consumption can be explained and that building variables, particularly those with greater time-invariant nature (such as building size and type) were largely the significant predictors of energy consumption. Similarly, a study by Guerra Santin (2009) based on a sample of 15,000 houses across the Netherlands, found that when controlling for building variables, socio-demographic and heating behaviour explained 4.2% of the variability in domestic energy consumption, while building factors accounted for 42%. Such findings not only indicate the prominent role of building physical factors, but show that even when researchers consider a large number of variables measuring a variety of predictor types (including building factors, socio-demographics, and self-reported behaviours), just over or under half of the variability in domestic energy use can be explained. This highlights the complexity associated with household energy use and the current understanding of this.

3.4 An integrated approach to the study of building energy performance

In more recent years, researchers have shown increased interest in an integrated approach to the study of building energy performance and in particular the socio-technical nature of energy consumption (Lowe et al. 2018; Love & Cooper 2015; Chiu et al. 2014). Researchers are increasingly recognising that a more thorough understanding of the interaction between physical and social factors that drive household energy use is needed and that this understanding be grounded on evidence-based empirical research (Hamilton et al.

2017, Huebner et al. 2015; Chiu et al. 2014; Kavousian et al. 2013; Howden-Chapman et al. 2009).

A study by Chiu et al. (2014) for example, based on 10 case study homes under the UK's Retrofit for the Future program, combines post-retrofit in-depth interview data and observation walk-throughs with technical data that included five minutely temperature, electricity and gas data. The combination of data strands allowed researchers to identify potential energy consequences of occupant self-reported behaviour in the physical data. Another study by Love (2014) collected social and technical data from 13 social housing case studies with the aim of understanding how and why occupants may change their heating behaviour after building fabric retrofit. In this study the combination of social and technical data strands indicated some interesting discrepancy and contradiction with regards to measured and reported temperature, which in turn become the subject of further investigation.

While studies of this nature have generally been based on relatively small sample sizes, they demonstrate the value of investigating energy use 'in context' and of collecting and combining empirical data about both the social and physical elements of buildings to better understand how occupants use energy in buildings and how they interact with new technology.

3.5 Chapter summary

- Energy consumption in the residential building sector is complex, depending on a mix of factors including building physical and occupant socio-demographic and behavioural factors.
- Energy demand research and the energy efficiency challenge have traditionally been defined in technical terms and studies have largely focused on a building physics approach examining the thermal performance of materials and the efficiency of heating and cooling systems.
- The performance of energy efficiency improvements and expected benefits of energy efficiency policies have been subject to a considerable level of uncertainty, with energy research frequently showing a discrepancy between predicted and actual energy use data.
- In recent years interest in the socio-technical nature of energy has increased with studies combining expertise and data about both the social and physical elements of buildings to better understand how and why people use energy in buildings.
- The need for better evidence-based empirical research including energy use data matched with descriptions of physical form, occupancy characteristic and appliances and services is increasingly being recognized in the literature. Potential drivers of energy consumption,

derived from a review of the literature in this chapter (and examined in the fieldwork Chapters 5-7) include:

- Building size
- Building type
- Building age
- Fabric efficiency
- Household income
- Household age
- Household education
- Thermostat set-points
- Number of rooms cooled
- Occupancy
- Appliance usage
- Lighting usage

Chapter 4: Research Methodology

This chapter presents the methodological framework of this research and the methods of data collection. It begins by briefly summarizing key findings arising from the literature review, before indicating why the research follows the philosophical foundations of pragmatism. The chapter then describes the three research strategies selected to address the research question and objectives, which include: 1) a cross-sectional quantitative household survey, 2) a longitudinal mixed method multi-case study, and 3) building energy modelling. Finally, the chapter describes the ethical and cultural concerns addressed before the start of data collection.

4.1 Key findings from the literature and a restatement of the research question and objectives

Table 4.1 summarizes the key findings arising from the literature review which provided the rationale for the research question and objectives outlined further below.

Table 4.1: A summary of key findings from the literature review

Literature	Brief summary	Key findings
Chapter 2	A review of residential energy demand in Kuwait, its magnitude, concerns, and current policy interventions.	There is limited data and research available about the Kuwaiti housing stock, its fabric, energy consuming equipment, disaggregation of energy use, and occupants demand for services. While a mandatory Energy Conservation Code of Practice for Buildings has been enforced since 1983, there is very little evidence of its impact in practice. Residential energy demand research has largely been based on energy modelling which has had little empirical grounding. Villas are the main housing type for Kuwaiti nationals and account for the bulk of previous and future government housing projects.
Chapter 3	A review of the residential building sector characteristics and the key drivers of residential energy demand on an international level.	Energy demand in the residential sector is complex and driven by physical and social factors including building fabric performance, building system types, and occupant behaviour. The energy efficiency challenge worldwide has traditionally been defined in technical terms and research has largely focused on a physics-based agenda. In recent years researchers have recognised that a better understanding of both the physical and social elements of energy use, grounded on evidence-based empirical research, is essential.

In light of the literature review findings, the main research question, defined in Section 1.2, is as follows:

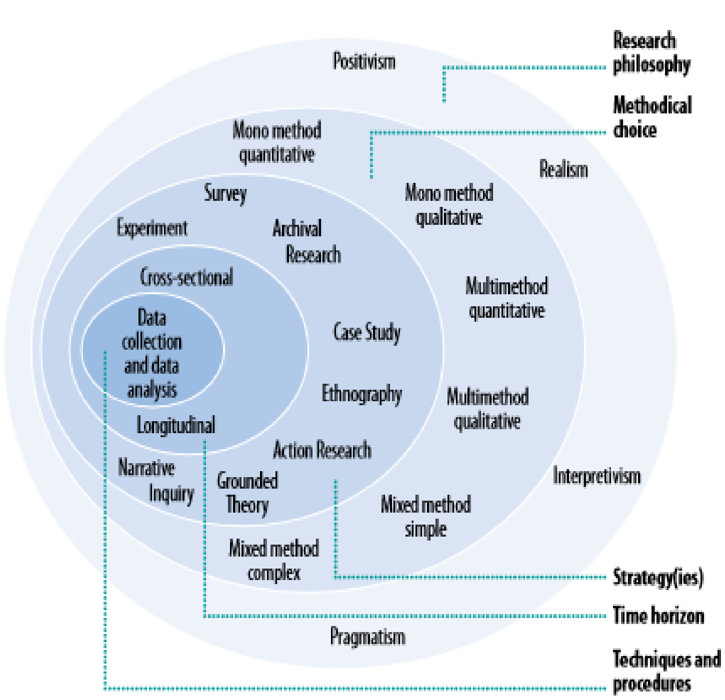
"What are the key physical and social drivers of energy use in Kuwaiti villas?"

The research objectives of the study are to:

1. Develop a comprehensive information base about the physical and social characteristics of Kuwaiti villas on a national level.
2. Monitor energy use and internal temperature and survey social and physical building components in a number of case study villas over a period of one year.
3. Develop energy models grounded with empirical monitored and surveyed data.
4. Determine the relative importance of different physical and social drivers identified and provide recommendations to inform policy in this field.

4.2 Research methodology

Research methodology refers to the framework within which research is conducted (Saunders et al. 2009). Figure 4.1 illustrates different layers associated with research methodology and presents a summary of the approach adopted for this study. To ensure the research question and objectives are adequately addressed, the research adopted a mixed methodology approach, and was conducted over three main phases in consecutive order with findings from each phase informing the next. This included a cross-sectional quantitative household survey, followed by a longitudinal mixed method multi-case study and finally building energy modelling. The sections below further explain why these particular methods were selected instead of other available methods.



Level	Approach adopted
Philosophy	Pragmatism
Methodical choice	Mixed method
Strategies	Survey, multi-case study and building energy modelling
Time horizon	Cross-sectional survey and longitudinal multi-case study
Techniques and procedures	Survey: - Questionnaire Multi-case study: -Energy and temperature monitoring -Physical and social surveying Building energy modelling: -Simergy

Figure 4.1: Diagram of research onion plus table summarizing the approach adopted for the study

Source: Saunders et al. 2009

4.2.1 Philosophy: Pragmatism

Research philosophy as a term encompasses the development of knowledge and the nature of that knowledge (Saunders et al. 2009). There are a number of research philosophies that vary in what they consider acceptable knowledge (epistemology), and in the assumptions they make about how the world is viewed (ontology). The philosophy of positivism, associated primarily with the natural sciences, centres on the discovery of generalizable explanations or theories and uses quantitative and experimental methods to test hypothetical-deductive generalizations (Saunders et al. 2009). In contrast, the philosophy of interpretivism, associated largely with the humanities and some branches of the social sciences, attempts to understand and explain a phenomenon using qualitative approaches to inductively and holistically understand rich human experiences in context-specific environments (Saunders et al. 2009). The philosophy of pragmatism maintains that the significance of research is in the finding's practical consequences and thus concepts are only as relevant in as much as they are relevant for practice (Creswell 2006). Under the pragmatist philosophy integration of different philosophical perspectives and methods in addressing the research question and objectives is possible.

To better identify and understand key drivers of domestic energy use in Kuwait, the philosophical foundation of this research is based on the philosophy of pragmatism. Different methods will be combined to link judgment and analysis, and provide multiple perspectives to address the research question and objectives.

4.2.2 Research approach: Mixed method

With regards to the methodical approach or choice, there are broadly three types to consider: quantitative, qualitative and mixed method approaches. The quantitative research approach aims to develop empirical knowledge about a phenomenon by collecting numerical data and analysing it using statistical, mathematical or computational techniques (Saunders et al. 2009). It is used to quantify defined variables (a variable being a characteristic with two or more possible values) and identifies correlations between them, which can be generalizable to larger populations (Saunders et al. 2009). The qualitative approach however aims to develop knowledge about a phenomenon in its natural setting by collecting non-numerical data (text, observations) that describes meanings and dynamics associated with that phenomenon. It is primarily exploratory in nature, seeking to understand underlying reasons into a particular situation (Merriam (2009). While quantitative research is criticised for being unable to provide insight into 'why' a particular situation in occurring, qualitative research is criticised as being too contextual to underpin generalization or theorization (Merriam (2009).

In recent years, a mixed method approach to research, which involves the integration of both qualitative and quantitative data collection and analysis methods into a single study, has become increasingly more common within the built environment (Bryman 2004; Amaratunga et al. 2002; Tashakkori and Teddlie 2003; Creswell 2003). Such an approach ideally allows for combining the complementary strengths of different methods to better understand the complexities of multi-dimensional phenomena (Bryman 2004; Amaratunga et al. 2002). Several typologies within the mixed-method approach have been described by researchers known as MM typologies (Creswell 2002, Teddlie and Tashakkori 2006, Miles & Huberman 1994), although no exhaustive, complete list exists due to the diverse nature of mixed method studies and their tendency to change and adapt as data is gathered (Teddlie & Tashakkori 2006; Maxwell & Loomis 2003; Patton 2002).

As there is limited information available on residential energy use in Kuwait and the subject of residential energy use is not well understood, the decision was made to adopt the mixed-method approach. The most appropriate MM typology selected was based on the classification developed by Teddlie & Tashakkori (2006), which considers the implementation process and number of phases/strands in a study. As Figure 4.2 shows the fieldwork follows a sequential multi-strand mixed method typology, in which the study is conducted over three main phases in a sequential time order. Findings from the first phase (quantitative household survey) informed the criteria for sample selection of cases in the second phase (longitudinal multi-case study), and monitored and surveyed data collected from the second phase informed the development of energy models in the third phase (building energy modelling).

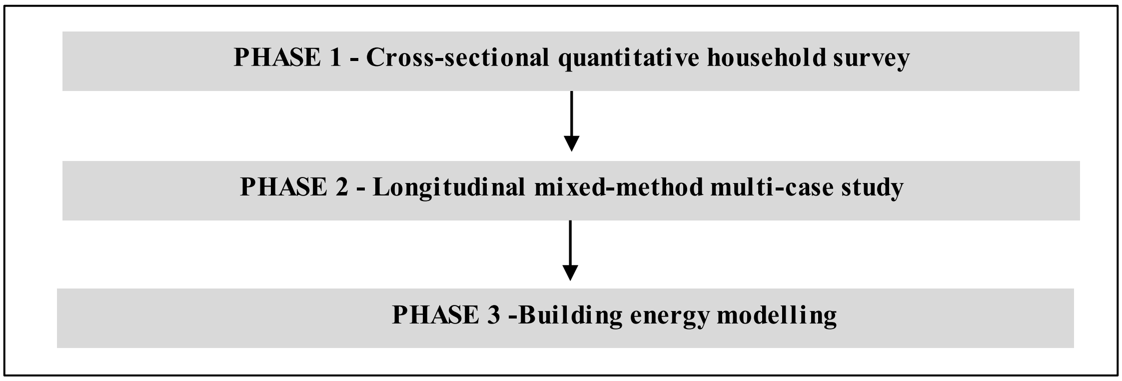


Figure 4.2: Sequential multi-strand mixed method approach

4.2.3 Research strategies, time horizon and data collection techniques

A research strategy is the overall plan of how a researcher will address the research question (Saunders et al. 2009). In the context of the mixed-method approach of this study, data is collected using three main strategies as noted above. Sections 4.2.3.1-4.2.3.3 below describe the purpose and data collection techniques and implantation of each strategy.

4.2.3.1 Quantitative household survey

Description and purpose of strategy

A survey is a research strategy that involves the structured collection of data (often several variables) from a sizeable population (Floyd & Fowler 2014; De Vaus 2014). They are commonly used to answer ‘what’, ‘who’, and ‘how much’ questions (Saunders et al.2009). The purpose of the survey of this study was to establish descriptive baseline information about Kuwaiti villas (including building and occupant-related characteristics) and to identify potential drivers of energy demand and their relative importance.

Techniques and Implementation

A number of data collection techniques can be applied for surveys including questionnaires, interviews and observations. Questionnaires are the most common method used for survey data collection as they allow for structured gathering of data that can easily be coded, analyzed and interpreted through statistical software (De Vaus 2014). Dillman (2007) has noted three data variable types (question content types) that can be collected through questionnaires. These include attribute variables (respondent characteristics such as age, gender, education, income), behaviour variables (what respondents did in the past, present, or will do in future), and opinion variables (how respondents feel about something).

The household survey for this research consisted of a standard questionnaire with a number of close-ended questions aimed at gathering data about respondent and dwelling attributes (age, income, building form and fabric), behaviours (thermostat control, appliance use, space heating and cooling) and opinions (comfort within homes). The questionnaire was conducted through face-to-face interviews with the homeowner or household representative, with the aid of 12 trained interviewers. A thorough interviewer briefing session ensured all interviewers were aware of questionnaire meaning, purpose, and content. More detail regarding questionnaire content and sample selection is provided in Section 5.1.

4.2.3.2 Mixed-method multi-case study

Description and purpose of strategy

A case study is a research strategy that involves an in-depth investigation of a phenomenon within its real-life context (Yin 2014). Such a strategy is ideal when 'why' or 'how' questions are being asked as it enables an understanding of the dynamics present within a specific setting (Saunders et al. 2009). Yin (2014) distinguishes between four case study types based on two discrete dimensions: single v multiple case, and holistic v embedded case. A single case approach is used where a case represents an extreme, unique or typical case, while a multiple case approach is used to compare and contrast findings between two or more cases. The second dimension (holistic v embedded), refers to the unit of analysis. A holistic case study is concerned with the case as a whole and primarily uses qualitative methods, while an embedded case involves more than one unit of analysis within a case, using a mix of methods - qualitative and quantitative (Scholz and Tietje 2002).

The case study strategy of this research consists of multiple case studies using an embedded case design in which sub-units within cases (such as building form and fabric, building systems and occupant behaviour) are examined using both quantitative and qualitative methods. The purpose of the multi-case study was to explore and understand how and why energy is used in occupied villas to better identify key physical and social energy use drivers. The intention was not to generalise beyond the sample of villas, but for the approach and findings to act as a platform to inform further research.

Techniques and Implementation

The energy performance of case study villas was examined through a mix of methods/techniques including longitudinal monitoring and surveying followed by the development of building energy models grounded in empirical data. The villas were monitored for 12 months to account for seasonal and climatic effects.

Longitudinal monitoring and surveying consisted of the following which are descried in more detail in Section 6.1.1:

- Document analysis (a review of historic utility bills and floor plans to obtain basic factual information about each villa prior to the start of monitoring).
- Energy use and indoor environmental monitoring (weekly electricity meter readings and internal temperatures and lighting monitored every 20 minutes, in rooms that made up at least 95% of the volume of the building).
- Physical surveys of building fabric and services (a walk-through process to inspect and photograph building elements).
- Social surveys of building occupants (semi-structured occupant interviews undertaken prior to the start of monitoring, and a series of follow-up interviews undertaken throughout the monitoring period).

The combination of techniques in this way allowed for overcoming shortcoming of individual methods, which include the risk of self-reporting bias associated with occupant interviews (due for example to imperfect memory), and the limited depth associated with analyzing quantitative monitored data in isolation (Saunders et al. 2009).

4.2.3.3 Building energy modelling

Description and purpose of strategy

Building energy modelling is commonly referred to as the computerized simulation of a building to explore, predict and quantitatively assess its energy consumption and environmental performance (Raslan & Mavrogianni 2013; Kavgic et al. 2010; Swan & Ugursal 2009). The aim of energy modelling in this study was to provide further insights into key determinants of energy use by quantifying end-use energy breakdowns (not measured in the monitoring) and by providing an opportunity to explore the potential for energy efficiency interventions.

Techniques and Implementation

Multi-zonal models were developed for each villa using the software program Simergy (version 2.5.1 - Digital Alchemy 2018). Simergy is a building energy modelling program that incorporates detailed information about building systems, internal loads and schedules, building site and climate. It is an interface to Energy Plus, an energy simulation engine, validated by the US department of Energy, generating annual, monthly or hourly energy demand for a building based on specific weather files (EnergyPlus.net).

To reduce assumptions and uncertainties, modelling was informed by physical and social data collected during the longitudinal multi-case study monitoring and surveying. Real weather data (during the year of monitoring) was also used in simulations including air temperature, relative humidity, and solar radiation retrieved from Kuwait International Airport weather station 405820 (KIA n.d). All model runs also include shading from adjacent buildings. More details about model development and calibration are described in Sections 7.1 and 7.2.

4.3 Data analysis techniques and procedures

Several data analysis techniques and procedures were used to address the quantitative and qualitative components of this study. This included the analysis of data within different research strategies, as well as the triangulation of data within and between research strategies. Techniques and procedures are briefly described below and explained in more detail in the relevant Chapters 5-7.

4.3.1 Data analysis within research strategies

4.3.1.1 Quantitative analysis

Statistical analysis methods were used in the analysis of the quantitative household survey, energy modelling and in the analysis of the quantitative elements within the multi-case study (energy and internal temperature monitoring data). Broadly, two types of statistical methods are used in the analysis of quantitative data: descriptive statistics and inferential statistics (De Vaus 2014). Descriptive statistics include the summarisation and comparison of variables numerically using frequencies, measures of central tendency (mean, median and mode) and dispersion (inter-quartile range and standard deviation). Inferential statistics however include the application of tests to make inferences and predictions from the sample data and generalise findings to the population.

For the quantitative household survey, both descriptive analysis and multiple linear regression analysis using SPSS version 22 (IBM 2013) were applied. The later involved assessing the contributions of the different predictor variables on energy consumption. For the energy modelling data and the quantitative elements of the multi-case study, descriptive statistics were applied using Microsoft Excel. Further details are included in Section 5.1.

4.3.1.2 Qualitative analysis

Due to the non-standardised and diverse nature of qualitative data, it is widely acknowledged that there is no standard procedure for analysing such data (Saunders et al. 2009). To support adequate interpretation and meaningful analysis of qualitative data however, it is recommended that one or a combination of the following processes is followed: summarisation of meanings, categorisation of meanings and or structuring of meanings using narrative (Saunders et al. 2009; Patton 2002; Strauss & Corbin 2008). Such processes in turn aid in the identification of key themes or patterns in the data and assist the researcher to draw better conclusions (Miles & Huberman 1994.).

In this study, the semi-structured occupant interviews (within the multi-case study) were drafted to allow for data to be collected and grouped into pre-defined categories to direct analysis whilst also allowing for the emergence of unexpected concepts and ideas. Qualitative data collected was summarised and then organised with various pieces of information allocated to appropriate categories such as space cooling and heating, lighting and appliance use, household cleaning, and occupancy. Such analysis continued as key themes and patterns in the data were identified following repetitive behaviours mentioned in each follow-up interview (such as cooling during periods of travel, AC maintenance, and heating/cooling for certain occupant types). Once all qualitative data was collected, a final summary of key occupant energy consuming behaviours was tabulated, and a discussion of their relative impact on energy use was made under key categories that represented key themes. Relevant quotes are included as evidence within the discussion where appropriate. Furthermore, given the nature of the longitudinal study, the overall process of data collection and analysis was interactive such that analysis (after 3 months of internal temperature and energy monitoring) helped shape the direction of subsequent follow-up interview questions, which in turn assisted in the identification and verification of themes in the qualitative data.

To facilitate analysis of large amounts of qualitative data in a timely manner and assist in identifying themes, Computer Assisted Qualitative Analysis Software (CAQDAS) can be used (Saunders et al. 2009; Weitzman 2000). Limitations associated with the use of such software however include programme complexity and computer literacy which can potentially obstruct the focus on depth and meaning within data (Saunders et al. 2009; Weitzman 2000). In this study no qualitative software was used and analysis was undertaken manually. Given the longitudinal time scale and the relatively small sample size, the author deemed there was sufficient time to manually summarise and categorise text, without the potential risk of obstructing the focus on meaning.

4.3.2 Triangulation of data

Bryman and Bell (2003) define triangulation as *"the use of more than one method or source of data in the study of a social phenomenon so that findings may be cross-checked*." In mixed method research triangulation is perceived as a validation technique increasing the accuracy of inferences made (Bryman & Bell 2003; Brannen 2005; Saunders et al. 2009). In the context of data analysis, triangulation is commonly applied for corroboration (to identify if results are the same), elaboration (to identify different perspectives), complementarity (to identify supporting results) and/or contraction (to identify refuting results) (Brannen 2005; Morgan 1998; Mathison 1988).

In this thesis triangulation was applied:

- Within the multi-case study strategy
  - To determine whether findings from the qualitative occupant interviews and quantitative monitoring of energy and internal temperature were complementing or contradicting each other.
  - To determine whether discrepancies (contradictions) were found between measured and modelled energy use.
- Between the quantitative household survey, multi-case study and energy modelling.
  - The totality of findings from the quantitative household survey,mixed method multi-case study, and energy modelling were triangulated to corroborate findings and better identify key drivers of energy consumption in Kuwaiti villas.

4.4 Piloting the techniques

Prior to undertaking the quantitative household survey and multi-case study, two pilot studies were undertaken. The first involved the examination of a typical Kuwaiti villa for four weeks in 2014 (between August 24 till September 22) to test case study methods. The second involved the piloting of the household survey questionnaire for one week in February 2015.

4.4.1 Pilot testing case study methods

The purpose of this pilot study was:

- to scope and test case study methods
- to inform questions in the quantitative household survey questionnaire

In piloting techniques of this nature, it is common for researchers to approach their acquaintances, colleagues or friends. In this case it was useful to test out techniques in a villa owned by the researcher's friend, who showed interest and cooperation in the study. The pilot study consisted of the following data collection sequence:

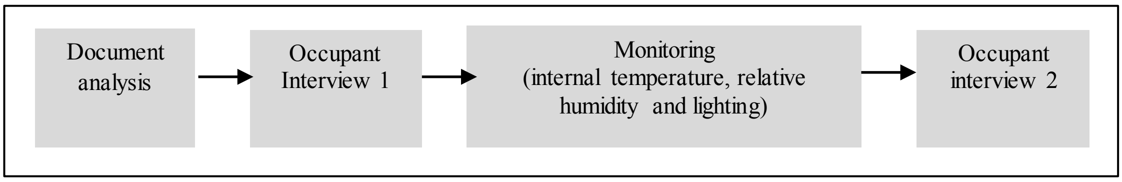


Figure 4.3: Data collection sequence

Document analysis involved collection of utility bills (dating back to 2011) and floor plans to better understand the villa's energy consumption patterns and physical layout. The first occupant interview was then undertaken to understand building and occupant background information, including form, fabric and services and occupant routines. Internal temperature, relative humidity and lighting levels were then monitored every 20 minutes for four weeks through the use of 20 HOBO data loggers (model type: U12-012, accuracy: ± 0.35°C, (onsetcomp.com)), installed in almost every room of the villa (in places that suitably represent the room's conditions i.e. away from direct sunlight). Electricity meter reading were also recorded several times during this period, however this was not done with equal time spans. Finally, the second occupant interview was undertaken at the end of monitoring, to note down energy using practices and occupancy during the monitoring period. All interviews were recorded and transcribed.

Data collected from the different methods was then summarised, integrated and corroborated to better understand key determinants of energy use in the pilot villa. Figure 4.4 briefly summarises some of these with more analysis provided in Appendix C.

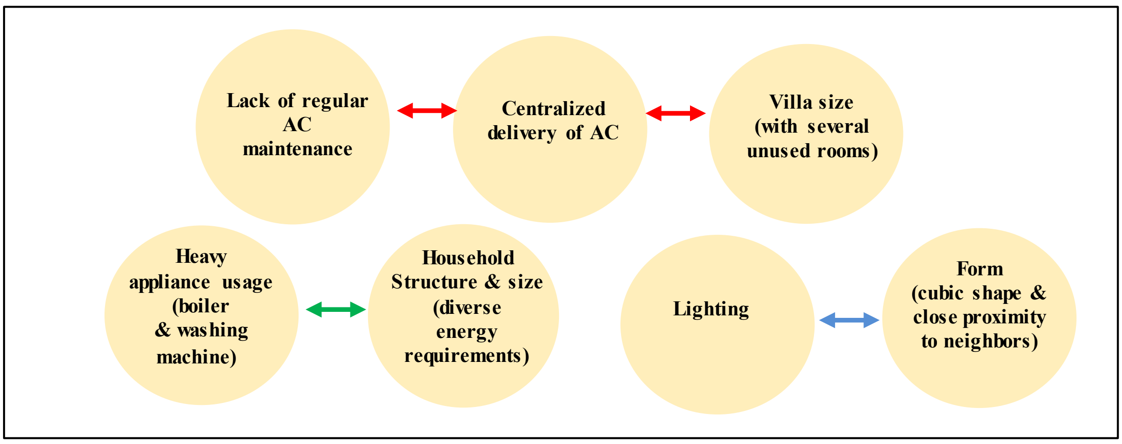


Figure 4.4: Key determinants of energy use in pilot villa and potential links between them

In brief, the pilot study indicated that centralized delivery of AC is a key determinant of energy use, and that there is a potential link between the villa's large floor area and demand for cooling. It was also observed that a change in occupancy (presence/absence of some occupants) is unlikely to impact energy use from cooling, especially as occupants had a relaxed attitude towards thermostat control; settings are set on automatic, cooling the entire villa including unoccupied spaces/rooms to low temperatures despite hot external conditions. The study also suggested a potential link between the villa's shape (dense, cubic and very close proximity to adjacent villas) and occupants' tendency to switch lights on during the day (further increasing internal heat loads). Finally, it was found that homeowners do not regularly maintain their AC systems and that occupants tend to inefficiently operate appliances (specifically the washing machine and boiler).

In addition to the above, the pilot study indicated that using a mixed method for data collection allows for a better understanding of energy use with qualitative interview data helping to explain observations in quantitative monitored data and vice versa. For example, during monitoring data showed regular spikes in temperature and lighting levels every afternoon between 2-4pm in the main ground floor living room, while other rooms, controlled by the same central AC unit, did not. In the post-monitoring interview, it was discovered such spikes were due to regular behaviour by an elderly occupant, opening the villa's main external door (adjacent to the living room) wide open every afternoon to get some sunlight and warmth (while the AC is operating).

Lessons learnt from this pilot study include:

- The need to periodically record electricity meter readings i.e. every Saturday, to better detect variations and patterns
- The need to monitor external temperature using a Stevenson screen (an enclosure to shield from dust, wind and rain).
- The need for a more structured physical survey to be carried out after the first occupant interview (including photographing air condition units, boilers, thermostat controls, and noting appliance stocks – number and wattage) rather than rely on occupant self-reported information.
- The need for a robust data storage system to facilitate data input and analysis
- Given the magnitude of disaggregated monitored data to be collected in the main study, a decision was made regarding what key parameters to analyse in depth and why, to better address the research question and objectives. While internal temperature, lighting and relative humidity are all monitored, the focus in the analysis is largely on internal temperature. Considering Kuwait's climate and peak electricity demand (occurring during the summer months when external conditions are

extremely hot and dry with average temperatures in excess of 35°C and average relative humidity ranging between 15% and 20% – Figure 2.2) as well as initial findings from the pilot study, internal temperature was deemed more critical than relative humidity in this context. With regards to lighting, data is only briefly analyzed to complement data reported by occupants during follow-up interviews as described in Section 6.1.3.

4.4.2 Pilot testing the survey questionnaire

The purpose of the second pilot study was to test the survey questionnaire and determine:

- the fluency and adequacy of questions, including their wording, ordering, and content
- the ease and feasibility of obtaining an adequate number of responses to the questionnaire in the selected location: cooperative society complexes (co-ops)
- a preliminary approach for data analysis

This pilot study was undertaken at Mishref co-op (Mishref is a large residential subdistrict in the district of Hawalli), and consisted of a sample of 10 homeowners/household representatives living in villas. Potential respondents were approached by the researcher and asked whether they would be interested in participating in the study after explaining its purpose. In Kuwait, co-op's are central and integral public spaces well distributed within residential neighborhood that include facilities such as medical clinic, post office, subsidized grocery store, electricity bill payment office etc. Membership in a neighborhood's co-op and use of its services (such as medical clinic) is exclusive for residents of that neighborhood that have a registered address within that area. A justification of why co-ops were selected as a location for questionnaire administration in provided in Section 5.1.2.

While piloting the questionnaire onsite, a number of revisions were noted and later incorporated into the final version of the questionnaire. These include:

- The addition of a new question to define the number of families living in a villa (i.e. 'single nuclear family', 'extended family - grandparents, aunts etc', or 'multiple families - homeowners' family in addition to a non-related family renting a floor in the villa'.
- The redrafting of questions about 'domestic hot water' usage (DHW) after better understanding the different systems respondents actually have.
- Modifying the response categories for questions about 'total household income', 'dwelling year of built', 'refurbishment works' and 'number of rooms in the villa' to be more representative.

Similarly, after undertaking the pilot study the researcher was able to better assess the potential of the co-op as a location for questionnaire administration, and determine which places in the co-op are ideal. It became evident that finding a target respondent who is also willing to participate (and give approximately 15 minutes of their time) at the co-op was time-consuming and somewhat challenging. Therefore, for the main study, where 250 respondents are required throughout the six districts of Kuwait, the assistance of qualified interviewers was deemed necessary.

Due to the modest number of respondents, preliminary data analysis for the pilot study was conducted using Microsoft Excel software. Data was simplified, organized and a quantitative descriptive approach was followed to generate results. Preliminary analysis showed that the sample is fairly homogenous regarding variables measuring household profile (villa tenure, main householder employment status, level of education, and household size), space cooling and heating use, and stock of electrical appliances. This, in addition to previous literature about villa characteristics, was considered when estimating the sample size for the main survey in Section 5.1.2.1.

4.5 Research quality: Validity and reliability

To assess the quality of research two key concepts are considered: reliability and validity. Reliability refers to the consistency of research findings; the extent a researcher's data collection and analysis methods yield reliable results (Saunders et al. 2009). Validity refers to the accuracy of research findings; the extent a researcher's data collection and analysis methods yield valid results (Saunders et al. 2009). Validity is broadly distinguished into internal and external validity. Internal validity refers to the accuracy of results within a study and the extent to which a causal relationship between variables can be determined between variables, while external validity refers to the extent results are generalizable to other research settings.

As this research includes both quantitative and qualitative elements it is important to consider how validity and reliability are determined in both contexts. While tests and criteria are broadly used to establish validity and reliability in quantitative research (including statistical significance and error), there is little consensus as to how qualitative research is assessed; qualitative text is open to a variety of interpretation, and no one set of themes can be deemed correct (Sarantakos 2005; Yardley 2000). Broadly demonstration of validity and reliability in qualitative research requires a focus on methodology (Dixon-Woods et al. 2004) and rigor in result interpretation (Lincoln et al. 2011; Leung 2015). This includes ensuring a transparent and systematic methodological framework with appropriate sampling, data collection and analysis (Leung 2015).

Tables 4.2-4.4 further describe how potential threats to reliability and validity (noted by Robson 2002) were addressed in the different research strategies of this study.

Table 4.2: Potential threats to reliability

Potential threats to reliability	Application to this research
Participant error (participants give different answers at different times of the research) Participant bias (participants behave in ways they believe agrees with what the researcher is looking for) Observer error (mistakes made in recording data) Observer bias (researcher's tendency to see what is intended to see).	**Quantitative household survey** • A questionnaire with a set question and structure was drafted. • Questionnaires administered (interviews conducted) at a set time during the day. • Participants reassured of confidentiality of responses. • A thorough interviewer briefing session ensured all interviewers were aware of the questionnaire meaning, purpose, and content. • All interviewers were given guidelines regarding the type of respondent to approach, the number of respondents required from each residential neighbourhood, and a specific starting point and path of travel for questionnaire administration. • Results analysed both descriptively and through multiple linear regression to reduce risk of observer bias. **Multi-case study:** • Occupant interviews were semi-structured and data was recorded and transcribed. • A neutral time of day and week were selected to conduct interviews. • Interview data was analysed in light of monitored energy and temperature data to reduce risk of observer bias. • Monitoring equipment (HOBOS) were placed in different villas on the same or subsequent day and were all programmed to start recording at the exact same time. • HOBOS were mounted in locations that provide an accurate representation of internal conditions (i.e. near existing thermostats, away from drafts and heat sources). • Periodic collection of monitored data throughout the 12-month period ensured HOBOs were adequately functioning. **Energy Modelling:** • A pre-defined modelling strategy was followed for all villas to ensure consistency in model development (Section 7.1.1). • Models were repeatedly checked for data input errors.

Table 4.3: Potential threats to internal validity

Potential threats to internal validity	Application to this research
Internal Validity History (unanticipated events occurring during the study that may affect a dependant variable) Confounding (a third variable influences the dependent and independent variables) Mortality (loss of participants from a study due to injury, death, travel etc.), Instrumentation (a change in the way a variable is measured during the study).	**Quantitative household survey** • To determine the causal relationship (factors effecting energy use), variables were input into the regression model based on a screening process to determine which had a significant relationship with energy use (Section 5.3). • To detect the presence and impact of bias due to outliers in the regression model, regression diagnostics were checked. (Section 5.3). **Multi-case study** • The full data collection plan was clearly defined prior to the start of longitudinal monitoring and surveying. • All monitoring equipment (HOBOS) was calibrated before and after monitoring to ensure accurate readings. • External temperature was recorded both on site (villa rooftop) as well as collected from Kuwait metrological weather station. • The periodic data collection and the analysis of different data strands (monitored energy, internal temperature and occupant behaviours) allowed for the early detection of any factors (sudden household change/tragedy, equipment damage or faults in the data etc.) that could potentially risk interval validity. **Energy Modelling** • A model calibration process was followed for all villas (Section 7.1). • To improve the accuracy of model outputs, model inputs were informed by physical and social data collected during the monitoring and surveying process, including real weather data and shading from adjacent buildings (Table 7.1). Model assumptions and their potential impact on results have also been reported (Section 7.2.2).

Table 4.4: Potential threats to external validity

<table>
<tr><th>Potential threats to external validity</th><th>Application to this research</th></tr>
<tr><td>External validity (generalizability)

Non-representativeness
(of the research sample)

Artificiality
(findings from smaller studies do not apply to realistic settings)

Lack of internal validity.</td><td>Quantitative household survey
• The survey target population was determined based on the Cochran’s sample size formula (Section 5.1.2.1)
• To ensure the sample consisted of households throughout the six districts of Kuwait, the sample was proportionally stratified by geographical region, based on the number of villas in each district (Table 5.2).
• A brief comparison of the survey data with available, published national statistics data (relating to the villa stock) was also made to determine the representativeness of the survey sample and validity of the sampling strategy (Table 5.3).

Multi-case study
• While the intention was not to generalise beyond the sample of households adopting a multi-case study approach, as opposed to a single case study, improves external validity.

Energy Modelling
• The intention of the modelling was not to generalise beyond the sample of households but for the approach (empirically grounded models) and findings to inform future research.

Triangulation of findings
• Comparing findings of the multi-case study, energy modelling and quantitative household survey allowed for cross-checking, which in turn increases external validity of the research’s final conclusions.</td></tr>
</table>

4.6 Health, safety and cultural constraints associated with data collection in villas

Given the nature and time scale of the multi-case study, a number health, safety and cultural constraints were encountered during data collection as described below.

Health and safety

To ensure the health and safety of household occupants and the researcher caution was undertaken while carrying out the following:

- Electricity meter readings

Meters in the case study villas are of the analog accumulation type with a cyclometer display (as commonly installed in villas in Kuwait by the MEW). After examination of these meters (type and age) it was deemed unsafe to install current clamps to record measurements. Instead, meters readings were manually recorded every Saturday (via direct observation by the researcher or a photograph of the meter sent by the homeowner to the researcher) during the entire monitoring period. Readings were taken to the nearest kWh.

- Physical surveys

Care was undertaken when recording system and appliance wattages, particularly for heavy items (such as televisions, fridges, and washing machines) and items with difficult accessibility (such as AC units and water heaters located on rooftops).

Cultural aspects

Issues relating to household access, convenience, privacy and confidentiality were also encountered and addressed in the following ways:

- Restricted access to homes and convenience

Data loggers were launched centrally before being deployed on site to minimize unnecessary disturbance for household occupants on the first day of monitoring. The longitudinal study was also designed to enable the researcher to go into the villas to both download logger data and to undertake face-to-face interviewers on the same day every three months. This was both practical and convenient for the household and researcher. Although some time was required to physically download data loggers from different rooms, this process allowed the researcher to observe any changes in lighting fixtures, thermostat controls or appliances that may have occurred and not have been mentioned during interviews.

- Household privacy and confidentiality

Ethical guidelines were followed to ensure commitment to privacy and confidentiality such as identifying villas with an ID rather than their addresses as well as safely storing recorded interview data (as outlined further in section 4.7). The researcher also reassured homeowners of confidentiality of all information supplied and clearly explained how data will be used. Care was also taken not to intrude into private or sensitive topics including internal family relations.

4.7 Ethical practice and data protection

Ethical standards adopted in this research primarily address confidentiality, participant anonymity, and informed consent. The UCL research ethics committee (Project ID Number: 6083/001) deemed this research exempt from the requirement to obtain full ethical approval (as it was established the study involved ‘interaction’ rather than ‘intervention’ with human participants). In accordance with the university guidelines, the research was registered under and conducted according to the UK Data Protection Act 1998 (UCL Data Protection Registration No Z6364106/2014/08/43). This included the commitment to confidentiality and participant anonymity (such as password protection of documents identifying anonymous villas, safely storing interview data etc.).

As the study was conducted in Kuwait, the researcher also reviewed and adhered to local Data Protection Legislation (Law No. 32 of 1982 concerning the Civil Information System (32/1982) Appendix D), the main requirement of which is to seek informed consent from the head of the household (regardless of gender) in writing. A consent form was thus drafted, outlining the nature of the project as well as the research protocol, and risks and benefits relating to the decision to participate. This was presented to the head of the household for approval and signature before undertaking any form of data collection.

4.8 Chapter summary

- The research follows the philosophical foundations of pragmatism and adopts a sequential multi-strand mixed method approach.
- Three research strategies have been selected to address the research question and objectives, including 1) a cross-sectional quantitative household survey, 2) a longitudinal mixed method multi-case study, and 3) building energy modelling.
- The appropriate data collection techniques selected for each research strategy were described including questionnaires, monitoring and physical and social surveying.

- Several data analysis techniques to address the quantitative and qualitative components of the study were outlined. Analysis includes the examination of data within different research strategies, and the triangulation of data within and between research strategies.
- Data collection and analysis techniques were tested through two pilot studies; the first included the examination of a typical Kuwaiti villa for four weeks to test case study methods, while the second involved piloting with 10 households the survey questionnaire.
- Potential threats to research reliability and validity were outlined and their application to this research discussed.
- Ethical concerns associated with the research were discussed including confidentiality, participant anonymity, and informed consent.

Chapter 5: Quantitative Household Survey

This chapter describes the methodology adopted for the implementation of the quantitative household survey, including the questionnaire structure, sampling strategy, and data analysis methods used. Survey results and key findings are then presented.

5.1 Survey methodology

5.1.1 Survey questionnaire

The household survey of this study consisted of a standard questionnaire with a number of close-ended questions, drafted specifically to fit the context of Kuwait (based on knowledge gained from the literature review and pilot case study). It aimed to collect data about building and occupant-related characteristics and is divided into five main parts as illustrated in Table 5.1. Questions were primarily in the form of category questions (where only one response can be selected from a given set), list questions (where multiple responses can be selected), likert questions (based on a rating scale to measure attitudes and opinions) and quantity questions (where a specific number is prompted). In developing the survey, a number of relevant questionnaires were reviewed, including the Carbon Reduction in Buildings (CaRB) questionnaire (Lomas et al. 2006), the UK Department of Energy and Climate Change Energy Follow Up Survey (EFUS) questionnaire (BRE 2013), University College London's Residential Energy Use in Oman household questionnaire (Sweetman et al. 2014), and the US Department of Energy and Energy Information Administration Residential Energy Consumption questionnaire (EIA 2009). To ensure different respondents were able to understand the questions, the source questionnaire (initially drafted in English) was translated into the Arabic language using a mixed translation technique (Usunier, 1998). Please refer to Appendix E for sample questionnaire in both languages.

Table 5.1: Quantitative household survey questionnaire structure

Section	Description of questions	Rationale
Household socio-demographic profile	Villa tenure; main householder employment and education status; household size and age.	This data sets the basic socio-demographic context and provides key information for interpreting survey results.
Building form and fabric characteristics	Construction date; villa type; built up area (m²); number of floors; number of unused rooms; refurbishment works; level of wall and roof insulation; glazing type; window shading; building cladding material	This data enables an understanding of the physical characteristics of the villa stock to better determine its overall efficiency and potential costs and benefits of fabric improvements.
Space conditioning and domestic hot water use	Air-conditioning (AC) type and age; AC use throughout the year; number and cooling capacity of AC units; number of rooms cooled; AC thermostat settings and control; AC maintenance; Space heating; occupant thermal comfort during different seasons and control of this; domestic hot water (DHW) type; DHW fuel; DHW control.	This data allows for a better understanding of building system characteristics, performance and efficiency, as well as occupants demand for and interaction with these.
Lighting and appliances	Main lighting type; natural daylight quality; number of electrical appliances and their frequency of use.	This data enables an understanding of costs and benefits of potential appliance efficiency schemes.
Electricity consumption	Estimated annual electricity bill in KWD; electricity payment interval; awareness of online payment options; concern about energy use and payment.	This data enables the calculation of energy consumption in kWh and the examination of relationships between energy use and other variables measured by the survey.

5.1.2 Survey sampling strategy and sampling bias

A sample is broadly defined as '*a sub-group or part of a larger population*' (Saunders et al. 2009). Two main groups of sampling techniques are available that allow for the selection of a valid sample of respondents from a larger population: probability sampling and non-probability sampling. With probability sampling, the chance of each respondent being selected from the population is known, which allows for the statistical generalization of research findings (within the boundaries of random error) to the population from which the sample is drawn. With non-probability sampling, the probability of each respondent being selected is unknown, and thus one is unable to make generalization based on statistical grounds (Saunders et al. 2009).

In this study the following constraints were accounted for when designing the respondent sampling strategy due particularly to the novelty of the research approach in the region and privacy concerns:

1. Restricted access to homes
2. Lack of willingness to share data
3. Cultural restrictions associated with conducting interviews at private residences.

Such constraints played a central role in determining the methodology for sample selection illustrated in Figure 5.1. While the earlier stages of the sample were selected based on probability sampling principles, the last stage of questionnaire administration is not strictly random, but rather based on quota sampling (Figure 5.1). Quota sampling is a technique that ensures a sample represents specific characteristics of a population defined by the researcher (De Vaus 2014). This technique is often used at the final stage of household surveys to achieve a representative sample while avoiding potentially high non-response rates (Turner 2005), as it enables interviewers to continue beyond non-responding households until they achieve an adequate number of responding households to fulfill the quota.

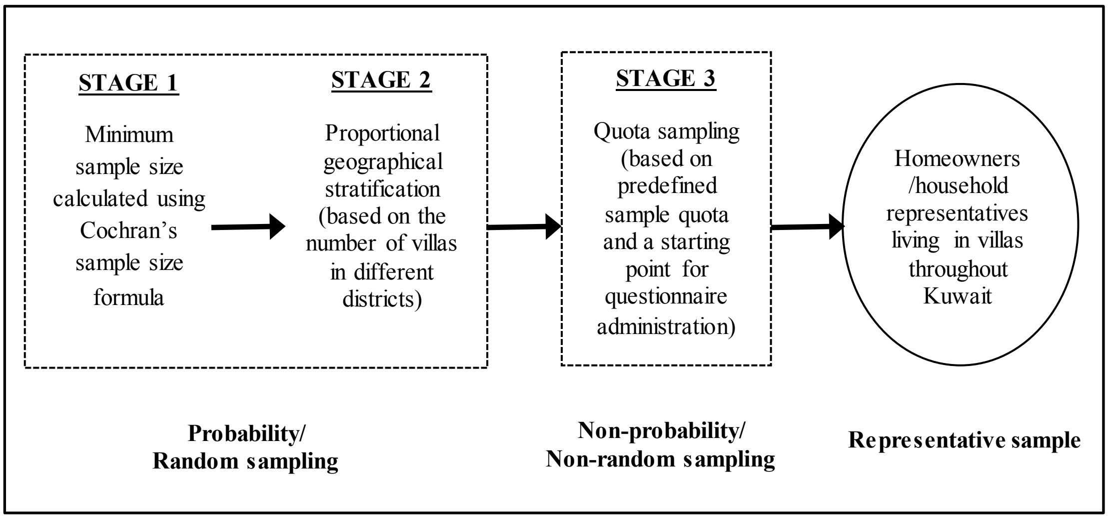


Figure 5.1: Sample selection process

5.1.2.1 Determining sample size

To determine the minimum sample size (n), the Cochran's sample size formula was applied (Figure 5.2), which allows for calculating a sample given a desired level of precision (sampling error), a desired confidence level, and an estimated proportion of the attribute in a population (Cochran 1977).

$$n = \frac{z^2(pq)}{e^2}$$

Where:
n = the sample size
z = standard error with the chosen level of confidence
p = estimated percent in the population
q= 100-p
e = acceptable sample error

Figure 5.2: Sample size formula

The survey target population was defined as 'homeowners/household representatives living in single family detached villas in Kuwait'. Based on figures from the Public Authority for Civil Information (PACI 2013), there were 105,764 villas in Kuwait (at the start of undertaking this research). In formula 1, the sample proportion is an estimation of what one expects the results to be for particular variables, and can often be determined through using results from previous surveys or pilot study. If one is unsure, 50% is typically used as a conservative value as it provides the largest sample size. In this case, the estimated percentage in the population (*p)* is approximated to be 65 as the population is assumed to be fairly homogenous (based on available literature about villas and piloting of the questionnaire – Section 4.4.2). A confidence level of 90% (corresponding to a standard error z=1.645) and an acceptable sampling error (*e*) of 5% were also both deemed to be appropriate for the indicative nature of this survey (Smithson 2003; UN DESA 2005). This resulted in the calculation of a sample size of 250 respondents'/homeowners to survey.

