An Investigation into the Determinants of Residential Electricity Consumption in Makkah, Saudi Arabia with Particular Reference to the Occupant Behavioural Aspects

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IN THE NAME OF ALLAH, THE MERCIFUL, THE COMPASSIONATE

Declaration

I certify that this thesis constitutes my own work/investigation, except where otherwise stated. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

I declare that this thesis describes original work that has not previously been presented for the award of any other degree of any institution.

Signed: Hatem Nojoum

Date: 13th November 2022

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Abstract

Saudi Arabia is the largest exporter of petroleum liquids and holds the largest production capacity of crude oil in the world. However, the apparent development in the country has increased the demand for the built environment, resulting in higher energy consumption and environmental pollution. Saudi Arabia had the highest total electricity consumption in the GCC countries in 2020, consuming 359 TWh. However, it had the second lowest electricity consumption per capita at 10.31MWh per person. This is because Saudi Arabia has the largest population compared to other GCC countries, and its electricity consumption is spread over a large area. The statistics by ECRA show that residential buildings in Saudi Arabia consume almost 50% of the total electricity sold while commercial, government, industrial, and others account for 15%, 13%, 20%, and 4%, respectively. It has also been demonstrated that an energy code and a standard implementation can significantly improve the energy efficiency of buildings. However, the primary objective of this code is to encourage the construction of more efficient buildings and energy supply systems. Theoretically, this approach may reduce the overall energy consumption associated with building characteristics, which is a major objective the government has been trying to accomplish. However, reducing electricity consumption in dwellings is a very sophisticated concept that starts with the early design stages and continues after the occupancy phase.

There is a growing demand for electricity on a national and international scale, even though the quality of homes and HVAC systems is gradually improving. Occupant behaviour, among other factors like building characteristics, household socioeconomic characteristics, meteorological conditions, is observed to play an important role in residential electricity consumption, which is usually neglected during the design stage. Therefore, this research aims to investigate the influential factors of residential electricity consumption in Makkah, Saudi Arabia, with a particular emphasis on the influence of occupant behavioural aspects. Understanding the complexity of the abovementioned factors requires a research strategy that draws from quantitative and qualitative techniques, including collecting public questionnaires, electricity consumption records, meteorological data, and qualitative-related documents and reports. Therefore, simple descriptive and advanced statistical analyses (e.g., one-way ANOVA, independent-sample t-test, and correlation coefficients) were used in this research to identify the relationship and differences between the variables and electricity consumption.

The findings suggest a statistically significant correlation between occupant behaviours, such as the use of lighting, air conditioning, temperature control, presence patterns, and the number and use of electrical appliances and electricity consumption. Concerning household

socioeconomic characteristics, family size, length of residency, household income, tenure, electricity tariffs, respondent's gender, age, and employment status, and the presence of teenagers, housemaids, and drivers in the household were proved to be determining factors in the use of electricity. In addition, there was a statistically significant correlation between building attributes, such as dwelling type, floor area, the total number of rooms, bedrooms, and bathrooms, and lighting and air conditioning type and electricity consumption. There was also a statistically significant correlation between temperature, humidity, solar radiation, wind speed, and CDD and electricity consumption.

Multiple linear regression (MLR) analyses were also used to determine the variability in electricity consumption explained by occupant behaviours, building attributes, and household socioeconomic characteristics. Since the study's samples were gathered in the same city, meteorological conditions were not included in the MLR models. As a result of the first MLR model (Model 1), occupant behaviour alone explained 47.9% ($R^2 = 0.479$) of the variance in electricity consumption. The variation increased by 5.9% ($R^2 = .538$) with the addition of the building attributes. The addition of household socioeconomic characteristics caused the variation to increase by 7.7% ($R^2 = .615$). In the second MLR model (Model 2), while controlling for building variables, 26.1% ($R^2 = 0.261$) of the variability in electricity consumption for the first step (only building attributes), an increase of 27.7% ($R^2 = .538$) for the second step (building attributes and occupant behaviour), and the variance increased by 7.7% ($R^2 = .615$) for the last step (building attributes, occupant behaviours, and household socioeconomic characteristics). As a result, this study highlights that occupant behaviour is the most significant determinant of residential electricity consumption, which could account for 30–50% of the variation in electricity use.

The study contributes to the body of knowledge within this field by providing a solid foundation for developing more energy-efficient residential buildings in Saudi Arabia, considering every possible influence on households' energy consumption, especially occupant behaviour. In addition, since the study of occupant behaviour has been conducted for decades in several countries like China, the United States, Canada, and Australia as well as many in northern and western Europe, one of this study's objectives is to introduce this field in the Kingdom of Saudi Arabia and to encourage the establishment of a set of investigations that are specifically focused on Saudi Arabian culture considering local conditions, such as social, technical, construction, and climatical conditions.