To ensure the sample consists of households throughout the six districts of Kuwait the target population was then proportionally stratified by geographical region (based on the number of villa in each district). Several residential neighborhoods within each district were then randomly selected. Rather than administrating surveys at individual household addresses (for reasons mentioned above in Section 5.1.2), the decision was taken to administer questionnaires at residential co-ops within the randomly selected neighborhoods. As explained in Section 4.4.2, co-ops in Kuwait are key public spaces well distributed within residential neighborhoods that include a central market, and various shops and services. Membership in a neighborhood's co-op and use of its services is exclusive for residents with a registered address in that neighborhood. As the number of co-ops varies in the different districts, 25% of the total number of co-ops in each district was randomly selected as a starting point to collect data from (as illustrated in Table 5.2 below). Data collection was then performed through face-to-face interviews, with the aid of 12 qualified interviewers, who were given set sample quotas in terms of the following:

1. The type of respondent to approach – a villa homeowner or household representative living in the specified district.
2. The number of respondents required.

Critics of the quota sampling highlight that there is an element of sample bias which could impact the representativeness of the sample as interviewers may tend to approach those that are accessible and approachable to them. The effect of interviewer behaviour on achieving a representative sample in this study is minimized by:

1. The inclusion of an adequate sample size (Figure 5.2).
2. Prior stages of the sample being selected with probability methods (Figure 5.1).
3. Interviewers given predefined sample quotas and required to ask potential respondents two screener questions before starting the survey: 1) to determine if they lived in this district, 2) if they are a homeowner or a key household representative.
4. Interviewers notified of a path of travel to follow to achieve the quota required.
5. A thorough interviewer briefing session ensured all interviewers were aware of questionnaire meaning, purpose, and content.

Table 2 presents relevant villa and co-op statistics and Figure 3 highlights the location of the different districts and the numerous co-op locations selected within these.

Table 5.2: Villa and co-op statistics in different districts of Kuwait

Kuwait Districts	Area (km²)	Number of villas	Proportion of villas per district (%)	Sample required per district	Number of Co-ops	Number of selected co-ops
Asima	200	16,019	15	38	20	5
Hawalli	84	20,513	19	48	18	4
Ahmidi	51,200	20,622	19	47	20	5
Jahra	12,130	13,124	12	30	15	4
Farwaniya	190	19,789	19	47	13	4
Mubarak Alkaber	94	15,697	16	40	11	4
TOTAL	17,818	105,764	100	250	97	24

Source: Author generated based on statistics from PACI (2013)

Note : The 'number of selected co-ops' in each district was based on 25% of co-ops in that district

5.1.3 Survey data processing and analysis methods

Data processing involved preparing collected data for analysis by classifying and coding the data, as well as checking for missing information or incorrect responses that could impact the quality of the results. The data collected consisted of categorical variables (both nominal and ordinal data) and interval variables (discrete data). Each respondent was assigned a reference to allow data to be linked anonymously.

Data analysis consisted of a descriptive analysis and multiple linear regression analysis using SPSS (version 22) (IBM 2013). Descriptive analysis involved summarising the data set to illustrate key characteristics about the sample, its energy use, and representativeness in relation to the wider population. Multiple regression analysis involved assessing the contributions of the different predictor variables on energy consumption. Variables were input into the model based on a screening process to determine which had a significant relationship with energy use. A correlation matrix was created using Pearson's correlation coefficient to highlight the strength of the relationship with predictor variables measured at the numeric level (number of rooms, number of occupants, number of appliances, AC thermostat setting). For variables measured at the categorical rank order level (villa size, age, and household income) Spearman's rank correlation coefficient was used, and for variables measured at the categorical nominal level (villa type, tenure, type of families, education status, AC type, lighting type, glazing type, and insulation) the one-way Anova test was used to detect any differences between categories of a variable. All variables measured at the categoric level were transformed before being entered into the model; dwelling age (initially 6 categories) was transformed into a dichotomous variable with values grouped into post-1983 and pre-1983 villas. For dwelling size and household income dummy variables were used. The regression method utilised was forced entry regression, in which all predictors are forced into the model simultaneously.

5.2 Survey result analysis: Data description

5.2.1 Survey sample characteristics in relation to national statistics data

In an attempt to determine the representativeness of the survey sample, a brief comparison of the survey data with available, published national statistics data (relating to the villa stock) was made. This process was a useful interim step for checking the validation of the methodology and survey sample representativeness.

As illustrated in Table 5.3 the survey sample appears to be quite representative of households and villas in Kuwait with regards to villa type, villa age, household size (number of occupants), and household monthly income. Regarding annual electricity consumption however, the survey sample had a significantly higher average than that found in national statistics, and responses had a wide range in value. Possible explanations for this include:

- Energy consumption for the survey sample was deducted from occupant self-reported bills. This is likely to be estimated and include water and electricity as the current billing system requires householders to pay electricity and water bills simultaneously.
- A significant lack of awareness regarding electricity consumption among households, particularly as only 65% of the sample responded to this question. Low electricity tariffs and slack payment requirements from the MEW are likely to have contributed to this lack of awareness.
- The national average is based on consumption measured in 2009, six years prior to conducting this survey. Villa sizes are likely to have increased since 2009 especially following allowances for this by Kuwait Municipality in 2012 (a villa's total built up area is now 210% of its plot size - a rise of 40% from previous guidelines in 1996). Similarly, household size per villa is also expected to have risen considering the very rapid growth in Kuwait's population.

To improve the quality of this data for regression analysis in Section 5.3, national energy consumption data was laid over the sample's data to identify potential outliers.

Table 5.3: Survey sample characteristics in relation to national statistics

	Survey sample	National villa stock
Villa type	Government villas: 48% Private design/built villas: 52%	Government villas: 54% Private design/built villas: 46%
Villa age	Before 1960: 1% 1960-1983: 18% 1984-1995: 28% 1996-2009: 45% 2010-2014: 8%	Before 1960: 1% 1960-1983: 19% 1984-1995: 28% 1996-2009: 43% 2010-2014: 9%
Household size	9.3	8.0
Monthly household income (KWD/month)	Below 1,000 KWD ($3,330): 2% 1,000-2,500 KWD ($3,330-$8,326): 43% 2,501-3,500 KWD ($8,329-$11,656): 30% Greater than 3500 KWD ($11,656): 24%	2,200 KWD ($7327)
Average annual electricity bill and energy consumption	801 KWD ($2,668)/annum/villa 400,433 kWh/annum/villa	291 KWD ($969)/annum/villa 145,444 kWh/annum/villa

Sources: National data (PACI 2013;MEW (2009)

Note: Conversions from Kuwaiti Dinar (KWD) to US dollar ($) are based on the exchange rate at the time of writing: 1KWD=$3.33

5.2.2 Household socio-demographic profile

Table 5.4 presents details of the survey sample's socio-demographic profile. In more than half of the survey sample, the main householder is fully employed and university educated. The average total monthly household income is between 1,000-2,500 KWD ($3,330-$8,326) with households living in government villas tending to have lower incomes than those living in private bought/built villas. The majority of households consist of nuclear families (66%), while a smaller portion consists of larger extended families (30%). The average household size (number of occupants) is quite large with approximately 7.8 family members and 1.5 staff members per household. Most households (70%) have at least 1 or more staff members, while a smaller proportion (30%) have no staff at all. On average, most households have family members aged between 5 to 45, and household staff aged between 26-35.

Table 5.4: Household socio-demographic profile

Variables	Survey responses
Villa tenure	Owned: 92%, rented: 8%,
Main householder employment	Full time: 66%, part time: 19%, unemployed/retired:15%
Main householder education	University post-graduate: 4%, university undergraduate: 62%, high school: 31%, elementary: 4%
Family type living in villa	Nuclear family: 66%, extended family: 30%, multiple families: 4%
Number of occupants	Mean: 9.3
Family members age groups	0-4: 30%, 4-18: 64%, 18-25: 75%, 26-35: 72%, 36-45: 62%, 46-55: 56%, 56-65: 26%, over 65: 8%
Staff members age groups	19-25: 23%, 26-35: 44%, 36-45: 23%, 45-55: 5%
Total monthly household income (KWD)	Less than 1,000 KWD ($3,330): 2%, 1,000-2,500KWD ($3,330-$8,326): 43%, 2,501-3,500 KWD ($8,329-$11,656):30%, greater than 3,500 KWD ($11,656): 24%

5.2.3 Building form and fabric characteristics

Table 5.5 presents details of the survey sample's villa form and fabric characteristics. Most villas are large in size (floor area), with 44% of households living in 651-750m² sized villas and 15% of households in villas greater than 750m², which is almost 5 times larger than the average detached house in England, with a floor area of 152m² (EHS, 2017). Overall, 58% of villas are three floors or more in height. The average number of rooms per villa is 23, including many bedrooms, bathrooms, and living rooms. Privately built villas were generally larger than government-built villas in floor area, number of rooms and number of floors.

Almost half of the households have undertaken some form of refurbishment works, the vast majority of which consists of vertical extensions (an additional floor) to add additional space. Such refurbishments are likely to be driven by Municipality building codes continuously allowing for an increase in building size with time (1996, 2002, and 2012). Overall, newer villas are slightly larger than older villas (in the number of rooms and floor area), although no statistically significant association was found between dwelling size and age (possibly due to many older dwellings increasing in size due to later refurbishments). A positive correlation was found between the number of occupants and the total number of rooms, (Pearson's r=0.380, p-value=0.000), although the relationship is relatively weak. This is in line with the finding that a significant number of households (20%) have several completely unused rooms.

With regards to the building fabric, although most households reported that their villas are well or adequately insulated, a trend towards better levels of insulation was found among newer villas in comparison to those built before the 1983 energy conservation code. It was also found that newer villas tend to have double, triple, or solar reflective glazing, rather than single glazing. Almost all households shade their windows either with internal curtains or blinds or external aluminum shutters. The main cladding material used in villas was found to be concrete bricks and blocks, followed by sigma - a cement-based mixture and stone.

Table 5.5: Building form and fabric characteristics

Variables	Survey responses
Villa age	Before 1960: 1%, 1960-1983: 18%, 1984-1995: 28%, 1996-2009: 44%, 2010-2014: 9%
Villa type	Government: 48%, private: 52%
Villa size (m²)	Less than 350: 1%, 351-450: 2%, 451-550: 15%, 551-650: 23%, 651-750: 44%,751-850: 1%, >1000: 14%
Number of floors	1 floor: 3%, 2 floors: 39%, 3 floors: 46%, <4 floors: 12%
Number of rooms	Mean number of rooms per villa: 23. Mean number of rooms by type - Bedrooms: 7.2, staff bedrooms: 1.8, bathrooms: 5.4, living rooms: 2.6, dining rooms 1.4, washing rooms: 1.2, kitchen: 2.1, diwaniya: 1.1, basement: 0.5, Office: 0.3
Unused rooms	Yes: 21%, no: 79%
Number of unused rooms	1-2: 64%, 3-4: 30%, >5: 6%
Refurbishment works	Yes: 49%, no: 51%
Type of refurbishment	Vertical extension: 41%, horizontal extension: 12%, resealing windows: 20%, insulation (walls): 6%, upgrading AC equipment: 1%, upgrading hot water tank: 9%
Wall insulation	Well insulated: 75%, adequately insulated: 20%, poorly insulated: 2% not insulated: 3%
Roof insulation	Well insulated: 71%, adequately insulated: 23% poorly insulated: 2% not insulated: 3%
Glazing	Single: 30%, double: 31%, triple: 7%, solar reflective: 32%
Window shading	External shutters: 33%, internal curtains: 62%, overhangs: 4%, no shading: 1%
External cladding	Concrete blocks or bricks: 55%, sigma: 24%, stone: 20%, glass: 1%

5.2.4 Space conditioning and domestic hot water use

Table 5.6 presents details of the survey sample space conditioning and domestic hot water use. Findings show that all households use air-conditioning to cool their homes. Centralized AC systems are the primary method of cooling with 66% of the sample using a centralized system, 8% a mixed system (central and split units), and 26% split-units only. Almost all respondents (94%) with centralized AC use this method to cool their entire villa, while a smaller portion (74%) of respondents with split units use this method to do the same. The majority (44%) of households cool their villas for eight months of the year mainly from March to October, even though external conditions are moderate in March, see Figure 5.3.

Most households with centralized AC have either 5 or more direct expansion units and many do not know their cooling capacity, while households with split units have an average of 9 units, and all were aware of the unit's cooling capacity. Most respondents (43%) have AC equipment that is more than 9 years old, and although the majority (69%) regularly maintain their equipment once a year, a notable proportion do not (14%). Thermostats are used by all households to control AC equipment, and the average temperature setting is found to be 21°C (Figure 5.4). When villas are unoccupied for prolonged time periods (such as travel during the summer), only 54% of respondents always adjust their AC thermostat.

With regards to space heating, only 49% of households heat their villas in winter while 23% sometimes do and 28% don't. Almost all households that heat their villas use electric portable heaters as the main method of heating compared to using the air-conditioning system as a heater. Electricity is the main fuel used for domestic hot water (DHW), with roughly equal use of centralized and individual systems. Most respondents use DHW for 4 to 6 months of the year from October tillMarch, largely because water tanks in Kuwait are commonly located on the roof (thus water is in effect solar heated during the warmer months of April till September). When villas are unoccupied for prolonged time periods (e.g. while abroad during the heat of the summer), only 57% switch off their DHW.

Regarding thermal comfort, occupants reported that they tended to use non-passive control measures to cool down during summer including lowering the temperature on the thermostat and/or using additional cooling devices. Very few opted for passive responses such as taking off clothes or closing curtains. In winter however, a greater number of householders adapted passively by closing windows or putting on additional clothes.

Table 5.6: Space conditioning and domestic hot water use

Variables	Survey responses
Air-conditioning (AC) system type	Central: 66%, split: 26%, mixed (central and split): 8%
AC operation (months)	5-6 months: 14%, 7-8 months: 68%, 9-10 months: 16%, 11-12 months: 2%
Number central units	1-2: 12%, 3-4: 20%, 5-6: 25%, more than 6:25%, unsure: 18%
Number of split units	Mean: 9
AC thermostat temperature set points	Mean: 21°C, see Figure 5.4
Cooling capacity of central units (tons)	3 or less: 10%, 4-10: 38%, 10 or more: 10%, don’t know: 40%
Cooling capacity of split units (tons)	Less than 1: 4%, 1-2: 46%, 2.5 tons or more: 47%, don’t know: 3%
Rooms cooled by central AC	All rooms: 94%, bedrooms only: 6%
Rooms cooled by split units	All rooms: 74%, staff bedrooms: 9%, external kitchen: 7%, other:10%
AC age (years)	>1: 2%, 1-3: 10%, 3-6: 26%, 6-9: 18%, more than 9: 44%
AC maintenance interval	Once yearly: 69%, twice yearly: 13%, every two years: 4%, randomly: 14%
Adjusting AC settings during periods of prolonged absence	Yes: 54%, sometimes: 22%, no: 24%
Space heating during winter	Yes: 49%, sometimes: 23%, no: 28%
Space heating system type	Portable electric heaters: 91%, AC system heating mode: 9%
DHW system type	Central: 52%, local:46%, mixed:2%
Hot water usage – months/year	3-4: 29%, 5-6: 48%, 7-8: 20%, 9-10: 1%, 11-12: 2%
Switching DHW off during periods of prolonged absence	Yes: 14%, sometimes: 29%, no: 57%
Thermal comfort inside villa - summer	Cold: 3%,cool: 7%,slightly cool: 8%, neutral: 73%, slightly warm: 7% warm: 2%
Thermal comfort outside villa-summer	Neutral: 40%, slightly warm: 7%, warm: 10%, hot: 42%
Thermal comfort inside villa - winter	Cold: 2%, cool: 10%, slightly cool: 16%, neutral: 68%, slightly warm: 4%
Thermal comfort outside villa - winter	Cold: 28%, cool: 20%, slightly cool: 8% neutral: 42%, slightly warm: 2%
Strategy to cool down in summer	Lower thermostat temp.: 54%, use extra cooling devices: 19%, open windows: 16%, close curtains: 5%, remove some clothes: 11%, do nothing: 44%
Strategy to warm up in winter	Use heating devices: 36%, put on more clothes: 27%, close windows: 28%, do nothing: 53%

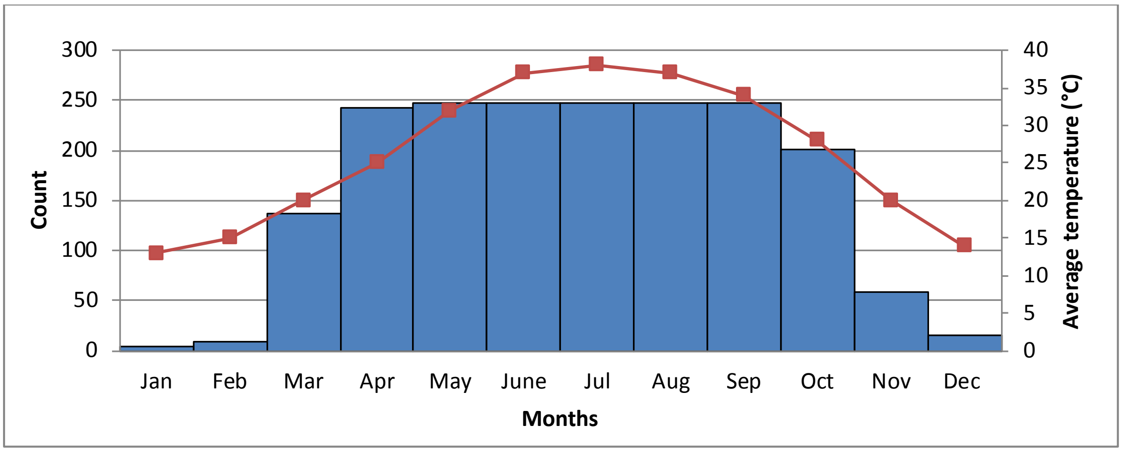


Figure 5.3: Monthly AC use by survey sample and average monthly external temperature for Kuwait

Note: external temperature data for Kuwait Sourced from Kuwait metrological centre: 1964-2015 (KMC, n.d)

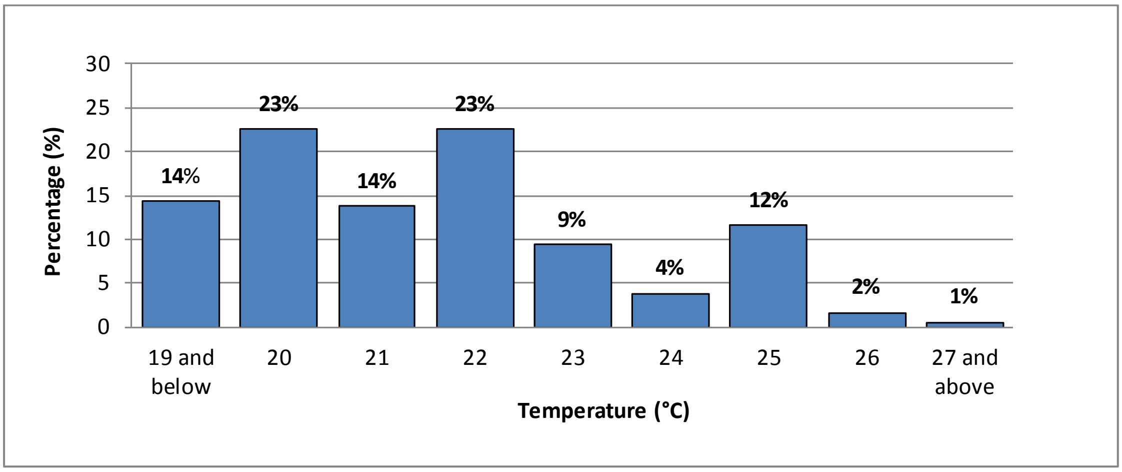


Figure 5.4: AC thermostat temperature set points

5.2.5 Lighting and appliances

Table 5.7 presents the survey sample's lighting and appliance use. Most households had adopted fairly efficient lighting practices; 66% of households use energy efficient bulbs (LED or CFL), while only 23% use incandescent bulbs, and the majority of respondents (76%) always switch lights off in unoccupied rooms.

The typical villa had approximately 32 appliances broken down by number and type in Table 8. Although a positive correlation was detected between the total appliance stock and the number of occupants (Pearson's r = 0.406, p-value = 0.000) indicating that larger households tend to have more appliances, this relationship is moderate as several households presumably have appliances in excess of occupants needs. Similarly, although a positive correlation was also found between appliance stock and household income (Spearman's rho =

0.339, p-value = 0.000), the relationship is fairly weak possibly due to the fact that low electricity tariffs may enable lower income households to afford the running costs associated with many extra appliances.

Table 5.7: Lighting and appliances

Variables	Survey responses
Main lighting type	Incandescent: 24%, florescent: 19%, LED: 57%
Switching lights off in unoccupied rooms	Always: 77%, often: 23%
Appliance stock (mean)	TV: 4, satellite receiver: 4, fridge: 3, freezer: 2, water cooler: 2, water pump: 1, toaster: 1, kettle: 2, microwave: 2, electric oven: 1, gas oven: 1, Gas stove: 2, electric stove: 1, vacuum: 2, washing machine: 2, clothes dryer: 1, games console: 1
Washing machine usage	Daily: 39%, every other day: 29%, every three days: 29%, once a week: 4%
Clothes dryer usage	Daily: 42%, every other day: 26%, every three days: 29%, once a week: 3%
Vacuum usage	Daily: 75%, every other day: 14%, every three days: 7%, once a week: 4%

5.2.6 Electricity consumption

Table 5.8 presents details of the survey sample's electricity consumption. It was found that the majority of households pay their electricity bills once annually. This indicates the lack of importance given to payment (especially as no protocols are currently set by law). More than half the respondents were also unaware that electricity bills could be paid online. In spite of this, when asked about their level of concern for the amount of energy used and the payment made for this, almost 80% of the sample claimed they are either very concerned or concerned.

The mean annual electricity bill for households was found to be 801 KWD ($2668)/annum (400,433 kWh/annum). As explained in Section 5.2.1 above this figure is likely to be influenced by some respondents reporting a total utility bill (water and electricity), as it is the norm in Kuwait to pay such bills simultaneously. To improve the quality of this data for the regression analysis, national consumption data was overlaid over the survey sample data to identify potential outliers. As less than 1% of the national villa stock consume more than 450,000 kWh/annum (900KWD or $2997 per annum), all cases that reported consumption greater than this value (62 cases) were considered outliers, with implausible energy consumption, and removed from the sample (Figure 5.5). A revised mean electricity bill was found to be 500 KWD ($1665)/annum (equivalent to 250,198 kWh/annum) for a total of 101 households.

Table 5.8: Electricity consumption

Variables	Survey responses
Electricity bill payment interval	3 months or less: 25%, every 6 months: 7%, every 12 months: 31%, more than 12 months: 10%, when prompted by MEW: 7%, don't know: 20%
Average electricity bill KWD/annum/villa	Mean: 801 KWD (equivalent to $2,668 at the time of writing) (based on a response by 65% of the sample)
Awareness of online bill payment option	Yes: 41%, no: 59%
Concern about energy consumption	Very concerned: 48%, concerned: 30%, neutral: 11%, unconcerned: 11%
Concern about energy payment	Very concerned: 44%, concerned: 35%, neutral: 10%, unconcerned: 11%

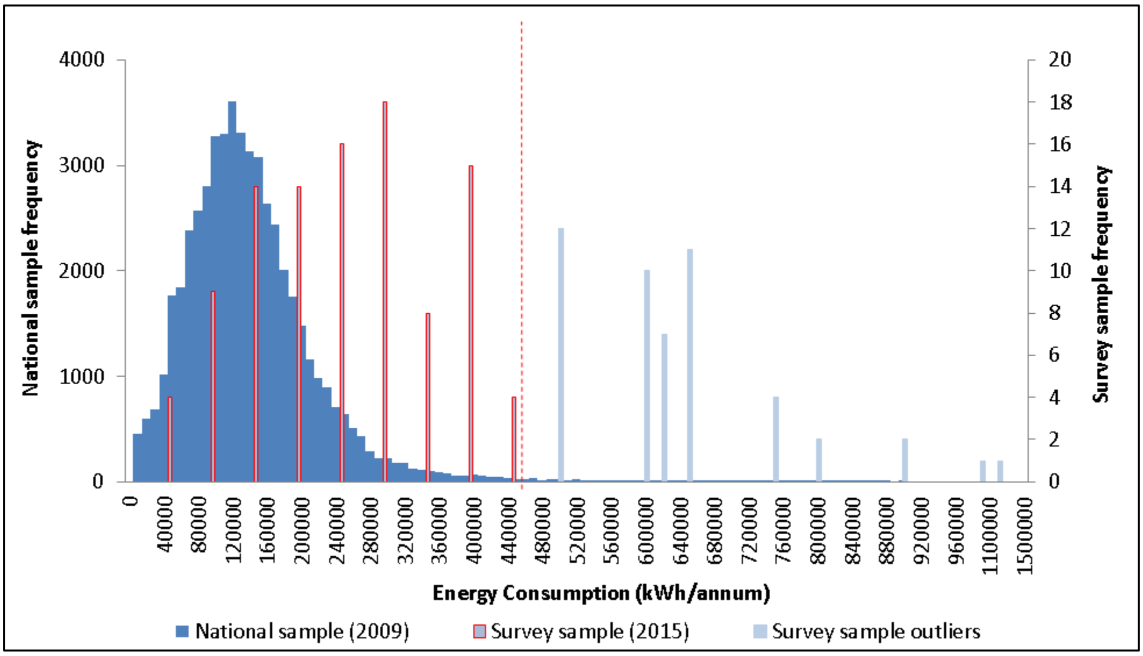


Figure 5.5: Villa yearly electricity consumption: National sample vs. Survey sample

Note: Survey sample responses greater than 450,000 kWh/annum were considered outliers

5.3 Survey result analysis: Regression analysis

A multiple regression was undertaken to determine how much of the variance in energy consumption (the dependant variable) could be explained by different predictor variables. The analysis was performed on two sets of annual electricity consumption data measured in kWh:

1) Original consumption data with outliers (163 cases),

2) Consumption data with outliers removed based on the national statistics (101 responses)

All predictor variables were screened before being input into the model to determine whether they had significant relationships with electricity consumption data. Table 5.9 illustrates the six predictor variables found to be significantly correlated with energy consumption and thus input into the model. Figure 5.6 presents box plots to further illustrate the nature of these relationships. As shown, electricity consumption tended to increase as the number of rooms, number of occupants, villa size (total floor area), and household income increased. In contrast, electricity consumption generally decreased as AC thermostat temperature set points and villa age increased.

Table 5.9: Variable description and correlations with electricity consumption data

Independent variables	Description	Correlation with electricity consumption data	
		Original data: with outliers (163 cases)	Adjusted data: without outliers (101 cases)
Villa age	Categorical rank-order (6 categories)	No correlation	Spearman's rho = -0.284, p-value = 0.004
Number of rooms	Continuous	Pearson's r = 0.208, p-value = 0.004	Pearson's r = 0.421, p-value = 0.000
Villa size (total floor area)	Categorical rank-order (9 categories)	No correlation	Spearman's rho = 0.266, p-value = 0.007
Number of occupants	Continuous	Pearson's r = 0.206, p-value = 0.005	Pearson's r = 0.269, p-value = 0.006
Household income	Categorical rank-order (4 categories)	No correlation	Spearman's rho = 0.295, p-value = 0.003
AC thermostat temperature setting	Continuous	Pearson's r =-0.174, p-value = 0.046	Pearson's r = -0.348, p-value = 0.003

Note: Correlations are significant at the 0.01 level

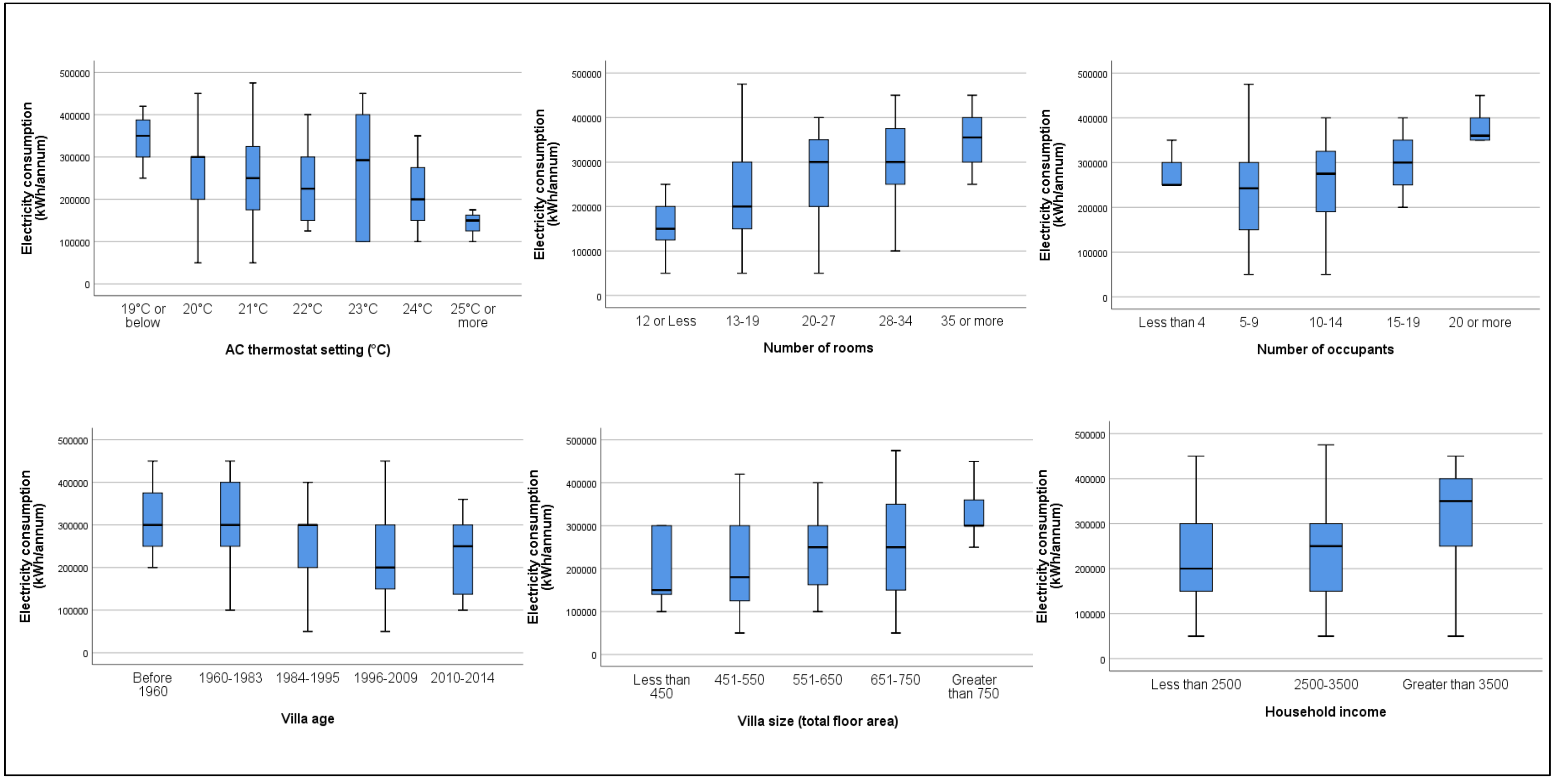


Figure 5.6: Box plots of electricity consumption and different variables measured

Note: electricity consumption data with outliers removed (101 responses)

A regression model was then run, for both sets of electricity consumption data (with and without outliers). The model was significant for both data sets when accounting for AC thermostat temperature setting, number of rooms, and number of occupants; for electricity data with outliers R^2=0.12, and for electricity data without outliers R^2=0.32. For the data set with outliers removed, the variables explained a greater degree of the variance in energy consumption. The adjusted R^2 (a modified version of R^2 adjusted for the number of predictors in a regression model) for the data set without outliers is equal to 0.28, which is close to the R^2 value of 0.32, indicating that the model generalizes fairly well. While it is likely that a greater degree of the variability in energy may have been explained if real metered energy consumption data was used, model findings provide valuable initial insight into potential energy use drivers that can be examined in future studies.

The coefficients of the regression equations (unstandardized betas) indicate the relationship between energy use and each predictor variable as well and the degree to which each predictor affects the outcome (if all other predictors are held constant). For every 1 degree rise in thermostat temperature setting, energy use decreases by 22,000 kWh/annum (approximately 10%) if household size and number of occupants remain constant. The relative contribution of each predictor variable in influencing energy use was further illustrated with the standardized betas. All predictor variables significantly contribute to the model, with thermostat temperature setting having the greatest impact on energy use, followed by the number of rooms and number of occupants (Table 5.10). The number of rooms is believed to be a more accurate measure of dwelling size in this survey because of its numerical form (compared to villa size in m² measured in rank order level), and the likelihood that occupants are more aware of how many rooms they have than their floor area (in m²).

Table 5.10: Linear model of predictors of electricity consumption

	Unstandardized coefficients		Standardized coefficients	Significance		Collinearity
	B	SE B	Beta	t-statistic	P-value	VIF
Constant	221,000	35,400	-		0.000	-
AC thermostat temperature setting	-22,000 (-34,100, -9930)	6,050	-0.378	-3.64	0.001	1.04
Number of rooms	2,950 (563, 5,330)	1,190	0.274	2.47	0.016	1.19
Number of occupants	4,500 (594, 8,400)	1,960	0.258	2.33	0.025	1.22

Note: R^2= 0.316; adjusted R^2=0.284, Durbin Watson = 1.981

95% confidence intervals for B reported in parentheses.

To assess the validity of the model, regression diagnostics were checked. Regression diagnostics are methods used to evaluate model assumptions and detect the presence and impact of potential outliners, and include statistical tests and the visualisation of residuals through scatterplots (Field 2013). Residuals are the differences between the observed value of the dependent variable and the predicted value and should ideally be small and unstructured. Definitions of terminology associated with regression diagnostics, model assumptions and outliers are provided in Appendix F.

Residual statistics for this model show that no case is beyond 2.5 standard residuals, and the values on Cook's Distances all lie well below 1 indicating that no single case is affecting the model as a whole. Similarly, the assumption of independence of residuals is met as no serial correlation was detected between residuals and the Durbin Watson value of 1.981 is very close to 2. All the Variance Inflation Factors (VIF) are less than 5 indicating non-existence of multi-collinearity (correlations) between independent variables. The assumption of normality has also been met and the Kolmogorov Simrnov test showed normality to residuals (P-value=0.20). The assumptions of linearity (between dependant and independent variables) and homoscedasticity (equal variance between data values for dependent and independent variables) are also satisfied as scatter plots of standardised residuals against standardised predicted values revealed no major problems with outliers.

In line with other studies (Huebner et al. 2015; Guerra et al. 2009), the regression model has shown that a greater degree of the variability in energy consumption can be explained when combining both physical and occupant related variables. Although only 31.6% of the variability in energy use was explained, this is deemed reasonable given the complexity associated with household energy use and the current understanding of this, as well as the quality of the reported energy data used in the regression analysis. Previous research has indicated that even when all variables assessing a range of predictor types are used, just under half of the variability in domestic energy use can be explained (Huebner et al. 2015).

5.4 Chapter summary

- The quantitative household survey consisted of a cross-sectional interviewer-administered questionnaire designed to gather detailed information about building physical characteristics, occupants' socio-demographic background and energy-use behaviours.

- The methodology for sample selection attempted to obtain a suitable study sample considering the social norms within Kuwait, which in itself, required a different approach to conducting research.
- Energy consumption for the survey sample was deducted from occupant self-reported bills that were estimated. Such values contain a greater level of uncertainty than actual meter readings recorded by the researcher in the multi-case study (Chapter 6).
- Data analysis consisted of descriptive analysis followed by multiple linear regression analysis using SPSS (version 22) to identify key determinants of energy use in Kuwaiti villas and their relative importance.
- Key findings:
    - The regression model showed that a greater degree of the variability in energy consumption can be explained when combining both physical and occupant related variables.
    - Regression analysis indicates that an occupant driven cooling behaviour (air-conditioning thermostat temperature set points) is the main driver of energy use, followed by the number of rooms and the number of occupants. Together, these variables explain 32% of the variability in energy consumption.
    - Other variables such as villa age, household income, and villa size (in m²) were not found to be significant predictors of energy use in the regression analysis.
    - Descriptive analysis revealed key findings about occupant behaviour likely to be contributing to wasteful consumption, including a tendency among households to leave the cooling switched on during months of the year when external temperature is moderate, or when the villa is unoccupied for prolonged periods, as well as irregular AC maintenance.

Chapter 6: Longitudinal Mixed-Method Multi-Case Study

This chapter begins by describing the methodology adopted for the implementation of the monitoring and surveying methods of the multi-case study. Quantitative and qualitative data collected from each case study is then examined and key findings are drawn.

6.1 Mixed-method multi-case study methodology

6.1.1 Longitudinal monitoring and surveying data collection framework

Figure 6.1 presents the framework for longitudinal monitoring and surveying, which lasted for 12 months to account for seasonal and climatic effects throughout the year. A review of historic utility bills (covering the period between 2011-2014) and floor plans was undertaken prior to the start of monitoring and surveying to obtain basic factual information about each villa. The mixed method approach included:

- Energy use and indoor environmental monitoring – energy consumption was recorded by the researcher through weekly electricity meter readings. This allowed for greater accuracy compared to energy consumption noted in the quantitative survey (Chapter 5) which was based on self-reported electricity bills. Internal and external temperatures were also monitored every 20 minutes, in rooms that made up at least 95% of the volume of the building. Between 15 and 20 Onset HOBO data loggers (model type: U12-012, accuracy: ± 0.35°C (onsetcomp.com) were used per villa (one or two per room). External temperature was also monitored by placing three hobos outdoors (on the roof) in a Stevenson screen.
- Physical survey of building fabric and services - this consisted of a walk-through survey, following the first occupant interview, to inspect and photograph building elements such as walls, windows, number and type of lights, the location and settings of controls, number and type of appliances, AC system power ratings, and hot water tanks. At the same time as the survey, homeowners were asked about specific on-site devices and how they were used.
- Social survey of building occupants - this consisted of two types of qualitative occupant interviews: 1) first occupant interview, prior to the start of monitoring, and 2) a series of

follow-up interviews throughout the monitoring period. The purpose of the interviews and a summary of the schedule are provided in Table 6.1, with full schedules provided in Appendix G and H. All interviews were semi-structured, lasted about one hour and were conducted in the occupants' homes. In designing interview schedules a number of similar studies that have used qualitative interviews to determine the effect of occupant behaviour were reviewed (Chiu et al. 2014; Wall & Crosbie 2009). After the final (12 month) follow-up interview, occupants were asked a couple of concluding questions about what they believe their electricity bill has been over the past year, and how they felt being part of this study and having sensors in their home. All interviews were recorded and transcribed to facilitate analysis.

Table 6.1: Multi-case study occupant interviews (purpose and schedule summary)

	First occupant interview	Follow up interviews
Purpose	To gather background information about household's socio-economic status, building and system characteristics and occupant routines.	To document occupant behaviours and any changes that may have occurred to these during monitoring.
Schedule summary	1. Household background information (Employment, education status, and household income, size and age) 2. Dwelling form and fabric characteristics (building age, room functions, previous refurbishment works, insulation, glazing, and window shading) 3. Space conditioning and hot water use (equipment and operation, control settings) Lighting and household appliance stock) 4. Lighting and appliances use (quantity, location and description) 5. Occupant behaviour (Thermal comfort, thermal control strategies, occupant weekday/weekend routines, system maintenance, concern about energy use and amount paid for energy.)	1. Space conditioning (Cooling/heating, rooms occupants felt were cooler/hotter, window operation, thermal comfort) 2. Occupancy patterns (Effect of weather on lifestyle, time spent indoors, household routine, rooms used the most) 3. Household cleaning and cooking (Use of washing machines, vacuums and reasons for this, number of meals prepared, use of kitchen appliances) 4. Lighting and appliance use (patterns of use and reasons for this) 5. Building systems maintenance (Maintenance of AC and other systems) During follow-up interviews previous plots of monitored temperature, lighting and metered energy data were also presented for discussion.

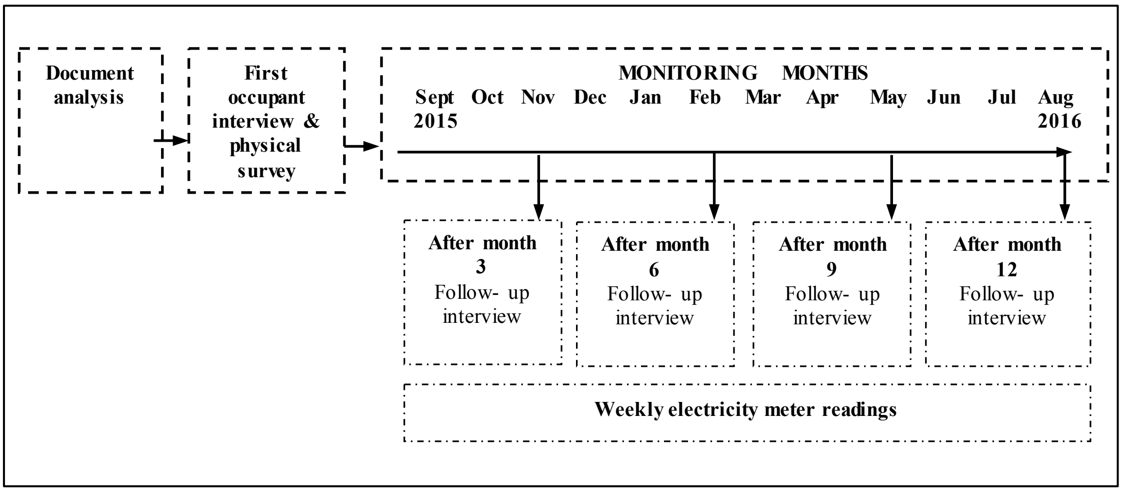


Figure 6.1: Monitoring and surveying data collection framework

6.1.2 Case study sampling strategy

Villas were selected using a maximum variation purposive sampling strategy. This entails the recruitment of a diverse sample based on pre-defined criteria set by the researcher (Saunders et al. 2009). In this study the criteria were defined to ensure that the research question is adequately addressed, and based on findings from both the literature review and cross-sectional quantitative household survey. Criteria included the rationale to increase sample diversity in terms of villa age (a proxy for fabric efficiency), villa size (total built up area), household size (number of occupants and family structure), villa type (private or government built villa) and household income, in order to assess the impact of such factors on energy use. Criteria were classified into primary and secondary; with the primary criteria defining the cases selected and the secondary used to ensure that an appropriate balance exists between cases to enable more informative findings and case comparisons (Table 6.2). While the objective was to examine different types of villas, care was also taken to ensure all fell within the norm (of typical villas in Kuwait) in terms of general form and fabric, building services, and household size, based on findings from the quantitative household survey in Chapter 5 and those reported in De Wolf et al. (2017).

Table 6.2: Case study selection criteria

	Classification	Rationale
Primary criteria		
Villa age	Pre – 1983 code Post – 1983 code	This criterion is a proxy for fabric efficiency as it accounts for the timing of enforcement of the MEW 1983 code.
Villa size	Less than 600m² Greater than 600m²	This criterion allows for an assessment of building size on energy use especially as municipality codes have allowed for large increases in villa sizes over the past 30 years and 74 % of villas are primarily centrally cooled (quantitative household survey)
Household size and structure	Working couple with kids Retired couple Extended family	This criterion allows for an examination of occupants (routines and requirements) by ensuring a mix of occupant types exists between cases.
Secondary criteria		
Villa type	Private Government	This criterion is considered on a secondary level as all villas are required to abide by the same energy and building codes.
Household income	Less than 2,500 KWD/month Greater than 2,500 KWD/month	This criterion provides an indication of the economic standard of households. Although energy tariffs are very low at present, understanding how different income households consume energy would provide valuable information to assess the impact of future tariff changes on different sectors of society.

A sample size of four villas was deemed appropriate to ensure sufficient examination within the time and resource constraints of a PhD. Three of the four villas were recruited from the sample of 250 villas that formed part of the larger household survey of this research. The fourth villa is the pilot study villa (Section 4.4.1). This villa was selected for several reasons:

- The process of contacting appropriate villas from the larger household survey was very time-consuming and resulted in a significant number of blank responses. This was largely due to the sensitive socio-cultural environment in Kuwait and unwillingness of many households to participate in the full 12 month monitoring and surveying study.
- The pilot villa fit the criteria required
- The household representative of the pilot villa was well aware of the study (devices and document requirements) and was willing to participate and collaborate.

Figure 6.2 illustrates the location of the different case study villas. Villa plots and floor plans are presented in Figures 6.3-6.5. Tables 6.3-6.5 also describe key villa characteristics, which ranged from older (pre-1983 code) uninsulated and single glazed buildings to newer (post-1983 code) insulated and double-glazed buildings. All villas consisted of a reinforced concrete skeleton of beams and columns with non-load bearing concrete walls. Household occupants varied from a retired couple to larger families with young and/or grown-up children. As is common in Kuwait, all villas are centrally cooled throughout, via a number of packaged direct expansion air conditioning (AC) units with air cooled condensers. Each packaged unit (located outdoors on the rooftop) serves a number of rooms and is controlled by a single thermostat (located in only one of the rooms being cooled). Split units, which work on a room by room basis, are primarily used in staff bedrooms and the main external kitchen. During winter AC units were not used for heating in any of the villas, despite some having a heating setting.

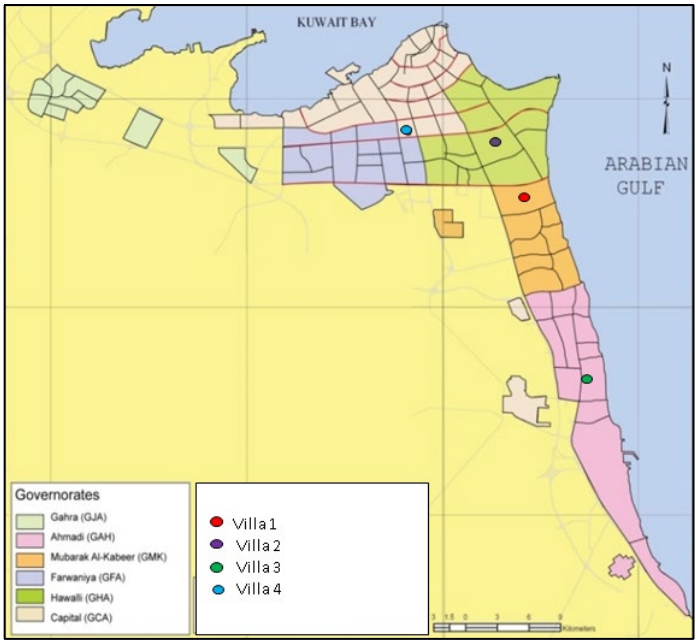


Figure 6.2: A map illustrating the location of the different case study villas

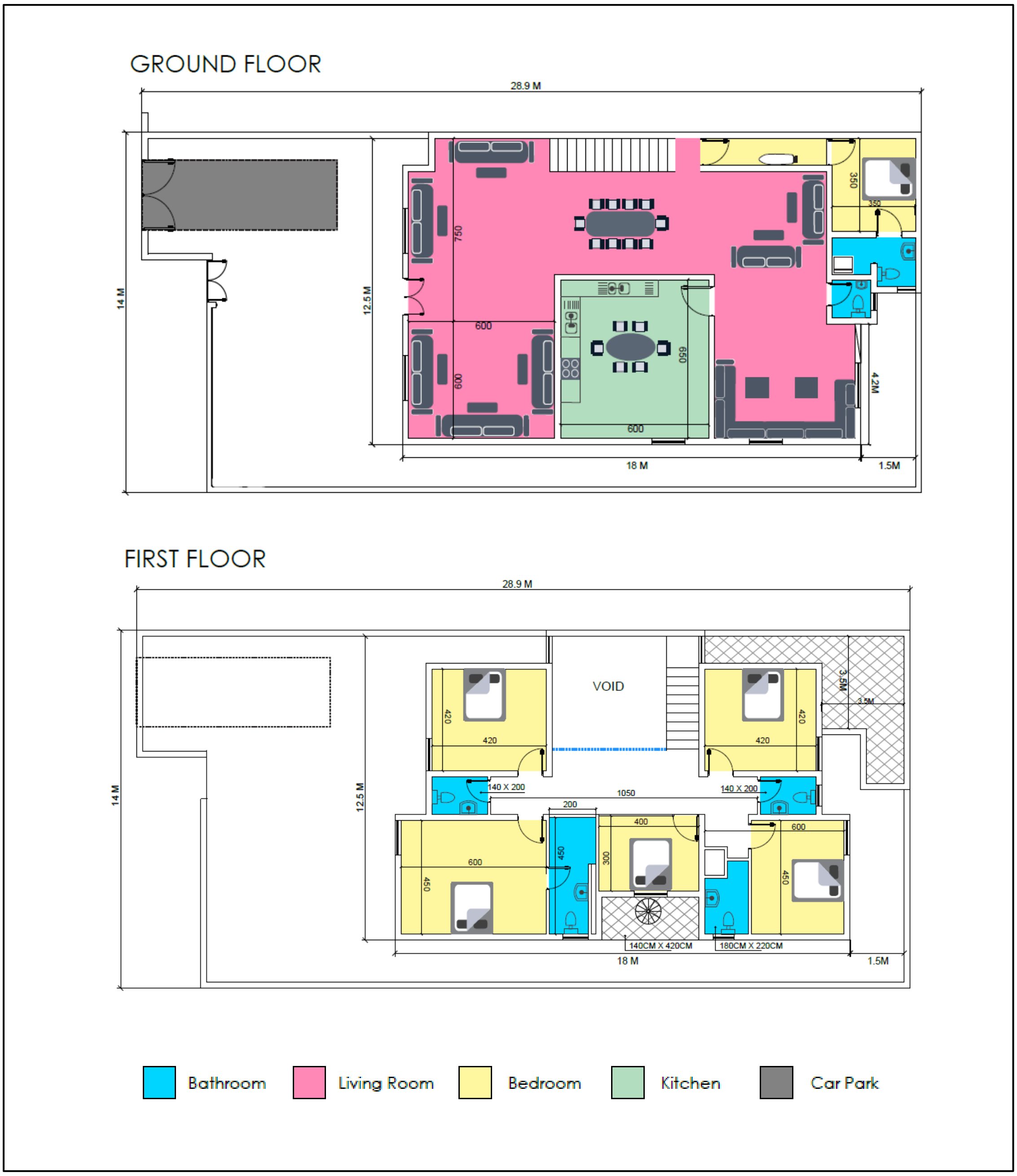


Figure 6.3: Villa 1 plots and floor plans

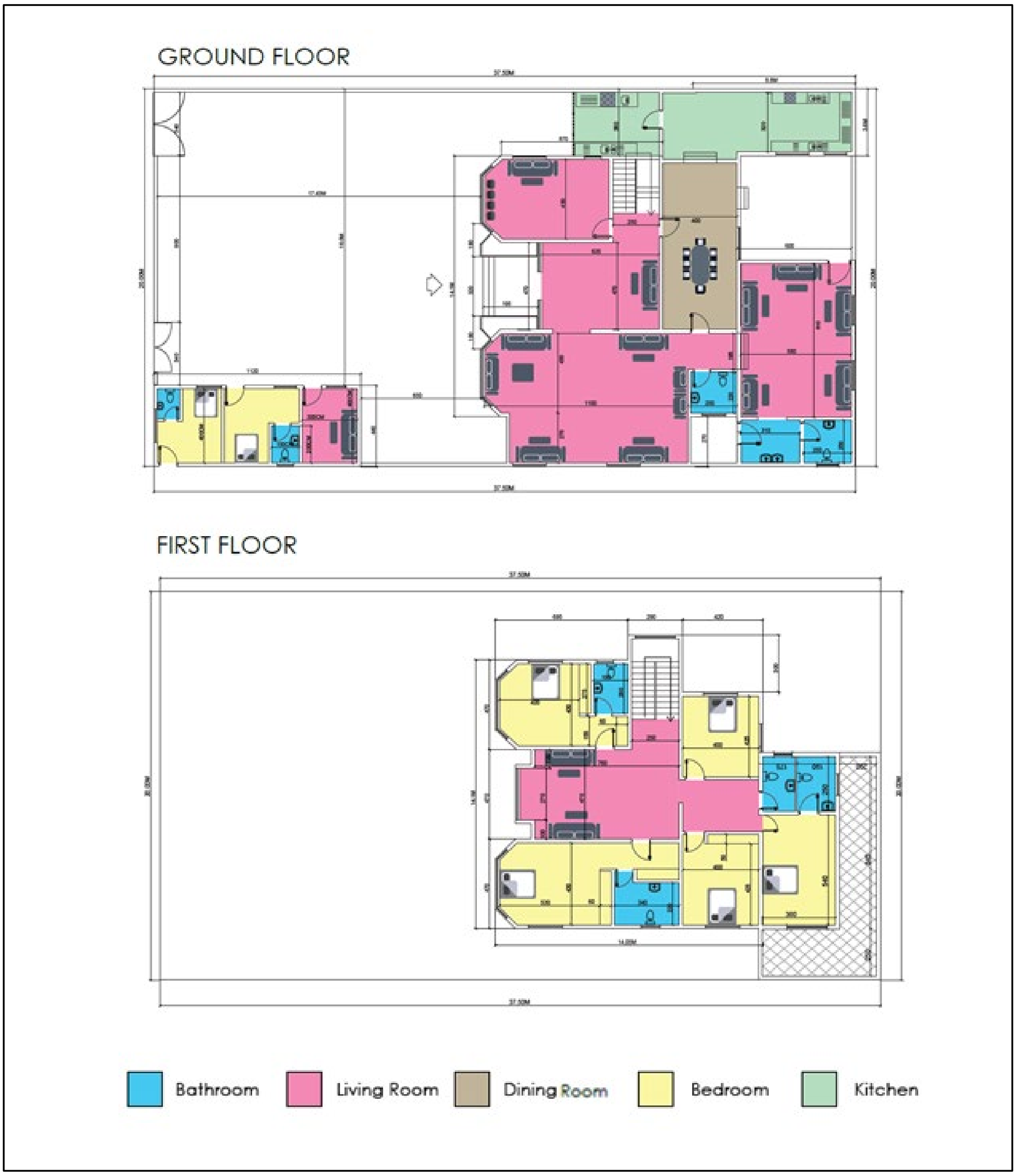


Figure 6.4: Villa 2 plots and floor plans

Figure 6.5: Villa 3 plots and floor plans

Figure 6.6: Villa 4 plots and floor plans

Table 6.3: Main characteristics of case study villas

	Villa 1	Villa 2	Villa 3	Villa 4
Occupant description	Middle aged working couple with four children aged between 8-16 years, two female staff, one male driver	Retired couple with one working adult son, two female staff and one male driver	Young couple (working husband and housewife) three children aged 6 months– 7 years, and two female staff	Middle-aged working couple, two teenage children, an aunt, an elderly grandmother, two female staff, one nurse, and three male staff.
Number of occupants	9	6	7	12
Year of construction	1982	1981	2010	1999
Villa type	Government	Private	Private	Private
Tenure	Bought by existing homeowners in 2011	Built and owned by existing homeowners	Built and owned by existing homeowners	Bought as a new build in 2000
Plot size (m²)	400	750	375	400
Internal floor area (m²)	397	568	705	809
Number of floors	2	2	3	4 (one of which is a basement)
Household income (monthly)	2,300 KWD ($7,611)	2,700 KWD ($8,934)	1,500 KWD ($4,963)	3,000 KWD ($9,926)
Villa renovations/ extensions	New central AC packaged units installed in 2013 to recent 2010 MEW code standards	Ground floor family living room, bedroom 3, external kitchen, dining room and staff bedrooms were built as later extensions in the mid 1990's to pre 1983 code standards.	None	None

Note: conversions to US dollars based on rates as of June 6, 2018 (1KWD=$3.31)

Table 6.4: Air-conditioning system characteristics of case study villas

System		Villa 1	Villa 2	Villa 3	Villa 4
Air Conditioning (AC)	**Number of central units**	2 (1 for ground floor and 1 for first floor) Each unit controlled by 1 digital thermostat	4 (2 for ground floor and 2 for first floor) Each unit controlled by 1 analogue thermostat	5 (2 for ground floor, 2 for first floor, 1 for second floor) Each unit controlled by 1 digital thermostat	5 (1 for basement, 2 for ground floor, 2 for first floor) Each unit controlled by 1 analogue thermostat
	Central AC installation year	2014	1981	2010	1999
	Number of split units	1 (in staff bedroom)	7 (in staff bedrooms, family living room, dining room, main kitchen, bedroom 2 & 3)	3 (in staff bedroom & main external kitchen)	6 (in staff bedrooms, ironing room, main kitchen & bedroom 6)
	Split unit installation year	Unit installed in the late 1980's before the current homeowners bought the villa in 2011.	Family living room, main kitchen, dining room & bedroom 3 units installed in 1995. Staff units installed in 2000. Bedroom 2 unit installed in 2015	Installed in 2010	Staff units installed since 1999. Kitchen units installed in 2002. Bedroom 6 unit installed in 2015
	Total AC cooling capacity (kW)	63	95	109	137
	Central AC cooling capacity (kW)	56	56	95	105
	Split unit cooling capacity (kW)	7	39	14	32

Note: AC units were found to be oversized by 40-60% when compared to simulated AC units calculated from the energy models of each case study villa in Chapter 7, table 7.7. In Kuwait it is common for AC units to be oversized to ensure rapid cooling and to accommodate for increases in internal heat gains.

Table 6.5: Space heating, hot water and lighting system characteristics of case study villas

System		Villa 1	Villa 2	Villa 3	Villa 4
Space Heating	Type	No heating used	3-4 portable oil-filled electric heaters	3 portable oil-filled electric heaters	4-5 portable oil-filled electric heaters
	Location		Family living room, bedroom 2 & 3 and female staff bedroom	Bedroom 2 & 3, family living room	Bedrooms 2, 3 & 4, and female staff bedroom
	Power rating (W)		1500W	1300W	800W
Hot water	Type	Central tank	Central tank	Local tanks	Central tank
	Installation year	2012	1981	2010	in 1999
	Location	Roof	Roof	In cabinets above local usage points	Roof
Lighting	Number and type of bulbs	80 bulbs (60 LEDs & CFLs; 20 incandescent)	100 bulbs (65 LED & CFL; 35 incandescent)	150 bulbs (110 LED & CFL; 40 incandescent)	200 bulbs (90 LED & CFL; 110 incandescent)
	Power rating (W)	LED & CFL: 10W Incandescent: 60W	LED & CFL: 15W Incandescent: 60W	LED & CFL: 15W Incandescent: 60W	LED & CFL: 15W Incandescent: 60W
	Lighting load intensity (W/m²)	4.5	5.4	5.7	9.8

6.1.3 Multi-case study data analysis

Descriptive statistical analysis methods were used in the analysis of the quantitative elements of the multi-case study (energy and temperature data). Relevant statistics applied include the summarisation and comparison of data numerically using measures of central tendency (mean, median and mode) and dispersion (standard deviation). This was undertaken using Microsoft Excel, with the aid of MACROS (codes) for data organisation. Data frameworks were established for each case to organise data input and facilitate like-for-like case comparisons.

As explained in Section 4.4.1, while internal temperature, relative humidity and lighting were all monitored simultaneously, the researcher made the decision to focus on internal temperature in the analysis (considering its relative importance in the context of the Kuwaiti climate in which summers are very hot but dry - with average temperatures in excess of 35°C and average relative humidity ranging between 15% and 20% – Figure 2.2). Monitored lighting levels were only briefly analysed largely to complement data reported by occupants during follow-up interviews, while relative humidity data was only checked.

Internal temperatures in different rooms during summer months were compared with those during winter months to determine any patterns and standard deviations were calculated. Interesting observations were noted and discussed during follow-up interviews which allowed for the opportunity to explore whether certain reported behaviours explain overall differences in energy use between villas. Indoor temperature data was also compared with monitored external temperatures as well as metered energy consumption for each villa, individually and as a group, with various scatter plots drawn. To provide a more accurate estimate of average internal temperatures in each villa, average volume weighted internal temperatures were calculated to account for differences in room volumes.

For the qualitative data, the approach for analysis involved the summarisation and categorisation of data to support meaningful analysis as described in Section 4.3.1.2. Key themes and patterns in the data were identified following repetitive behaviours mentioned in each follow-up interview such as cooling during periods of travel, AC maintenance, and heating/cooling for certain occupant types. Once all qualitative data was collected, a final summary of key occupant energy consuming behaviours was tabulated, and a discussion of their relative impact on energy use was made under key categories that represented key themes. Relevant quotes are included as evidence within the discussion. No qualitative software was used; analysis was undertaken manually as explained in Section 4.3.1.2.

To facilitate interpretation of quantitative data in context of the qualitative data and vice versa, monitored and surveyed data was downloaded and analysed every three months. The results of this analysis are presented under three main sections below: measured energy consumption, indoor air temperature and occupant impact.

6.2 Multi-case study result analysis and discussion

Within each villa, energy consumption is driven by a unique and dynamic interaction between the building fabric, its systems and occupants. The sections below will examine key findings under the following three headings:

- Measured energy consumption
- Indoor air temperature
- The impact of occupants on energy use

6.2.1 Measured energy consumption

Annual energy (electricity) consumption comprises the annual cooling, heating, lighting, appliance, hot water and auxiliary energy used to drive HVAC system performance.

Table 6.6 and Figure 6.7 present the annual and seasonal metered energy consumption of each villa (measured in kWh), normalised by floor area and number of occupants. In all villas energy use (kWh/m² and kWh/m²/occupant) was highest during the summer and lowest during the winter, indicating the strong impact of AC cooling on overall energy consumption, particularly as villas are centrally cooled throughout in summer (including unused spaces/rooms), while in winter, heating (via portable electric heaters) was used only intermittently and only in some occupied room (as discussed in Section 6.2.3).

Comparing individual villas, it was found that energy use intensities (kWh/m²) and energy use normalised by occupants (kWh/m²/occupant) in villas 1 and 4 were both relatively higher during the winter and lower during the summer compared to villas 2 and 3. This suggests that, in addition to central cooling, other factors are important in driving energy use in villas 1 and 4, including appliance use and hot water. Villa 1, in particular, had more stable energy use (kWh/m² and kWh/m²/occupant) throughout the year compared to the other villas. Some explanations for such consumption were partly sought during occupant interviews, which indicated that villa 1 occupants spent much more time at home during winter, using many appliances throughout the day including kitchen appliances, mobile and tablet chargers, TVs, as well as electrical lighting. Similarly, relatively lower summer energy use is, to some extent, due to villa 1 homeowners increasing thermostat settings by 1°C for one month during a family holiday in July (unlike in other households where no thermostat adjustments were made during summer travel).

Table 6.6: Seasonal and annual metered energy consumption in the case study villas throughout the entire monitoring period (September 2015-August 2016))

	Villa1		Villa2		Villa3		Villa4	
Measured annual energy use (kWh)	86,943		97,128		122,670		182,025	
Internal floor area (m²)	397		568		705		809	
Number of occupants	9		6		7		12	
	Villa1		**Villa2**		**Villa3**		**Villa4**	
	kWh/ m²	**kWh/m²/ occupant**	**kWh/ m²**	**kWh/m²/ occupant**	**kWh/ m²**	**kWh/m²/ occupant**	**kWh/ m²**	**kWh/m²/ occupant**
Annual energy use	219	24	171	29	174	25	225	19
Autumn (Sept-Nov)	52	5.7	31	5.2	43	6.1	51	4.3
Winter (Dec-Feb)	47	5.2	13	2.2	16	2.3	35	2.9
Spring (Mar-May)	54	6.0	34	5.7	38	5.4	52	4.3
Summer (Jun-Aug)	62	6.9	81	14	73	10	81	6.8

Note: In all villas the central AC was switched off at the end of November and switched back on at the start of March

Figure 6.7: Variation in weekly metered energy consumption in the different villas

6.2.2 Indoor air temperature

The combination of other strands of data including internal temperature enabled further exploration of the drivers of energy use. Figure 6.8 illustrates the average volume weighted internal temperatures of each villa throughout the year indicating when the AC was switched ON and OFF. This includes all measured internal and external temperature data including when occupants were away on vacation. The same graph excluding the time periods occupants were away on vacation is presented in Appendix I, and a table illustrating the extent to which average internal temperatures may have varied if they were based on data from only one room rather than all villa rooms, is presented in Appendix J.

In general, when the AC was switched ON (during summer, spring and autumn), internal temperatures remained relatively stable in all villas despite wide differences between external and internal temperatures. Villa 2's internal temperature had a higher degree of variability than other villas possibly due to its older inefficient central AC units and greater number of split units, more likely to be used intermittently than central cooling (which is controlled to operate continuously). In villa 1, increased variability observed specifically during higher external temperatures is due to homeowners increasing central AC thermostats by 1°C for one month during a family vacation in July and reducing them back down in August. Internal temperatures in the older uninsulated and single glazed villas (1 and 2) were also found to be higher than in the newer insulated and double-glazed villas (3 and 4) when the AC was switched ON. This, is due in part to homeowners in older villas using higher thermostat set points (as indicated in Table 6.7 below), may also be due to increased heat gains into the building through infiltration and the fabric.

In contrast, during winter, when the AC was switched off, newer villas had higher internal temperatures than older villas, which again could be due to electric heating and incidental heat gains (occupancy, solar, appliance gains) being retained more effectively within the building fabric. Interestingly, Figure 6.8 shows that for several days in winter, villas 1 and 2 had average internal temperatures below the generally recommended threshold of 18°C for health set by the World Health Organization (WHO, 1987). In villa 2 in particular, there were 49 days when internal temperatures were below 18°C, while in villa 1, 9 days were below this threshold. During the three month follow-up interview (in December 2015 – Appendix H), homeowners in these villas both indicated they felt '*very cold*' inside their homes, while those in villas 3 and 4 felt '*neutral'*. As noted in Table 6.5 above, heating, in the form of portable electric heaters, was used intermittently in some rooms in villas 2, 3 and 4 during the coldest days in December and January (Table 6.5), while in villa 1 no heating was used with the homeowner explaining that they "*rather wear clothes and blankets"* as electric heaters, in their opinion, are *"not safe"*.

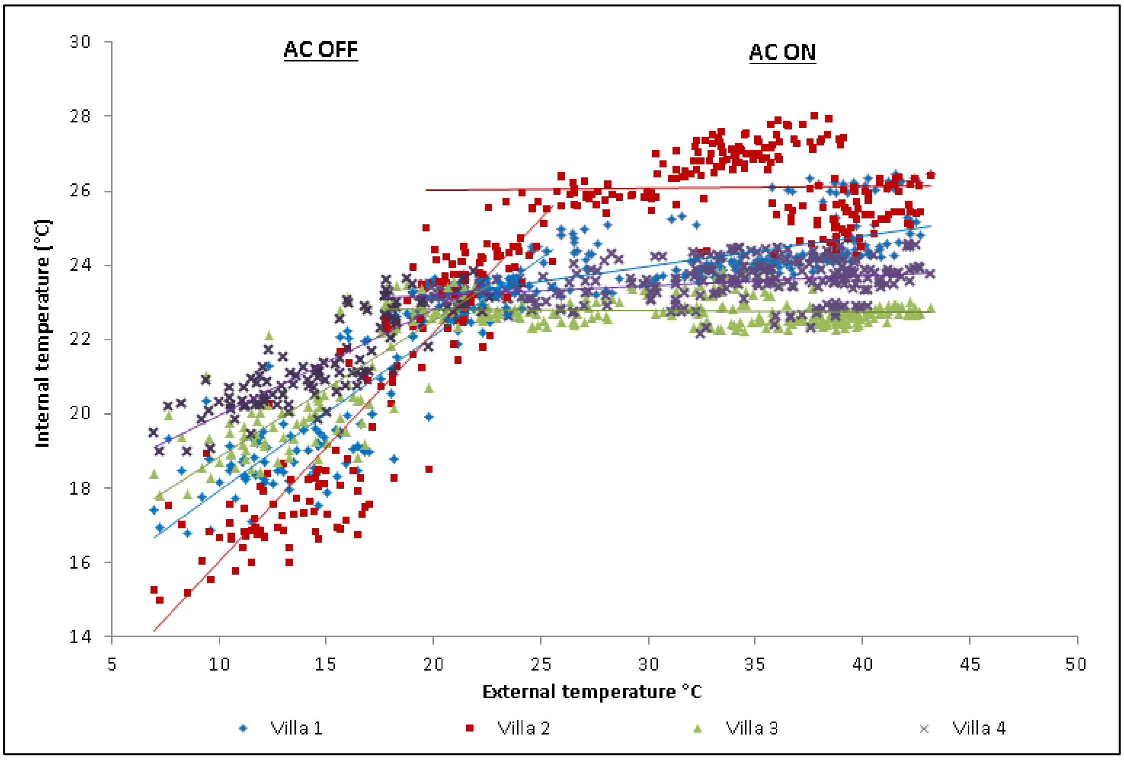


Figure 6.8: Daily average volume weighted internal temperatures vs. external temperature thoroughout the entire monitoring period, indicating when the AC is switched ON and OFF

Figure 6.9 shows the variation of average summer and winter internal temperatures of individual rooms. Bedrooms (with exception to staff bedrooms and bedroom 2 in villa 4), were cooler during summer and warmer during winter compared to other rooms. In the 9 months follow up interview and physical survey it was noted that homeowners in villa 4 set the thermostat in bedroom 2 (which simultaneously controls cooling in bedroom 2 and the main kitchen) to higher settings (25.5°C), as the room is used by an elderly, bed-ridden occupant who requires and prefers warmer temperatures. This also led villa 4 homeowners to install two split units in the main kitchen to provide additional cooling in that space. Similarly, all staff bedrooms were relatively warmer during summer as they are intermittently cooled by split units, are close to sources of heat gain i.e. washing machine/ironing facilities, and (in villas 3 and 4) located on the roof. During winter, bedrooms were generally warmer as electric heaters were used more in these spaces compared to the rest of the villa. Furthermore, comparing room temperatures during summer and winter, greater fluctuations were noticed between rooms in villas 2 and 4. In villa 2 this is potentially due to many split units used throughout the newer extensions, while in villa 4 fluctuations between rooms can be attributed to a diverse occupant age group with different requirements for thermal comfort (middle aged homeowners and teenage children prefer cooler temperatures in their first floor bedrooms and living space, while an elderly occupant prefers warmer temperatures in the ground floor).

To indicate the degree of variation within rooms, Figure 6.10 presents the standard deviations of temperature during summer and winter. In all villas, internal temperatures in rooms (with exception to staff bedrooms and bedroom 3 in villa 2 coold by split units) were more stable during summer when the central AC was swtiched on, than during winter, as indicated by lower standard deviation values of approximelty 0.2°C to 1.2°C in summer. Most rooms in newer (post-1983 code) villas also had lower standard deviations of temperature compared to rooms in older (pre-1983 code) villas during both summer and winter, suggesting that measures such as fabric insulation and double glazing are likely to be contributing to more unifrom internal temperatures.

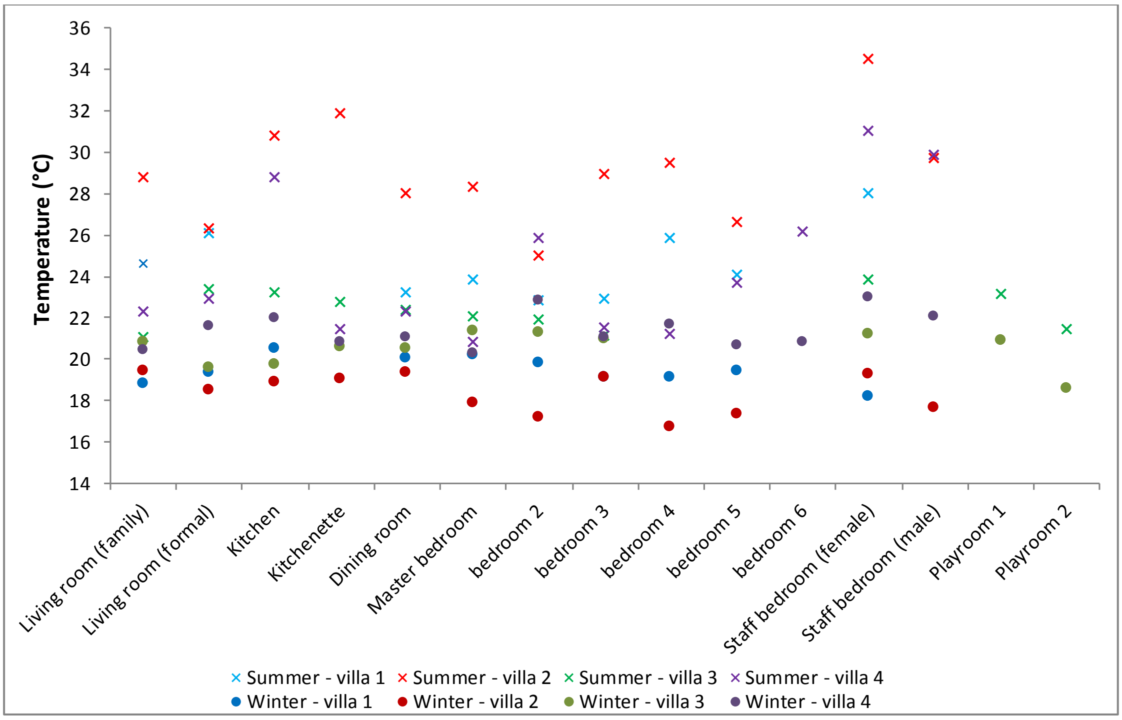


Figure 6.9: Average room temperatures during summer (June, July, August) and winter (December, January, February)

Note: Rooms present in each villa are specifically marked, i.e. only villa 4 has a bedroom 6

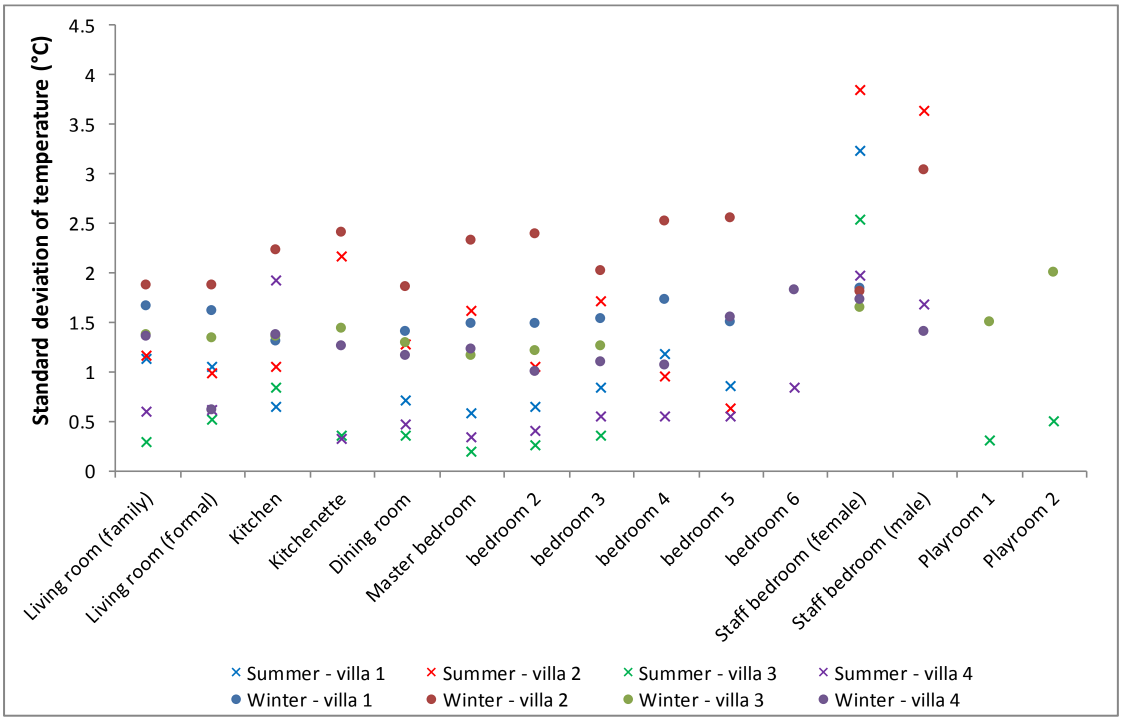


Figure 6.10: Standard deviations of temperatures in individual rooms during summer (June, July, August) and winter (December, January, February)

Furthermore, to examine whether central units were delivering what they were expected to (as per thermostat settings), the percentage of time room temperatures fell within thermostat set points (+/- °C) is presented in Table 6.7. Generally, more disparity was found in the internal temperatures of rooms in villa 2, compared to villas 1, 3 and 4, which is likely due to the very old and inefficient central units and thermostats in this villa. Several rooms in villas 1, 3, and 4 also had higher temperatures than thermostat set points for a relatively large percent of time; in particular bedroom 4 in villa 1, the master bedroom in villa 3, and the kitchen, bedrooms 5 and 6 in villa 4. Such variation could be due to a number of reasons including higher internal heat gains from equipment (as is possibly the case in the kitchen of villa 4), higher solar heat gains (bedroom 4 in villa 1 and the master bedroom in villa 3 both have relatively larger window openings) and/or improper balancing of the AC system (i.e. improper airflow delivery through the ductwork).

Table 6.7: Percentage of time internal temperatures were within thermostat set points in case study villas during summer (June-August)

Central AC unit	Thermostat set point (°C)	Rooms cooled	Percentage of time temp. was within set point (+/- 1°C)(%)
Villa 1			
Unit 1		Kitchen	68
	23 →	Dining room	71
		Living room (family)	21
		Living room (formal)	34
Unit 2		Master bedroom	65
		Bedroom 2	66
	23 →	Corridor	70
		Bedroom 3	89
		Bedroom 4	3
		Bedroom 5	59
Villa 2			
Unit 1	25 →	Living room (formal)	49
Unit 2		Kitchenette	0
	25 →	Dining room	12
Unit 3	25 →	Master bedroom	1
		Bedroom 4	0
Unit 4		Bedroom 2	78
	25 →	Bedroom 5	44
Villa 3			
Unit 1		Kitchenette	100
	21 →	Living room (family)	100
		Bedroom 3	100
Unit 2		Master bedroom	42
	21 →	Bedroom 2	62
Unit 3		Dining room	100
	23 →	Living room (formal)	79
Unit 4	23 →	Playroom 1 (ground floor)	65
Unit 5	22 →	Playroom 2 (second floor)	100
Villa 4			
Unit 1	23 →	Living room (formal)	79
Unit 2		Dining room	100
	23 →	Living room (family)	98
Unit 3		Kitchen	4
	25 →	Bedroom 2	63
Unit 4		Bedroom 5	1
	21 →	Master bedroom	99
		Kitchenette	96
Unit 5		Bedroom 3	76
	21 →	Bedroom 4	94
		Bedroom 6	0

Note: in all villas, all central units were set to operate all day and night (with no time clock control) and thermostat fan set to automatic. Arrows in the table indicate in which room the unit thermostat (controlling the unit) is located.

6.2.3 The impact of occupants on energy use

The impact of occupants on energy use, including household size (number of occupants), household income, and occupant energy-use behaviours are described in Sections 6.2.3.1 and 6.2.3.2 below. Section 6.2.3.3 briefly discusses some variations found between actual and reported occupant perceptions and behaviours.

6.2.3.1 Household size and household income

As shown in Table 6.8, villas with more occupants (villas 1 and 4) had higher annual energy use intensities, higher energy use intensities during periods when the AC was switched off, as well as higher plug load intensities. Although data from a greater sample of cases is required to better determine the impact of household size on energy use, such findings suggest a positive association between the two. Regarding household income, no clear association with energy use was detected when comparing the four villas. The percentage of income spent on energy in each villa however was found to be relatively low (less than 1.4%, see Table 6.8), when compared with UK households that spend on average 4.4% of their total expenditure on energy in 2015 (Ofgem 2017). Low energy expenditure is likely due to the highly subsidized electricity tariffs and high income [average UK household income is about £28,400 (ONS, 2018)], which enable households to afford the running costs associated with high appliance use.

Table 6.8: Household size and income parameters

	Villa 1	Villa 2	Villa 3	Villa 4
Number of occupants	9	6	7	12
Plug load intensity (W/m2)	29.1	9.5	16.4	21.4
Annual energy use (kWh/m²)	211	171	173	225
Average energy use per week when AC switched off (kWh/m²/week)	3.5	0.9	1.4	2.6
Annual electricity bill (KWD)	174 ($576)	194 ($642)	245 ($811)	363 ($1,202)
Annual household income (KWD)	27,600 ($91,356)	32,400 ($107,244)	18,000 ($59,580)	36,000 ($119,160)
Percentage of income spent on energy (%)	0.6	0.6	1.4	1.0

Note: conversions to US dollars based on rates as of June 6, 2018 (1KWD=$3.31)

6.2.3.2 Occupant energy consuming behaviours

Regarding occupant energy consuming behaviours, key findings are summarised in Table 6.9, and discussed below.

AC operation and control

All households switched their central AC units on for about 7-9 months of the year even when outdoor conditions were relatively mild (from March till May and September till November), and units were controlled to operate continuously with no time clock control. Occupants in villas 2 and 4 also tended to open windows during milder weather periods, a behaviour likely to affect AC performance and energy use. Similarly, during periods of travel when most occupants vacated the building, homeowners, with exception to those in villa 1, made no adjustments to their central AC thermostat settings (leaving cooling on all day at the same set points). In villa 1, increasing thermostats by 1°C during a one month holiday in July contributed to the reduction in energy use that month compared to June and August; July consumption was about 37% and 39% lower than in June and August respectively, due both to lower thermostat settings and no appliance and lighting use that month. Reducing appliance use in summer has a double effect on energy use; it directly reduces electricity use, but also reduces heat gains and so reduces cooling energy use by the AC. Thermostat adjustments during periods of travel, is a behaviour likely to be influenced by the structure of the household; villas 1 consists of a working couple with younger children that travel together, whereas villas 2 and 4 in particular consist of more diverse families with different travel routines (such villas are rarely empty at any given time). Similarly the duration of travel may also influence such behaviour; occupants in villa 3, did not travel for more than a week throughout the monitoring period, and were perhaps not motivated to adjust thermostats.

Regarding the use of split units, which are largely located in staff bedrooms, it was observed that as external temperatures increased in summer, staff in all villas, tended to keep units switched on almost all day (even when rooms are unoccupied). Temperatures recorded in these rooms were also found to be notably higher than the temperature the split unit was set to. This was especially the case in villas 1, 2, and 4, which had relatively older split units, which were also possibly undersized (thus unable to deliver the required cooling). Split units were also used in the main kitchens in villas 2, 3, and 4. During summer in villa 3, the units were operated on a 24-hour basis with the homeowner explaining that "*when it's hot outside the kitchen units are always on, even at night. We have things in there we don't want to spoil*". In this context, the homeowner was referring to foods such as rice, pasta, potatoes, cereals (stored outside the fridge, mostly in plastic containers), suggesting that they are, in effect, using their kitchen as a large pantry. Kitchen units in villas 2 and 4 however were switched off in the late evenings by staff.

AC maintenance

None of the households undertook regular servicing, instead servicing was only done once a problem had occurred with the AC plant. Homeowners in villas 1, 2 and 4 also opted to clean their AC external filters themselves before first operating their central units in spring rather than call a professional to do this. Such behaviour may have led to AC defects remaining undetected, especially as all homeowners reported that, within a few weeks of operation, technicians were called in to fix some developing problems. Although all homeowners were able to notice when there was a problem with their AC, they generally did not understand what the solution was and were happy as long as it was rapidly fixed. For example, in villa 4 the homeowner explained that "I *think it was the thermostat or something minor…it was a consumer piece that they changed*", and in villa 1 the homeowners noted that "*we think it was a fuse in the system*". In villa 2, which had the oldest AC units (almost 35 years old), the homeowner described how "*thermostats have to be set to 25-26°C…anything lower causes the system to shut down*".

Household cleaning and appliance use

In all villas, as is common in Kuwait, staff are responsible for household cleaning and cooking activities, all of which require the use of energy consuming appliances such as washing machines, dryers etc. Both household size and a strong desire for comfort and convenience are likely to impact on the frequency of household chores and appliances use. In villa 4 for example, which has the highest number of occupants, laundry is carried out daily for several hours with homeowners noting that "*we like our clothes ready quick…We also don't like wearing new clothes without washing them first".* Similarly in villa 1, which has four teenage children, appliance use is relatively high, with homeowner stating that *"when the kids are home the downstairs TV is always on, all day sometimes… and their mobile, tablet and lap top chargers are always plugged in. Kitchen equipment, the kettle, toaster are also used countless times!*"

Table 6.10 further presents a breakdown of plug loads for appliances in each villa. Typical daily appliance usage schedules (plug load schedules) which were input into individual energy models (in Chapter 7) of each case study villa are presented in appendix L3. Schedules were based on data collected during the physical survey (at the start of monitoring) and occupant follow-up interviews. During follow-up interviews in particular, it was found that occupants (in all villas) tended to use appliances more in winter than summer. This is because occupants spent more time at home in winter and also due to the use of electric plug-in heaters in some rooms.

Lighting use and control

In villas 1 and 4, occupants tended to switch lights on during the day, which as explained by homeowners during the interviews, is due to limited daylight in the building. A brief lighting analysis (Appendix K) found that villas 1 and 4 were relatively darker than villas 2 and 3, presumably because such villas have more dense, cubic shapes and are in very close proximity to adjacent villas compared to villas 2 and 3 which are well setback from neighboring villas, have larger windows and more natural daylight. During the evenings, all villas, with exception to villa 2, tended to use lights generously even in some unoccupied rooms/spaces. Homeowners in all villas (except villa 4) also tended to use more energy efficient bulbs (LED's and CFL's) than incandescent bulbs throughout their homes as indicated in Table 6.5 above.

Table 6.9: A summary of key occupant energy consuming behaviours

	Villa 1	Villa 2	Villa 3	Villa 4
AC period of operation	8 months (Mar-Oct)	8months (Mar-Oct)	8 months (Mar-Oct)	9 months (End of Feb-mid Nov)
Central AC thermostat settings during operation (when occupants present)	All thermostats set to automatic at 23°C.	All thermostats set to automatic at 25°C	Thermostats set to automatic at 23°C (ground floor), 21°C (first floor) and 22°C (second floor).	Thermostat set to automatic at 21°C (first floor), 23°C (basement and half of ground floor) and 25°C (half of ground floor).
Split unit AC control during periods of operation (when occupants present)	Unit in staff bedroom switched on when room is occupied only but during summer unit often left on when room is vacant. Settings ranged from 18-21°C	Units switched on when rooms are occupied. During summer units often left on when rooms are vacant. Settings ranged from 19-21°C	Unit in staff bedroom often left on when room is vacant. Kitchen unit always on even when vacant (at night). Settings ranged from 20-22°C	Units switched on when rooms are occupied. During summer units often left on when rooms are vacant. Settings ranged from 19-22°C
Time main occupants vacated their villa for travel during the year	4 weeks (in July)	6 weeks (mid-July till end of August)	1 week (mid-August)	3 weeks (mid-August till end of August)
Number of occupants in villa after main occupants vacated	None	1 male household staff	None	2 household occupants and 6 household staff
AC control during periods of travel (when main occupants vacated building)	Central AC thermostat increased by 1°C in July to 24°C and back down to 23°C in August. Staff split unit switched off.	Central AC thermostat left unchanged at 25°C throughout. All split units switched off.	Central AC thermostat left unchanged at 21– 23°C. All split units switched off.	Central AC thermostat left unchanged at 21 -25°C. Split units operated as normal as many occupants remained at home.
Window and curtain control	Windows not opened when AC on. Curtains pulled down in most rooms during the summer.	Windows often opened in spring and autumn (even when AC on). Curtains pulled down in unoccupied rooms during the summer.	Windows not opened when AC on. Curtains pulled down in unoccupied rooms during the summer.	Windows often opened in spring and autumn (even when AC on). Curtains pulled down in unoccupied rooms during the summer.
AC maintenance	AC filters cleaned before AC operation in spring. Irregular servicing during period of operation.	AC filters cleaned before AC operation in spring. Irregular servicing during period of operation.	AC filters cleaned one month after AC operation. Irregular servicing during period of operation.	AC filters cleaned before AC operation in spring. Irregular servicing during period of operation.
Household cleaning and appliance usage	1 washing machine cycle per day, daily ironing, and daily cooking (3 meals)	1-2 washing machines cycles per day, daily ironing, and daily cooking (2 meals)	Continuous use of washing and drying machines, daily ironing, daily cooking (3 meals)	Continuous use of washing and drying machines, daily ironing, daily cooking (3 meals)
Light usage and control	Some lights switched on during the day. Lights used generously in the evenings even in unoccupied rooms	Lights not switched on during the day and very minimally used in the evenings	Lights not switched on during the day. Lights used generously in the evenings even in some unoccupied rooms.	Some lights switched on during the day. Lights used generously only in occupied rooms in the evenings.
Space heating	No heating used	Electric heaters used intermittently in Dec and Jan in some rooms (see Table 6.4)	Electric heaters used intermittently in Dec and Jan in some rooms (see Table 6.4)	Electric heaters used intermittently in Dec and Jan in some rooms (see Table 6.4)
Hot water usage	Oct till April	Oct till April	Oct till April	All year round

Table 6.10: Appliance plug loads in each villa

	Villa 1		Villa 2		Villa 3		Villa 4	
	Quantity	Total wattage	Quantity	Total wattage	Quantity	Total wattage	Quantity	Total wattage
Televisions	3	590	3	620	4	715	9	1345
Television receivers	3	72	3	72	5	120	6	144
Fridge	3	440	1	240	2	370	4	650
Freezer	1	350	1	350	2	440	3	540
Toaster	1	900	1	800	1	900	2	1700
Kettle	1	1800	1	1200	2	2400	3	3600
Microwave	1	1200	1	600	1	800	1	800
Water cooler	-	-	1	70	-	-	-	-
Coffee machine	1	510	-	-	1	510	2	1200
Blender	1	280	-	-	1	280	1	280
Fryer	1	1000	-	-				
Washing machine	1	1800	1	350	1	350	3	875
Clothes dryer			-	-	1	1800	1	2000
Water pump	1	725	-	-	1	725	1	725
Laptop	1	40	1	50	1	40	4	120
Desktop	-	-	1	75	-	-	-	-
Phone charger	8	32	5	20	4)	16	12	48
Tablet charger	2	20	2	20	1	10	3	30
Iron	1	1100	1	950	1	1000	1	1100
Games console	-	-	-	-	1	253	1	250
Alarm system	-	-	-	-	1	30	-	-
Massage chair	-	-	-	-	1	200	-	-
Oxygen condenser	-	-	-	-	-	-	1	500
Electric bed	-	-	-	-	-	-	1	350
Hair dryer	1	710			1	600	2	1800
TOTAL WATTAGE	-	**11579**	-	**5397**	-	**11559**	-	**18057**
WATTAGE/ M²	-	**29.1**	-	**9.5**	-	**16.4**	-	**22.3**

6.2.3.3 Variations between actual and reported occupant perceptions and behaviours

The mixed-method nature of the longitudinal study allowed for the detection of variations between actual and reported occupant behaviours and perceptions. Variations were found between measured annual energy use and homeowners' perceptions of this, as well as between some actual and reported AC thermostat set points and AC split unit control.