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Abbreviation

AEC	Architecture, Engineering, and Construction Industry
ANOVA	Analysis of Variance
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BSI	British Standards Institution
b/d	Barrels per Day
CCL	Climate Change Levy
CDD	Cooling Degree Days
CDSI	Central Department of Statistics and Information
CO_2	**Carbon Dioxide**
DHES	Dwelling, Household, Economic, and System
DHW	Domestic Hot Water
ECRA	Electricity & Cogeneration Regulatory Authority
EE	Energy Efficiency
EEA	European Environment Agency
EER	Energy Efficiency Ratio
EIA	U.S. Energy Information Administration
EPBD	Energy Performance of Buildings Directive
EU	European Union
FAO	Food and Agriculture Organization
GCC	**Gulf Cooperation Council**
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HDD	Heating Degree Days
HVAC	Heating, Ventilation and Air Conditioning
ICTs	Information and Communication Technologies
IEA	International Electricity Agency
IECC	International Energy Conservation Code
KAPSARC	King Abdullah Petroleum Studies and Research Centre
kWh	Kilowatts per Hour
LEED	Leadership in Energy and Environmental Design
MENA	Middle East and North Africa
MLR	Multiple Linear Regression

MOMRAH	Ministry of Municipal Rural Affairs and Housing
MRDA	Makkah Region Development Authority
NIDLP	National Industrial Development and Logistics Programme
OCRF	Occupant Characteristic-Related Factors
OECD	The Organisation for Economic Co-operation and Development
PV	Photovoltaic Technology
REDF	Real Estate Development Fund
SBC	Saudi Building and Energy Code
SBCNC	Saudi Building Code National Committee
SEC	Saudi Electricity Company
SEEC	Saudi Energy Efficiency Centre
SGAS	Saudi General Authority for Statistics
SGS	Saudi Geological Survey
SHGC	Solar Heat Gain Coefficient
SMP	Smart Meter Project
SPARK	King Salman Energy Park
UKCCP	United Kingdom's Climate Change Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value Added Tax
VCR	Videocassette Recorder
WWR	Window-to-wall Ratio

Chapter One:

Introduction

Chapter 1: Introduction

1.1 Overview

The concern for the environment has recently increased worldwide. It is anticipated that climate change is the most significant environmental threat and challenge in modern times. Climate change is not the only issue that concerns the globe since many more issues affect every human, animal, and nation, such as water pollution, acid rain, Ozone layer depletion, air pollution, and global warming. Therefore, sustainability has significantly increased the global focus on energy-related analysis (Delzendeh *et al.*, 2017). The climate change agreement known as *"The Paris Agreement"* has been signed by a total of 193 countries to preserve the environment and fight climate change, as well as to expedite and enhance the actions and investments necessary for a sustainable future with lower carbon emissions (The United Nations Framework Convention on Climate Change UNFCCC, n.d.). There are many other international agreements such as the Kyoto Protocol; European agreements (i.e., the European Emissions Trading Scheme and the Energy Performance of Buildings Directive EPBD of the European Union; and UK national measures (i.e., the United Kingdom's Climate Change Programme UKCCP and the Climate Change Levy CCL; all demonstrate its prominence (Delzendeh *et al.*, 2017).

It has been noted that a considerable number of environmental crises could threaten civilisation's existence, such as the energy crisis caused by the high consumption of energy resources to meet the high energy demand in the world. Moreover, massive energy consumption is considered one of the most significant issues facing Saudi Arabia. Lahn and Stevens (2011) mentioned in their book *'Burning Oil to Keep Cool the Hidden Energy Crisis in Saudi Arabia'* that Saudi Arabia is consuming so much energy internally, leading to an unstable status in the world oil market because the nation is one the world's largest exporter of oil. They stated:

> "Saudi Arabia's place in the world oil market is threatened by unrestrained domestic fuel consumption. In an economy dominated by fossil fuels and dependent on the export of oil, current patterns of energy demand are not only wasting valuable resources and causing excessive pollution but also rendering the country vulnerable to economic and social crises" (Lahn and Stevens, 2011, p. 1)