Homeowners in all villas overestimated their annual energy use with total consumption reported at the start of the study being relatively higher than total measured consumption at the end of the study (Table 6.11). As noted in Setion 5.2.6, this is likely due to homeowners' reporting a total utility bill (water and electricity), as it is the norm in Kuwait to pay such bills simultaneously, as well as a lack of awareness about consumption with bills being paid randomly. The percentage difference between actual and reported consumption was relatively higher in villas 1 and 3 compared to villas 2 and 4, possibly because in villas 1 and 3 electricity bills are paid every two years or more, while in villa 2 they are paid every three months, and in villa 4 once annually.

Table 6.11: Variation between actual and reported annual energy use (kWh)

	Villa 1	Villa 2	Villa 3	Villa 4
Actual	86,943	97,128	122,670	182,025
Reported	150,000	125,000	200,000	250,000
Percentage difference (%)	53	25	48	31

Internal temperature monitoring also showed that room temperatures varied, to some degree, from thermostat set points reported by homeowners, particularly during the hot summer season, with greater variations noted in villa 2 (uninsulated, single glazed with older AC units) and less variations in villa 3 (insulated, double glazed, and newer AC units). No variation was found however between what occupants reported where the coldest and warmest rooms and what was found by monitored temperature data. Similarly regarding the use of split units, although homeowners of villas 1 and 2 reported that these are switched on only when a room is used, monitoring data found that as external temperatures increased in summer, units tended to be kept on throughout the day in staff bedrooms and the main kitchen.

Such findings indicate the importance of verifying reported energy data and internal temperature data with measured data.

6.3 Chapter summary

- A longitudinal mixed method multi-case study examination of four villas was undertaken to better identify and understand physical and social determinants of energy use.
- A maximum variation purposive sampling strategy was used for the recruitment of villas.

- Selection criteria were developed to ensure different villas are examined to adequately address the research question and objectives.
- Energy consumption of the case study villas was based on weekly meter readings recorded by the researcher.
- Quantitative monitored and metered energy data was analysed through the use of Microsoft Excel and SPSS, while qualitative interview data was analysed manually.
- Key findings:
    - Energy use in all villas was highest during the summer, when villas were centrally cooled throughout than during the winter, when heating was used only intermittently and only in some occupied rooms.
    - The impact of fabric improvements (associated with the 1983 code) on reducing energy use could not be determined, with no distinct reduction in measured annual energy use intensities (kWh/m²) found in newer post-1983 code villas compared to older pre-1983 code villas. Fabric improvements however did create more uniform internal temperatures especially during the hot summer and cold winter seasons.
    - Pre-1983 code villas experienced several days during the winter with average internal temperatures below 18°C.
    - A number of occupant-controlled cooling behaviours impacting energy use were identified including the tendency to leave central AC thermostat settings unchanged during periods of summer travel and during months of the year when external temperatures were moderate (and windows left open), as well as irregular AC maintenance.
    - Villas with more occupants were found to have higher annual energy use intensities, higher energy use intensities during periods the AC was switched off, as well as higher plugs load intensities.
    - No clear association between household income and annual energy use was found.
    - A positive association between villa size (internal floor area) and annual energy use was found.

Chapter 7: Building Energy Modelling

This chapter describes the methodology adopted in the development of energy models for each case study villa, before presenting model output results and key findings.

7.1 Energy modelling methodology: Model development and calibration

The aim of energy modelling in this study was to generate further insight about the impact of energy use drivers by 1) quantifying end-use energy breakdowns (not measured in the monitoring) and 2) providing an opportunity to explore the potential for energy efficiency interventions by predicting the impact of changes to building fabric, systems and occupants. Multi-zonal models were developed for each villa using the software program Simergy version 2.5.1 (Digital Alchemy 2018) as described in Section 4.2.3.3.

To reduce assumptions and uncertainties, modelling was informed by physical and social data collected during the longitudinal study. Real weather data (during the year of monitoring) was also used in simulations including air temperature, relative humidity, and solar radiation retrieved from Kuwait International Airport weather station 405820 (KIA n.d). A comparison between external temperature and relative humidity monitored by the researcher, metrological data retrieved from KIA weather station, and the KISR weather file commonly used in building simulations is presented in Appendix L1. All model runs presented also include shading from adjacent buildings. Table 7.1 and 7.2 describe model input parameters, and Table 7.3 illustrates different visualizations of simulated villas.

To facilitate model development, the following modelling strategy was followed for all villas:

1. Developing a library in Simergy with appropriate construction and internal load templates.
2. Generating building geometry (by drawing over actual architectural DWG drawings).
3. Assigning appropriate construction templates for each villa, and defining individual custom windows, external doors, and surrounding internal walls.
4. Creating thermal zones based on a consideration of the function of the space, the method used to condition the space, its position relative to the exterior, and the measured data available. Such considerations are based on guidelines suggested by

Raftery et al (2011). For model floor plans with thermal zones indicated refer to Appendix L2.

5. Assigning appropriate internal load templates and schedules to different thermal zones.
6. Creating zone HVAC groups and assigning appropriate HVAC templates to each.
7. Model calibration. The purpose of model calibration is to explore discrepancies between model prediction and measured building performance and determine if such discrepancies can be accounted for by reviewing model input assumptions (Coakley et al. 2014). While many approaches to model calibration have been suggested, ranging from manual to automated (a thorough review of calibration approaches is available from Coakley, et al. (2014), there remains no consensus on a formal calibration methodology or process (Raftery et al. 2011; Coakley et al. 2014). Broadly, statistical indices are used as international reference criteria for validating calibrated models as defined by ASHREA Guideline 14 (ASHRAE 2002), the International Performance measurement and Verification Protocol (IPMVP) (EVO 2007) and the Federal Energy Management Program (FEMP) (USDOE 2008). Criteria indicate how well modelled energy consumption matches measured energy data at a selected time interval such as hourly or monthly (Coakley et al. 2014). In this study three main calibration steps were undertaken:
    i. Baseline modelling following a defined strategy for model development (outlined in steps 1-6 above) and using empirical physical and social data collected during the monitoring and surveying study as well as empirical weather data.
    ii. Running simulations and comparing modelled and measured energy data both annually and monthly, as well as modelled and measured internal temperature data to detect major variations. This process consisted of checking and fixing any model input errors and further refining schedules.
    iii. Model validation using standard statistical criteria defined by (ASHREA 2002; EVO 2007; USDOE 2008) for the mean bias error (MBE) and the coefficient of variations of the root mean squared error (CV (RMSE)): this involved calculating the MBE and CV(RMSE) for each villa. The MBE is a measure of how closely simulated data corresponds to monitored data and is calculated as shown in equation 1. CV(RMSE) is a measure of the variability between measured and simulated data and is useful for capturing situations where errors are self-cancelling. CV(RMSE) is calculated as shown in equation 2. For this study, as metered energy consumption was recorded at a weekly basis for each villa, monthly, rather than hourly, criteria are applied.

$$MBE(\%) = \frac{\sum_{i=1}^{Np}(m_i - s_i)}{\sum_{i=1}^{Np}(m_i)} \qquad (1)$$

Where m_i and s_i are the measured and simulated data points for each model instance 'i' and N_p is the number of data points at interval 'p' ($N_{monthly}$ =12).

$$CV\ RMSE(\%) = \frac{\sqrt{\sum_{i=1}^{Np}(m_i - s_i)^2 / N_p}}{\overline{m}} \qquad (2)$$

Where m_i and s_i are the measured and simulated data points for each model instance 'i' and N_p is the number of data points at interval 'p' ($N_{monthly}$ =12), and $\overline{m}$ is the average of the measured data points.

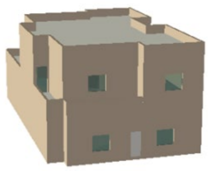
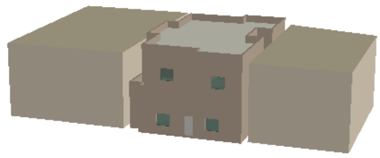
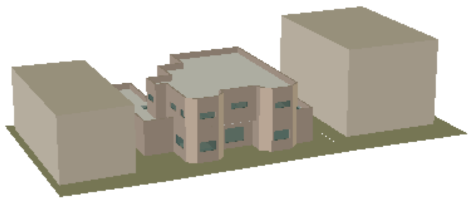
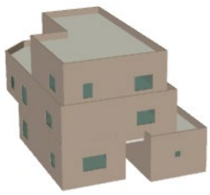
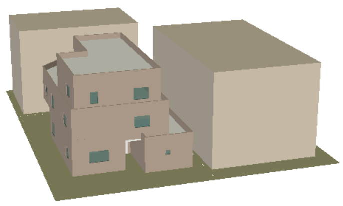
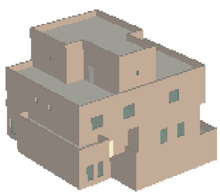
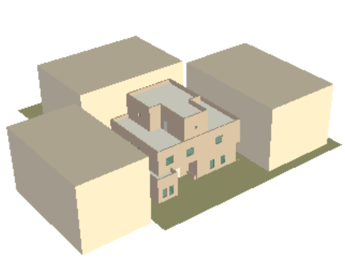
Table 7.1: An overview of the input variables included in the modelling exercise and their source

General inputs	Description	Source
Location	Kuwait	N/A
Simulation weather file	Custom weather file covering the monitoring period from 2015 to 2016 based on data retrieved from Kuwait International Airport 405820	(KIA, n.d)
Modelling software	Simergy version 2.5.1	(Digital Alchemy 2018)
Fabric efficiency and infiltration	Wall, roof, window U-values, thickness, and building infiltration	Construction details based on physical observation are provided in Table 7.2. For older villas (1 and 2) fabric U-values were based on those noted in published residential energy simulations for villas of similar age in Kuwait (Ameer & Krarti 2006; Al-Ragom 2003; Al-ajmi & Hanby 2008; Cerezo et al. 2015; De Wolf et al. 2017; Assem & Al-Ragom 2009). For newer villas (3 and 4) fabric U-values were based on requirements from the MEW 1983 code (MEW 1983)
Space cooling	Number and size (capacity) of central and split AC units, thermostat set points, period of operation and coefficient of performances (COP). In Simergy COP varies with external temperature based on inbuilt performance curves.	Number of AC units, thermostat set points and period of operation are based on physical and social survey data (Tables 6.4 and 6.9). The input value representative of COP at the average external temperature (35C°) in each model was assumed based on system age and MEW 1983 and 2010 code requirements (MEW 1983 & 2010). AC capacities were left to be sized automatically by Simergy. A comparison between modelled and actual AC sizing is provide in Table 7.7).
Space heating	Portable electric heaters	Heating (incorporated as part of winter plug load schedules – Appendix L3) was based on physical and social survey data
Occupancy	Number of occupants and occupancy schedules	Number of occupants and occupancy schedules were based on social survey data (see Table 6.3 and Appendix L3)
Plug loads	Number of electrical appliance and usage schedule	Plug load intensity (W/m²) and usage schedules were based on physical and social survey data (Table 6.10 and Appendix L3).
Lighting	Number and wattage of lighting fixture and usage schedule	Lighting load intensity (W/m²) and usage schedules were based on physical and social survey data (Tables 6.5 and 6.9, and Appendix L3).
Hot water	Electric hot water heater operated from October till April	Default peak flow rates used based on ASHREA standard for private residences: sinks 19L/h, showers 114L/h

Table 7.2: Main building and occupancy simulation parameters

	Villa 1	Villa 2	Villa 3	Villa 4
External wall construction	100mm brick, 15mm cement mortar, 120mm concrete block, 15mm cement plaster finish (no insulation)	40mm stone, 15mm cement mortar, 150mm concrete block, 15mm cement plaster finish (no insulation)	20mm cement plaster, 180mm autoclaved aerated concrete with inbuilt insulation, 15 mm cement plaster finish	40mm stone, 15mm cement mortar, 40mm insulation, 150mm concrete block, 15mm cement plaster finish
External wall U-value (W/m².K)	2.31	2.31	0.57	0.57
Roof construction	20mm tiles, 15mm cement mortar, 20mm sand screed, 150mm concrete block, gypsum board (no insulation)	20mm Tiles, 15mm cement mortar, 20mm sand screed, 150mm concrete block, gypsum board (no insulation)	20mm Tiles, 15mm cement mortar, 20mm sand screed, 40mm insulation,150mm concrete block gypsum board	20mm Tiles, 15mm cement mortar, 20mm sand screed, 40mm insulation,150mm concrete block, gypsum board
Roof U-value (W/m².K)	0.69	0.69	0.39	0.39
Glazing type	6mm single pane tinted glazing with aluminium frames	6mm single pane tinted glazing with aluminium frames	6mm double tinted reflective glazing with aluminium frames	6mm double tinted glazing with aluminium frames
Glazing U-value (W/m².K)	6.41	6.41	3.33	3.61
Glazing ratio (%)	4.3	8.2	5.9	3.27
Infiltration (ACH)	0.8	0.8	0.4	0.5
Cooling (COP @ Text 35°C)	2.4	1.7	2.4	2.0
Occupancy (Occ/m²)	0.02	0.01	0.01	0.01
Lighting (W/m²)	4.5	5.4	5.7	9.8
Plug load (W/m²)	29.1	9.5	16.4	22.3
Annual average fabric heat gains (W)	3063	6164	3850	5852
Annual average total heat gains (W)	10030	12284	10306	15480
Annual average heat gain parameter (W/m²)	26	22	15	19

Table 7.3: Visualization of simulated villas

	Visualisation of front of villa	Contextual visualisation of villa with adjacent buildings
Villa 1	 **South**	
Villa 2	 **North**	
Villa 3	 **North**	
Villa 4	 **West**	

7.2 Model testing, validation and constraints

7. 2.1 Log of key model adjustments

Throughout the modelling process, several input adjustments and re-runs of simulations were undertaken after comparing measured and simulated energy consumption.

To improve model accuracy and reliability, Raftery et al. (2011) recommends that such changes be made according to a 'hierarchy of sources' such that sources based on direct observation should be the first priority, followed by data gathered from benchmark studies, standards, and finally default model inputs. Table 7.4 presents a log of key adjustments undertaken including the rational for this and impact on annual energy use.

Table 7.4: Key model adjustments and impact on annual energy use

Change	Description/rationale	Approximate impact on annual energy use (kWh)			
		Villa 1	Villa 2	Villa 3	Villa 4
Real weather data	A custom weather file with real weather data from the year of monitoring was created and used instead of the standard KISR weather file initially used.	+7,000 (6.9)	+10,000 (10.2)	+5,000 (4.6)	+3,000 (1.7)
Shading from neighbours	The shading effect from adjacent buildings was modelled as solar obstructions.	-800 (0.7)	-100 (0.1)	-300 (0.3)	-1,000 (0.6)
Plug load schedules	Custom schedules were created and used in winter and summer to account for increased use of appliances during winter.	+3,000 (2.8)	+1,000 (0.9)	+1,000 (0.9)	+4,000 (2.2)
DHW Schedules	DHW was initially modelled throughout the year in all villas, but was later adjusted to reflect actual usage (from Oct till April in villas 1-3 and all year in villa 4 only).	-2000 (1.8)	-1500 (1.4)	-3500 (3.0)	No change
Cooling control settings	Initial model outputs indicated zones had relatively lower internal temperatures than what model thermostats were set to. This was because the supply air temperature controller was set to 12.8°C (the default lower limit) and air was continuously cooled to this limit. This was adjusted (with the support of the software developer) to vary between 12.8°C and 18°C (default lower and upper limits) resulting in more representative internal temperatures in different zones.	- 4,000 (3.7)	-7,000 (6.5)	-3000 (2.7)	-4,000 (2.2)

Note: symbols of [+] and [-] indicate an increase or decrease in absolute values in kWh. The percentage change due to each consecutive adjustment is indicated in parentheses.

7.2.2 Model validation and constraints

Building energy modelling is a complex process with many parameters that carry an associated level of uncertainty (Raftery et al. 2011; Coakley et al. 2014). Great discrepancies between modelled and measured energy performance have frequently been reported by many studies, often with a limited understanding of the reasons for this (Cali et al. 2016; Wilde 2014; Menezes et al. 2012). Thus before interpreting model results, it is important to consider model validation and constraints in this study. Table 7.5 presents the extent to which the four villa models comply with standard statistical criteria for model calibration indicated in Section 7.1.1. As shown, statistical indices for villas 2 and 4 are within the criteria while those of villas 1 and 3 are not. Models of villas 1 and 3 however are considered valid in light of the purpose of the modelling exercise of this research, which is primarily to assist in understanding the energy performance of individual villas given what empirical data is available. Attempting to reduce discrepancy between modelled and measured performance, without an underpinning logic supported by empirical data would be inappropriate.

While model development followed a systematic process and inputs were largely informed by real data, discrepancies in villas 1 and 3 could possibly be due to assumptions regarding fabric and and AC efficiencies. Inputs associated with these parameters were not based on forensic investigations but on visual examinations, a consideration of building age, and MEW code requirements (as noted in Table 7.1 above). Similarly, some discrepancy could also be due to differences between actual and simulated building operation data (associated with occupant behaviours and schedules); especially as real behaviour cannot be fully replicated in a simulation.

Table 7.5: Calibration of villas relative to statistical criteria for calibration (ASHRAE 2002; EVO 2007; USDOE 2008)

	Villa 1	Villa 2	Villa 3	Villa 4	Monthly criteria		
					ASHREA Guideline 14	IPMV	FEMB
MBE (%)	-20	-3	11	-1	±5	±20	±5
CVRMSE (%)	37	15	23	12	15	-	15

7.3 Modelling result analysis

Once models were appropriately grounded in the monitored and surveyed data, and shown to reasonably simulate villas they represent, the following analyses was undertaken:

- Simulated vs. measured energy consumption – to illustrate discrepancies between measured and simulated consumption through examining annual and peak consumption, and accounting for external and internal temperatures
- End-use energy distribution –to illustrate and quantify key energy end-uses
- A differential sensitivity analysis - to quantitatively assess the importance of various factors on energy use. This involved the variation of one input in each

simulation to determine its direct impact on an output value, while other inputs remained at their base values (Lomas & Eppel 1992).

7.3.1 Simulated vs. measured energy consumption

A comparison of annual measured and simulated energy use, normalized by floor area, is presented in Figure 7.1. This shows relatively greater variation (about 22%) in villa 1 compared to the other villas. A comparison of monthly measured and simulated energy use is presented in Appendix L4.

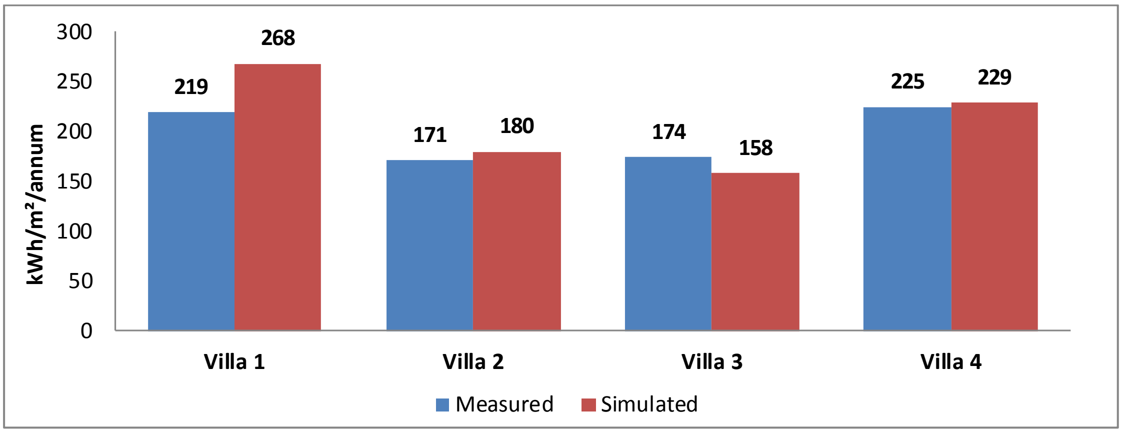


Figure 7.1: Measured vs. simulated annual energy consumption (kWh/m²/annum)

To enable further comparisons, Figures 7.2-7.5 illustrate measured and simulated weekly energy consumption in Watts per m² against external temperature (Figures 7.2-7.3) and against the change in external and internal temperatures (delta T) (Figure 7.4-7.5) in each villa during periods the AC is switched ON and OFF. Graphs are presented in this way to illustrate the two separate relationships which occur due to different power inputs into the building; when the AC is OFF there is a fixed power input, while as soon as the AC is ON the amount of energy that goes into a building changes. Such graphs provide insight into the technical performance of villas; the gradient of the lines (shown by equations on each graph) provide an indication of heat gains from the building fabric and ventilation in response to external temperature and delta T, while the y-axis intercept (in Figures 7.4 and7.5) also provide an indication of solar, unmetered and metabolic gains. All graphs exclude periods when occupants were away on vacation.

Looking at the gradients of graphs for AC ON in Figures 7.2 and 7.3 (external temperature) and Figures 7.4 and 7.5 (delta T), one notices some variation in the percentage difference between measured and simulated data. For example, comparing gradients of the simulated and measured graphs when the AC is ON in Figures 7.2 and 7.3, it appears that villa 1 and 4 are about 50% and 30% more efficient than the model suggests and villa 2 and 3 are 30% and 40% less efficient. In Figures 7.4 and 7.5 however, villa 1 and 4 are about 60 and 45% more efficient than the model suggests and villas 2 and 3 are 10% and 30% less efficient. While theoretically the gradeints of graphs in Figures 7.4 and 7.5 (delta T) provide a better indication of technical performance of buildings, this is greatly dependant on whether both the modelled and measured internal temperatures are accurate. In this case more certainty is associated with measured internal and external tempeatures compared to modelled internal temepratures (which are in effect dependent on the modelled cooling system). Thus, comparisons of measured and simulated gradients in Figures 7.4 and 7.5 (with external temperatures) are likely to be providing more reliable information.

Another intersting observation can be found when considering annual energy use (Figure 7.1) in relation to weekly energy use (Figures 7.2-7.5) in Villa 2. Measured annual energy use was relatively lower in villa 2 comapred to villas 3 and 4, which at face value, may lead one to asuume that that this type of building is more ideal. Considering weekly measured enery use relative to external temperature (Figure 7.3) however, one finds that villa 2 uses the most cooling energy per unit degree rise of external temperature (1,255W for every degree of cooling) compared to other villas (which is also not being captured, to the same extent, by the modelling - Figure 7.2). Similarly, considering weekly measured energy use relative to delta T (Figure 7.5) it appears that this increase cannot be explained by lowering internal temepratures when external temperatures are rising. This in turn indicates that villa 2 is the worst performing in terms of using most energy when it is most difficult to provide it and expensive to generate (peak demand). Such performance is likely due to villa 2's very old, inefficient central AC units, together with its uninsulated, single glazed fabric, with many exposed surfaces and skylight openings.

For Villa 1, however, which is also uninsulated and single glazed, there was no significant increase in measured energy use as external temperatures rose. The villa required about 4 times less energy (296W) for every degree of cooling than villa 2, and about 3 times less energy than the insulated and double glazed villas 3 and 4. Although this, in part, could be due to villa 1's newer efficient central AC units (installed in 2013), smaller building size and less exposed surface areas, such relatively low cooling energy use also suggests there could be a potential difference in the actual fabric performance of the villa compared to assumptions made. This could, in turn, explain the relatively greater variation observed between measured and simulated energy use in this villa in Figure 7.1. To better explain this, detailed forensic investigation of the building is required, which was beyond the scope of this PhD.

Furthermore, looking at Figures 7.2-7.5, a smoother transition was found between measured AC ON/OFF in all villas compared to simulated AC ON/OFF. This is because central AC cooling was modelled to be switched on and off at a specific day in the year (as found during the monitoring study). In reality however, although occupants switched their central AC's on and off at a specific day, during such time (March/April and October/November) external temperatures were relatively mild, and occupants also tended to adjust thermostat settings more. This behaviour is likely to have caused the smoother transition between measured AC on/off compared to simulated AC on/off (where no such transition was modelled). Similarly, as Table 7.6 shows, more variation between measured and simulated average volume weighted internal temperature was found during the spring and autumn seasons in all villas (with simulated temperatures being cooler than measured). This is likely due to timing in which AC units are being switched on and off.

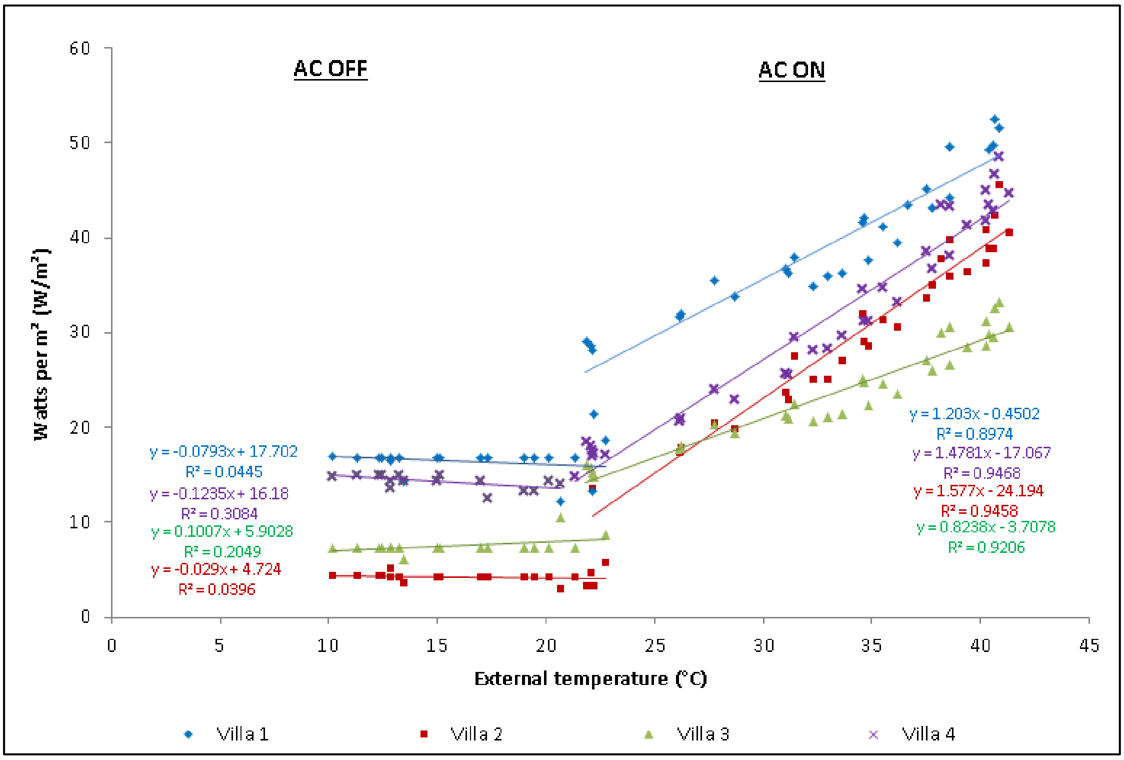


Figure 7.2: Simulated weekly energy use (Watts per m²) vs. external temperature for periods the AC is ON and OFF

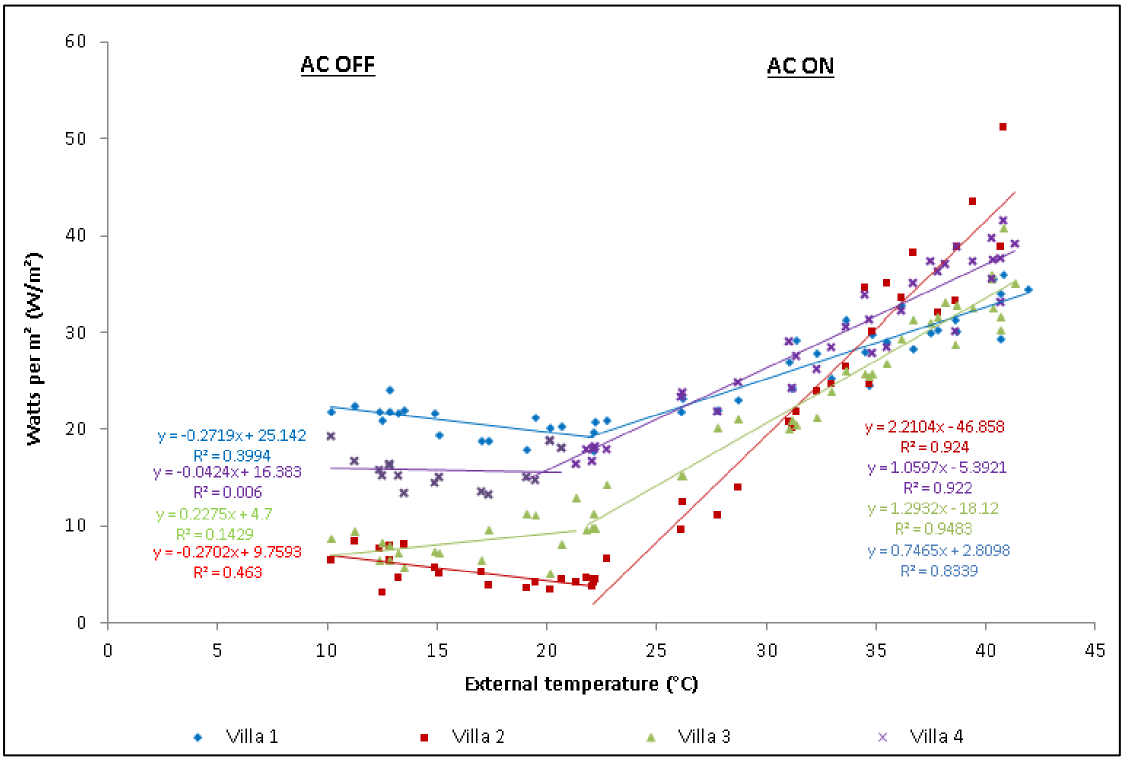


Figure 7.3: Measured weekly energy use (Watts per m²) vs. external temperature for periods the AC is ON and OFF

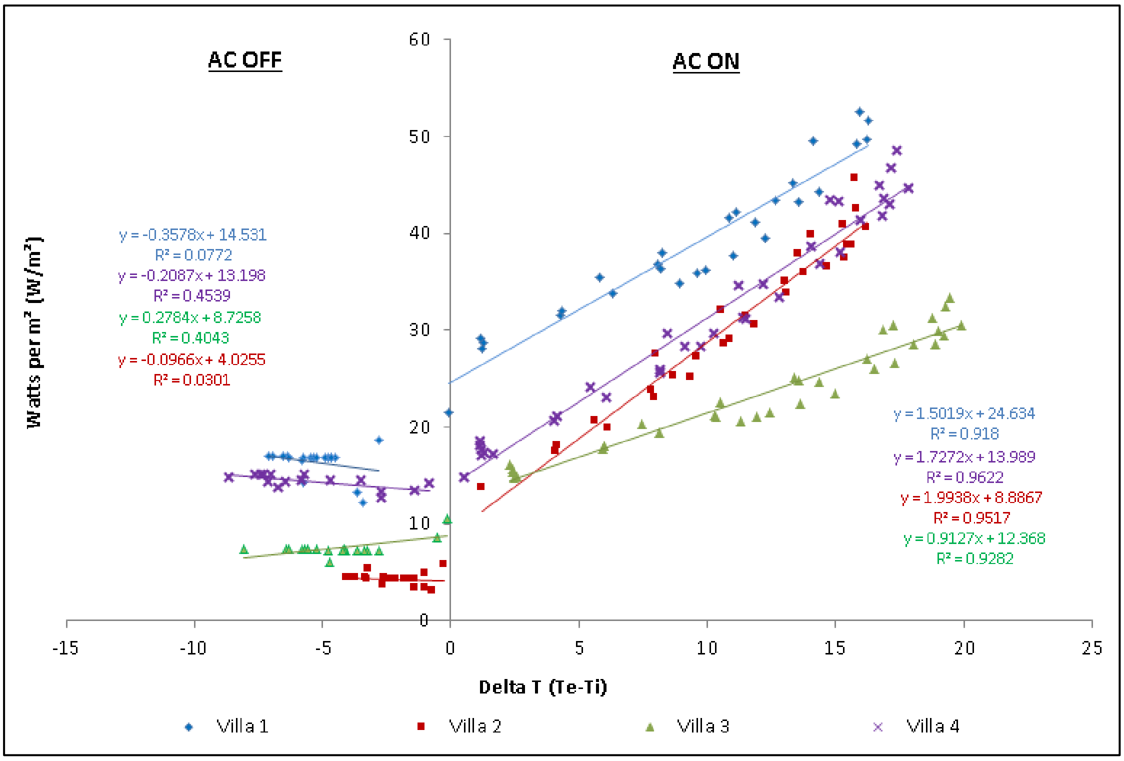


Figure 7.4: Simulated weekly energy use (Watts per m²) vs. delta T for periods when the AC is ON and OFF

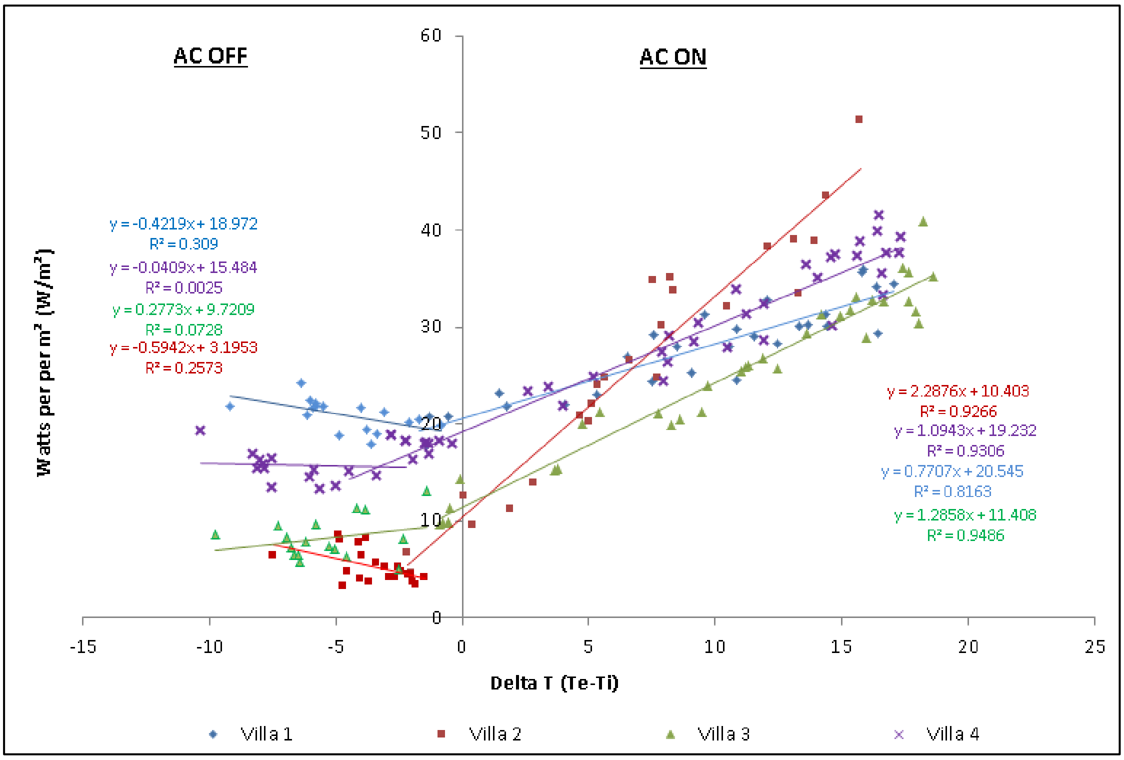


Figure 7.5: Measured weekly energy use (Watts per m²) vs. delta T for periods the AC is ON and OFF

Table 7.6: Measured and simulated average volume weighted internal temperature (°C) in case study villas

	Villa1			Villa2			Villa3			Villa4		
	M	S	D	M	S	D	M	S	D	M	S	D
Annual average	22.9	22.7	0.4	23.7	21.9	1.6	22.2	20.7	1.4	22.9	22.0	0.9
Autumn	23.4	23.6	-0.2	25.1	23.1	2.0	23.2	21.9	1.3	23.3	22.2	1.1
Winter	19.4	19.1	0.3	18.3	17.1	1.2	20.2	19.3	0.9	21.1	20.4	0.7
Spring	23.9	22.7	1.1	25.6	23.2	2.4	22.6	20.5	2.1	23.6	22.1	1.5
Summer	24.9	24.4	0.5	25.8	24.8	1.0	22.6	21.4	1.2	23.7	23.4	0.2

Note: M is the measured internal temperature, S is the simulated internal temperature, D is the difference between measured and simulated internal temperature. Autumn: Sep-Nov, winter: Dec-Feb, spring: Mar-May, and summer: Jun-Aug.

Additionally, to examine whether AC cooling capacities are a potential explainer of the observed effects in energy consumption and internal temperature (Figure 7.1 and Table 7.6), a comparison of installed (actual) and simulated capacities was made and presented in Table 7.7. As shown installed AC units are oversized by 40% to 60% compared to simulated units. If installed AC units were undersized one would expect that they would not cope with providing enough cooling during the summer and thus measured internal temperatures would be higher than simulated and measured energy consumption lower than simulated. However as installed AC units are oversized, observed effects in energy consumption and temperature (Figure 7.1 and Table 7.6) are likely due to other reasons such as uncertainty associated with fabric and AC efficiencies, uncertainty regarding when AC units were switched on in the spring, or occupants' actual thermostat adjustments. The comparison between simulated and installed AC capacities also suggests there may be considerable potential to improve efficiencies of actual AC units through better maintenance, particularly as poorly maintained units are unlikely to meet required cooling demands. Further research however is required to identify actual AC operational efficiencies, which were not measured in this study.

Table 7.7: Installed and simulated AC cooling capacity (in kW)

	Villa 1	Villa 2	Villa 3	Villa 4
Installed capacity				
Central	56.3	56.3	95.0	105.4
Split	7.0	38.7	14.1	31.7
Total	63.3	95.0	109.1	137.1
Simulated capacity				
Central	38.7	31.7	45.7	56.3
Split	3.5	31.7	14.1	24.6
Total	42.2	63.4	59.8	80.9
Percentage difference (%)				
Between total installed & simulated	40	40	58	51

7.3.2 End-use energy distribution

Figures 7.6 presents modelled end-use energy breakdowns in each villa (in kWh/m²); no disaggregated electricity data was collected as part of this study and so no comparisons can be made with measured. Figure 7.7 presents modelled end-use energy breakdowns as a percentage of total energy use. As shown, energy consumption for space cooling varied, ranging from 50% to 75% of overall energy use in different villas. Figure 7.8 further illustrates the cooling load breakdowns of each simulated villa. In villa 2, uninsulated and single glazed, 70% of cooling was found to be due to heat gains from the fabric and ventilation/infiltration, with solar gains also being relatively important. In villa 1, however, which is of a similar fabric and age to villa 2, cooling load due to appliance use was the dominant factor. This could, in part, be due to a larger number of younger occupants using more electric appliances as noted in Section 4.1.2 above. Villa 4, which also has a large household size, has a large proportion of cooling driven by appliance use.

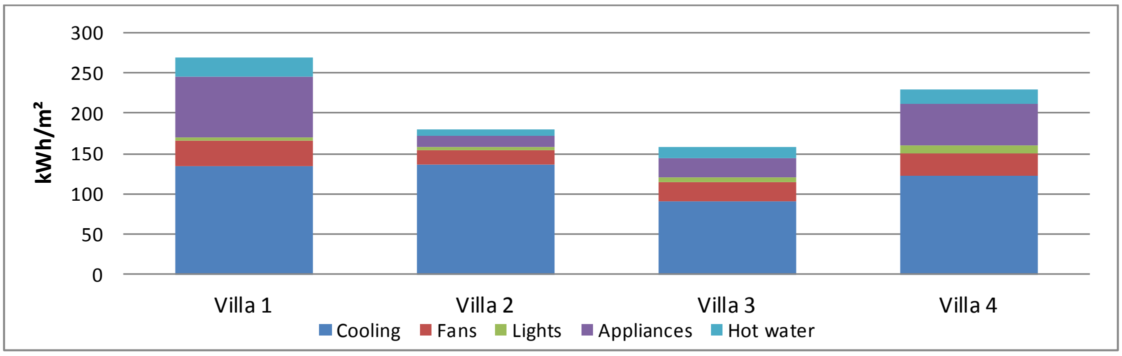


Figure 7.6: Modelled end-use energy distribution in each villa

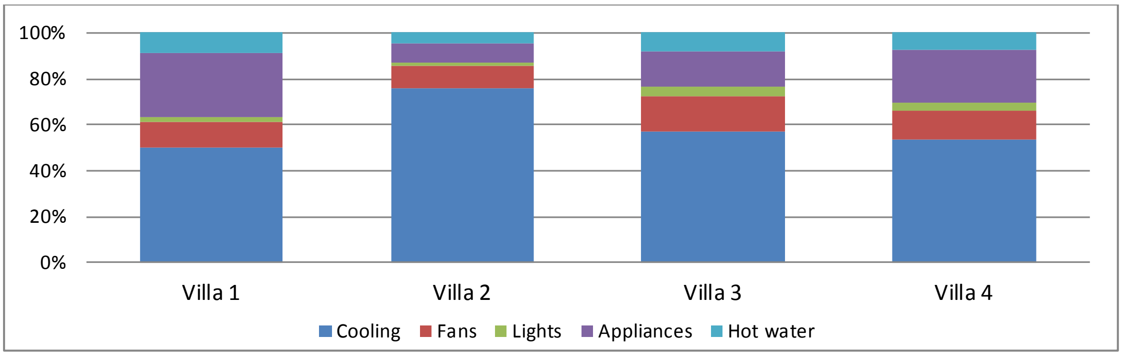


Figure 7.7: Percentage of modelled end-use energy distribution in each villa

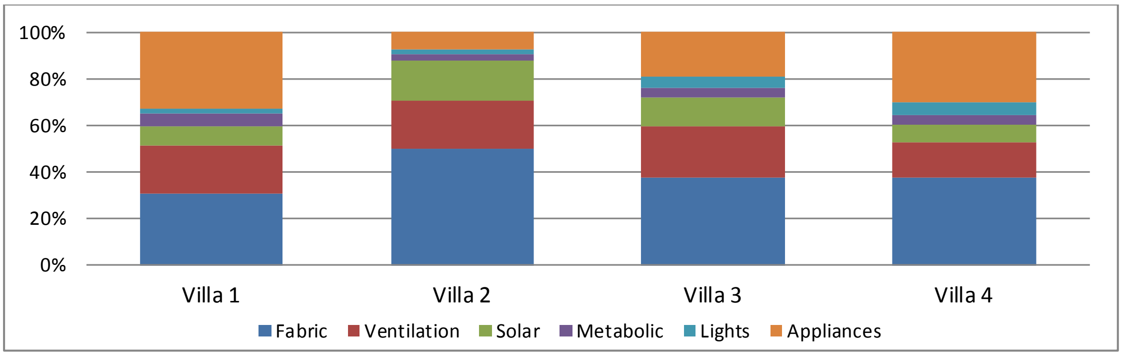


Figure 7.8: Percentage of modelled cooling load breakdown in each villa

7.3.3 Sensitivity analysis

To provide some insight into the importance of physical and social factors effecting energy use and the potential impact of different policy interventions, a differential sensitivity analysis was undertaken. For the older pre-1983 code villas 1 and 2 a number of physical variations were tested to quantify the impact of fabric improvements to MEW 1983 code standards). In villa 2, where the AC units are over 35 years old, an additional variation accounting for improved AC efficiency was also tested. For the newer post-1983 code villas however, a number of behavioural variations were tested including increasing thermostat set points by 1°C, during the cooling period, and not cooling large unused rooms. Tables 7.7-7.9 illustrate the impact of such variations on energy use in each villa.

Upgrading villas 1 and 2 to 1983 code standards results in a 33% and 56% reduction in annual energy use and a saving of 70KWD ($232) and 112KWD ($371) in the annual electricity bills respectively (Tables 7.8 and 7.9). If tariffs represent the actual cost of electricity, this intervention would amount to substantial savings of 1,636 KWD ($5,416) and 2,630KWD ($8,702) in annual electricity respectively. In villa 2, only replacing the old AC central units reduces annual energy use by 21%, which amounts to an annual saving of 42KWD ($139) and a potential saving of 991 KWD ($3,278) if actual electricity production cost is considered.

In villas 3 and 4, an increase of 1°C in thermostat set points reduces annual electricity consumption by 7% and 11%, while switching the cooling off in unused spaces reduces annual energy use by 10% and 5% respectively (Table 7.10). As Tables 7.8-7.10 indicate, current subsided electricity tariffs are unlikely to motivate homeowners to adjust their cooling behaviour or upgrade their building fabric as returns appear to be low. Therefore, if electricity costs remain subsidized other forms of incentive or regulation are likely to be required to motivate energy efficiency interventions.

Table 7.8: Savings due to fabric improvements in villa 1

	Villa 1				
	Wall insulation	**Roof insulation**	**Double glazing**	**Infiltration**	**All measures combined**
Savings (kWh/annum)	29,836	2,097	1,744	9,469	34,811
Savings as a percentage of total kWh/annum (%)	29	2	2	9	33
Financial savings in KWD at current subsidised rate: 0.002fils/kWh	60 (199)	4 (13)	3 (10)	19 (63)	70 (232)
Financial savings in KWD at cost of production: 0.047fils/kWh	1,402 (4,641)	98 (324)	82 (271)	445 (1,473)	1,636 (5,416)

Note: improved u-values (W/m².K) walls 0.57, roofs 0.39, Glazing 3.33. Infiltration: 0.5ACH
Financial savings in US dollars, based on conversion rates of 1KWD = $3.31 (June 6 2018), are indicated in parentheses.

Table 7.9: Savings due to fabric improvements and AC system efficiency in villa 2

	Villa 2					
	Wall insulation	**Roof insulation**	**Double glazing**	**Infiltration**	**AC efficiency**	**All measures combined**
Savings (kWh/annum)	30,728	2,272	4,226	11,764	21,078	55,951
Savings as a percentage of total kWh/annum (%)	31	2	4	12	21	56
Financial savings in KWD at current subsidised rate:0.002fils/ kWh	61 (202)	5 (17)	8 (26)	24 (79)	42 (139)	112 (371)
Financial savings in KWD at cost of production: 0.047fils/ kWh	1,444 (4,778)	107 (354)	199 (658)	553 (1,830)	991 (3,278)	2,630 (8,702)

Note:improved u-values (W/m².K) walls 0.57, roofs 0.39, Glazing 3.33. Infiltration: 0.5ACH. AC efficiency: 2.4COP
Financial savings in US dollars, based on conversion rates of 1KWD = $3.31 (June 6 2018), are indicated in parentheses

Table 7.10: Savings due to changes in occupant cooling behaviour in villas 3 and 4

	Villa 3		Villa 4	
	Thermostats increased by 1°C	**Cooling off in unused playroom (19% of building volume cooled at 22°C)**	**Thermostats increased by 1°C**	**Cooling off in unused basement (24% of building volume cooled at 23°C)**
Savings (kWh/annum)	7,911	11,144	20,456	9,298
Savings as a percentage of total kWh/annum (%)	7	10	11	5
Financial savings in KWD at current subsidised rate: 0.002fils/ kWh	16 (53)	22 (73)	41 (136)	19 (63)
Financial savings in KWD at cost of production: 0.047fils/ kWh	372 (1,232)	524 (1,735)	961 (3,182)	437 (1,447)

Note: Financial savings in US dollars, based on conversion rates of 1KWD = $3.31 (June 6 2018), are indicated in parentheses

7.4 Chapter summary

- Multi-zonal energy models were developed for each case study villa using the software program Simergy (version 2.5.1).
- Models were grounded with empirical data collected during longitudinal monitoring and surveying as part of the multi-case study (Chapter 6), including real weather data retrieved from KIA weather station, to better predict energy use.
- To facilitate model development, a set modelling strategy was followed for all villas which included model calibration. All models were validated by presetting the extent to which they comply with standard statistical criteria for model calibration.
- Throughout the modelling process, several input adjustments and re-runs of simulations were undertaken after comparing measured and simulated energy consumption, and a log of adjustments kept.
- Key findings:
    - Space cooling accounts for 50% to 75% of total modelled energy use in case study villas. Switching cooling off in used rooms in villas 3 and 4 reduced modelled annual energy use by 10% and 5% respectively.
    - Drivers of cooling energy are varied, with 30% of modelled cooling energy in some villas attributable to heat gains from appliances.
    - No distinct reduction was found in measured and modelled annual energy use intensities (kWh/m²) of villas with improved levels of efficiency (insulation and double glazing).
    - Increasing thermostat set points by 1°C in villas 3 and reduced annual energy use by 7% and 11% respectively.
    - Future case study modelling requires the collection of more data about actual fabric, ventilation and AC operational efficiencies.

Chapter 8: Discussion

This chapter presents a discussion of results from the quantitative household survey, longitudinal mixed method multi-case study and energy modelling reported in Chapters 5,6 and 7. Results are discussed through the use of the triangulation method and findings are examined in light of other studies including those mentioned in the literature review in Chapters 2 and 3. The chapter is structured around the research sub-questions (preseted in Chapter 1), which have been drafted to address underlying elements of the main research question: "what are the key physical and social drivers of energy demand in Kuwaiti villas?".

8.1 The triangulation of data collected from different methods

As explained in Section 4.3.2, triangulation is a technique that involves the use of more than one method to collect data on the same topic. This facilitates validation of findings and allows for a deeper understanding of the phenomenon being studied. In this research the triangulation of data from different methods is applied for corroboration (to identify if results are the same), elaboration (to identify different perspectives), complementarity (to identify supporting results) and/or contraction (to identify refuting results). Figure 8.1 summarises this process.

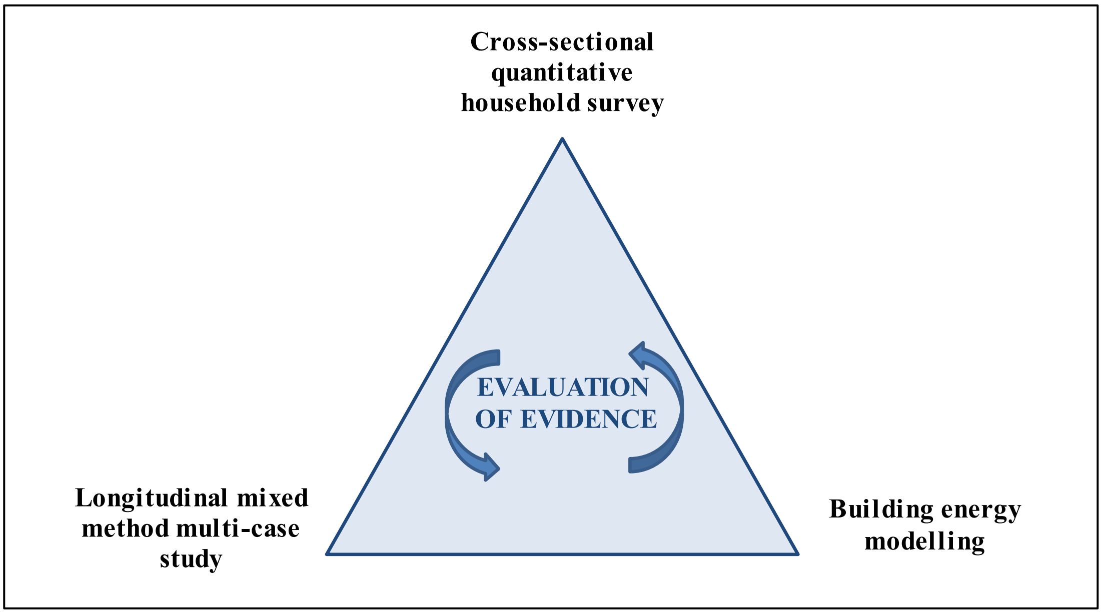


Figure 8.1: Triangulation of data from different methods employed in this research

The sections below discuss overall findings from these methods under headings that reflect different research sub-questions.

8.2 How does energy use vary across seasons in different villas?

- Tracking the evolution of energy use over a period of one year in the multi-case study has shown that energy use intensities (kWh/m^2) in all villas is highest during the summer, lowest during the winter, and relatively similar during the spring and autumn seasons.

In all case study villas, energy use intensities (kWh/m^2) presented in Table 6.6, were notably higher during the summer months (June to August) when average external temperatures were 39°C and maximum temperatures higher than 50°C, compared to the winter months (December to February) when average external temperatures were 14°C and minimum temperatures as low as 5°C. This indicates the strong impact of central AC cooling on overall energy use; during the entire summer, and warmer parts of spring and autumn, all case study villas were centrally cooled throughout (including many unused rooms and spaces), while during winter, heating via portable electric heaters, was used only intermittently and only in some occupied rooms. Although no disaggregated electricity data was collected as part of the longitudinal study, modelled end-use energy breakdowns presented in Figure 7.7, show that energy consumption for space cooling ranged from 50% to 75% of overall energy use in individual villas, again indicating the notable impact of central cooling. Model results also suggest that drivers of cooling energy are varied, with 30% of cooling energy in some villas attributable to heat gains from appliances (Figure 7.8,). The sections below will further discuss key drivers of energy use, and in particular cooling energy use, examined in this research.

8.3 Do better insulated villas consume less energy and are they more uniform in their internal temperatures?

- While the impact of fabric improvements (insulation and double glazing) on reducing energy use could not be clearly determined in this research, findings suggest they have created more uniform internal temperatures during the hot summer and cold winter seasons.

This research attempted to assess the impact of insulation and glazing through the examination of villa age (used as a proxy for fabric improvements). In the quantitative survey, analysis found that villa age had a relatively weak negative correlation with energy use (Table 5.10) and was not a significant predictor of this in the regression model. This suggests that although newer post-1983 code villas may tend to consume less energy than older pre-1983 code villas, the effect is minimal, possibly due to poor code implementation and an increase in building size, which may be diluting the benefits of an improved fabric. The latter (increase in building size) is particularly due to Kuwait Municipality building codes allowing for considerable increases in built up areas over the past 20 years (a villa's total built up area can now be 210% of its plot size - a rise of 40% from 1996 – Table 2.5), which in turn implies the need to cool and equip more spaces.

Similarly, the longitudinal multi-case study and energy modelling, indicates no distinct reduction in measured and modelled annual energy use (kWh/m²) between newer post-1983 code villas (3 and 4) and older pre-1983 code villas (1 and 2). However, in Chapter 7 when examining *peak* demand during the summer months, it was found that pre-1983 code villa 2 used the most measured energy per unit degree rise of outdoor temperature (1,255W for every degree of cooling) as shown in Figure 7.3, although it's *annual* measured energy use intensity was lower than both post-1983 code villas 3 and 4. Further examination of energy use relative to the difference between external and internal temperatures (delta T – Figure 7.5) suggests that this increase in villa 2 was not due to lowering internal temepratures when external temperatures were rising, and more likely due to an inefficient fabric. Thus villa 2 appears to be the worst performing in terms of using most energy when it is most difficult to provide it, and expensive to generate (peak demand) - an effect that was not being captured to the same extent by the energy modelling (Figure 7.2).

Increased peak demand was not however found in pre-1983 code villa 1, as initially expected. While this could, in part, be due to villa 1's relatively newer AC units and smaller, compact building size and shape, it was still quite puzzling why energy use was not increasing with external temperature in this villa to the same extent as in villa 2. When compared with simulation results, a wider variation was found between measured and simulated annual consumption in villa 1 relative to all other villas (Figure 7.1), suggesting there could be a potential difference in the actual fabric performance of this villa relative to assumptions made. To better decipher this, forensic investigation is required, which was beyond the scope of this thesis. This forensic investigation would also need to identify actual operational efficiencies of the AC units and actual air infiltration rates not measured in this study.

Regarding internal temperature however, findings from both the multi-case study and energy modelling indicate that fabric improvements associated with the MEW 1983 code have created more uniform internal temperatures, with most rooms in post-1983 code villas found to have lower standard deviations of temperature compared to rooms in pre-1983 code villas during both summer and winter seasons (Figure 6.5). This could suggest a certain degree of comfort taking in the insulated villas - as one insulates a building it become easier to cool so occupants take the benefit not as reduced energy but better comfort - particularly as occupants in these villas maintained lower/cooler temperatures on their thermostats (Table 6.7). The influence of insulation on creating more stable indoor temperatures is in line with findings from other researchers (Fang et al. 2014; Al-Homoud 2005).

8.4 Do villas with a larger internal floor area consume more energy than smaller villas?

- Villas with larger internal floor area are more likely to have higher annual energy use (kWh) than smaller villas.

In the quantitative survey, the ‘number of rooms’ was found to be a significant predictor of energy use in the regression model (Table 5.10). In this survey the ‘number of rooms’ is believed to be a more accurate measure of dwelling size because of its numerical form (compared to ‘villa size in m^2’ measured in rank order level), and the likelihood that occupants are more aware of how many rooms they have than their floor area (in m^2). Similarly, data from the multi-case study (Table 6.6) confirms that villas 3 and 4 with bigger built up areas had higher annual energy use (kWh/annum) compared to smaller villas 1 and 2, although annual energy use intensities (kWh/m2/annum) in villas with more occupants (villas 1 and 4) were higher. Combining such findings there appears to be evidence that building size is a key driver of energy use, which is also in agreement with findings from previous studies (Huebner et al. 2015; Kelly 2011). Similarly, Figure 2.5 in the literature review suggests that while the average Kuwaiti villa has a similar energy use per unit of floor area to the average UK dwelling, energy use is significantly higher possibly because villas are about 6 times the size of an average UK home.

The impact of building size in Kuwait is likely being enhanced by the fact that most villas are centrally cooled; larger built up areas suggest the need to cool more spaces - including many unused spaces– ultimately increasing energy use. Simulation findings, in particular, show that in newer villas 3 and 4, where a number of spaces were left unused, switching the cooling off in these spaces could, in theory, reduce annual energy consumption by 10% and 5% respectively (Table 7.10).

8.5 Do villas with more occupants consume more energy than villas with fewer occupants?

- Villas with more occupants are more likely to have higher annual energy use (kWh and kWh/m²) than those with fewer occupants.

In the quantitative survey, the 'number of occupants' was also found to be a significant predictor of energy use (kWh/annum) in the regression model (Table 5.10). Similarly, findings from the multi-case study (Table 6.8) indicate that villas 1 and 4, which had relatively more occupants, had higher annual energy use intensities (kWh/m²), higher energy use intensities during periods the AC was switched off, as well as higher plugs load intensities (W/m²). Combining such findings, there appears to be some evidence that household size is an important determinant of energy use in Kuwait. This is in line with findings from other studies (Huebner et al. 2015; Druckman & Jackson 2008; Brandon & Lewis 1999) that also show a positive correlation between the number of occupants and annual energy use.

8.6 Do households with a higher income consume more energy than those with a lower income?

- No clear indication of the impact of household income on energy use was observed.

With regards to household income, no clear association with energy use was found in the quantitative household survey or multi-case study. In the multi-case study the percentage of income spent on energy in each villa was also found to be relatively low (between 0.6-1.4% - Table 6.8), especially when compared with UK households that spend on average 4.4% of their total expenditure on energy (Ofgem 2017). While the impact of income on energy use is reported in other studies (Guerra Santin et al. 2009; Abrahamse & Steg 2009; Biesiot & Noorman 1999), the income effect in this context is minimal presumably because low electricity tariffs allow lower income households to afford higher levels of energy use, including the running costs associated with high appliance use.

8.7 What occupant behaviours affect energy use in villas and how?

- Occupant behaviours likely to impact energy use in villas include occupant driven cooling behaviours like AC thermostat set points, irregular AC maintenance, AC control during periods of prolonged travel or absence, opening doors and windows during AC operation, as well as high appliance use.

In the quantitative survey, regression analysis found that AC thermostat temperature set points is the most significant driver of energy use in the villas surveyed. The regression model indicates that for every 1 degree rise in thermostat temperature settings, energy use decreases by approximately 10%, when all other factors remain constant (Table 5.10). Similarly, simulation findings in Table 7.10, show that in newer case study villas, 3 and 4, where occupants used lower thermostat set points compared to those in older villas, a 1 degree rise in thermostat settings decreased annual energy use by 7% and 11% respectively. The effect of temperature set points on variations in energy use has also been reported by several researchers worldwide (Haas et al, 1998; Al-Mumin et al. 2003; Linden et al. 2006; Steemers & Young 2009; Guerra Santin 2009; Abrahamse & Steg 2009).

The impact of other variables measuring occupant energy-consuming behaviours including the duration of cooling, AC maintenance, window opening behaviour and appliance use was also examined in both the quantitative survey and multi-case study. Statistical analysis showed that such variables did not have significant relationships with energy use and were not significant predictors of this in the regression model. This could, in part, be due to the complexity associated with measuring occupant behaviour through surveys and analyzing this data through regression, as indicated in past studies (Huebner et al. 2015; Shipworth 2005). The multi-case study however enabled more in-depth examination of such variables in natural settings as presented in Table 6.9.

Key findings from the multi-case study (Section 6.2.3.2) include a tendency among households to leave their central cooling switched on for about 7-9 months of the year even when external weather conditions were mild and windows are left open (from March till May and September till November), or when villas are fully or partially vacated for a long period in the summer. For example, while homeowners of villas 2, 3, and 4 made no adjustments to their central AC thermostats during their summer travels, those in villa 1 increased settings by 1°C during a one-month vacation in July. This behaviour in villa 1, together with no active appliance use, reduced measured energy use by about 35% compared to the months of June and August.

The multi-case study also found that homeowners did not regularly maintain their AC system and called professional service staff only when there was a problem with their AC plant. Homeowners in three of the four villas also opted to clean their AC external filters themselves before operating their central units in spring, a behaviour that may have led to AC defects remaining undetected. All homeowners also reported that, within a few weeks of operation, technicians were called in to fix some developing problem with their AC. While homeowners were able to notice when there was a problem, they generally did not understand what the solution was and were happy as long as it was quickly fixed. Lack of regular maintenance over time is likely to lead to most units operating at lower efficiencies as indicated by Heinemeier et al. 2012.

Furthermore, findings from the multi-case study suggest there could be considerable potential for winter heating and energy use to increase in Kuwaiti villas. Winter external temperatures in Kuwait, although generally mild, can occasionally reach lows of 6-7°C (Figure 6.8, Section 6.2.2), and pre-1983 code villas in particular experienced several days in which average internal temperatures were below the recommended threshold of 18°C for heath set by the WHO (1987). However in determining whether winter heating and energy use are likely to increase, it is important to also consider whether there is a cultural element associated with winter in Kuwait. It is very likely that Kuwaiti households 'welcome' the short cold spells of winter and are happy to adapt to it as they have been particularly after the long relentless heat of summer. A study by Hitchings et al. (2015), examined the cultural features associated with winter heating in Wollongong Australia (whose climate, similar to Kuwait, consists of hot summers and relatively milder winters) and found a distinguished local approach to winter characterized by "*downplaying the hardships of seasonal cold and a determined focus on the return of summer*" (Page 170). Further research is thus required to better understand the various ways in which Kuwaiti households perceive and live with winter cold at home.

Finally, the multi-case study also provided insight on the impact of electrical appliance use on energy, especially as villas were found to have a very high number of kitchen appliances, mobile and tablet chargers, TVs, washing machines and dryers (Table 6.10). In particular it indicated that reducing appliance use in summer has a double effect on energy use; it directly reduces electricity use, but also reduces heat gains and so reduces cooling energy use by the AC. A breakdown of modelled cooling load presented in Figure 7.8, further shows that in villas 1 and 4 up to 30% of the cooling load was driven by appliance use compared to villas 2 and 3, likely due to their higher plug load intensities.

8.8 Why do occupants control their energy using systems and appliances in the ways they do?

- Factors likely to influence occupants' energy consuming behaviour include the physical size of villas, an expectation for comfort and convenience, occupants' physiological state (age and health), the structure of the household and a lack of awareness about energy use.

The multi-case study provided further insight into why occupants behave in certain ways (i.e. why they control their AC systems in the ways they do). A key factor likely to influence energy consuming behaviours is the physical size of villas, with larger villas suggesting a need to centrally cool and equip more spaces (many of which may be unused). Similarly, the study suggests that the operation of electrical appliances such as washing machines seems to be driven by occupants' strong requirement and expectation for comfort and convenience. Homeowners in three of the four villas for example reported that several laundry loads are carried out daily as occupants expect to have their clothes ready quick.

Furthermore, occupants' physiological state (age and health) was also found to somewhat influence behaviour particularly in villa 3 and 4. In villa 4 an elderly bed-ridden occupant, with specific temperature preferences, set the central AC thermostat (that simultaneously controls cooling in her bedroom and the main kitchen) to relatively higher settings. This in turn led the homeowners to install two additional split units in the main kitchen to provide additional cooling in that space for staff preparing meals. Similarly, in villa 3, the presence of three young children, below the age of 7, prompted the homeowners to ensure certain temperatures are maintained especially during winter, although they themselves prefer cooler temperatures.

The study also suggests that the behaviour of adjusting thermostats during periods of travel (described in Section 8.4 above) is likely to be influenced by the structure of the household. Villa 1, where thermostat adjustments were made during summer travel, consists of a working couple with younger children that travel together as a unit; whereas villas 2 and 4 consist of more diverse families with different travel routines (such villas are rarely empty at any given time).

All such factors are likely to be further triggered by low electricity tariffs and slack payment requirements currently enforced in Kuwait. As reported by several researchers (Alsayegh et al. 2018; Wolf et al. 2017; Ameer & Krarti 2016; Wood & Alsayegh 2014; Alotaibi 2011; Al-ajmi & Loveday 2010; Sadek et al. 2006; Al-Ragom 2003; Al-Mumin et al.

2003) such low tariffs have made households largely unaware of the actual impact of their energy behaviours and decisions.

8.9 Are there variations between actual and reported occupant behaviours and perceptions?

- Variations were found between measured annual energy use and occupant perceptions of this, with occupants tending to overestimate consumption. Some variations were also found between actual and reported AC thermostat set points and AC split unit control.

In the quantitative household survey annual electricity consumption reported by the survey sample had a significantly higher average than that found in national statistics, and responses had a wide range in value (Table 5.3 and Figure 5.5). Similarly, in the multi-case study, all homeowners overestimated their electricity bill, with consumption reported at the start of the study being relatively higher than total measured consumption recorded at the end of the study (Table 6.11). This suggests that simply providing homeowners with their actual energy consumption is unlikely to motivate them to take action to reduce energy use, as they already believe they are spending more than they actually are. Instead homeowners need to be made aware of the real cost of the energy they consume through electricity tariff redesigns.

Internal temperature monitoring in the multi-case study also showed that some room temperatures varied from thermostat set points initially reported by homeowners, particularly during the hot summer season, with greater variations found in villa 2 and less variations in villa 3 (Section 6.2.2, Figure 6.9). No variation was found however between what occupants reported were the coldest and warmest rooms and what was found by monitored temperature data. This suggests that while homeowners are able to describe their family preferences including why they set thermostats, they may not always accurately describe actual internal temperatures.

Some variations were also noted regarding the use of split units in the multi-case study in villas 1, 2 and 4. While homeowners of such villas reported that split units are switched on only when a room is used, monitoring data found that as external temperatures increased in summer, units tended to be kept on throughout the day in staff bedrooms and the main kitchen (even when rooms are unoccupied). Temperatures recorded in these rooms were also notably higher than the temperature the split unit was set to, especially in villas 1 and 2 which had relatively older units that were also possibly undersized and thus unable to deliver the required cooling.

Such variations suggest the importance of verifying reported energy and internal temperature data with measured data. The value of such verification in assisting researchers to determine what kinds of information can be reliably and accurately obtained from occupants and whether occupants behave in consistent ways, has increasingly been reported by researchers in recent years (Lowe et al. 2018; Love and Cooper 2015; Chiu et al. 2014).

8.10 Implications for policy

The following implications for policy are made based on the main research findings:

- The government should seek to look not only at annual energy use but peak power impact of interventions. Policies to encourage the adjustment of central AC thermostats to higher temperature settings during periods of summer travel for example, could potentially save considerable energy at times of peak demand in Kuwait. Such policies would also reduce carbon emissions and capital infrastructure costs for power generation. This can be in the form of a public information campaign launched, prior to the summer travel season, to urge households to adjust AC set points with evidence as to the impact this will have for the country (in terms of evaded energy costs and long-term energy security). An investigation into what is deemed a safe, acceptable internal temperature range for an unoccupied villa in the hot Kuwaiti summer (to prevent damage to furniture, plants, appliances) is also required.
- The enforcement of AC maintenance and replacement schemes to ensure more efficient performance of AC units can also result in notable energy savings. Lack of regular AC servicing seems to lead to distress maintenance and purchases in which homeowners are willing to accept quick solutions provided by the technician (at a time when they and others are overheating), which may not always lead to the most efficient future operation of the unit. Similarly the introduction of smart AC's, which report back performance to servicing companies, could result in better management of servicing loads by such companies, although the potential challenges of this (including connectivity, installation and price) require further exploration.
- Developing policies that require more efficient appliances in villas (replacing or upgrading old appliances and setting efficiency standards for new appliances) could greatly impact overall energy use as it would directly reduce energy use by the appliance as well as reduce heat gains and thus cooling energy use by the AC.

- Policies that promote a reduction in either villa size (to suit the number of occupants and their needs) or the area that is cooled (via better zoning of the cooling system for example) could reduce energy use. This is important as villas were found to have many rooms (some of which unused) that are centrally and continuously cooled for 7 to 9 months of the year.
- In Kuwait a redesign of current heavily-subsidized electricity tariffs is essential and very likely to impact occupant energy-consuming behaviours and awareness. Paying the actual cost of energy could, for example, change space conditioning behaviour by encouraging occupants to only cool rooms that are being used. A tariff redesign would also require enforcement of a robust, regular payment structure (i.e. quarterly per annum) to support adjustment (by households) to electricity price increases.
- Findings show no clear evidence that fabric improvements associated with the 1983 code have made a significant difference in energy use. This could be due to several reasons including non-compliance, poor workmanship, or inaccurate assumptions about actual fabric performance. To better inform interventions about fabric improvements, a more detailed forensic investigation of actual fabric efficiency is thus needed. It is also useful to determine if Kuwait Municipality building codes, which have allowed for progressive increases in internal floor areas, are counteracting efficiency effects imposed by the 1983 code and its recent revisions. This would provide insight on whether policy goals from different government agencies are in alignment.
- To better measure and evaluate the real impact of interventions, policy should be evidenced by empirical monitoring ideally undertaken in a systematic longitudinal manner, rather than relying solely on self-reported data (of energy use or other physical variables such as internal temperature). Although historically measured data has been difficult to collect due to cost, time, and privacy concerns, the deployment of smart meters in many countries and increased connectivity via the 'Internet of things' is progressively reducing these challenges. In Kuwait it is important for the government to invest in such platforms and technologies to facilitate data collection.

While the policy measures suggested above can potentially save considerable energy in Kuwait, particularly during periods of peak demand, there is likely to be some resistance towards such measures by Kuwaiti citizens. In particular, homeowners are likely to oppose electricity tariff increases, especially as all previous attempts to reduce subsidies (for Kuwaiti residential consumers) have faced opposition and been declined by Kuwaiti parliament (KEO, 2019). Historically low electricity tariffs and a poor billing system in Kuwait (with no requirements for regular payments) have made households largely unaware of the impact of their energy consuming behaviours and decisions. Lack of awareness of actual energy consumption makes it difficult for households to envision the potential benefits of demand reduction and improve their consumption efficiency.

To enhance acceptability of potential tariff redesigns, as well as other measures suggested, it is important for the government to ensure energy efficiency and demand reduction goals are clear with a consistent, simple mandate for implementation. It is also crucial that the government adequately support and prepare households for interventions through information campaigns, demonstration projects, and training programs. Finally, it is imperative that the government emphasizes the strategic importance of energy savings by households to the long-term economic and energy stability of the country as a whole.

8.11 Chapter summary

- Results from the quantitative household survey, longitudinal mixed method multi-case study and energy modelling are discussed through the use of the triangulation method.
- Several physical and social drivers of energy use in Kuwaiti villas have been outlined. These include:

  Physical drivers
    - Large villa sizes
    - Centralized delivery of AC

  Social drivers
    - Low AC thermostat settings
    - Irregular AC maintenance
    - AC control during periods of prolonged summer travel
    - Opening doors and windows during AC operation
    - High appliance use
    - Household size
- A number of policy recommendations have been made. These include policies to encourage higher AC thermostat set points during periods of summer travel, AC maintenance and replacement schemes, improving appliance efficiencies, a reduction in villa sizes, electricity tariff redesigns, and the development of a platform for collecting reliable national-level data about the residential building stock including energy, building, and occupant data.

Chapter 9: Conclusions, Recommendations and Future Research

This chapter outlines a summary of the research conclusions based on analysis of key findings discussed in Chapter 8. Implications for policy and recommendations for future work are then presented. Finally the chapter states the contribution to knowledge made by this research.

9.1. A summary of key findings

This research aimed to identify key social and physical drivers of energy use in Kuwaiti villas to enable more informed analysis of interventions in this field. The three key elements of this research include: 1) a cross-sectional quantitative household survey, 2) a longitudinal mixed-method multi-case study and 3) building energy modelling.

The main research findings are summarized as follows:

1. The quantitative household survey developed a comprehensive information base about the physical and social characteristics of Kuwaiti villas at a national level, and indicated that thermostat temperature set points had the greatest impact on energy use, followed by the number of rooms and number of occupants.

2. The longitudinal mixed-method multi-case study demonstrated the contextually distinct nature of energy demand and the dynamic interaction that exists between building fabric, systems and occupants. It provided valuable empirical data about household energy use, internal temperatures, building and system characteristics and occupant energy-use behaviours that was used to ground models to better predict energy use.

3. Models grounded with empirical data show that space cooling accounts for 50% to 75% of total energy use in villas, indicating that the centralized delivery of AC is a key driver of energy use. Model results also suggest that drivers of cooling energy are varied, with 30% of cooling energy in some villas attributable to heat gains from appliances.

4. The multi-case study indicated that villas with more occupants (villas 1 and 4) had higher annual energy use intensities (kWh/m²), higher energy use intensities during periods when the AC was switched off (kWh/m²/week), as well as higher plug load intensities (W/m²). This is in line with findings from quantitative survey and thus combining such findings there appears to be some evidence that household size is an important determinant of energy use in Kuwait.

5. With regards to household income, no clear association with energy use was detected in the multi-case study or in the quantitative household survey. This is presumably because low electricity tariffs allow lower income households to afford higher levels of energy use including the running costs associated with high appliance use.

6. The multi-case study and energy modelling found no distinct reduction in measured and modelled annual energy use intensities of villas with improved levels of efficiency (insulation and double glazing). Similarly, no strong association was found between villa age (used as a proxy for fabric efficiency) and energy use in the quantitative household survey. Such measures however are likely to have contributed to more uniform internal temperatures measured in the longitudinal study particularly during the hot summer and cold winter seasons.

7. The multi-case study and quantitative survey also indicate that villas with a larger internal floor area are likely to have higher annual energy use (kWh/annum). Results suggest this is being accentuated by the centralized delivery of AC, in which many unused rooms are cooled for about 7-9 months of the year.

8. The multi-case study highlighted several key occupant driven cooling behaviours like low AC thermostat set points, irregular AC maintenance, AC control during periods of prolonged summer travel, and opening of windows while the AC is in operation. Other important behaviours include high appliance use and lighting use during the day.

9. Factors likely to influence occupants' energy consuming behaviour include the physical size of villas, an expectation for comfort and convenience, occupants' physiological state (age and health), the structure of the household and a lack of awareness about energy use

10. This research has shown the importance of examining energy use through a mix of methods and over an extended period of time. It particularly demonstrates the importance of verifying occupant perceptions of energy use and temperature with measured data.

11. Research findings have supported the development of policy recommendations that could potentially save considerable energy in Kuwait, especially during periods of peak demand. These include policies that encourage higher AC thermostat set points during the summer travel period, AC maintenance and replacement schemes, improving appliance efficiencies, promoting a reduction in villa sizes or the area that is cooled to suit the number of occupants and their needs, electricity tariff redesigns, and endorsement of robust national databases with empirically measured energy building and occupant data.

9.2 Recommendations for future work

The section below discusses potential future research beyond that investigated in this thesis, examining the three main elements of this study in turn.

Quantitative household survey

Although survey findings provided important insights about key drivers of energy use further development of the survey and its administration is required. In particular a survey of a larger random sample of villas using actual metered energy data is needed to obtain results that are more generalizable to the wider stock or population of villas in Kuwait. Given the cultural constraints associated with such a survey (indicated in Section 5.1.2) a study of this nature would require extensive resources and a partnership between government and research institutions. The potential of making such a survey longitudinal in design (in which the same household is approached at yearly intervals, for example, to track changes in energy consumption as well as in key physical and social variables) should be explored.

Longitudinal mixed-method multi-case study

While the longitudinal multi-case study provided valuable empirical data and insights, findings are indicative and further research is necessary to establish how representative they are of the national stock. Such research should also undertake detailed forensic examinations of the building to better determine levels of actual fabric efficiency, ventilation heat gains and AC operational efficiency. Also, as average winter internal temperatures in older villas were occasionally found to be below the recommended threshold of 18°C for health (WHO, 1987), future studies can explore how Kuwaiti households perceive and adapt to winter cold at home and the potential for winter heating and energy use to increase.

Building energy models

The modelling study demonstrated the value of grounding building energy models with empirical data. Opportunities to extent research in this field include the development of a Kuwaiti stock model, as a policy design and evaluation tool, to assist with evaluating the energy demand of the existing residential stock and the wider impact of energy efficiency interventions. Substantiating the stock model development process with longitudinal empirical data (including model input parameters associated with occupant behaviour, building form, fabric and systems) can enhance the reliability of model predictions. In addition to different categories of the single-family villa, the scope of this model can be further expanded to incorporate other dwelling types in Kuwait including flats in mid-high rise apartment blocks, which currently house the vast majority of the country's expatriate population. Such a model would be a useful tool to assess the wider impact of interventions, including for example, those urging occupants to increase central AC thermostats during periods of summer travel, on national peak demand and energy use.

9.3 Contribution to knowledge

In achieving the research aim, the study has made the following original contributions to the residential energy demand research field in Kuwait:

1. The study has, through the quantitative household survey, provided a comprehensive information base about the physical and social characteristics of Kuwaiti villas on a national level, of which published data is virtually non-existent. National data is important in understanding residential energy use as well as in developing and validating models of energy use.
2. The mixed-method multi-case study has demonstrated a novel data gathering approach collecting longitudinal context-based physical and social data from different case study villas in Kuwait, including energy use and internal temperature data, of which published data is again non-existent. Unique elements of this approach include:
    a. A comprehensive set of longitudinal indoor temperature data for Kuwaiti villas, providing insight into cooling and heating of households in almost every room at 20-minute intervals (while many studies only collect temperature data in one or two rooms of a dwelling). This is important

because temperature is a driver of energy use, and measuring this in a small percentage of a building's volume could potentially result in uncertainties and inaccuracies. As shown in this study some large variations were found in the average temperatures and the standard deviation of temperatures between rooms within different villas (including rooms cooled by the same central AC unit).

b. The interactive feedback between monitoring and occupant interview data demonstrates the value of longitudinal studies of energy use that also incorporate a longitudinal social element. Integrating knowledge of the physical systems and their use - via monitoring - with knowledge of social practices - via periodic in-depth occupant interviews - has enabled a more robust investigation of energy use including variations between reported and actual occupant perceptions and behaviours. This has also allowed for better grounding of energy models.

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Appendices

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1. First occupant interview schedule in English
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Appendix I: Graphs of internal temperatures vs. external temperature in each case study villa

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1. External temperature and relative humidity: A comparison between monitored data, metrological data and the KISR weather file
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Appendix A: Comparative summary of MEW 1983 code and its subsequent revisions

Basic energy conservation requirement for residential buildings

ELEMENT	DESCRIPTION	STANDARD		
		2014	2010	1983
Air conditioning units				
Direct expansion (most common in residential buildings)	W/m²	56 villas 60 apartments	60 (all residential)	65
Air-cooled chiller	W/m²	70 villas 75 apartments	71 (all residential)	
Water cooled chiller				45
<250RT	W/m²	53 villas 57 apartments	53 (all residential)	
250<RT<500	W/m²	46 villas 49 apartments	46 (all residential)	
>500RT	W/m²	44 villas 47 apartments	44 (all residential)	
Lighting				
	W/m²	7 villas 7 apartments	10 (all residential)	15

Operating parameters and guidelines for estimating power ratings for AC systems are also provided in the code. To estimate peak cooling demand and annual cooling and electrical energy requirements two design weather conditions are defined for Kuwait's coastal (2km from coast) and interior zones in the 2010 and 2014 versions, in comparison to the 1983 code.

Minimum required energy conservation measures for residential buildings

ELEMENT	DESCRIPTION	STANDARD			
		2010 and 2014		1983	
Building envelope					
Walls and Roofs		Walls	Roofs	Walls	Roofs
Heavy construction, medium light external colour	W/m².K	0.568	0.397	0.57	0.4
Heavy construction, dark external colour	W/m².K	0.426	0.256	For other times of buildings with medium and light construction it is left to the designer to decide on measures to be taken. It is only noted that the overall u-values should be decreased to obtain the equivalent thermal gain	
Medium construction, medium –light external colour	W/m².K	0.483	0.341		
Medium construction, dark external colour	W/m².K	0.426	0.199		
Light construction, medium-light external colour	W/m².K	0.426	0.284		
Light construction, dark external colour	W/m².K	0.369	0.170		
Exposed floor	W/m².K	0.566		Not considered	
Columns	W/m².K	0.568			
Beams	W/m².K	0.0398			
Ventilation					
	ACH	The higher of ASHREA's latest ventilation rate of 20 CFM/person or 0.5 ACH + exhaust air is used 0.5		A standard ventilation rate of 5 CFM/person was used	
Infiltration					
Exterior envelope	Requires buildings to be tight with no cracks or open joints. Buildings using pre-cast concrete elements in the wall constructions must have joints permanently sealed with an appropriate sea such as silicone based compounds			Requires buildings to be made tight with no cracks or open joints.	
Windows and doors	All windows and exterior doors must to be sealed and weather stripped				
Seals and weather stripping	All exterior doors and windows must be sealed and weather stripped				
Exhaust fans	All exhaust fans must have dampers to automatically shut when fans are not in use				

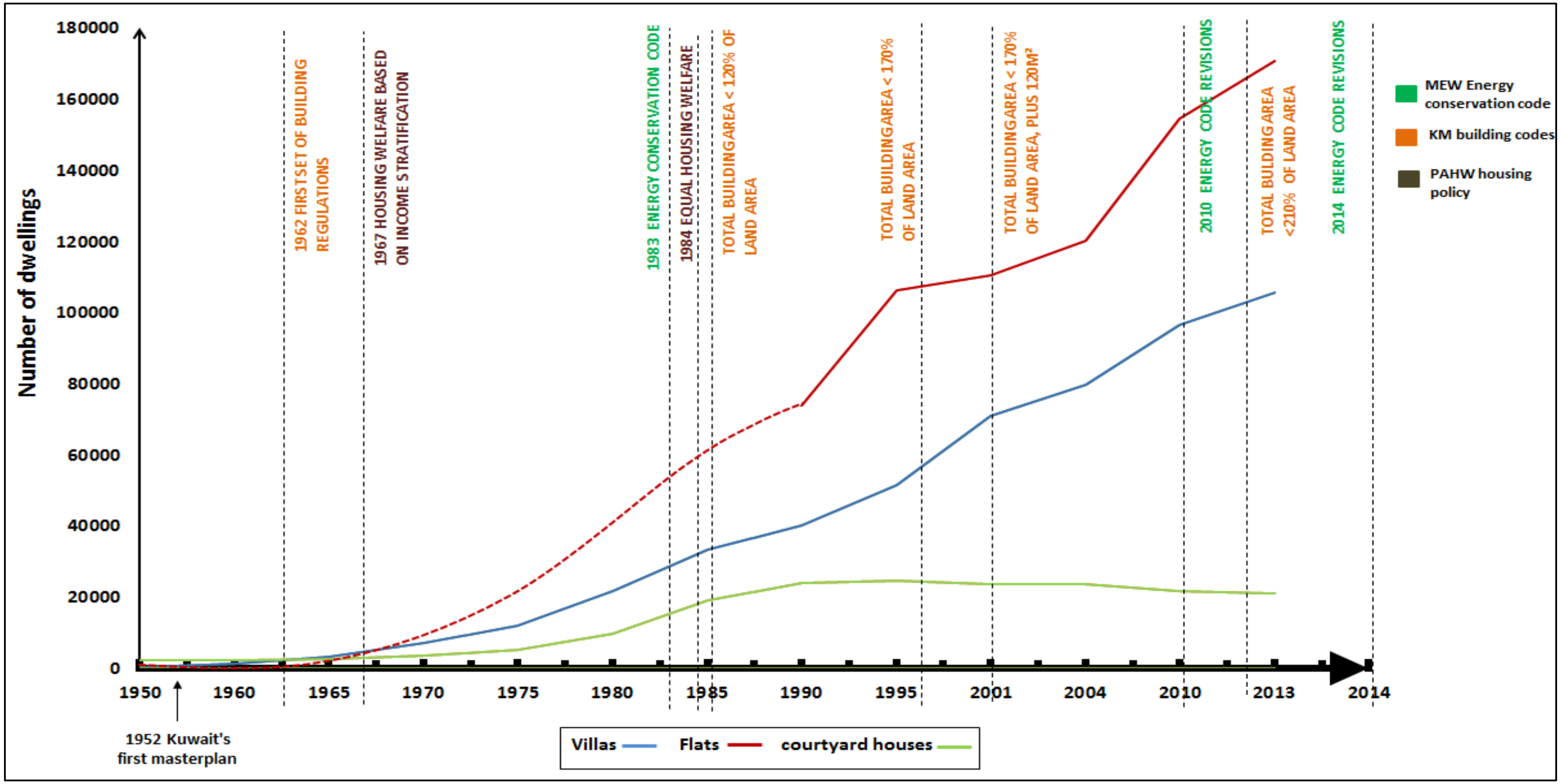
The 2014 also includes a further construction description: 'very light construction light colour has been (requiring U values of 0.23 for walls, and 0.16 for roofs)

Glazing requirements for buildings

ELEMENT	STANDARD							
	2010							1983
Glazing type	**Solar heat gain coefficient**	**Visible light transmittance coefficient**	**U-value (W/m²C)**	**Window to wall ratio (%)**				
				East	**West**	**South**	**North**	
6 mm single clear	0.72	0.80	6.21	≤5	≤3	≤4	≤5	With regards to glazing the 1983 code notes that any type of glazing can be used when 0-10% of the wall area is glazed. If 11-15% of the wall area is glazed any type of double glazing can be used.
6mm single reflective	0.31-0.37	0.16-0.27	6.41-6.44	6-10	3-10	4-10	6-10	
6mm double tinted	0.36-0.40	0.30-0.57	3.42-3.44	11-15	10	10	11-15	
6mm double reflective	0.25	0.23	3.38	16-50	10-45	10-45	16-50	
6mm double spectrally selective (high performance)	0.23	0.53	1.71	51-100	45-75	45-75	51-100	

The 2014 code prevents the use of single glazing and glazing type depends solely on window to wall ratio: 0-15% double tinted, 16-50% double reflective, 51-100% double spectrally selective.

Appendix B: A timeline illustrating the evolution of the Kuwaiti housing stock



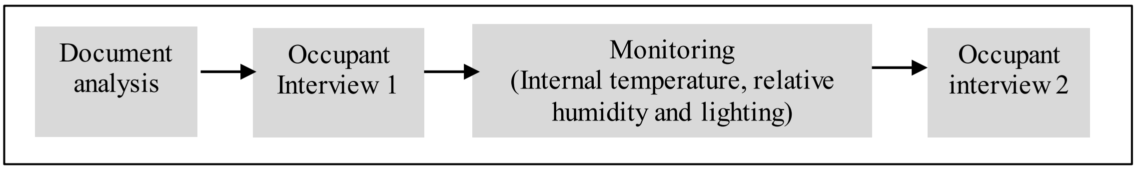
Note: Today the PAHW provides a standard housing model for citizens, however from 1967-1984 two housing models were provided based on citizen income

Appendix C: Pilot study: data collection and analysis

The pilot case study villa is located on a 400m² plot of land. It consists of four floors and total built-up area of 809 m². The existing homeowners bought the villa in 2001 as a new build (constructed between 1999-2001).

Pilot study villa

<u>Data collection</u>



<u>Occupant interview schedule 1</u>

Please provide information regarding the following:

Household and villa background information
Household structure-

- Number of household occupants: Adults, children, household domestic staff
- Age of occupants
- Homeowner occupation/income level

Dwelling characteristics-

- Type of villa (private/government)
- Year of construction
- Period of construction
- Have there been any major/minor refurbishment works undertaken since the villa was built
- Are you aware of whether your villa is built in accordance to the Energy Conservation Code guidelines?
- Describe the number and function of different rooms in the villa: bedrooms, bathrooms, reception rooms, play rooms, staff quarters, and kitchen

Dwelling form and fabric characteristics

- When designing your villa what key design criteria did you consider? Did you consider any environmental aspects such as orientation, solar heat gain? (question applicable only to homes designed by homeowners themselves)
- Are you aware of the type of insulation used in the construction (walls and roof)?
- Are you aware of the type of glazing used in the villa?

Building services

- Please describe the cooling system of your home? Are you aware of the type and number of A/C units being used? Please explain.
- During the winter months, how do you heat your home?
- What role does your hot water tank play and how is it operated throughout the year?
- Please describe the number and type of electrical appliances used in the villa television sets, personal computers, washers/dryers, ovens, refrigerators, vacuum cleaners.
- Are you aware of the type and power demand of the light fixtures used in your home? Please explain.

Occupant behavior

- How often do you maintain your AC system?
- What time of year do you turn the AC system on?
- Do you tend to open windows while the AC is on (when the weather is cooler)?
- How often do you adjust the AC thermostat controls? Are individual room separately controlled?
- Who is responsible for adjusting thermostats?
- How are window shutters/curtains operated during the day?
- Which area/floor of the villa does your family use the most?
- Do you and other household members tend to turn on all the lights in the room? If no, how many?
- Do you and other household members turn lights off when leaving a room?
- What time are appliances being used and for how long? Televising sets, personal computers, washing machines and dryers, ovens, refrigerators, vacuum cleaners.
- Please describe the daily routine of household members in your home?

Occupant interview schedule 2

Please provide information regarding the following:
Changes to energy using practices and occupancy during the monitoring period

- Has there been any change to household occupancy since monitoring started
- Has there been any change to occupants daily routine and or use of certain rooms since monitoring

Changes to building services or construction elements

- Have there been any construction repairs or changes done to the building fabric (walls, glazing, roof, tiling etc.
- Have there been any changes to building systems (AC settings, boiler operation,
- Have there been any fault or deficiency with any of the building services or appliances (AC, boiler, washing machine

Summary of key findings from document analysis, occupant interviews, physical survey and monitoring

Villa floor sizes and functions

Floor	Size (m²)	Functions
Basement	172.8	2 open plan living rooms used on special occasions and an office.
Ground	308.5	2 open plan living rooms, 1 dining room, 1 bedroom with bathroom, 1 diwaniya, 1 main kitchen, and 2 male staff bedrooms.
First	262.6	5 bedrooms with bathrooms, 1 living room, and 1 kitchenette.
Second	64.4	1 Female staff bedroom, 1 laundry, 1 ironing room.

Household occupant details

Occupants	Age	Occupation
Homeowner – father	46	Sea captain
Homeowner –mother	38	Housewife and private business scuba-diving center owner/instructor
Daughter	18	University student
Son	14	High school student
Grandmother	70	Retired/bedridden
Aunt	36	Employee and part time PhD student
Cook	28	Prepares food for the household
Driver	26	Driver
Nurse	38	Cares for grandmother
Female household staff 1	36	Cleaning, laundry
Female household staff 2	37	Cleaning, laundry

Construction details

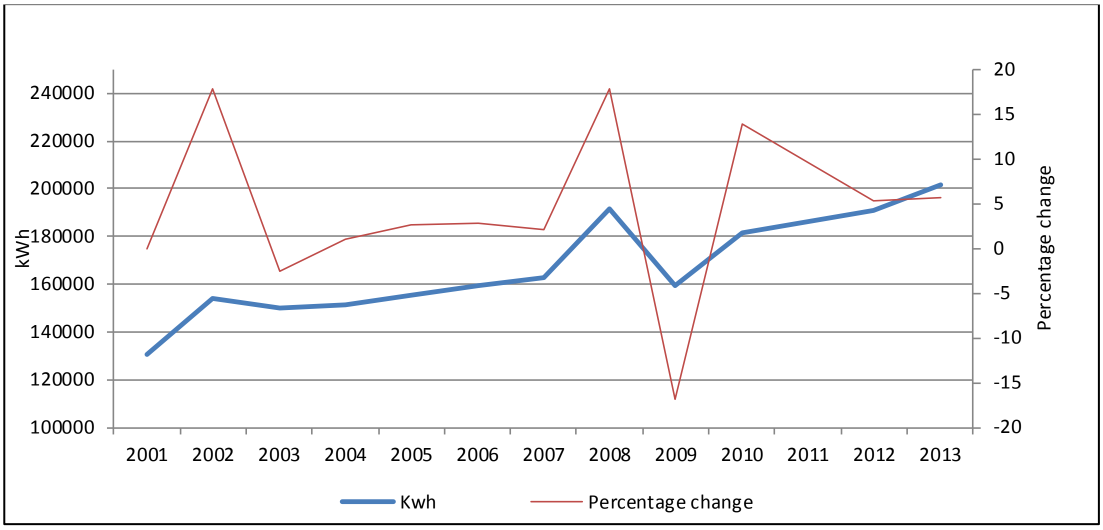
Fabric	Description
Construction	Skeleton frame construction, consisting of beams, slabs and columns using reinforced concrete as the principal construction material.
External walls	Interviewee was unsure of the type of wall in the villa but based on the measured wall thickness (greater than 30cms), it is assumed that the wall is a classic wall with two concrete blocks sandwiching a layer of insulation.
Roof	The roof is flat and consists of a reinforced concrete slab.
Windows	A double pane of 6mm glass incorporated within an aluminum frame. Outer panes are slightly tinted to reduced solar gain and provide some privacy. Window openings are relatively small in size and open both horizontally and vertically. Were sealed in 2001 and again in 2009
Doors	External doors are of a standard aluminum type. Internal doors are wooden.
Facade	The external facade is cladded with a locally produced block.
Floors	Tiling with carpet rugs distributed throughout
Internal walls	Sand-cement plaster and paint
Curtains/shutters	There are no external shutters on windows. Curtains are lightweight and decorative.

Building services

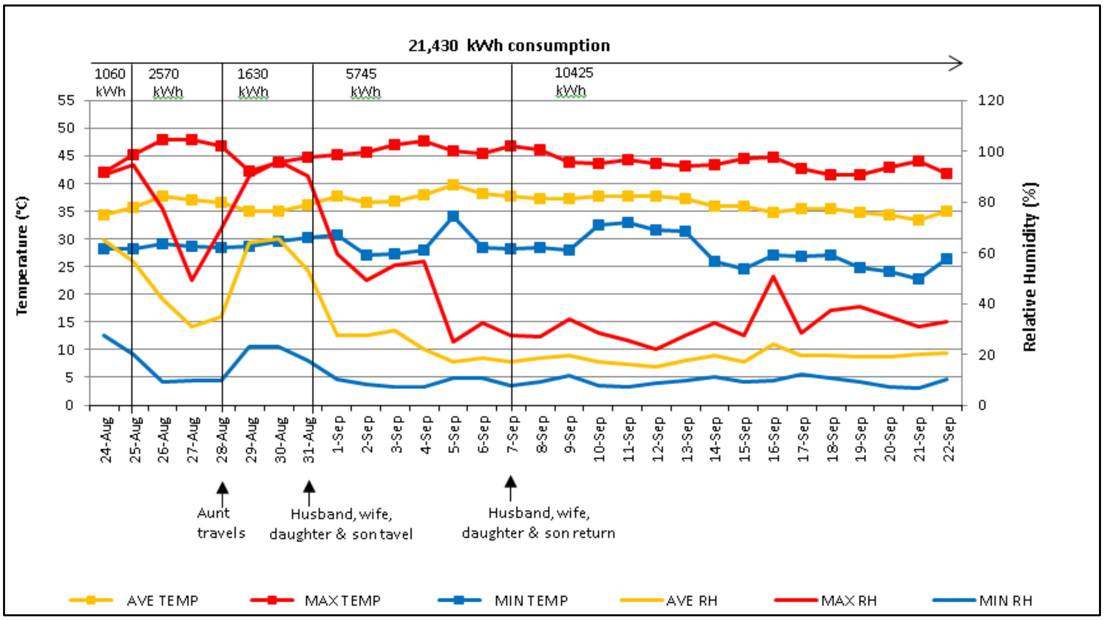
Element	Description
Air-conditioning	5 Packaged direct expansion units on the roof to serve various rooms in different floors. Two for the ground floor, two for the first floor and one for the basement. A number of mini split units are also used in staff bedrooms and the main kitchen.
Hot water	There is one large hot water tank on the roof for providing hot water.
Cooking	Gas cylinders are used in the main kitchen. Electric ovens are used to reheat food and for lighter meals.
Lighting	Most light bulbs are 60 watt incandescent (halogen) bulbs. The homeowner has switched a lot of bulbs to energy saving 5-15 watt CFL and LED bulbs including in the main kitchen, staff bedrooms, and laundry room.

Appliances

Appliance	Quantity	Location	Appliance	Quantity	Location
TV's	9	All bedrooms and living rooms	Washing machine	3	Laundry
Satellite receiver	6	All bedrooms and living rooms	Dryer	1	Laundry
Desktop	2	Aunt bedroom and living room	Electric bed	1	Grandmother bedroom
Laptop	3	Aunt room and daughter room	Oxygen condenser	1	Grandmother bedroom
Fridge	4	Kitchen	Lifter	1	Grandmother bedroom
Freezer	3	Kitchen	Hot water tank	1	Roof
Coffee machine	2	Kitchenette & Diwaniya	PlayStation	1	Son's room
Toaster	2	Kitchenette &Kitchen	microwave	1	Kitchenette
Kettle	3	Kitchenette &Kitchen	Electric oven	2	Kitchenette &Kitchen
Fryer	1	Kitchen	Blender	1	Kitchen



Pilot Villa historical annual energy consumption – An increase of almost 54% since 2001



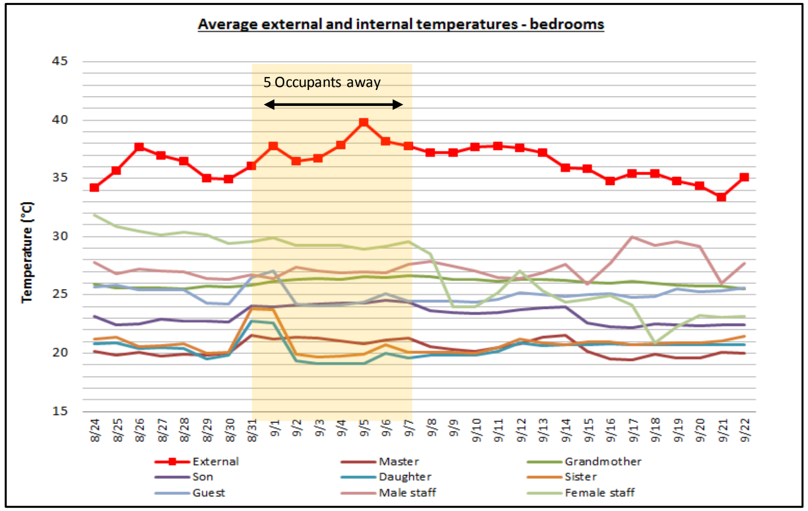
External temperature, relative humidity conditions and energy consumption (based on electricity meter readings) during the monitoring period

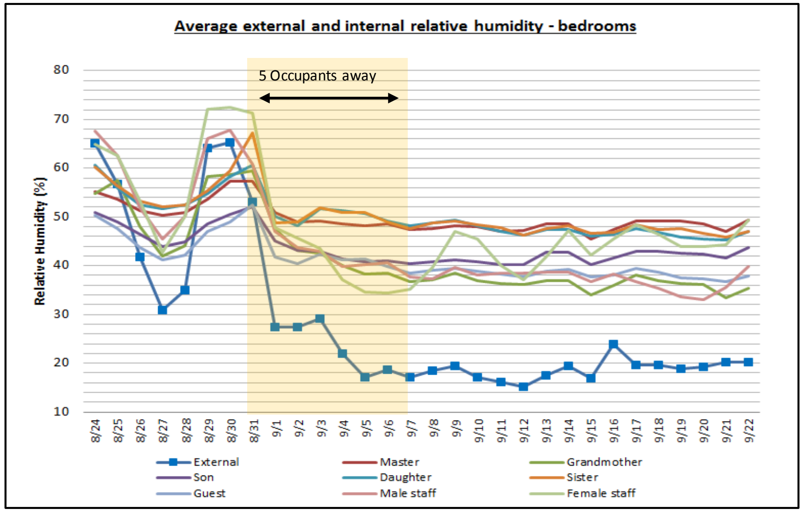
Internal temperature, relative humidity and lighting in different rooms of the pilot villa (August 24 2014-September 2014)

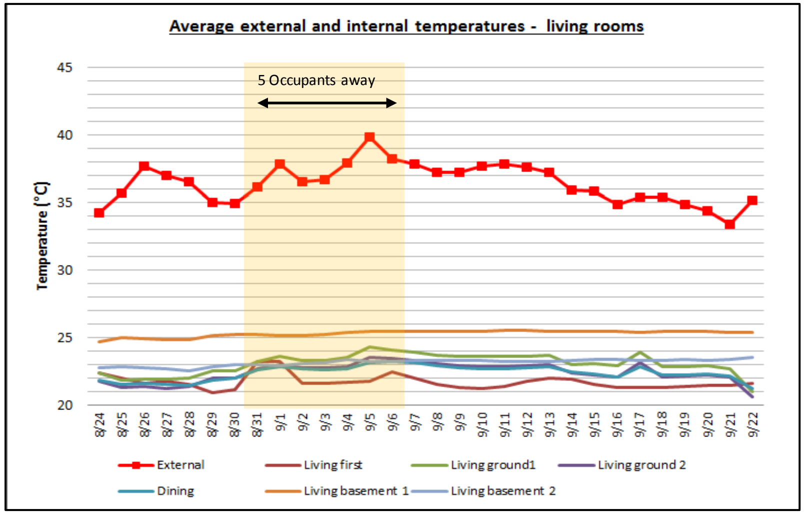
Room	Parameters											
	Temperature (°C)				Relative Humidity (%)				Lighting (Lux)			
	Mean	Max	Min	Stdev	Mean	Max	Min	Stdev	Mean	Max	Min	Stdev
Bedrooms												
Master bed – first	20.4	22.5	18.8	0.78	49.7	80.5	40.3	3.56	13.1	153.7	3.9	18.6
Sister – first	20.8	24.9	18.5	1.05	50.5	79.0	42.9	5.55	6.4	130.1	3.9	12.3
Daughter – first	20.4	23.7	18.4	0.93	49.9	80.1	40.6	4.74	7.0	106.4	3.9	10.0
Son – first	23.3	24.9	21.3	0.84	43.5	62.5	38.2	3.67	15.2	106.4	3.9	22.5
Guest – first	25.0	28.0	22.9	0.80	41.0	64.4	34.6	4.28	15.2	106.4	3.9	22.5
Grandmother – ground	26.1	27.8	24.8	0.50	41.7	69.1	30.1	8.45	37.4	461.2	11.8	49.7
Driver– ground	27.3	31.8	24.4	1.71	43.7	78.0	25.5	11.1	31.2	216.8	3.9	38.4
Female staff- second	27.1	33.1	18.9	3.28	47.3	89.1	25.6	12.7	16.9	540.0	3.9	61.1
Kitchens												
Kitchenette – first	21.0	23.0	19.9	0.59	51.0	75.3	42.8	5.08	5.61	19.7	3.9	3.7
Main Kitchen – ground	23.9	27.9	21.3	0.98	41.7	80.2	30.9	8.57	52.6	279.9	3.9	47.7
Living rooms												
Living room – first	21.7	24.0	20.1	0.60	49.4	72.1	41.5	5.22	8.3	185.3	3.9	16.3
Living room 2G - back ground	22.4	25.0	20.1	0.80	48.4	79.8	39.1	6.19	8.5	59.1	3.9	5.4
Living room 1G - front ground	23.1	26.7	20.3	0.92	46.5	79.2	35.4	6.84	201.9	3078.6	11.8	376.1
Living room 2B – back basement	25.3	26.1	24.2	0.24	39.3	48.2	31.1	3.55	14.4	90.7	11.8	9.2
Living room 1B -front basement	23.1	23.7	21.4	0.47	44.8	57.8	35.5	3.97	12.8	35.5	3.9	3.9
Others												
Corridor – second	30.3	34.8	27.1	1.57	38.6	65.3	27.0	8.25	51.8	508.5	3.9	68.1
Dining room – ground	22.4	23.9	20.8	0.58	47.4	81.3	36.8	6.68	8.44	193.2	3.9	20.6
Diwaniya –ground	27.3	29.3	24.2	0.87	38.3	54.2	29.9	3.66	16.2	926.3	3.9	36.7
Office– basement	25.8	26.1	24.7	0.21	41.1	48.8	34.3	2.88	3.9	11.8	3.9	0.21

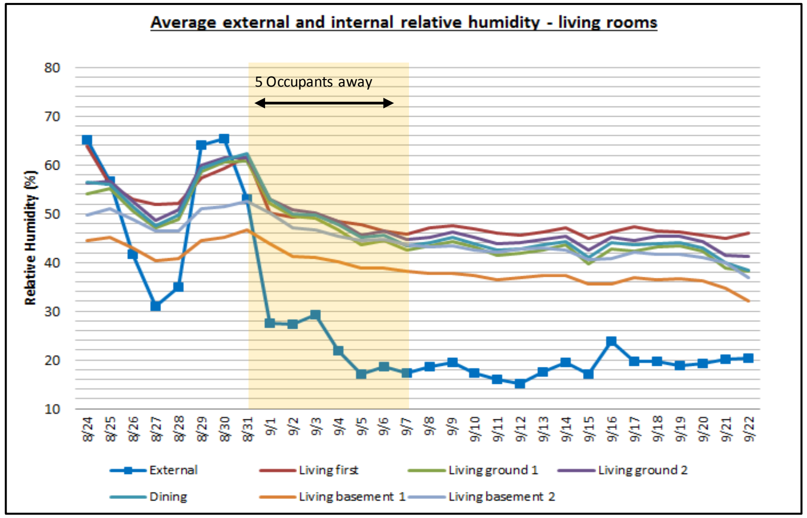
With exception to staff rooms, internal temperatures in all rooms remained fairly stable throughout the monitoring period and were only slightly influenced by external temperatures. With regards to RH, all rooms were slightly influenced by external RH, with staff bedroom being more influenced.

Graphs of internal temperature and relative humidity in different rooms









Appendix D: Kuwaiti Data Protection Legislation (Law No. 32 of 1982 concerning the Civil Information System (32/1982)

دستور الكويت

قانون رقم 32 لسنة 1982 في شأن نظام المعلومات المدنية

مادة (18):
مع عدم الإخلال بأحكام المادة السابقة، يجوز للجهات الحكومية والأشخاص الاعتبارية الخاصة والأفراد أن يحصلوا من الهيئة على ما يحتاجونه من معلومات مسجلة في نظام المعلومات المدنية بشرط موافقة الهيئة بعد التحقق من حاجة الطالب إلى هذه المعلومات وجدواها والغرض منها وأي شروط أخرى تراها لازمة، وللهيئة الحق في رفض الطلب وإخطار الطالب بذلك كتابةً.
ويجوز التظلم من القرار الصادر بالرفض خلال الموعد المحدد إلى مجلس الإدارة، ويكون قرار المجلس الصادر في موضوع التظلم نهائيًا.
ويصدر الوزير قرارًا بالبيانات التي يجب أن يشتمل عليها الطلب والرسوم المقررة.
مادة (19):
يحظر على من حصل على معلومات بناءً على المادة السابقة، أن يستخدمها في غير الغرض الذي وافقت الهيئة على إعطائها له من أجله، ويجب عليه الالتزام بالشروط التي أعطيت له المعلومات بمقتضاها.
ومع عدم الإخلال بالعقوبة المقررة في المادة (35) يجوز للهيئة وقف تزويد المخالف بالمعلومات التي يطلبها مستقبلاً للمدة التي تحددها.
مادة (38):
للمساكن حرمة، فلا يجوز دخولها بغير إذن أهلها، إلا في الأحوال التي يعينها القانون وبالكيفية المنصوص عليها فيه.

Law No. 32 of 1982 concerning the Civil Information System (32/1982)

Article No. 18
Without prejudice to the provisions of the preceding article, government agencies, corporate authorized personnel's and individuals from the public may obtain from the civil information what they require upon obtaining the approval from the civil information authority. The civil information authority will only approve such requests after studying such requests to validate the need and the purpose for such requests and the civil information authority has the right to reject the application and notify the applicant in writing.
In case the applicants request was rejected by the civil information authority, the applicant may appeal against the decision to the civil authority Governing Council by the assigned deadline and the Council will issue the final verdict on the subject.
The minister issues a decision including the data that must be included in the request application and the assessed fees.

Article No. 19
It is prohibited to use the information obtained for any purpose other than the purpose by which the information was granted for and the applicant must adhere to the conditions under which the information was given to him.
Without prejudice to the penalty prescribed in Article 35, the civil commission may stop providing in the future any information requested by the offender for a period the civil information authority may specify.

Article 38
The home is inviolable; therefore, save in the cases determined by Law and in the manner stipulated therein, no person may enter any home without the dweller's permission.

Appendix E1: Quantitative household survey schedule (English version)

Household energy consumption questionnaire

Respondent ID		**Interview date**	
Respondent telephone #		**Start time**	**hrs mins**
Residential district		**End time**	**hrs mins**
Residential neighbourhood		**Interviewer name**	

Please answer the following questions. Information provided will be treated with the utmost confidentiality.

PART 1: HOUSEHOLD BACKGROUND INFORMATION

1. **Is your villa:**
   a. Owned by yourself or someone in your household
   b. Rented by yourself or someone in your household
   c. Occupied without the payment of rent

2. **What is the employment status of the main householder (the homeowner/decision maker in the household)?**
   a. Employed full-time
   b. Employed part-time
   c. Working from home
   d. Not employed/ retired

3. **Can you estimate in which of the following categories your total household income falls:**
   a. Less than 1000 KD/month
   b. Between 1000-2500 KD/month
   c. Between 2500-3500 KD/month
   d. Greater than 3500 KD/month

4. **How many families live in your villa:**
   a. One single/nuclear family
   b. Extended family (grandparents, aunts, uncles)
   c. Multiple families (the homeowner's family in addition to a non-relative family renting an independent floor/section of the villa)

5. **How many people live in your household and what is their age group?**

	Age							
	0-4	**4-18**	**18-25**	**25-35**	**35-45**	**45-55**	**55-65**	**Over 65**
Household member								
Household staff	N/A							N/A

6. **What is the highest level of education of the main householder (the homeowner/decision maker in your household)?**
   a. University post-graduate
   b. University undergraduate
   c. High school
   d. Primary school
   e. Other please specify

PART 2: BUILDING FORM AND FABRIC CHARACTERISTICS

7. **In what year was your villa built?**
   a. Before 1960 b. 1960-1983
   c. 1984-1995 d. 1996-2009
   e. 2010-2012 f. 2013-2014

8. **Is your villa:**
   a. Designed and Built by the Public Authority for housing welfare (government)
   b. Designed and built privately by yourself/someone in your household
   c. Designed and built privately then bought by yourself/someone in your household

9. What is the approximate size (m²) of the land on which your villa is built?
_______________ m²

a.	Less than 350	b.	351-450	c.	451-550
d.	551-650	e.	651-750	f.	751-850
g.	851-950	h.	950-1000	i.	Greater than 1000

10. What is the approximate built up area of your villa (m²)
_______________ m²

a.	Less than 350	b.	351-450	c.	451-550
d.	551-650	e.	651-750	f.	751-850
g.	851-950	h.	950-1000	i.	Greater than 1000

11. How many floors (including basement) are there in your villa?
a. 1 floor
b. 2 floors
c. 3 floors
d. 4 floors or more

12. How many of the following room types are there in your villa?

Room type	Number	Room type	Number
Bedroom		Washing room	
Bathroom		Staff bedrooms	
Living room		Diwaniya	
Kitchen		Basement	
Dining room		Office	

13. Are there any unused rooms or spaces in your villa?
a. Yes
b. No
If yes, please specify ________________________________

14. Have you undertaken any refurbishment work since the villa was built?
a. Yes
b. No
If yes please specify the type of work:
a. Extension vertically (addition of extra floor)
b. Extension horizontally (addition of space to an existing floor)
c. Resealing windows/doors
d. Upgrading/replacing hot water tank
e. Insulating walls
f. Insulating the roof
g. Upgrading/replacing AC equipment
h. Other, please specify

Insulation is often added to the walls and roof of a building to reduce heat gain or loss and therefore reducing the energy demands of the cooling or heating system.
15. Regarding wall insulation in your villa, would you describe the walls as being:
a. Well insulated
b. Adequately insulated
c. Poorly insulated
d. Not insulated
e. Don't know
16. Regarding roof insulation in your villa, would you describe the roof as being:
a. Well insulated
b. Adequately insulated
c. Poorly insulated
d. Not insulated
e. Don't know

17. Please select the type(s) of glazing in your villa:

a. Single glazing
b. Double glazing
c. Triple glazing
d. Solar reflective glazing
e. Don't know

18. Please select the type(s) of window shading devices in your villa:

a. External shutters
b. Internal curtains or blinds
c. Overhangs
d. No shading devises
e. Other, please specify

19. What is the major external material of your villa:

a. Brick
b. Concrete or concrete block
c. Glass
d. Stone
e. Other, please specify

PART 3: SPACE COOLING/HEATING AND HOT WATER USAGE

20. What type of air-conditioning (AC) equipment does your villa have?

a. A central air-conditioning system
b. Individual split units in the windows or walls
c. Both a central system and individual split units
d. No air-conditioning equipment

21. If you have AC equipment, which months of the year do you use AC in the villa?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

If you have a central AC system in your villa, please answer questions 20-24.

22. How many central AC plant (direct expansion systems) do you have in your villa:

a. 1-2
b. 3-4
c. 5-6
d. More than 6
e. Don't know

23. What is the average cooling capacity per plant?

a. 3 tons or less
b. 4-10 tons
c. 10 tons or more
d. Don't know

24. How old is your central AC system?

a. Less than 1 year old
b. 1-3 years old
c. 3-6 years old
d. 6-9 years old
e. More than 9 years old

25. Which room(s) in your villa is/are cooled by the central AC system?

a. All rooms
b. Kitchen
c. Office
d. Bedrooms
e. Basement
f. Dining room
g. Living rooms
h. Diwaniya
i. Other, please specify

26. Do you have a thermostat that controls the central AC equipment?

a. Yes
b. No

If yes, which temperature (°C) is your thermostat usually set to?

a. 19°C and below
b. 20°C
c. 21°C
d. 22°C
e. 23°C
f. 24°C
g. 25°C
h. 26°C
i. 27°C and above

Which settings do you usually use?
a. Automatic mode
b. Constant on mode
c. Don't know

Who is responsible for adjusting the thermostat?
a. All household members including household staff
b. All household members excluding household staff
c. Household owners only

Do you adjust thermostat settings when the villa is unoccupied for prolonged periods (such as travel)?
a. Yes always
b. Sometimes
c. Never

If you have window or wall mounted split units, please answer questions 23-25.

27. How many window or wall mounted split units do you have in total?
Number of units ______________

28. What is the average cooling capacity per split unit?
a. Less than 1 ton
b. 1 - 2 tons
c. 2.5 tons or more
d. Don't know

29. Which room(s) of your villa is/are cooled by split units?

a. All parts	b. Kitchen	c. Office
d. Bedrooms	e. Staff bedrooms	f. Basement
g. Living rooms	h. Diwaniya	i. Other, please specify

30. How often do you maintain your AC equipment?
a. Once a year
b. Twice a year
c. Once every two years
d. Randomly (as and when needed)
e. Never

31. Do you leave windows open while the AC is on?
a. Yes
b. Sometimes
c. No

32. During the winter months do you heat your villa?
a. Yes
b. Sometimes
c. No

If yes or sometimes, how do you heat your villa?
a. Electric heaters
b. AC system turned into heating mode
c. Other, please specify

Which room(s) of your villa do you heat?

a. All rooms	b. Kitchen	c. Office
d. Bedrooms	e. Basement	f. Dining room
g. Living rooms	h. Diwaniya	i. Other, please specify

33. Please rate your perception of thermal comfort in the following:

	Cold -3	Cool -2	Slightly cool -1	Neutral 0	Slightly warm 1	Warm 2	Hot 3
Inside your home in *Summer*							
Outside in *Summer*							
Inside your home in *Winter*							
Outside in *Winter*							

34. In general, when you are too *hot* in your villa, what do you do to cool down? (Select all applicable)

a. Lower the temperature on the cooling control (AC thermostat)
b. Use additional cooling devices such as electric fans
c. Open window(s)
d. Take off some clothes
e. Pull down curtains/external shutters
f. Do nothing
g. Other please specify

35. In general, when you are too *cold* in your villa, what do you do to get warm? (Select all applicable)

a. Use heating devices (electric heaters)
b. Put on more clothes
c. Close windows
d. Do nothing
e. Other, please specify

36. What type of hot water system do you have in your villa?

a. A central hot water system (central device supplying multiple extraction points)
b. A local hot water system (individual devices supplying single extraction points)
c. Mixed system (both a central and local system)
d. No hot water system
e. Don't know

37. What main source of fuel do you use for water heating?

a. Electricity
b. Gas
c. Oil
d. Don't know

38. If you have a hot water system, which months of the year is the system operated?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

39. Is the hot water heating system switched on when the villa is unoccupied for prolonged periods (such as travel)?

a. Yes
b. Sometimes
c. No

PART 4: LIGHTING AND HOUSEHOLD APPLIANCE STOCK

40. What major type of lighting is used in your villa?

a. Incandescent bulbs
b. Fluorescent bulbs
c. LED/energy saving bulbs
d. Don't know

41. Do you or your household members switch off lights in unoccupied rooms?

a. Yes always
b. Often
c. Rarely
d. Never

42. How would you describe the level of natural daylight in your villa?

a. Very good
b. Poor
c. Good
d. Very pool
e. Average

43. Please note how many of the following appliance you have in your villa

Appliance type	Quantity	Appliance type	Quantity
TV's		Electric oven	
Satellite receiver		Gas oven	
Fridge		Gas hob/stove	
Freezer		Electric hob/stove	
Water cooler		Vacuum	
Toaster		Washing machine	
Kettle		Clothes dryer	
Microwave		Games console	
Dishwasher		Water pumps (i.e. for pressurized hot water)	
Other, please specify			

44. If you have any of the following appliances, please estimate how often they are used.

Appliance type	Daily	Every other day	Every 3 days	Once a week
Washing machine				
Clothes dryer				
Vacuum				

PART 5: ELECTRICITY CONSUMPTION AND BILL PAYMENT

45. How often do you pay your electricity bill?

a. Every 3 months or less
b. Every 6 months
c. Every 12 months
d. More than every 12 months
e. As and when prompted by the MEW
f. Don't know

46. Can you estimate your average electricity bill per year?

Bill KWD __________

47. Are you aware that you can check and pay your electricity bills online through the MEW website?

a. Yes
b. No

48. How concerned are you about the amount of energy you use?

a. Very concerned b. Concerned
c. Neither concerned or unconcerned d. Unconcerned

49. How concerned are you about the amount you pay for energy?

a. Very concerned b. Concerned
c. Neither concerned or unconcerned d. Unconcerned

Appendix E2: Quantitative household survey schedule (Arabic version)

استبيان حول استهلاك الطاقة المنزلية

هاذا الاستبيان هو جزء من دراسه علميه لتقيم سلوكيات وآليات استهلاك الطاقه في المنازل (الفلل) السكنيه في دوله الكويت. يُرجى من حضرتكم التكرم بالاجابة على الأسئلة التالية. مع العلم بانه سيتم التعامل مع المعلومات المقدمة بمنتهى السرية.

جزء 1: معلومات حول خلفية الحياة العائلية

1. هل الفيلا التي تسكنها:

أ. تملكها بنفسك أم يملكها شخص ما فى عائلتك.
ب. تؤجرها بنفسك أم يؤجرها شخص آخر فى عائلتك.
ج. تسكنها دون دفع ايجار لها.

2. ما هو الوضع الوظيفى لرب العائلة (مالك المنزل/ صانع القرار فى العائلة)؟

أ. يعمل دوام كامل
ب. يعمل نصف دوام
ج. يعمل من المنزل
د. لا يعمل/ متقاعد

3. هل يمكنك تقدير دخل العائلة من بين هذه الفئات المالية:

أ. اقل من 1000 د.ك /الشهر
ب. ما بين 1000-2500 د.ك/ الشهر
ج. ما بين 2500-3500 د.ك/ الشهر
د. أكبر من 3500 د.ك/ الشهر

4. ما هو عدد الأسر التى تعيش الفيلا:

أ. أسرة مفردة
ب. أسرة ممتدة (الحموله،الأجداد، العمات، الأعمام)
ج. أسرمتعددة (أسرة مالك المنزل بالاضافة الى أسرة غير قريبة للعائلة تستأجر طابق مستقل/جزء من الفيلا).

5. كم عدد الأشخاص اللذين يعيشون فى الفيلا وما هى فئاتهم العمرية؟

	العمر							
	4-0	18-4	25-18	35-25	45-35	55-45	56-55	اكبر من 65
عضو العائلة								
عماله منزليه	-------------							

6. ما هو اعلى مستوى تعليمى لرب العائلة (مالك المنزل/ صانع القرار فى العائلة)؟

أ. التعليم العالي
ب. التعليم الجامعي
ج. التعليم الثانوي
د. التعليم الابتدائي
ه. أخرى، يرجى التحديد

جزء 2: نموذج البناء وخصائص البنية

7. فى اى عام تم بناء الفيلا ؟

أ. قبل عام 1960 ب. 1960-1983
ج. 1984-1995 د. 1996-2009
هـ. 2010-2012 و. 2013-2014

8. هل الفيلا التي تسكنها:

أ. تم تصميمها وبنائها من جانب الهيئة العامة للرعاية السكنية (حكومة)
ب. تم تصميمها وبناء بشكل خاص عن طريقك/شخص ما فى عائلتك (خاص)
ج. تم تصميمها وبنائها بشكل خاص ثم تم شرائها عن طريقك/شخص ما فى عائلتك (خاص)

9. ما هو الحجم التقريبى ($م^2$) للأرض التى تم عليها بناء الفيلا؟
___________ $م^2$
أ. اقل من 350$م^2$
ب. 350-499 $م^2$
ج. 500-749 $م^2$
د. 750-1000 $م^2$
ه. اكبر من 1000 $م^2$

10. ما هو الحجم التقريبى ($م^2$) للفيلا ؟
___________ $م^2$
أ. اقل من 350$م^2$
ب. 350-499 $م^2$
ج. 500-749 $م^2$
د. 750-1000 $م^2$
ه. اكبر من 1000 $م^2$

11. ما هى عدد الطوابق (بما فيها السرداب) فى الفيلا ؟
أ. 1 طابق
ب. 2 طابق
ت. 3 طوابق
ث. 4 طوابق أو أكثر

12. ما هى عدد انواع الغرف فى الفيلا ؟

انواع الغرفة	العدد	انواع الغرفة	العدد
غرف نوم افراد العائله		**غرف غسيل**	
غرف نوم العماله المنزليه		**مطبخ**	
حمامات		**ديوانية**	
غرف المعيشة		**سرداب**	
غرف الطعام		**مكتب**	

13. هل توجد غرف أو مساحات غير مستغلة/مستخدمه فى الفيلا ؟
أ. نعم
ب. لا
اذا كانت الاجابة بنعم، يرجى التحديد ____________________

14. هل قمت بأية أعمال ترميم/تجديد منذ بناء او شراء الفيلا ؟
أ. نعم
ب. لا
اذا كانت الاجابة بنعم، يرجى تحديد نوع العمل:
أ. توسعة رأسية (بناء طابق اضافى) ب. توسعة أفقية (بناء مساحة لطابق موجود)
ج. اعادة انشاء او تسليم اغلاق النوافذ/الأبواب د. تجديد/استبدال خزان الماء الساخن
هـ. عزل الجدران و. عزل السطح
ز. تجديد/ استبدال جهاز التكييف ح. أخرى، يُرجى التحديد

غالباً ما يتم اضافة العازل الى حوائط وسطح المنازل لتقليل امتصاص أو فقدان الحرارة ومن ثمَّ تقليل استهلاك على الطاقة من أنظمة التبريد والتدفئة.

15. فيما يتعلق بعزل الحوائط، في رايك هل الحوائط في الفيلا:

أ. معزولة جيداً
ب. معزولة بطريقة كافية
ت. سيئة العزل
ث. غير معزولة
ج. لا أعلم.

16. فيما يتعلق بعزل السطح فى فيلتك، في رايك هل السطح في الفيلا:

أ. معزولة جيداً
ب. معزولة بطريقة كافية
ت. سيئة العزل
ث. غير معزولة
ج. لا أعلم.

17. يُرجى تحديد أنواع زجاج النوافذ فى الفيلا:

أ. زجاج فردى
ب. زجاج مزدوج
ت. زجاج ثلاثى
ث. زجاج شمسى عاكس
ج. لا أعلم

18. يُرجى تحديد أنواع وسائل تظليل النوافذ فى الفيلا:

أ. شترز خارجي
ب. ستائر داخلية
ت. دلايات (مضلات خارجيه)
ث. لا توجد وسائل تظليل
ج. أخرى، يُرجى التحديد

19. ما هى المادة الخارجية الرئيسية على جدران الفيلا ؟

أ. طابوق ب. بلوكات أسمنت
ت. سقما ث. حجر
ج. زجاج ح. أخرى، يُرجى التحديد

جزء 3: التبريد/ التدفئة واستخدام سخانات الماء الساخن

20. ما نوع نضام التبريد فى الفيلا ؟

أ. نظام تكييف مركزى
ب. وحدات "سبليت" فردية فى النوافذ أو الحوائط
ج. كلاً من النظام المركزى ووحدات "سبليت" الفردية
د. لا يجد جهاز تكييف

21. فى أى شهور العام تستخدم نضام التبريد فى الفيلا ؟

يناير	فبراير	مارس	ابريل	مايو	يونيو	يوليو	أغسطس	سبتمبر	أكتوبر	نوفمبر	ديسمبر

اذا كان لديك نظام تكييف مركزى فى فيلتك، يُرجى الاجابة على الاسئلة من 26-22

22. ما هو عدد وحدات التكييف المركزى التى تملكها فى الفيلا ؟

أ. 1-2
ب. 3-4
ت. 5-6
ث. أكثر من 6
ج. لا أعرف

23. ما هو متوسط قدرة التبريد لكل وحدة؟

أ. 3 طن أو أقل
ب. 4-10 طن
ت. 10 طن أو أكثر
ث. لا أعرف

24. ما هوعمر نظام التكييف المركزى لديك؟

أ. أقل من 1 سنة
ب. 1-3 سنوات
ت. 3-6 سنوات
ث. 6-9 سنوات
ج. أكثر من 9 سنوات.

25. ما هى الغرف التى يتم تبريدها عن طريق نظام التكييف المركزى؟

أ. كافة الغرف   ب. غرف المعيشة   ج. المطبخ
د غرف نوم افراد العائله   هـ. السرداب   و. المكتب
ز. غرف نوم العماله المنزليه   ح. الديوانية   ط. أخرى، يرجى التحديد

26. هل يوجد لديك نضام تحكم (ثرموستات) فى جهاز التكييف المركزى؟

أ. نعم
ب. لا

اذا كانت الاجابة بنعم، ما هى درجة الحرارة (سيليزية) التى يتم ضبط الثرموستات عليها؟

أ. 19°C وأقل   ب. 20 °C   ج. 21 °C
د. 22 °C   هـ. 23 °C   و. 24 °C
ز. 25 °C   ح. 26 °C   ط. 27 °C وأعلى

ما هو وضع الجهاز التحكمي (الثرموستات) الذي تستخدمه؟

أ. وضع اتوماتيكى
ب. وضع مستمر(دائم البروده)
ت. لا أعلم

من المسئول عن ضبط الثرموستات؟

أ. كافة أعضاء العائلة بما فيهم العماله المنزليه
ب. كافة أعضاء العائلة باستثناء العماله المنزليه
ت. مالكى المسكن فقط

هل تقوم بضبط وضع الثرموستات حينما تكون الفيلا خالية لفترات زمنية طويلة (فى حالة السفر مثلاً)؟

أ. نعم دايماً
ب. أحياناً
ت. لا مطلقاً

اذا كان لديك وحدات تكييف "سبليت" ، يُرجى الاجابة على الأسئلة 27-29.

27. ما هو العدد الاجمالى من وحدات "سبليت" في الفيلا ؟

عدد الوحدات ______________

28. ما هو متوسط طاقة التبريد لكل وحدة "سبليت"؟

1. أقل من 1 طن
2. 2 طن
3. 2.5 طن أو أكثر
4. لا أعلم

29. أياً من غرف الفيلا يتم تبريدها من خلال وحدات "سبليت"؟

أ. كافة الغرف   ب. غرف المعيشة   ج. المطبخ
د غرف نوم افراد العائله   هـ. السرداب   و. المكتب
ز. غرف نوم العماله المنزليه   ح. الديوانية   ط. أخرى، يرجى التحديد

30. ما هو عدد المرات التى تقوم فيها بصيانة جهاز التكييف في الفيلا ؟

أ. مرة فى السنة
ب. مرتين بالعام
ج. مرة كل سنتين
د. عشوائياً (كما وعند الحاجة)
ه. مطلقاً

31. هل تترك النوافد مفتوحة عند تشغيل جهاز التكييف؟

أ. نعم
ب. أحياناً
ت. لا

32. هل تقوم بتدفئة الفيلا خلال شهور الشتاء؟

أ. نعم
ب. أحياناً
ت. لا

اذا كانت الاجابة بنعم أو أحياناً، كيف تقوم بتدفئة فيلتك؟

أ. دفايات كهربائية
ب. نظام تكييف يتحول الى وضع التدفئة
ت. أخرى، يُرجى التحديد

ما هى الغرف التى تقوم بتدفئتها فى فيلتك؟

أ. كافة الغرف ب. غرف المعيشة ج. المطبخ
د غرف نوم افراد العائله هـ السرداب و. المكتب
ز. غرف نوم العماله المنزليه ح. الديوانية ط. أخرى، يرجى التحديد

33. يُرجى تحديد الحاله الحراريه التي تشعر بها في الحالات التاليه :

	برد 3-	براد 2-	براد قليلا 1-	معتدل 0	دافىء قليلا 1	دافىء 2	حار 3
داخل منزلك فى الصيف							
خارج منزلك فى الصيف							
داخل منزلك فى الشتاء							
خارج منزلك بالشتاء							

34 .بشكل عام، عندما تشعر بالحراة داخل الفيلا ، ما هي الاعمال التي تقوم بها لتبريد نفسك ؟ (اختر كافة العوامل القابلة للتطبيق)

أ. تخفيض الحرارة من جهاز التحكم التكيف (ثرموستات)
ب. استخدام جهاز تبريد آخر مثل المراوح الكهربائية
ج. فتح النوافذ
د. خلع بعض الملابس
هـ. اسداد الستائر/ الشترز الخارجى
و. لا اعمل شيء
ز. أخرى، يُرجى التحديد

35. بشكل عام، عندما تشعرفي البروده داخل الفيلا ، ما هي الاعمال التي تقوم بها لتدفنه نفسك ؟ (اختر كافة العوامل القابلة للتطبيق)

أ. استخدام أجهزة تدفئة (دفايات كهربائية)
ب. ارتداء مزيد من الملابس
ج. غلق النوافذ
د. لا أعمل شيء
ه. أخرى، يرجى التحديد

36. ما هو نظام تسخين الماء في الفيلا

أ. **نظام مركزي**
ب. **نظام وحدات** فردية
ج. كلاً من النظام المركزي وحدات فردية
د. لا يوجد نضام لتسخين الماء
ه. لا اعلم

37. كيف يتم تسخين الماء الساخن؟

أ. نظام يعمل بالكهرباء

ب. نظام يعمل بالغاز
ت. نظام يعمل بالغاز
ث. لا اعلم

38. فى أى شهور العام تستخدم نضام تسخين الماء في الفيلا ؟

يناير	فبراير	مارس	ابريل	مايو	يونيو	يوليو	أغسطس	سبتمبر	أكتوبر	نوفمبر	ديسمبر

39. هل يكون نظام تسخين الماء عاملاً حينما تكون الفيلا غير مأهولة لفترات طويلة (مثل السفر)؟

أ. نعم
ب. أحياناً
ت. لا

<u>جزء 4: الاضاءة وتخزين الأجهزة المنزلية</u>

40. ما هو نوع الاضاءة الرئسيية المستخدمة فى الفيلا ؟

أ. لمبات متوهجة
ب. لمبات فلورسنت
ج. لمبات ليد (LED)/موفرة للطاقة
د. لا اعلم

41. هل تطفىء أنت أو احد أعضاء عائلتك الأنوار فى الغرف الغير مأهولة؟

أ. نعم دائما
ب. غالباً
ج. نادراً
د. مطلقا

42. كيف تصف مستوى الاضاءة الطبيعية فى الفيلا ؟

أ. جيدة جدا
ب. جيدة
ج. متوسطة
د. سيئة
ه. سيئة جداً

43. يُرجى تحديد عدد الأجهزة التالية التى تملكها فى الفيلا

نوع الجهاز	الكمية	نوع الجهاز	الكمية
تلفزيون		فرن كهربائى	
جهاز استقبال "ريسيفر"		فرن غاز	
ثلاجة		طباخ غاز	
فريزر		طباخ كهربائى	
مبرد ماء		مكنسة كهرابائيه	
جهاز توستر		غسالة	
غلاية		مجفف ملابس	
مايكروويف		جهاز ألعاب منزلى	
غسالة أطباق		مضخات ماء	
اخرى			

44. اذا كنت تمتلك أياً من الاجهزة التالية، يُرجى تقدير عدد مرات استخدامها

نوع الجهاز	يومياً	يوم بعد يوم	كل 3 ايام	مرة فى الاسبوع
غسالة ملابس				
مجفف ملابس				
مكنسة كهربائيه				

<u>جزء 5: استهلاك الكهرباء وسداد الفواتير</u>

45. ما هيه الفتره التي تقضيها لتسديد فاتورة الكهرباء؟

أ. كل 3 شهور او اقل
ب. كل 6 شهور
ج. كل 12 شهر
د. اكثر من كل 12 شهر
ه. حينما تطلب مني وزارة الكهرباء والماء
و. لا اعلم

46. هل يمكنك تقدير متوسط فاتورتك من استهلاك الكهرباء فى العام الواحد؟

تكلفة الفاتورة ________________

47. هل تعلم أنه يمكنك مراجعة وسداد فواتير الكهرباء الخاصة بك من خلال استخدام الموقع الالكترونى لوزارة الكهرباء والماء؟

أ. نعم
ب. لا

48. ما هى درجة اهتمامك بكمية الطاقة التى تستهلكها؟

أ. مهتم جداً ب. مهتم
ج.الامر لا يشكل لي اهميه د. غير مهتم

49. ما هى درجة اهتمامك بالمبلغ الذى تدفعه نظير استهلاك الطاقة؟

أ. مهتم جداً ب. مهتم
ج. الامر لا يشكل لي اهميه د. غير مهتم

Appendix F: Definitions of terminology associated with regression analysis

- **Unstandardized beta** is a coefficient that represents the slope of the line between the independent variable and the dependent variable.
- **Standardized beta** is a coefficient that compares the strength of the effect of each independent variable on the dependent variable. The higher the value, the stronger the effect.
- **Confidence intervals** – the 95% confidence intervals for the unstandardized beta give an indication that the real value of the coefficient being estimated falls within that confidence interval. Intervals should ideally not contain 0.
- **Standard error of betas (SE B)** is an estimate of the standard deviation of the coefficient (the amount it varies across cases)
- **T-statistic** is calculated by dividing the coefficient by its standard error. T-statistics test the hypothesis that each coefficient is different from 0. They should be greater than 1.96 (for 95% confidence)
- **P-value** tests the hypothesis that each coefficient is different from 0. Should be greater than 0.05.
- **Residuals** are the differences between the observed value of the dependent variable and the predicted value. If a regression model is well fitted, the residuals are small with no pattern to them.
- **Standardized residuals** are used to determine whether the observed value of the dependent variable is different from its predicted value. A standardized residual greater than 3 indicates a cause of concern.
- **Outlier** is an extreme observation that affects the slope of a regression line. Outliers can be identified using Cooks distance.
- **Cooks distance** is a measure of the effect of a single case on the model as a whole (dependent and independent variables). Values greater than one indicate high influence.
- **Covariance ratio** is measure of the impact of each case on the variance of regression coefficients.
- **DFbeta** is a measure of how much a case affects the estimate of a regression coefficient
- **Multicollinearity or collinearity** refers to a correlation between two or more independent variables which can make it difficult to determine the separate effects of individual variables. It is assessed through checking correlation coefficients and the Variance Inflation Factor (VIF). A VIF of 10 or above suggests high collinearity.
- **Independence** refers to autocorrelation between values of the same variable across different cases. All cases (of a particular variable) should be independent of one another. This is assessed through the Durbin Watson (DW) statistic, which tests for the serial correlation between residuals. DW ranges between 0 and 4, with a value of 2 indicating no correlation.
- **Normality** refers to the extent to which data for the independent variables and the dependent variable are normally distributed. This is examined with a goodness of fit test such as the Kolmogorov Smirnov test.
- **Linearity** refers to the extent to which the relationship between the dependent and independent variable is linear. This is assessed through observation of residual scatter plots.
- **Homoscedasticity** refers the extent to which the data values for the dependent and independent variables have equal variance. This is assessed through observation of residual scatter plots.

Source: Field 2013

Appendix G: Multi-case study: First Occupant interview schedule and physical survey schedules

1. First occupant interview schedule

Briefing

- A short explanation of the interview structure
- Clarify that the interviewee can decline to answer any question and that there are no correct or wrong answers
- Clarify that the interview will be recorded
- Provide a confidentiality statement, explaining how data will be used and its anonymity
- Ask whether the interviewee has any questions before the interview starts.

Part 1: Household background information

- Could you tell me a little bit about yourself, such as what your profession is and how long you have lived in your villa?
- Could you tell me a little about the people who live in the villa, such as their age and occupation?
- Do you mind me asking what your total household income is?

Part 2: Dwelling form and fabric characteristics

I will now ask a few questions about the physical characteristics of your villa.

- So, in what year was your villa built?
- Do you know the approximate size (in m²) of the land on which the villa is built in, and the approximate built up area of the villa (in m²)?
- Are you aware of whether the villa was built in accordance with the Energy Conservation Code?
- Has there been any refurbishment works undertaken since the villa was built/bought i.e. extension vertically/horizontally, resealing windows/ doors, upgrading/replacing hot water tank, insulating walls
- What main criteria were considered when designing or purchasing this villa i.e. cost, location
- Do you know the type of insulation used in the construction of the walls and roof? i.e. aerated concrete blocks or a separate layer of insulation between blocks.
- Do you know what type of glazing is used in your villa? i.e. single, double, triple solar reflective
- How are your window shutters/curtains operated during the day?

Part 3: Space conditioning and hot water

I will now ask a few questions about building systems in your villa.

- First with regards to space cooling, does your villa have a central AC system, wall mounted split units, or a mixed system (central and split units)?

If the system is central or mixed, ask:

- Do you know how many central AC plant (direct expansion systems) are used in your villa?
- Do you know the rough cooling capacity per plant (tons)?

If the system is mixed or only wall mounted split units, ask:

- How many split units are used in your villa?
- Do you know the rough cooling capacity per split unit?
- Which rooms are cooled by the central AC system and which rooms are cooled by split units?
- For how many months of the year is your villa cooled on average?
- Is there a thermostat that controls the central AC equipment?
- If yes, which temperature (°C) is your thermostat usually set to and is it on automatic or constant on mode?
- Does this vary by room/floor and how?
- Who is responsible for adjusting the thermostat?
- Do you adjust thermostat settings when the villa is unoccupied for prolonged periods (such as travel)?
- How often is the AC equipment maintained?
- Do you or other household occupants tend to leave windows open while the AC is on?

- Now with regards to space heating, do you heat your villa during the winter months and how?
- If yes, which room(s) do you heat?

- Regarding hot water, could you describe the type of system used in your villa? i.e central hot water tank, local
- Which months of the year is the hot water system operated?

Part 4: Lighting and appliance use

I will now ask about lighting and electrical appliances.

- What major type of lighting is used in your villa?
- How would you describe the level of natural daylight in your villa?
- Do you and other household members tend to turn on all the lights in the room? If no, how many?
- Do you and other household members turn lights off when leaving a room?
- If you have any of the following appliances, please estimate how often they are used.

Appliance	Usage
TV	
Washing machine	
Clothes dryer	
Vacuum	
Kettle	
Microwave	
Oven	

Part 5: Occupant routines and perceptions

I will now ask you about your household routines and perceptions.

- Could you please describe a typical weekday routine for occupants in your villa?
- What about their routine on weekends?
- Please rate your perception of thermal comfort in the following:

	Cold -3	Cool -2	Slightly cool -1	Neutral 0	Slightly warm 1	Warm 2	Hot 3
Inside your home in *Summer*							
Outside in *Summer*							
Inside your home in *Winter*							
Outside in *Winter*							

- In general, when you are too *hot* in your villa, what do you do to cool down?
- In general, when you are too *cold* in your villa, what do you do to get warm?

Finally the last couple of questions are about your electricity bill.

- How often do you pay your electric bill?
- Could you please estimate your average annual bill?

2. Interview transcripts: Villa 1- September 2 2015

Note- In the transcript, occupants real names have been substituted with an equivalent description ie. husband, daughter, staff etc

Part 1: Household background information

- Could you tell me a little bit about yourself, such as what your profession is, your age, and how long you have lived in your villa?
  I'm a high school teacher. I teach home economics. I'm 39 years old. We bought the villa in May 2011 but moved in September 2012 after doing some renovations. So we've lived here for about 3 years.
- Could you tell me a little about the people who live in the villa, such as their age and occupation?
  Well I have four kids, three daughters and a son. My eldest is 16, my second is 14, third is 11 and my boy is 8. My husband is a colonel. He's 40 years old. We also have two female staff, one is 40 and the other is 33. They prepare meals, do the laundry and clean.
- Do you mind me asking what your total household income is?
  A month its about 2,300 KWD

Part 2: Dwelling form and fabric characteristics

I will now ask a few questions about the physical characteristics of your villa.

- So, in what year was your villa built?
  1982. It is a government villa. Before we bought it it was owned by a couple with no kids.
- Do you know the approximate size (in m²) of the land on which the villa is built in, and the approximate built up area of the villa (in m²)?
  The land is 400m² I think. Not sure about the built up area. Maybe between 350 to 400m²
- Are you aware of whether the villa was built in accordance to the Energy Conservation Code?
  No I'm not sure.
- Has there been any refurbishment works undertaken since the villa was built/bought i.e. extension vertically/horizontally, resealing windows/ doors, upgrading/replacing hot water tank, insulating walls
  Yes we have. Several actually. The main one was a 2m extension in the back towards the garden to make the daily living room bigger. We also knocked some internal walls on the ground floor to create an open feeling and a bigger kitchen. Another big change was moving the staircase, which was in the middle of the main entrance, to the edge of the wall. My father's villa is actually across the road and is very similar to ours, also a government villa. He advised us to close the light well opening on the first floor with glazing. He said that affected the performance of the AC on the first floor. So we did that too. All windows and doors we kept as they were. The only new window was the one installed in the new extension. We also kept the AC units as they were but last year [2014] we had to get new central units. We also did general redecoration like new bathrooms throughout, paint, new tiling and so on.
- What main criteria were considered when designing or purchasing this villa i.e. cost, location
  For us it's view...we like to have open space from both sides of the villa which we have here, and also cost.
- Do you know the type of insulation used in the construction of the walls and roof? i.e. aerated concrete blocks or a separate layer of insulation between blocks.
  No not really. I do know that the new extension wall near the garden was white block, I think with insulation.
- Do you know what type of glazing is used in your villa? i.e. single, double, triple solar reflective
  All windows are single except for the one the new wall which is double,
- How are your window shutters/curtains operated during the day?
  We have those automatic shutters on all our windows and only very light curtains. Generally we open the shutters during the day and close them in the evenings. When its very hot in the summer we usually keep them closed even during the day and end up opening lights. In the winter it's the opposite. We open windows and shutters and love the fresh air. If it gets too cold tough we close windows but keep the shutters open.

Part 3: Space conditioning and hot water

I will now ask a few questions about building systems in your villa.

- First with regards to space cooling, does your villa have a central AC system, wall mounted split units, or a mixed system (central and split units)?
  We have central AC with two split units, one in the staff bedroom and one in the outside diwaniya. The previous owner had many split units in different rooms to support the central AC I think, but we removed all of these and kept just the two.

If the system is central or mixed, ask:

- Do you know how many centralAC plant (direct expansion systems) are used in your villa?
  Two central AC plant, one for the first floor and one for the ground floor.
- Do you know the rough cooling capacity per plant (tons)?
  I think its 7 tons per plant.

If the system is mixed or only wall mounted split units, ask:

- How many split units are used in your villa?
  Two split units
- Do you know the rough cooling capacity per split unit?
  Not sure actually.
- Which rooms are cooled by the central AC system and which rooms are cooled by split units?
  All rooms are cooled by the central AC. The split only cool the staff bedroom and diwaniya.
- For how many months of the year is your villa cooled on average?
  From April untill October usually.
- Is there a thermostat that controls the central AC equipment?
  Yes. We have two thermostats one to control the central AC on the ground floor and one for upstairs.
- If yes, which temperature (°C) is your thermostat usually set to and is it on automatic or constant on mode?
  Thermostats are both set to automatic at 73°F ...about 23°C I think.
- Does this vary by room/floor and how?
  No, the ground and first floor thermostats are the same...they're both digital.
- Who is responsible for adjusting the thermostat?
  Only my husband!
- Do you adjust thermostat settings when the villa is unoccupied for prolonged periods (such as travel)?
  Yes we usually travel in the summer for a month or more and increase settings by about one.
- How often is the AC equipment maintained?
  Once a year before the summer.
- Do you or other household occupants tend to leave windows open while the AC is on?
  No never.
- Now with regards to space heating, do you heat your villa during the winter months and how?
  No, we don't use those electric heaters. We don't like them. I think they're dangerous. We just wear more clothes to keep warm.
- If yes, which room(s) do you heat?
- Regarding hot water, could you describe the type of system used in your villa? i.e central hot water tank, local
  We have a central hot water tank. We had a new one installed on the roof when we moved in.
- Which months of the year is the hot water system operated?
  Around October until April. We don't use it in summer

Part 4: Lighting and appliance use

I will now ask you about lighting and electrical appliances.

- What major type of lighting is used in your villa?
  Most of our lights are LED. We invest in these bulbs, except for chandeliers where we can't find the right fit.
- How would you describe the level of natural daylight in your villa?
  When we open the window shutters the natural daylight is really good because we have the open space in the front and back. But usually the shutters are down especially when its hot outside.
- Do you and other household members tend to turn on all the lights in the room? If no, how many?
  Not all but we do usually switch most lights on when we enter a room.
- Do you and other household members turn lights off when leaving a room?
  Yes we do. We also turn off the toilet exhausts. My husband is actually quite picky about this. By 10pm all our external lights [on villa external walls] are switched off too.
- If you have any of the following appliances, please estimate how often they are used, ie daily, every other day

Appliance type	Usage
TV	*Daily for about 6 hours*
Washing machine	*Washer dryer -Daily (one load a day)*
Clothes dryer	-
Vacuum	N/A
Kettle	*Daily at least 7 times*
Microwave	*Daily*
oven	*daily (once or twice)*

Part 5: Occupant routines and perceptions

I will now ask you about your household routines and perceptions.

- Could you please describe a typical weekday routine for occupants in your house?
  On weekdays the kids leave for school before 7am and return home by 1.30pm. My husband and I also leave to work between 7 and 7.30am and return around 2pm. We all have lunch together around 2.30/3 pm, and afterwards watch TV, relax in the living room and the kids do their homework. My husband usually goes out in the early evening... around 6pm ..to the gym or diwaniya. The kids don't usually go out on weekdays ...they're not part of after school activities or anything like that. I rarely go out unless I have some errands to run or friends and family to visit. By around 10pm everyone is usually in their rooms. The staff they are almost always in the villa...in the mornings when we are all out that's when they usually finish the laundry, cleaning and cooking.
- What about their routine on weekends?
  On the weekends we all wake up later around 9am. We have a big family breakfast. On Fridays we go out together from between 1pm till 6 or 7pm for lunch shopping. On Saturdays we also have lunch at my father's house between 1.30 untill 4.30pm then come home to spend the afternoon and evenings watching TV and relaxing.
- Please rate your perception of thermal comfort in the following:

	Cold -3	Cool -2	Slightly cool -1	Neutral 0	Slightly warm 1	Warm 2	Hot 3
Inside your home in *Summer*							
Outside in *Summer*							
Inside your home in *Winter*							
Outside in *Winter*							

- In general, when you are too *hot* in your villa, what do you do to cool down?
  We close the shutters. We also dress lightly.
- In general, when you are too *cold* in your villa, what do you do to get warm?
  We wear heavy woolen clothes ..drink lots of tea and keep warm.

Finally the last couple of questions are about your electricity bill.

- How often do you pay your electric bill?
  We try to pay it once a year but sometimes it's more than a year.
- Could you please estimate your average annual bill?
  I think it's about 300KWD.

2. Interview transcripts: Villa 2 – September 3 2015

Note- In the transcript, occupants real names have been substituted with an equivalent description ie. husband, daughter, staff etc

<u>Part 1: Household background information</u>

- Could you tell me a little bit about yourself, such as what your profession is, your age, and how long you have lived in your villa?
  I'm 65 years old and retired. I worked at the Public Authority for Applied Education and Training for over 30 years. I built this villa in 1981 and we have lived here since.
- Could you tell me a little about the people who live in the villa such as their age and occupation?
  There are 6 people living in the villa. Myself, my wife, and my son, as well as two staff and one driver. My wife is 60 years old and also retired. Our son is 28 years old. He is a civil engineer and works at Kuwait Municipality. We have three more children as well.. they are all married and with kids and live in their own homes. Our big gathering is on Saturday afternoons with all the grandkids.
- Do you mind me asking what your total household income is?
  Around 2,700 KWD

<u>Part 2: Dwelling form and fabric characteristics</u>

I will now ask a few questions about the physical characteristics of your villa.

- So, in what year was your villa built?
  In the early 80's…in 1981 construction was complete and we moved in.
- Do you know the approximate size (in m²) of the land on which the villa is built in, and the approximate built up area of the villa (in m²)?
  The land is 750m² and the built up area is today about 500 to 600m². Over the years we made several different extensions.
- Are you aware of whether the villa was built in accordance to the Energy Conservation Code?
  No.
- Has there been any refurbishment works undertaken since the villa was built/bought i.e. extension vertically/horizontally, resealing windows/ doors, upgrading/replacing hot water tank, insulating walls
  Yes. We first extended horizontally and vertically in the early 1990's…after the invation [gulf war]… to create a new diwaniya on the ground floor and bedroom on the first floor. We also extended on the ground floor to create an outdoor kitchen and this dining room where we are sitting now. More recently we created an additional bedroom for the driver on the ground floor annex. In all extensions we added split units rather than central AC.
- What main criteria were considered when designing or purchasing this villa i.e. cost, location
  Open space and location
- Do you know the type of insulation used in the construction of the walls and roof? i.e. aerated concrete blocks or a separate layer of insulation between blocks.
  There is no insulation in any of the walls, even the newer ones.
- Do you know what type of glazing is used in your villa? i.e. single, double, triple solar reflective
  All windows are single glazing including in the newer extensions.
- How are your window shutters/curtains operated during the day?
  We have light curtains on all bedroom windows and wooden shutters on the windows on the ground floor. Bedroom curtains and living room shutters are pulled down in the evenings. During the summer curtains are usually pulled down in empty bedrooms and rooms.

<u>Part 3: Space conditioning and hot water</u>

I will now ask a few questions about building systems in your villa.

- First with regards to space cooling, does your villa have a central AC system, wall mounted split units, or a mixed system (central and split units)?
  We have a mixed system. Central AC mainly for the main villa and split units for the newer extensions.

If the system is central or mixed, ask:

- Do you know how many centralAC plant (direct expansion systems) are used in your villa?
  Four central plants. Two for the ground floor and two for the first floor.
- Do you know the rough cooling capacity per plant (tons)?
  They vary. Some are 7 tons some less.

If the system is mixed or only wall mounted split units, ask:

- How many split units are used in your villa?
  Seven split units.

- Do you know the rough cooling capacity per split unit?
  About one or two tons
- Which rooms are cooled by the central AC system and which rooms are cooled by split units?
  The central AC cools most of the bedrooms upstairs and living rooms downstairs. The split units cool the extensions ... the staff bedrooms, the diwaniya, dining room, external kitchen, my son's bedroom and also another bedroom upstairs.
- For how many months of the year is your villa cooled on average?
  For about 7 months from April untill October.
- Is there a thermostat that controls the central AC equipment?
  Yes there are four thermostats to control each central unit...our thermostats are very manual ones.
- If yes, which temperature (°C) is your thermostat usually set to and is it on automatic or constant on mode?
  All thermostats are set to automatic at 25°C
- Does this vary by room/floor and how?
  No all thermostats have to be set to 25-26°C...anything lower causes the system to shut down
- Who is responsible for adjusting the thermostat?
  We can all adjust thermostats.
- Do you adjust thermostat settings when the villa is unoccupied for prolonged periods (such as travel)?
  No not really. The villa isn't completely unoccupied at any one time. My wife and I travel for a couple of months every summer but our son may still be here.
- How often is the AC equipment maintained?
  We don't have a regular maintenance contract... We call the technician whenever there is a problem.
- Do you or other household occupants tend to leave windows open while the AC is on?
  During the summer no, but during the autumn and spring when the weather is nice, windows are open even when the AC is on.
- Now with regards to space heating, do you heat your villa during the winter months and how?
  Yes. We sometimes use heaters in January if it's very cold. We have about 3 or 4. We don't use them the whole day, only when we need to. At night we switch them off.
- If yes, which room(s) do you heat?
  The diwaniya and bedrooms.
- Regarding hot water, could you describe the type of system used in your villa? i.e central hot water tank, local
  A central system with one tank on the roof.
- Which months of the year is the hot water system operated?
  From about mid- October untill end of April.

Part 4: Lighting and appliance use

I will now ask you about lighting and electrical appliances.

- What major type of lighting is used in your villa?
  We have a mix of bulbs. Some are energy saving and some are the normal bulbs.
- How would you describe the level of natural daylight in your villa?
  It's very good. On the ground floor especially we have a lot of windows and skylights. In the bedrooms windows are smaller but because we have open space to the front and back the daylight is good.
- Do you and other household members tend to turn on all the lights in the room? If no, how many?
  Yes but definitely not all. Except when we have guests or family over.
- Do you and other household members turn lights off when leaving a room?
  Yes always.
- If you have any of the following appliances, please estimate how often they are used, ie daily, every other day

Appliance type	Usage
TV	*Daily for about 5 hours*
Washing machine	*Daily*
Clothes dryer	N/A
Vacuum	N/A
Kettle	*Daily about 5 to 7 times*
Microwave	*Every other day*
Oven	*3 times a week*

Part 5: Occupant routines and perceptions

I will now ask you about your household routines and perceptions.

- Could you please describe a typical weekday routine for occupants in your house?
  I wake up very early every morning, around sunrise. I go to the nearby mosque for prayers. During the mornings I work on my charity [which does work abroad]. I also spend some time in the garden or run some errands if needed. My wife is up around 8am and occasionally leaves the house to visit friends or family and so on. We have lunch every day around 12.30 am. We sometimes have an afternoon nap, and sit in diwaniya for afternoon tea afterwards. We usually have early nights on most days. Our son has quite a different routine. On weekdays he leaves for work by 7am and is back by 2pm. After lunch he rests before going out in the early evening to the diwaniya or the gym or any other place.
- What about their routine on weekends?
  On weekends our routine is basically the same as on weekdays. On Saturday afternoons our children [married children and their families] come over for a gathering as I told you.
  Please rate your perception of thermal comfort in the following:

	Cold -3	**Cool -2**	**Slightly cool -1**	**Neutral 0**	**Slightly warm 1**	**Warm 2**	**Hot 3**
Inside your home in *Summer*							
Outside in *Summer*							
Inside your home in *Winter*							
Outside in *Winter*							

- In general, when you are too *hot* in your villa, what do you do to cool down?
  We lower the thermostat and pull down the curtains.
- In general, when you are too *cold* in your villa, what do you do to get warm?
  We use heaters, close all windows and dress very warmly.

Finally the last couple of questions are about your electricity bill.

- How often do you pay your electric bill?
  I pay the electricity bill every three months .
- Could you please estimate your average annual bill?
  About 250 KWD not more.

2. Interview transcripts: Villa 3 – September 7 2015

Note- In the transcript, occupants real names have been substituted with an equivalent description ie. husband, daughter, staff etc

Part 1: Household background information

- Could you tell me a little bit about yourself, such as what your profession is, your age, and how long you have lived in your villa?
  I'm 32 years old. I'm currently a stay at home mum. We've been living here since May 2011.
- Could you tell me a little about the people who live in the villa, such as their age and occupation?
  We are a family of 5. We have three young kids.. two girls and a boy. Our eldest is 7, our second is 5 and our youngest is 6 months. My husband is a banker, also 32 years old. We have two live-in nannies, one is 39 and the other 36.
- Do you mind me asking what your total household income is?
  1,500KWD

Part 2: Dwelling form and fabric characteristics

I will now ask a few questions about the physical characteristics of your villa.

- So, in what year was your villa built?
  Construction started in 2007 and was complete in 2010.
- Do you know the approximate size (in m²) of the land on which the villa is built in, and the approximate built up area of the villa (in m²)?
  The land is 375m². Not too sure about the built up area though.
- Are you aware of whether the villa was built in accordance to the Energy Conservation Code?
  I don't really know about that specific code but I'm sure the villa is built in accordance with the latest codes.
- Has there been any refurbishment works undertaken since the villa was built/bought i.e. extension vertically/horizontally, resealing windows/ doors, upgrading/replacing hot water tank, insulating walls
  No. Since we have moved in we have just been busy furnishing rooms.
- What main criteria were considered when designing or purchasing this villa i.e. cost, location
  We considered the orientation of the house and sunlight. We also considered a flexible design that will allow us to change the use of some rooms like the playroom when our kids are older.
- Do you know the type of insulation used in the construction of the walls and roof? i.e. aerated concrete blocks or a separate layer of insulation between blocks.
  We used the new white blocks on our walls. I assume they are the aerated blocks.
- Do you know what type of glazing is used in your villa? i.e. single, double, triple solar reflective
  All windows are double glazed with a tint.
- How are your window shutters/curtains operated during the day?
  We have curtains on all windows except the second floor playroom. During the day when it's hot we try to keep the curtains closed.

Part 3: Space conditioning and hot water

I will now ask a few questions about building systems in your villa.

- First with regards to space cooling, does your villa have a central AC system, wall mounted split units, or a mixed system (central and split units)?
  We have central AC with three split units, one in the staff bedroom, two in the main external kitchen.

If the system is central or mixed, ask:

- Do you know how many centralAC plant (direct expansion systems) are used in your villa?
  Five central AC plant, two for the ground floor, two for the first floor and one for the second floor.
- Do you know the rough cooling capacity per plant (tons)?
  No.

If the system is mixed or only wall mounted split units, ask:

- How many split units are used in your villa?
  Three split units.
- Do you know the rough cooling capacity per split unit?
  No I don't.
- Which rooms are cooled by the central AC system and which rooms are cooled by split units?
  Well the entire villa is cooled by the central AC plants. The only rooms cooled by split units are the staff room on the second floor and the outdoor kitchen.
- For how many months of the year is your villa cooled on average?
  We keep our AC on from the start of March till the end of October.

- Is there a thermostat that controls the central AC equipment?
  Yes.
- If yes, which temperature (°C) is your thermostat usually set to and is it on automatic or constant on mode?
  Thermostats on the ground floor are set to automatic at 23°C. On the first floor we set them at 21°C because we like our bedrooms quite cool. On the second floor playroom the thermostat is set to 22°C.
- Does this vary by room/floor and how?
  [as explained above]
- Who is responsible for adjusting the thermostat?
  My husband and I only adjust thermostats.
- Do you adjust thermostat settings when the villa is unoccupied for prolonged periods (such as travel)?
  Sometimes, it depends how long we travel for. If we do change them we set them all to 23°C.
- How often is the AC equipment maintained?
  We try to maintain the system once a year before we switch it on in March.
- Do you or other household occupants tend to leave windows open while the AC is on?
  No we don't.
- Now with regards to space heating, do you heat your villa during the winter months and how?
  We sometimes do. It depends on how cold it is. Last year we didn't.. it was not too cold. We use those movable electric heaters.
- If yes, which room(s) do you heat?
  The kids bedrooms mainly and sometimes our bedroom too and the upstairs living room. We have about three heaters so we move them around depending on where we are if we need them.
- Regarding hot water, could you describe the type of system used in your villa? i.e central hot water tank, local
  Its a central hot water tank system.
- Which months of the year is the hot water system operated?
  We don't use the hot water tank in the summer, we use it mainly from October until April May.

<u>Part 4: Lighting and appliance use</u>

I will now ask you about lighting and electrical appliances.

- What major type of lighting is used in your villa?
  Mainly LED bulbs except in fixtures that don't take those bulbs.
- How would you describe the level of natural daylight in your villa?
  We have a lot of natural daylight. Our windows are quite big and because it's a corner plot we have light coming in from different sides.
- Do you and other household members tend to turn on all the lights in the room? If no, how many?
  No we don't turn all lights on. Maybe just one or two switches. It depends really on what we are doing.
- Do you and other household members turn lights off when leaving a room?
  Yes we try to…and we ask the nannies to do the same especially in the playrooms.
- If you have any of the following appliances, please estimate how often they are used, ie daily, every other day

Appliance type	Usage
TV	*Daily for about 3 hours*
Washing machine	*Daily*
Clothes dryer	*Daily*
Vacuum	*Every other day*
Kettle	*Twice a day*
Microwave	*Occasionally, 3-4 times a week and more during holidays*
Oven	*Once in a while depending on the type of food being cooked*

<u>Part 5: Occupant routines and perceptions</u>

I will now ask you about your household routines and perceptions.

- Could you please describe a typical weekday routine for occupants in your house?
  On weekdays we are all up very early at around 5.30am. We need to leave by 6.15am to be able to get to school by 7. I usually do the school drop offs and pickups and in the afternoons I have to leave by 2pm to get to school by 2.30. We arrive back home at around 3, 3.15pm and the kids wash and have lunch at 3.30p. They then play in the upstairs or downstairs playrooms or finish homework… by7pm they are all in their bedrooms for bedtime. My husband leaves for work even earlier, at around 6pm and is back by 4pm. We have lunch together at around 4.30-5pm, usually in the

diwaniya. In the afternoons we usually hang around in the upstairs living room watching TV and relaxing. We sometimes go out in the evening when the kids are asleep..we're usually back by 10pm. In the mornings when everyone is a school and work I spend time with the baby, go to the supermarket and finish off anything I have too. The nannies prepare the meals, clean and do the laundry.

- What about their routine on weekends?
  On the weekends, we [all household] almost always go to the shale. We leave on Thursday evening and return back home on Saturday afternoon.
- Please rate your perception of thermal comfort in the following:

	Cold -3	Cool -2	Slightly cool -1	Neutral 0	Slightly warm 1	Warm 2	Hot 3
Inside your home in *Summer*		X					
Outside in *Summer*							X
Inside your home in *Winter*				X			
Outside in *Winter*	X						

- In general, when you are too *hot* in your villa, what do you do to cool down?
  We lower the thermostat, close curtains, dress lightly
- In general, when you are too *cold* in your villa, what do you do to get warm?
  We use heaters and I always have the kids dress warmly even indoors in winter…leggings long sleeves cardigans.

Finally the last couple of questions are about your electricity bill.

- How often do you pay your electric bill?
  We haven't paid it in a while...our last payment was probably two years ago.
- Could you please estimate your average annual bill?
  Not sure…maybe around 400KWD I think.

2. Interview transcripts: Villa 4 – September 7 2015

Note- In the transcript, occupants real names have been substituted with an equivalent description ie. husband, daughter, grandmother, aunt, staff etc

Part 1: Household background information

- Could you tell me a little bit about yourself, such as what your profession is, your age, and how long you have lived in your villa?
  I own a scuba diving center and work mainly from home giving lessons twice a week. I'm 38 years old and have lived here since 2001.
- Could you tell me a little about the people who live in the villa, such as their age and occupation?
  There's quite a few of us living here. There's my husband and two kids, his mother [grandmother] and his sister [aunt] as well as about 6 household staff. My husband is 46 years old and is a high seas marina captain. Our eldest daughter is 18 and is currently in her first year at university, and our son is 14 and still at school. Grandmother is about 70 years old and is quite ill. She spends most of her time in bed. Aunt is 36 and works at an environmental agency. She is also doing her PhD part time. We have two female housekeepers responsible for the cleaning, ironing and household chores, one female nurse for grandmother. They are all in their mid-30. We also have a male cook, and two male drivers. I think they are all in their late 20's.
- Do you mind me asking what your total household income is?
  About 3,000 KWD.

Part 2: Dwelling form and fabric characteristics

I will now ask a few questions about the physical characteristics of your villa.

- So, in what year was your villa built?
  The villa was built in 1999. We bought it as a new build in 2000… after doing a few minor changes we moved in early 2001.
- Do you know the approximate size (in m²) of the land on which the villa is built in, and the approximate built up area of the villa (in m²)?
  The plot is about 400m² and the built up area is probably double that.
- Are you aware of whether the villa was built in accordance to the Energy Conservation Code?
  I'm not aware of this.
- Has there been any refurbishment works undertaken since the villa was built/bought i.e. extension vertically/horizontally, resealing windows/ doors, upgrading/replacing hot water tank, insulating walls
  No major refurbishments just a few minor changes. When we first bought the villa we fixed the main kitchen, and resealed all the windows as we didn't feel they closed properly. We resealed them again two years ago as we could feel and hear air coming in. I think the previous owner built the villa for his personal use and invest a lot in good construction but when he decided to sell it he may be compromised on the final finishing like the windows.
- What main criteria were considered when designing or purchasing this villa i.e. cost, location
  Location is important..and cost too.
- Do you know the type of insulation used in the construction of the walls and roof? i.e. aerated concrete blocks or a separate layer of insulation between blocks.
  I think in our villa it's the separate layer of insulation between blocks. Our walls are quite thick as you can see.
- Do you know what type of glazing is used in your villa? i.e. single, double, triple solar reflective
  All windows are double glazed.
- How are your window shutters/curtains operated during the day?
  We have curtains on all our windows including sheers for privacy during the day. In the evenings just before sun set the staff pull down all the curtains.

Part 3: Space conditioning and hot water

I will now ask a few questions about building systems in your villa.

- First with regards to space cooling, does your villa have a central AC system, wall mounted split units, or a mixed system (central and split units)?
  We have central AC and a few split units.

If the system is central or mixed, ask:

- Do you know how many centralAC plant (direct expansion systems) are used in your villa?
  There are five central units…2 for the ground floor, 2 for the first floor and 1 for the basement.
- Do you know the rough cooling capacity per plant (tons)?
  About 7 to 10 tons I think.

If the system is mixed or only wall mounted split units, ask:

- How many split units are used in your villa?
  We have 6 split units ... 1 in the female staff bedroom, one in each of the male staff bedrooms, 1 in the ironing room, and 2 in the main kitchen.
- Do you know the rough cooling capacity per split unit?
  About 2 tons I think.
- Which rooms are cooled by the central AC system and which rooms are cooled by split units?
  Most of the villa is cooled by the central AC plant. It's just those few smaller rooms that are cooled by split units
- For how many months of the year is your villa cooled on average?
  Our AC is usually on from the end of February until mid-November .
- Is there a thermostat that controls the central AC equipment?
  Yes.
- If yes, which temperature (°C) is your thermostat usually set to and is it on automatic or constant on mode?
  Thermostats on the first floor are set to automatic at 21°C. The thermostat in the basement is set to 23°C. In the ground floor, one thermostat is set to 23°C while the other that controls cooling to grandmother's room is set to higher at 25°C as she doesn't like to be cold
- Does this vary by room/floor and how?
  [as explained above]
- Who is responsible for adjusting the thermostat?
  Everyone can adjust thermostats. I do tell the kids and the staff not to fiddle with them though.
- Do you adjust thermostat settings when the villa is unoccupied for prolonged periods (such as travel)?
  Sometimes, we adjust the first floor thermostats only. The house is never really empty though. We constantly have family members coming in, especially to visit grandmother.
- How often is the AC equipment maintained?
  We try to maintain the system once a year.
- Do you or other household occupants tend to leave windows open while the AC is on?
  We try not to but sometimes we do especially in the spring when the weather is nice outside but we still need the AC inside.
- Now with regards to space heating, do you heat your villa during the winter months and how?
  We only heat a few rooms using those small electric heaters.
- If yes, which room(s) do you heat?
  Grandmother, aunt, daughter and the female staff usually like to heat their bedrooms so we have heaters in there. They use them whenever they need to.
- Regarding hot water, could you describe the type of system used in your villa? i.e central hot water tank, local
  We have one large hot water tank on the roof so it's a central system I think.
- Which months of the year is the hot water system operated?
  We keep our hot water tank on all year even during the summer. A few years back we switched it off for a few weeks in June and the water was tepid and not hot enough. We like our water and showers hot.

Part 4: Lighting and appliance use

I will now ask you about lighting and electrical appliances.

- What major type of lighting is used in your villa?
  Most of our bulbs are LED bulbs. I actually changed most from the 60W bulbs to 15,or 7 W bulbs quite recently. We usually switch lights on during the day because it can get quite dark in some rooms, so these bulbs are just more efficient.
- How would you describe the level of natural daylight in your villa?
  Natural daylight is quite poor in our villa. Our street is quite narrow and we have neighbors on three sides all very close.
- Do you and other household members tend to turn on all the lights in the room? If no, how many?
  No just a few side lamps or switches. When my kids go into their rooms and switch all their lights on I always tell them to switch them back off and keep the LED on instead.
- Do you and other household members turn lights off when leaving a room?
  Yes but not always....I'm always reminding my kids about this
- If you have any of the following appliances, please estimate how often they are used, ie daily, every other day

Appliance type	Usage
TV	*Daily for about 6 hours*
Washing machine	*Daily*
Clothes dryer	*Daily*
Vacuum	*Daily*
Kettle	*Daily maybe 5 times or more*
Microwave	N/A
Oven	*Every other day I think… cook decides*

Part 5: Occupant routines and perceptions

I will now ask you about your household routines and perceptions.

- Could you please describe a typical weekday routine for occupants in your house?
  On the weekdays everyone has their own routine. My husband and son both leave around 6.30 for work and school. I'm up around 7 or 8am. On Sunday and Monday mornings at 10am I give diving lessons in the diwaniya. I can spend hours in the diwaniya without needing to go into the villa. Our daughter has quite a flexible schedule. She just started university so her timings are different every day depending on her courses. If not at university she spends a lot of time in her room. Aunt leaves to work every day around 7.30 and is back by 2.30om. In the afternoons she spends a lot of time either in her room or in the downstairs living room working on her thesis. She travels a lot for work. Grandmother also has her own routine. She has been unwell the past couple of years and spends most of the time in bed or on the wheelchair. She likes to sit in the living room in the afternoons. We have a lot of family visiting almost daily and our home is always open to them.
  The staff also has their routines. The housekeepers are responsible for cleaning and laundry, while the cook prepares meals for the entire house. He starts cooking at 9am until around 2pm. Food that is prepared is then left in the hot press until it is served. We have lunch around 3-4pm on weekdays.
- What about their routine on weekends?
  Fridays is our large family gathering in the basement for lunch. In the afternoon we usually go to the shale and return back home on Saturday evening…myself, my husband, kids and two household staff. Grandmother, aunt and other staff stay at home.
- Please rate your perception of thermal comfort in the following:

	Cold **-3**	**Cool** **-2**	**Slightly cool** **-1**	**Neutral** **0**	**Slightly warm** **1**	**Warm** **2**	**Hot** **3**
Inside your home in *Summer*							
Outside in *Summer*							
Inside your home in *Winter*							
Outside in *Winter*							

- In general, when you are too *hot* in your villa, what do you do to cool down?
  We close the curtains and adjust thermostats
- In general, when you are too *cold* in your villa, what do you do to get warm?
  We use heaters to keep warm and everyone wears thick jumpers!

Finally the last couple of questions are about your electricity bill.

- How often do you pay your electric bill?
  We try to do this once a year.
- Could you please estimate your average annual bill?
  Around 500KWD

3. Physical survey schedules

Full details for each villa are provided within the relevant sections of the main text in chapter 6

Appliance type	Quantity	Location	Description i.e. small, medium, large, Watts
TV's			
Satellite receiver			
Fridge			
Freezer			
Water cooler			
Toaster			
Kettle			
Microwave			
Dishwasher			
Other, please specify			
Electric oven			
Gas oven			
Gas hob/stove			
Electric hob/stove			
Vacuum			
Washing machine			
Clothes dryer			
Games console			
Water pumps (i.e. for pressurized hot water			
Other			

Air-conditioning	Type	Location	Description i.e. small, medium, large, Watts, setting used
Central			
Split			
Controls (thermostat)			

Construction elements	Type	Location	Description i.e. material, colour, texture
Walls			
Windows			
Doors			
Floors			
Roof			

Room type	Quantity/description	Room type	Quantity/description
Bedroom		Washing room	
Bathroom		Staff bedrooms	
Living room		Diwaniya	
Kitchen		Basement	
Dining room		Office	
Unused rooms		Other	

Lighting	Type	Description i.e. small, medium, large, Watts, number of bulbs
Bedrooms		
Living rooms		
Staff accommodation		
Kitchen		
Basement		
Diwaniya		
Other		

Appendix H: Multi-case study: follow-up occupant interview schedules with summary of transcripts

The tables below present questions from the four follow-up interview schedules. Responses to each question are summarized with quotes added where appropriate. The tables are presented under the five different headings of the interview schedule (noted in table 6.1 chapter 6): Space heating, occupancy patterns, household cleaning and cooking, lighting and electrical appliance use, and building systems maintenance. Findings for space conditioning and occupancy patterns are combined into four tables' winter, spring, Ramadan, and summer corresponding to the timings of the four follow-up interviews. Responses to the other sections, collected from occupants during the three, six, nine and twelve month interviews are combined (as very few changes in occupant responses to these were noted). Finally the concluding remarks noted during the final occupant interview are presented. In the transcripts occupants real names have been substituted with an equivalent description ie. husband, daughter, grandmother, aunt, staff etc

A short briefing was undertaken before starting each follow-up interview that included:

- An explanation of the structure of the interview noting that some questions are new while others are repeated
- Reassurance of confidentiality and that the interviewee can decline to answer any question if they wish to.
- Restatement that the interview will be recorded.

Space conditioning – winter: first follow-up interview – December 20-23 2015

WINTER	Villa 1	Villa 2	Villa 3	Villa 4
Now that the weather has cooled, did you switch the AC? If so how and when?	*The AC was switched off the last week of October maybe October 28. We put the thermostat on off but kept the fan on automatic for ventilation.*	*We turned it off more than a month ago. In the end of October. Using the thermostat.*	*We switched the cooling off around October 30th or the first week of November.*	*About three weeks ago I think. Towards the end of November 22nd or 23rd, all the cooling was* off.
Did you use any form of heating during winter? Type, setting, location, operation	*We have never used heaters. We would rather wear heavy clothes and blankets than use heaters… They're not safe.*	*Yes we used several heaters…the electric ones…sometimes we keep them on all day* Four oil-filled column electric heaters: -one in master bedroom 1 -one in the son's bedroom -one in the female staff bedroom -one in the ground floor diwaniya	*This year its quite cold so we used heaters in the kids rooms, our room, the nannies room and the diwaniya. They're not always on though. my daughter's room is especially cold I think because of those two large windows. We switch heaters on about 45 minutes before the kids come home from school and keep them on until they sleep sometimes even at night on a low setting if it was too cold. We won't be having them for long I hope… we're worried about the baby, she's learning to walk and might touch them, as well as the cats.* Five small oil-filled column electric heaters: -One in the daughters room -One in the son's bedroom -One in the master bedroom -One in the female staff bedroom. -One in the diwaniya (noted to be the coldest room with two large windows)	*The heaters in grandmother's room and daughters' room were on all day on some days but not always.. When grandmother would go from her bedroom to the living room she would also ask for the heater to move with her. In our room we only used the heater for a couple of days during the really cold spell. Aunt had one in her room but rarely used it . she was travelling most of the time* five oil-filled column electric heaters were: - One in master bedroom - One in grandmother's room - One in daughter's bedroom - One in aunt's bedroom - One in female staff bedroom - One in diwaniya
Did the house heat up quickly, and did the heaters make a difference?	N/A	*It really was quite cold and sometimes we felt the heaters are barely doing anything. They took a long time to heat the room ..definitely not enough heating.*	*It does take some time for the rooms to have a good temperature once we switch them on. In the diwaniya for example, if we're having lunch at 5pm, the heaters would be switched on at around 4.15pm.*	*Yes rooms heated up nicely and they made a difference.*
Are there different preferences for heating by different occupants?	N/A	*We all would like it to be warmer…my wife especially as she had muscle pain with cold.*	*We don't mind the cold but the kids need warmer temperatures.*	*Grandmother and daughter prefer warmer temperatures. My husband and I we actually like the cold.*
Which rooms were the coldest?	"*Our house is really very cold everywheres. We use blankets all the time*".	"*The bedrooms are the coldest especially the [bedroom 2] and the stairs*".	"*The diwaniya and my daughter's room …these rooms are north facing and have large windows".*	"*Our bedroom..its because we open windows for ventilation*".

Space conditioning – winter: first follow-up interview – December 20-23 2015

WINTER	Villa 1	Villa 2	Villa 3	Villa 4
Did you open the windows during this period? Which?	*Yes always for ventilation, especially the windows overlooking the garden on the ground floor. But we keep them open just a little because it can get too cold. In the mornings we open windows upstairs to get a flow of air for about 10 minutes while staff are cleaning.*	*We didn't really open windows much. The house is quite cold and because we have so many windows the cold air just comes through. On Saturdays when the family gets together the doors in the dining room are kept open as the kids run in and out of the garden and it gets cold.*	*The first floor bedroom windows are opened daily in the mornings for ventilation with bedroom doors kept open for 5-10 minutes to circulate air. On the ground floor we rarely open windows. If we do its only for cleaning which is also very rare.*	*Yes always. The window in the living room upstairs, and downstairs, our room and the guest room are always opened especially in the mornings for at least 10 minutes for ventilation. The windows in my room are left slightly open all day, even with the heaters were on. Windows in my daughter andaunt's rooms are not usually open and in son's room opening is timed because his room is above the kitchen exhaust.*
In general, how would you describe your thermal comfort during this period?	*Very cold*	*Very cold*	*Neutral.*	*Neutral… to warm sometimes*

Space conditioning – spring: second follow-up interview March 21-24 2016

SPRING	Villa 1	Villa 2	Villa 3	Villa 4
Was the AC switched back on as weather started to warm up? How? When?	*Yes, we switched the AC on the first week of March. Set both thermostats to 22-23°C.*	*We only switched the AC on a few days ago actually. The weather outside has been lovely*	*Yes, around March the 1st or end of February. Thermosets set to 21°C in the upstairs bedrooms and living and 23°C downstairs.*	*Yes. We switched it on February 15th. Our thermosets are set to 20-21°C upstairs, 23°C and 25°C on the ground floor and 23°C in the basement.*
Has any other form of cooling been used?	*No*	*No*	*No*	*No*
Do you open the windows during this period? If so which?	*No since opening the AC we haven't opened any windows.*	*No windows are open, except for the door to the garden in the dining room, especially on Saturdays*	*No windows are opened now. This would spoil the AC*	*Yes some windows are opened especially as the weather outside is still cool*
Which rooms are the warmest?	*Daughter's bedroom [bedroom 4] is the warmest and the staff bedroom too.*	*Definitely the indoor kitchen and the dining room because of the skylight and windows*	*Our bedroom is the warmest. There's a degree difference between our room and daughter's room even though they are cooled by the same unit. Also the playroom on the ground floor because the AC on that side is not working*	*The guest bedroom and I'm not really sure why. We put in a split unit in there for extra support last year when my mother-in laws brother came to stay. Also grandmothers room is quite warm because she prefers it like that. She uses the heater all year especially after showering.*
Do occupants have different requirements for cooling?	*My second prefers the cold and we always fight about this…I increase the thermostat and she lowers it*	*we don't have specific preferences, we prefer neutral cool environment at this time*	*We prefer cooler environments, but for our kids we like it to be warmer.*	*We [homeowners] definitely prefer the cold, but grandmother prefers warmer temperatures.*
In general, how would you describe your thermal comfort during this period?	*Slightly cool to cool. The condition is perfect now.*	*Neutral the weather is mild outside. The AC can get quite drafty when on though.*	*Warm to slightly warm. I think our AC is not working as it usually does.*	*Warm. I think because the weather is still mild outside its effecting our AC.*

Space conditioning –Ramadan (early summer): third follow-up interview June 13-16 2016

RAMADAN	Villa 1	Villa 2	Villa 3	Villa 4
Has there been any change to the operation of your AC system, including thermostat settings since our last discussion?	*No, no major changes to our AC …our thermostats are set to* 22-23°C, *but some rooms really feel much more warmer than that especially [*Daughters bedroom 3 & 4*] rooms.*	*No not really. Its much more hotter outside now so the split units are almost always on and we usually use lower settings for those.. 20°C rather than 22°C.. especially in the diwaniya and dining room. All our central AC thermostats have to be set to 25-26°C…anything lower causes the system to shut down.*	*Yes since we last talked we called in a technician to clean the filters, and to fix the AC on the ground floor… the one that wasn't working [*since the start of monitoring*]. This was around the end of April. Our thermostats are still set to between 20-22°C.*	*Since we talked last, we fixed 1 more AC on the ground floor [*grandmother*]..we keep that AC on 26-27°C now….to be honest I'm not really sure what the problem was but it wasn't something major. I think that the nurse has fiddled with the settings .. she might have felt hot. That particular AC we had kept switched off in the past. Our thermostats are still set as before, around 70-75°F (*21-23°C*) on the floor, 75°F on the ground floor living room and 75°F (*23°C*) for the basement. We do a lot of adjusting though especially on the first floor*
Has any other form of cooling been used?	*No*	*No*	*No*	*No*
How do you/household occupants operate AC split unit throughout the day?	*The split unit in the staff bedroom is only switched on when they are in the room. The other extra units we have in the kids bedrooms have never been switched on.*	*We only switch the split units in the diwaniya and dining room if we're using those rooms. The one in the main kitchen though is switched on more often as staff are always there. In the staff bedrooms I believe they also switch them on only when they're in their rooms"*	*When it's hot outside the kitchen units are always on, even at night. We have things in there we don't want to spoil So it's always on. In the staff bedrooms I'm not really sure. They control that.*	*The split units, in the staff bedrooms are always on because they keep coming in and out of their rooms. I'm not sure of the settings they use though. The Kitchen split units are also on almost all day and closed only in the late evening, when all lights are switched off.*
Do you open the windows during this period? If so which?	*No we haven't opened any windows …its too hot outside.*	*Window's aren't open now*	*No windows are opened.*	*No we don't open any windows intentionally. But [grandmother] sometimes still does if she feels cold.*
Which rooms are the warmest?	As noted in the 6 month interview.	As noted in the 6 month interview	*Our room and [daughter's] and the diwaniya downstairs."*	As noted in the 6 month interview
In general, how would you describe your thermal comfort (cold, cool, slightly cool, neutral, slightly warm, warm, hot) during this period?	*Slightly warm*	*Neutral to slightly warm*	*Neutral…but there are times when it still feels warm and we keep checking the thermostats*	*Hot and cold actually. I feel cold during the night and hot during the day.*

Space conditioning – end of summer: final follow-up interview September 13-18 2016

End of Summer	Villa 1	Villa 2	Villa 3	Villa 4
Has there been any change to the operation of your AC system, including thermostat settings since our last discussion?	*We travelled right after Ramadan for about a month and increased our thermostats by 1°C. We lowered them back down to 23 as soon as we arrived home.*	*No*	*Early September we set the kids bedrooms to 22C after being 21C during summer. The diwaniya is kept at 22-23C.*	*We haven't made any changes settings are as they are…sometimes we might have increased and lowered slightly but they're generally the same.*
Has any other form of cooling been used?	*No*	*No*	*No*	*No. The split unit in the guest room was used once or twice during summer in the weekend.*
How do you/household occupants operate AC split unit throughout the day?	*As before the split units in the staff bedroom is only switched on when they are in the room. We haven't used any other split unit.*	*In the bedrooms we switch the units on when we're in the room and off when we leave. Also in the diwaniya. Sometimes the unit in the dining room is on for longer. The one in the main kitchen is almost always on when staff are cooking.*	*The nannies control their own unit, but I think it's usually kept on even when they're not in the room. The unit in the kitchen is always on even at night especially as we have things in there that we don't want to be spoilt.*	*Split units were always switched on during summer.*
Do you open the windows during this period? If so which?	*No*	*No, but the garden door is left open sometimes especially when the kids visit.*	*No*	*Sometimes for ventilation and cleaning. [Grandmother] still opens the main door and sits by the sun but not as much as before because of her health.*
Which rooms are the warmest?	*Our youngest daughter's room [bedroom 4] is the warmest*	*The indoor kitchen*	*Our room even though our thermostat was kept at 21C. Also the ground floor playroom because of its many windows, and the diwaniya because we keep the thermostat there at 23C.*	*Grandmother because she likes it warm and uses a heater in there too. Our room gets pretty warm too because of its larger window and location. The diwaniya is also very hot.*
In general, how would you describe your thermal comfort (cold, cool, slightly cool, neutral, slightly warm, warm, hot) during this period?	*Neutral*	*Neutral to slightly warm*	*Neutral to cool*	*Cool*
Was your AC system draughty?	*No*	*Yes, especially in the diwaniya and main reception area. In the diwaniya it's a split unit and it gets very uncomfortable for someone to be sitting opposite the AC. In the main reception room to the AC is very draughty and noisy too*	*No*	*Only in our bedroom it is. Even though we set the settings on automatic, the AC seems to work continuously in our room especially when it was extremely hot outside.*
Have you travelled during the summer? If so when and did you adjust your cooling system?	*From the 3rd to the 29th July. As I said we increased thermostats by 1°C before leaving and returned it back to normal when we arrived home.*	*15th-22nd June without adjusting thermostats. Then from 11th July till 28th August we all travelled except [son]. He left for about a month from mid-July till mid-august. We haven't adjusted thermostats because the villa does not really become empty. Split units were all switched off.*	*From the 11th till 18th of August the house was empty. Staff would come and check up on the cats during that time though..*	*We travelled in August with the kids. From the 1st till 22nd and again from the 1st till 6th sep but just us without the kids this time.*

Occupancy patterns – winter: first follow-up interview December 14-17 2015

WINTER	Villa 1	Villa 2	Villa 3	Villa 4
What effect did the cold weather have on your lifestyle?	*We use the garden much more in winter. We spend the evenings here and weekends. We switch on the lights*[outside]*, the two fountains and take our TV and receiver outside too. We have lots of people come over*	*Well the main difference is that we use heaters and wear very warm clothing all the time.*	*We didn't really change our lifestyle or routine, except that we took out the heaters and dress warmly indoors and outdoors*	*No major change. The kids go to school or university as normal, [aunt] travels regularly and shale is still a regular weekend trip. We would have our bishts [traditional warm garment] with us wherever we're at home.*
Did you spend more time outside the villa (ie in malls parks)?	*Maybe a bit more.*	*Yes when the weather is good we do go to parks and outdoor places more.*	*No the same.*	*Not really.*
Did you have any specific winter weekend plans?	*Thursdays, Fridays and Saturdays we usually love being in our garden. Even on weekdays we love using the space we have.*	*We don't have different weekend plans..we just have our weekly gathering outside in the garden instead of the living room*	*We go to the shale as we would in the summer…but the kids don't swim they play in the sand.*	*No our plans are the same …we have our main Friday lunch and then we usually go to the shale.*
What is the routine like for the kids, adults, and staff during this time?	Routine as described in first interview.	Routine as described in first interview.	Routine as described in first interview.	Routine as described in first interview.
Which rooms did you use most in the house during this time?	*The garden outside and the living room*	*The diwaniya and garden most*	*The upstairs living room and diwaniya for lunch*	*The downstairs ground floor living room.*

Occupancy patterns – spring: second follow-up interview March 21-24 2016

SPRING	Villa 1	Villa 2	Villa 3	Villa 4
What effect did the warmer weather have on your lifestyle?	*We don't use the garden much now.. We spend most of our time in the living room.*	*Well we can wear much warmer clothes and we're much more comfortable.*	*Since early February our routine has changed but not because of the weather because of my father's illness.*	*It didn't really have any major effect on our lifestyle…we go about our normal routines as usual*
Do you spend more time outdoors as the weather is warming up?	*We spend less time in the garden and more time outside in malls.*	*At the beginning we did but now as the weather is warming up we just use the garden before sunset. I started planting vegetables and fruits in the garden and check up on them in the mornings*	*Not really.*	*No as before.*
Do you have any specific weekend plans in spring	*We go out shopping and eat out more. We meet friends outside more as well*	*No…the family still comes over every Saturday afternoon as normal.*	*We go to the shale but not too often these days.*	*We still go to shale in the weekends.*
What is the routine like for the kids, adults, and staff during this time?	Routine as described in first interview.	Routine as described in first interview.	The homeowner's father passed away in February and the family as a whole has spent less time at home and more time with homeowner's mother	Routine as described in first interview.
Spring weekday routines – kids, adults, staff	Same as winter (3 month interview)	Same as in winter(3 month interview)	Same as in winter(3 month interview)	Same as in winter(3 month interview)
Which rooms do you use most in the house now that the weather is warmer?	*Downstairs living room*	*Diwaniya*	*Upstairs living room*	*Downstairs living room*

Occupancy patterns – Ramadan (early summer): third follow-up interview June 13-16 2016

RAMADAN	Villa 1	Villa 2	Villa 3	Villa 4
What effect did Ramadan have on your family's routine (kids, adults, staff)?	*The entire household routine has changed. We all* [except staff] *stay up till dawn. The kids wake up around 2pm in the afternoon, and me and my husband around 9am on weekdays. The ground floor TV is almost always on 24 hours a day. We have fotor at home except on Thursdays and Saturdays. The kids are on holiday but rarely go out during the day because it's too hot and you know they're fasting. We go out in the evenings after Isha prayer [around 9pm] to see friends and family. My husband goes to work now at 9am and returns by 3pm…rather than going upstairs he has his nap before fotor in the downstairs living room. The staff prepare for fotor from around 10am.*	*Since Ramadan started, our morning and evening routines have changed. We wake up later than usual now, around 9.30 am, then usually relax or go grocery shopping, read, or visit relatives. In the afternoon before fotor, we take a quick nap, usually in the diwaniya. In the evenings we stay up later till around 12am, praying watching TV, visiting friends and family as you do during this month. We have fotor at home all week, except on Thursdays we go to my father's home. Our children [grown up] and their families come over for fotor twice a week, every Sunday and Tuesday.*	*We spend much more time at home during Ramadan, especially during the day. Every day we have our fotor outside the house, either at my in-laws or at my parents', so we leave* [our house] *around 6pm and return by 11pm or 12 pm.* *The kids also sleep much later during Ramadan and wake up close to noon. My husband goes to work around 9am. The staff also sleep later and wake up around 9am.*	*The routine is fairly quiet and slow during Ramadan especially during the day. Activity only happens around fotor time. We have fotor three time a week at home and 4 times outside. The staff wake up around 8-9am, the rest of the household around 11am, and the kids around 2pm.My daughter has spent 20 days of Ramadan at my mum's house*
Do you spend more time outdoors or indoors?	*We spend much more time indoors at home especially during the day when it's too hot outside*	*Definitely more time indoors. The weather is too hot…my husband only gardens during the late afternoons or early evenings now.*	*Indoors… mostly at our home or at my parents' home.*	*Indoors*
Do you have any specific weekend plans during Ramadan?	*On Saturdays we break our fast at my father's house. We stay there until 10pm-11pm then return back home. Fridays we spend at home.*	*No*	*Now that its Ramadan the weekends are not much different from the weekdays. We don't go to the shale as on normal weekends of the year.*	*Not really. On Fridays our normal lunch has become a gathering over fotor, and we don't go to the shale during this month.*
Which rooms do you use most during Ramadan?	*Downstairs living room*	*Diwaniya*	*Master bed, diwaniya and the upstairs living room*	*Downstairs living room, and bedrooms (master, aunt, grandmother)*

Note – the word 'fotor' frequently reported during interviews refers the main *meal during sunset* in Ramadan.

Occupancy patterns – End of summer: final follow-up interview September 13-18 2016

End of Summer	Villa 1	Villa 2	Villa 3	Villa 4
What effect did the hot weather have on your family's routine (kids, adults, staff)?	*In the summer the kids visit friends more, we go to the mall and movies more as well.*	*Because its hotter outside we spent less time in the garden. The staff cleaning routine is the same. We were also away for a large part of the heat.*	*It's not the weather, it's because it was summer holiday for the kids that our routine changed. We went on a holiday for week. The kids would visit family and friends more.*	*Our routines remained generally the same. Nothing major has changed because of the weather.*
Do you spend more time outdoors or indoors?	*Indoors*	*We spend more time indoors*	*We spent less times indoors and more outdoors especially in the Shale. The Eid holiday we spent in the shale as well as every summer weekend.*	*We would go every weekend to the shale and so I guess there we would be outdoors on the beach.*
Do you have specific weekend plans during the summer holiday?	*As I said because its summer holiday for me and the kids we don't relay have different plans on weekdays and weekends its all the same. Its just my husband is at work.*	*We did go to the shale from time to time during the weekends. If we're not at the shale our kids would visit us here*	As above	As above
Which rooms do you use most during summer?	*The downstairs living room*	*The diwaniya*	*The first floor living room, and 2nd floor play room*	*Grandmother's room as she is always in there. The upstairs living room was also used more this summer because [son] installed his playstation there.*

Household cleaning and cooking

	Villa 1	Villa 2	Villa 3	Villa 4
How often does your household use the washing machine and dryer? Number of loads a week?	3 month interview *Once a day.* 6 month interview *We just* [March] *bought a new washing machine/dryer and I told the staff not to use it more than once so it won't break down.*	3 month interview *About twice a day, but the staff control this*	3 month interview *We use the machines constantly. Whenever we need to. Staffs make decisions themselves. School uniforms are washed daily, bed sheets weekly.*	3 month interview *Daily we like our clothes ready quick…We also don't like wearing new clothes without washing them first. The staff decide the loads. We bought a new washing/dryer for the female staff..,so now we have three one for the household one for the female staff and one for the male staff*
Why are clothes put for washing this often?	3 month interview *We don't' really need to use it more than once.*	3 month interview *That's how we've been doing it ..for a while now*	3 month interview *The kids are always getting their clothes dirty I guess that's why*	3 month interview *We love having clean clothes!*
How often are clothes ironed and why?	3 month interview *Daily*	3 month interview *Daily*	3 month interview *Daily*	3 month interview *Daily*
How often is the vacuum used and why?	No change since first interview. No vacuuming just sweeping daily	No change since first interview. No vacuuming just sweeping daily	No change since first interview. Occasional vacuuming	No change since first interview. Vacuuming twice a week
Does the household staff have specific cleaning routines to follow? Has this changed since our last discussion?	Staff routine has not changed since first interview. *One of the staff is responsible for cleaning the bedrooms, bathrooms and doing the laundry while the other is responsible for the kitchen, cooking, cleaning the fridge.*	Staff routine has not changed since first interview *One cooks and irons, and the other cleans and does the laundry*	Staff routine has not changed since first interview *Generally the first floor is cleaned on a daily basis (bedrooms bathrooms) but places like the diwaniya are not. The two housemaids help one another. When the kids are in school one would be cleaning while the other cooks.*	Staff routine has not changed since first interview *One is responsible for cleaning bedrooms and bathrooms on the first floor, the other the ground floor and diwaniya. They share the laundry load. Cook prepares lunch for everyone. Driver cleans the cars, and nurse cares for grandmother.*
How many meals are prepared daily? Does the family have a set time for meals?	3 month interview *We cook three meals every day, breakfast, lunch and dinner. Breakfast between 6-7am on weekdays and 9am on weekends. Lunch at 3 pm, and dinner between 8-9pm.* 9 month interview - Ramadan *Two meals are cooked, one served at around 6.30pm and the other around 11pm.*	3 month interview *One main meal is prepared and served between 12.30-1pm.* 9 month interview - Ramadan *In Ramadan the meal is cooked and served for fotor [6.30pm].*	3 month interview *Usually we cook two main meals.. kids lunch and our lunch – which is the kids dinner.* 9 month interview - Ramadan *One meal is usually prepared.* 12 month interview *Over the summer holiday we prepare 3 meals breakfast, lunch and dinner as kids spent more time at home.*	3 month interview *One meal is prepared and served between 3-4 pm. Breakfasts and dinners are made on request. On Fridays, lunch is served between 12.30-2pm in the basement* [extended family lunch with around 20 members]. 9 month interview - Ramadan *We have one main meal (fotor) and in the late evenings, only a light meal is prepared if requested.*
How often (how many hours) is the oven used/week?	No change since first interview	No change since first interview	No change since first interview	No change since first interview
How often is the microwave/ week?	No change since first interview	No change since first interview	No change since first interview	No change since first interview
How often is the kettle used/week?	No change since first interview	No change since first interview	No change since first interview	No change since first interview
Have you bought any new kitchen appliances (fridges, freezers)? why?	*No*	*No*	*No*	*No*

Lighting and appliance use

	Villa 1	**Villa 2**	**Villa 3**	**Villa 4**
Has there been any change to the type of light fixtures/fittings used?	3 month interview *No change at all ...we use energy lights whenever we have to replace anything*	3 month interview *Not really, I try to go for LED whenever I can*	3 month interview *No. Every time a bulb burns we replace it with an energy bulb..15 watt bulbs.*	3 month interview *No change. We use the 7w or 15 w bulbs on almost all our fixtures.*
How often is the TV watched in the house? Does the family watch TV together or alone, and when?	3 month interview *When the kids are home the downstairs TV is always on all day sometimes. As well as their mobile, tablet and lap top chargers are always plugged in. Kitchen equipment, the kettle, toaster are also used countless times.* 9 month interview *In Ramadan we watch a lot more TV*	3 month interview *We watch TV daily. Mainly in the diwaniya where the TV is usually always on. In the bedrooms…it depends really.* 12 month interview *Less during summer as we travelled for some time.*	3 month interview *We don't' have family TV time. We watch TV in the evenings and keep it on sleep mode. The kids watch TV on weekends, not really on weekdays* 12 month interview *During summer we watch tv much more ..in the first floor it would be on all day from morning till night.*	3 month interview *We watch TV daily. In the downstairs living room the TV is on if the family is sitting there. Grandmother always has her TV on, my kids for a couple of hours and we in the evenings only. We like to keep it on sleep mode.*
How often are laptops used?	3 month interview *Sometimes. What we really use are mobile chargers, everyone has a mobile the kids the staff, about 8 mobile phones so charges are used 24 hours.* No change in other follow-up interviews	3 month interview *I use my laptop almost daily and so does [son].* No change in other follow-up interviews	3 month interview *We use laptops occasionally.* No change in other follow-up interviews	3 month interview *Occasionally.* 9 month interview *Since the start of Ramadan and the summer vacation [son] has used the game console more.*
How often is the internet used?	*Daily* (same response in all follow-up interviews)	*Daily* (same response in all follow-up interviews)	*Daily* (same response in all follow-up interviews)	*Daily* (same response in all follow-up interviews)
Have you bought any new electrical appliances?	*No* (same response in all follow-up interviews)	*No* (same response in all follow-up interviews)	12 month interview: *Bought a blender*	12 month interview: *New kettle for staff as well as a new Wi-Fi router, phone and Ipad for myself*

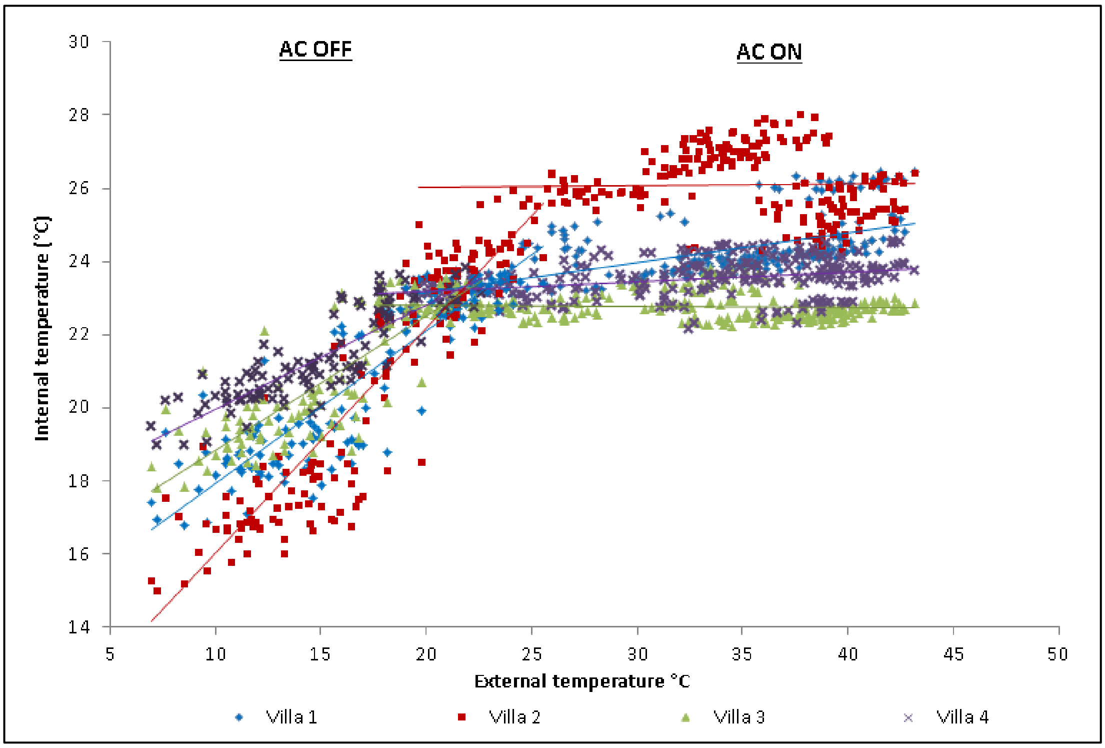
Building systems maintenance

	Villa 1	Villa 2	Villa 3	Villa 4
Have you maintained or repaired any aspect of the AC units since our last discussion? How and why?	6 months interview: *Before using the AC my husband cleaned the filters himself.* 9 month interview: *Our AC stopped working a while ago [*the first of week of April] *after a power cut in the area that lasted for a couple of hours. It was down for about 2 days after that before we realized that it was warmer on the ground floor. We called the AC technician to fix it and its perfectly fine now.* When asked about the nature of the problem they explained that *we think it was a fuse in the system nothing major.*	6 months interview: *I usually always clean the filters myself before switching the AC on…they were very dusty this time…the units are not maintained or cleaned regularly by any technician … we call whenever something goes wrong.* 9 month interview: *One of the central units for the ground floor kept shutting down so we called in a technician ... maybe twice. He said the problem was with the thermostat. All thermostats are set to 24-26C.any lower causes the system to shut down.* 12 month interview: *A technician was called in again to check the unit in the driver's room and the central in the main reception [ground floor living].*	6 months interview: *When we first switched the AC on after winter it wasn't really working well. It felt warmer than usual maybe because we didn't clean the filters before switching it on.* 9 month interview: *We called in a technician to clean the filters and fix the ground floor AC that was not working for a while [since start of monitoring]* 12 month interview: *The nanny's split unit stopped working for a few days in July and the room was really hot because the washing machines are in there too. So we called someone in for that.* *The main AC I don't think we had any issues with that.*	6 months interview: *The main staff clean the AC filters. We call the technicians as and when problems come up. They usually always come instantly. So far they have come for two of the ACs, the basement and the first floor* When asked about the nature of the problem the homeowner noted that: *I think it was the thermostat or something minor…it was a consumer piece that they changed* 9 months interview: *The AC on the ground floor that cools grandmother's bedroom, dining room and main kitchen was fixed.* 12 month interview: *I think yes since our last meeting we called in a technician once…can't remember though.*
Have you maintained or repaired the boiler/hot water tank since our discussion? How and why?	*No* (same response in all follow-up interviews)	*No* (same response in all follow-up interviews)	*No* (same response in all follow-up interviews	3 months interview: *Our hot water system broke down. We had to have major repairs to the entire system including pipes, pump and hot water tank. This was the first time this has happened since we moved in 15 years ago. The problem lasted a week but we had to replace the pump and hot water tank.* 6, 9, and 12 month interviews: *No*
Have you maintained or repaired any other appliance in the house since our last discussion? Which? How? Why?	*No* (same response in all follow-up interviews)	*No* (same response in all follow-up interviews)	No (in the 3, 6 and 12 interview) 9 month interview: *The alarm system stopped working and was not fixed since.*	Homeowner's response was 'no' in the both the 3, 6 and 9 month occupant interviews

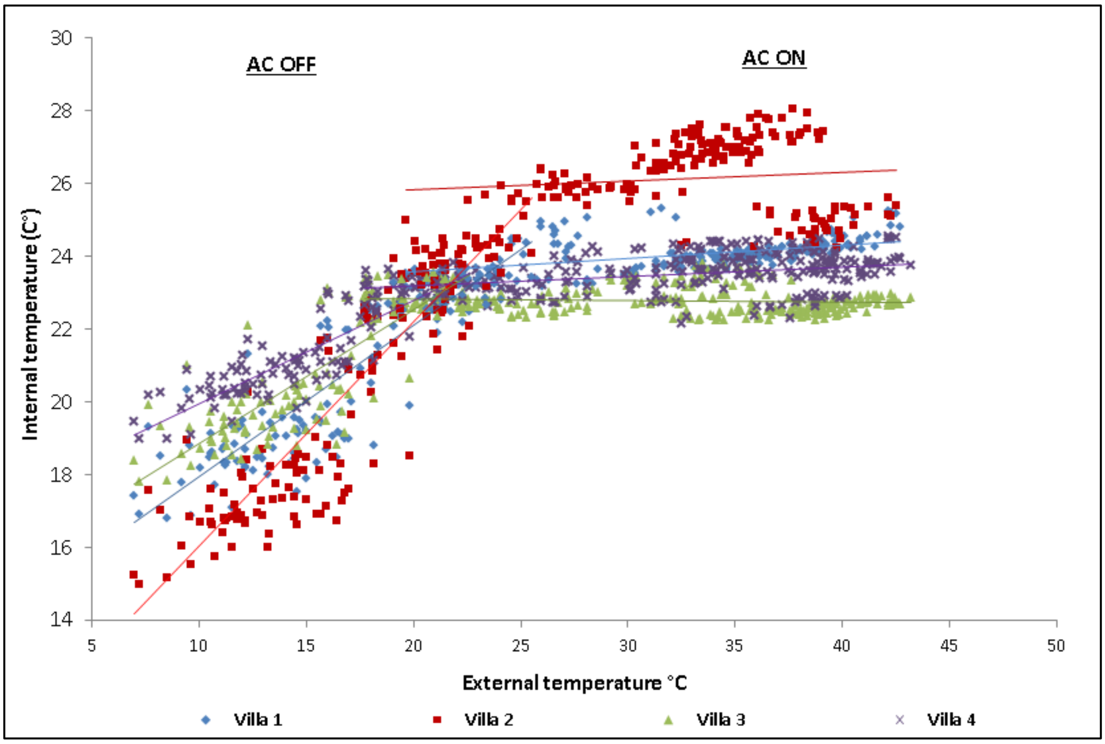
Concluding remarks during final follow-up interview September 13-18 2016

	Villa 1	Villa 2	Villa 3	Villa 4
Do you know how much you spent on electricity this past year? Do you know how this compares to last year?	*I don't think it differed much from last year…we haven't changed anything major in the villa or in the way we live. We haven't paid the bill yet so I can't give an exact number.*	*About 200 KD I think. Quite similar probably to last year.*	*Absolutely no idea.*	*To be honest I cannot say. We haven't paid the bill since last year but I'm sure it will be a lot especially as we bought many new devices this year (washing machines', new compressor and so on*
How was it having sensors in your house?	*It was completely fine actually. In the beginning the kids and staff were asking about them but very quickly they were unnoticed.*	*We got used to them and don't notice them anymore.*	*I think they have made us, in an indirect way, more careful about closing things like lights in the room, the water tap.*	*Not bothered at all. We see them visually but that's fine.*
How did you find being part of a study in general? Is there something we could have done differently?	*It didn't affect our lives or anything. I think we are just happy to have helped and wish u the best.*	*I'm proud to be part of something that may increase awareness of electricity in our homes especially because this is such a valuable resource which our grandparents did not have the luxury of as we do.*	*It's really nice being part of something useful. Can't think of anything you could have done differently but \ do share your recommendations with us.*	*Not at all we are very happy to have participated*

Appendix I: Graphs of internal temperatures vs. external temperature for each case study villa



Daily average volume weighted internal temperatures vs. external temperature thorough the entire monitoring period (including when occupants were away on vacation)



Daily average volume weighted internal temperatures vs. external temperature (excluding periods when occupants were away on vacation)

Appendix J: Potential variations in the average internal temperature of each case study villa when considering monitored temperatures in all rooms compared to only one room

The table below illustrates the average annual, winter and summer internal temperatures (◦C) in all monitored rooms compared to just the family living room or master bedroom, indicating the percentage difference between these.

	Villa 1				
	All monitored rooms (◦C)	**Living room (family) (◦C)**	**% difference between living room & all rooms**	**Bedroom (Master bed) (◦C)**	**% difference between bedroom & all rooms**
Annual average	22.9	22.6	1.3	22.7	0.9
Winter (Dec-Feb)	19.4	18.7	3.7	20.1	3.5
Summer (Jun-Aug)	24.9	24.7	0.8	23.8	4.5
	Villa 2				
	All monitored rooms (◦C)	**Living room (family) (◦C)**	**% difference between living room & all rooms**	**Bedroom (Master bed) (◦C)**	**% difference between bedroom & all rooms**
Annual average	23.7	25.4	6.9	24.1	1.7
Winter (Dec-Feb)	18.3	19.4	5.8	17.9	2.2
Summer (Jun-Aug)	25.8	28.7	10.6	28.3	9.2
	Villa 3				
	All monitored rooms (◦C)	**Living room (family) (◦C)**	**% difference between living room & all rooms**	**Bedroom (Master bed) (◦C)**	**% difference between bedroom & all rooms**
Annual average	22.2	21.4	3.7	22.2	0.0
Winter (Dec-Feb)	20.2	20.8	2.9	21.4	5.8
Summer (Jun-Aug)	22.6	21.0	7.3	22.1	2.2
	Villa 4				
	All monitored rooms (◦C)	**Living room (family) (◦C)**	**% difference between living room & all rooms**	**Bedroom (Master bed) (◦C)**	**% difference between bedroom & all rooms**
Annual average	22.9	22.1	3.6	20.7	10.1
Winter (Dec-Feb)	21.1	20.4	3.4	20.2	4.4
Summer (Jun-Aug)	23.7	22.3	6.1	20.8	13.0

Appendix K: Multi-case study brief lighting analysis

The following are brief descriptions of some lighting trends observed in the monitored data, which were discussed with the homeowners during follow-up interviews:

Villa 1

- Variations were found in bedrooms lighting levels between weekdays and weekends particularly during the morning hours. On weekdays bedrooms were lighter for a short period (6-7am), because occupants waking up for school/work, tend to open curtains or switch lights on. On weekends bedrooms were lighter at later hours of the morning as occupants were sleeping in for longer hours.
- Lighting levels in the female staff bedroom increased between 2pm-4pm on weekdays and weekends, which was noted to be when they usually iron clothes or rest after the household finish thier lunch.

Villa 2

- No variations were observed between weekday and weekend bedroom lighting in the master bedroom or bedroom 2 (both are used by the homeowners, who are retired and unlikely to vary their daily morning routine). In bedroom 3 (working son) slight variations were found; the room was darker during the morning hours on the weekend. Lighting in the spare bedrooms 4 and 5 remained very low and dark on weekdays and weekends.
- The dining room and the kitchenette were the brightest rooms on both weekdays and weekends due to the large windows and skylight openings in these spaces.
- The ground floor family living room was also bright during the day due large window openings. In the evenings this space was regularly brighter on most Saturday (as this is when and where the family has its weekly gathering with their other grown-up kids and grandkids that come to visit).
- All other rooms including the upstairs living room and ground floor living rooms were relatively dark throughout the week.

Villa 3

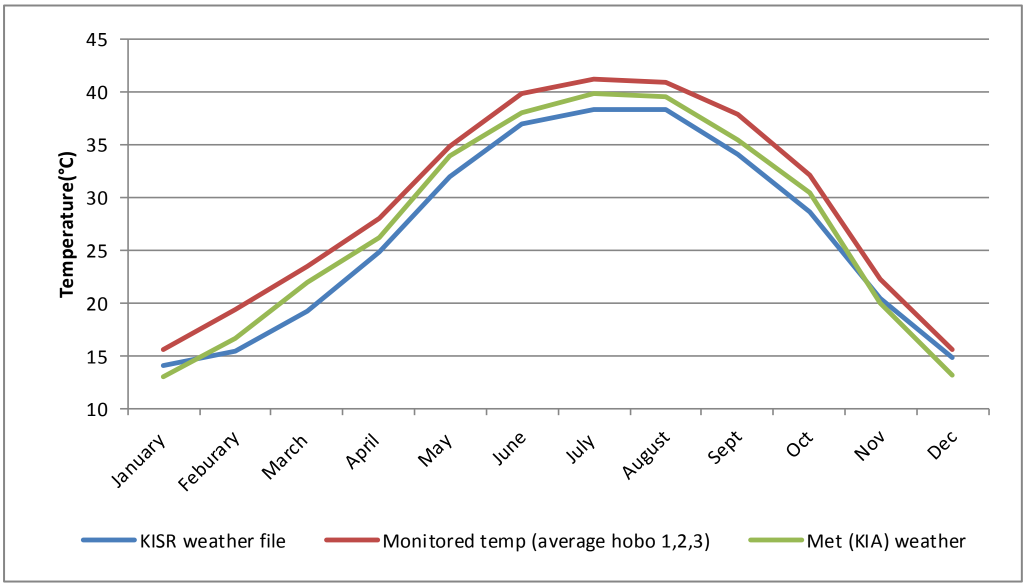
- Variations in bedroom lighting levels were found on weekdays and weekends; on weekdays bedrooms were lighter at 6am-7am as occupants woke up for school and work, while on weekends more light was detected later around 10am-11am.
- Bedrooms 2 and 3 (young kids' bedrooms) were generally dark after 7pm on weekdays and weekends as their bedtime does not change throughout the week.
- Peaks in the lighting levels were detected around midday in the staff bedroom, second floor playroom, stairs, bedroom 3 and ground floor dining room as natural light is seeping through the large windows in these spaces.
- The stairs, ground floor kitchenette and formal living were relatively dark throughout the day. During weekdays at around 5am-6am light was regularly detected for a short period in the kitchenette (as staff prepared kids school snacks), while on weekends it was darker at those times.

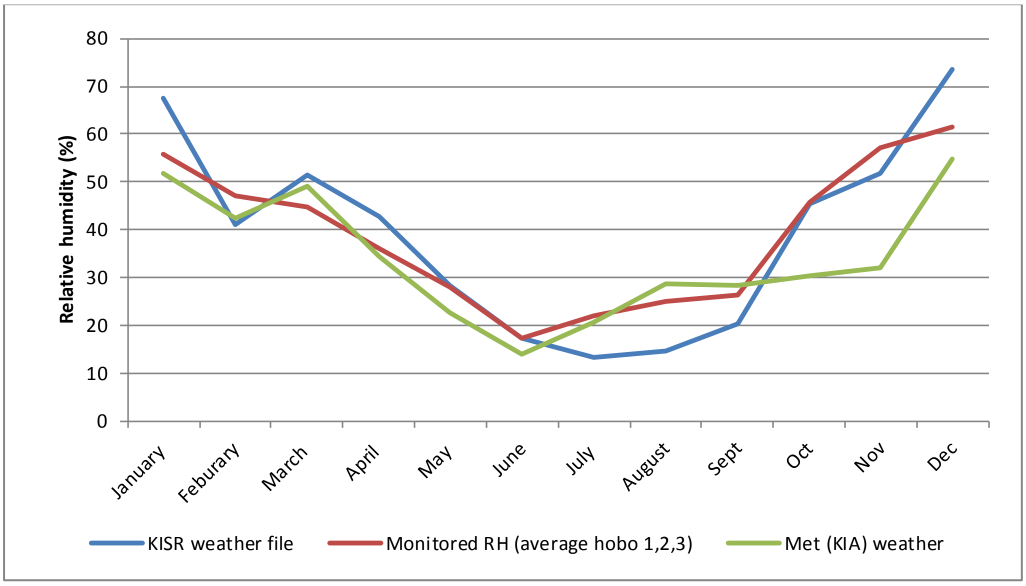
Villa 4

- Light was detected for a short period in bedroom 5 (teenage son) between 6am-7am on weekdays (as he prepared for school) and on weekends after 9am. Other bedrooms were relatively darker during the early morning hours. In the evenings minimum lighting was used in bedrooms.
- The female staff bedroom on weekdays was regularly lit from 5am-6am (on weekends around 7am) then later in the evening from 5pm-10pm (while ironing or resting).
- Peaks in the lighting level on the ground floor living room were detected daily between 2pm-3pm particularly during spring and summer. Follow-up interview data revealed this is because an elderly occupant sits in this space with the external doors wide open to get some natural light.
- The dining room was relatively dark throughout the day, with light detected only between 3.30pm-4.30pm (which was noted to be the households usual lunch time).

Appendix L: Building energy modelling

1. **External temperature and relative humidity: A comparison between monitored data, metrological data and the KISR weather file**





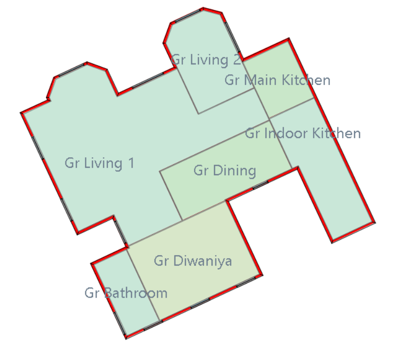
2. Model floor plans with thermal zones for each case study villa

Villa 1

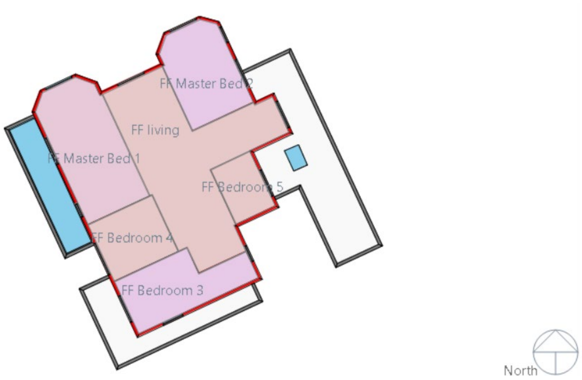
Ground floor

First floor

Villa 2

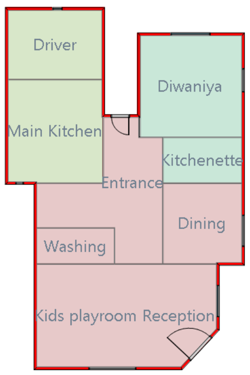


Ground floor

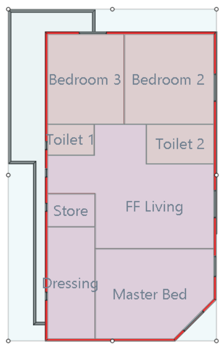


First floor

Villa 3



Ground

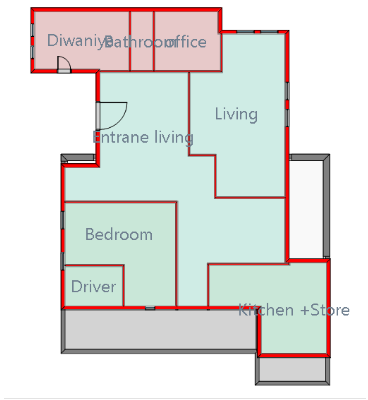


First floor

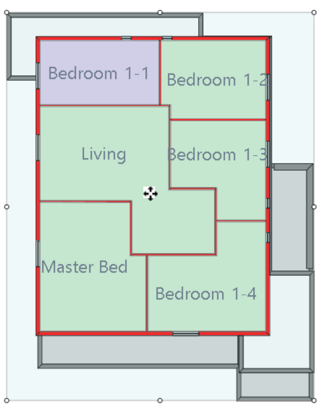
Second floor

Villa 4

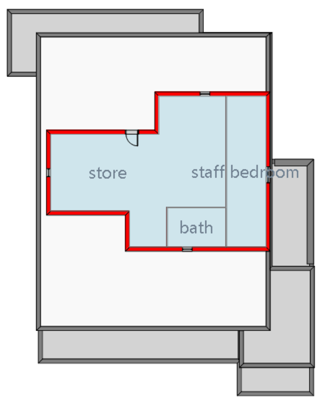
Basement



Ground floor

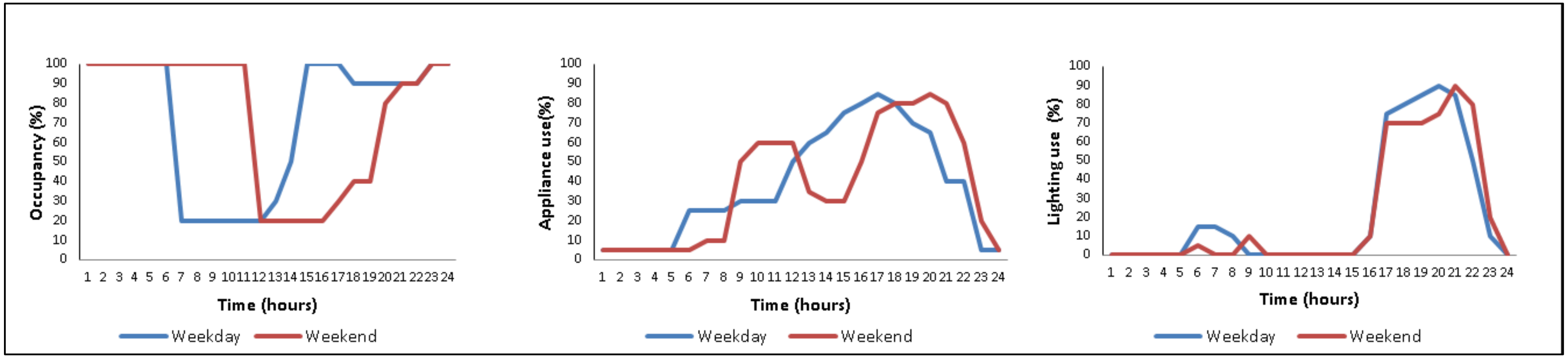


First floor

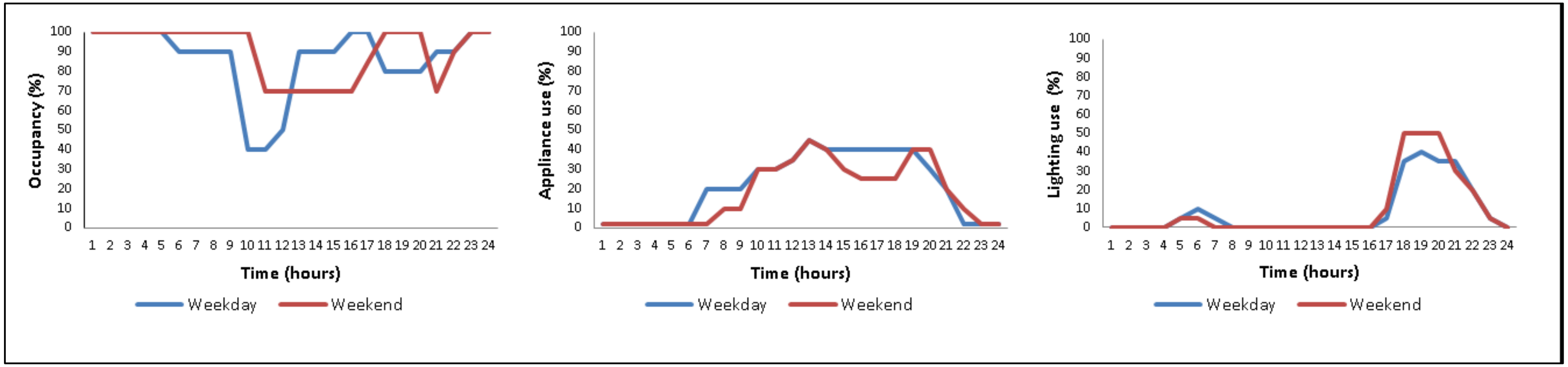


Second floor

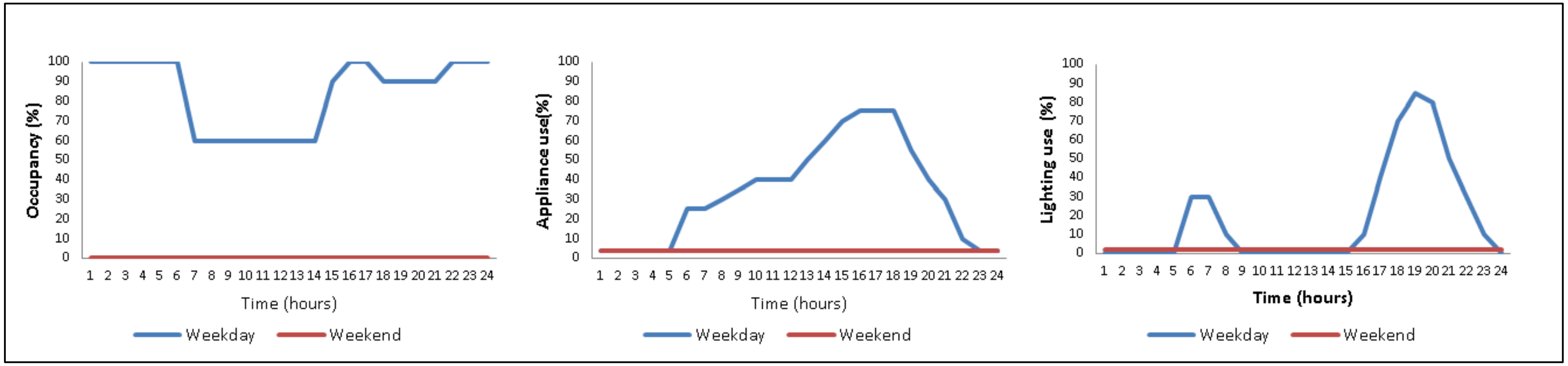
3. Typical weekday and weekend occupancy, appliance and lighting schedules for each case study villa



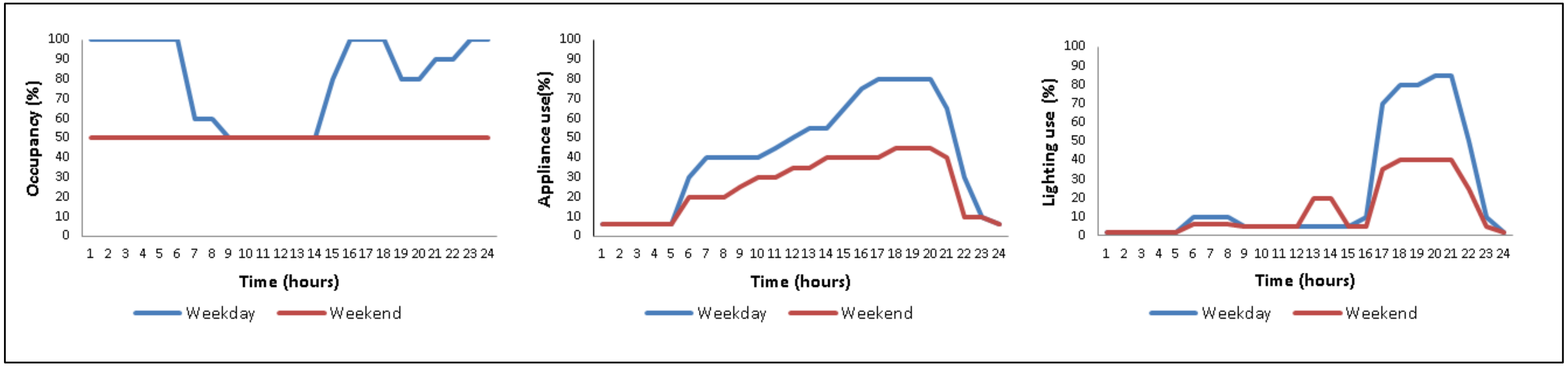
Villa 1 typical weekday and weekend occupancy, appliance and lighting schedules



Villa 2 typical weekday and weekend occupancy, appliance and lighting schedules



Villa 3 typical weekday and weekend occupancy, appliance and lighting schedules



Villa 4 typical weekday and weekend occupancy, appliance and lighting schedules

4. Monthly measured and simulated energy consumption for each case study villa