The United Nations Environment Programme UNEP (2009) highlighted that buildings use 40% of global energy and are responsible for one-third of global greenhouse gas emissions. Wilde (2018) further reported that buildings influence many other dangerous crises in addition to greenhouse gas GHG emissions such as surface water run-off, climate change, and smog formation and acidification. Furthermore, buildings in Saudi Arabia exhaust a considerable amount of the produced electricity, with air conditioning thought to be the highest consumer of the buildings' electricity (Saudi Energy Efficiency Centre SEEC, 2018). Nowadays, addressing the need for energy-efficient buildings by the architecture, engineering, and construction AEC industry is becoming common in many countries, including Saudi Arabia. Therefore, Due to the significance of a high-quality indoor environment and the issues raised by high energy consumption, particularly in buildings, the Saudi Arabian government has implemented policies and regulations to improve building energy efficiency to guarantee a high-quality indoor environment, including dwellings. The Saudi Building and Energy Conservation Code SBC is an example of one of these initiatives. In 2004, the government obligated the architecture, engineering, and construction industries to implement performance-based building and energy regulations to reduce energy consumption in buildings.

The energy efficiency policies in buildings concentrate on the building's characteristics and mechanical systems, such as insulation, heating, ventilating, air conditioning, indoor air quality, lighting, and service water heating. However, the concept of energy consumption in buildings is very sophisticated since it is affected by various factors, for instance, the technical construction details, climate conditions, the quality of the installed heating or cooling system and maintenance, the thermophysical properties of the building elements, and the occupant behaviour and activities towards energy utilisation (Delzendeh *et al.*, 2017). Human behaviour in buildings significantly impacts a building's overall energy consumption, even if the results of current research and studies on the subject are fragmented. When a building's occupants turn on or off the heating or cooling system, adjust the thermostat, open or close a window, or turn on or off a light, the energy balance changes, impacting the overall energy use of the building. Therefore, an accurate estimate of energy consumption is one of the most fundamental requirements for architects and researchers to produce highly energy-efficient buildings.

As the growth of the building interconnects and the upturn in energy demand and cost in Saudi Arabia, the awareness of energy use reduction has increased among AEC industries, researchers, decision-makers, and families and individuals. Accordingly, the high demand for energy and the shortage of literature focusing on occupant behaviour in Saudi's residential buildings have led to unique challenges. There is an urgent need to conduct comprehensive research into the primary factors influencing energy consumption in residential buildings in Saudi Arabia, including occupant behaviours.

1.1 Research Motivation

The construction industry plays a crucial role in accomplishing sustainable development in any nation (GhaffarianHoseini *et al.*, 2013). Hussin, Abdul Rahman and Memon (2013) demonstrated that buildings are a contributor to environmental problems due to the massive use of resources during the construction and operation stages, which results in environmental pollution. Buildings also generate waste and possibly harmful atmospheric emissions (UNEP, 2009). Consequently, because of the visible and profound interrelationship between buildings and environmental issues, the term "building energy performance" has emerged. According to the British Standards Institution BSI, building energy performance is defined as “measurable results related to energy efficiency, energy use, and energy consumption” (2012, p. 3). Researchers have shown an essential need to study building energy performance in the past few years. The primary goals of these studies is to reduce energy consumption, reduce carbon emission, and develop sustainable energy resources. Energy consumption also requires intensive research because it comprises a substantial share of the world’s energy demand (Alghoul, Rijabo and Mashena, 2017).

The report of BP Energy (2018) declared that the global primary energy consumption growth in 2017 was 2.2%, up from 1.2% in the previous year. It also recounted that the world total energy consumption was 13,511.2 million tonnes of oil equivalent. According to the International Energy Agency IEA (2013), more than 40% of primary energy consumption is currently used on buildings, whereas the residential sector is considered the largest consumer of energy at a global level. Another study undertaken by the European Environment Agency EEA (2015) demonstrated that the households sector accounted for 26% of the total energy consumption in the European Union EU Member States. Similarly, about 29% of the total primary energy in Saudi Arabia is consumed by the construction sector (SEEC, 2018). Residential buildings consume approximately 50% of the country's overall electricity sales (Electricity & Cogeneration Regulatory Authority ECRA, 2020). The good news is that since the construction sectors are considered the largest energy consumers, they also have an immense potential for reducing GHG emissions (UNEP, 2009; Aldossary, 2015).

There is a wide range of interrelated factors that influence energy consumption in buildings, such as climatic conditions and location; the culture of citizens and the policies of the country; level of demand, supply, and source of energy; the design of building and materials; and the income and behaviour of the occupants (UNEP, 2009; Chen *et al.*, 2015). The IEA has experience in studying building energy use and sets six parameters that influence the energy use in a building. These parameters are indoor design criteria, building energy and services systems, building operation and maintenance, building envelope, climate, and occupant behaviour (Yoshino, Hong and Nord, 2017). Steemers and Yun (2009) further identified the main factors affecting household energy consumption, as shown in Figure 1.1. They found that the number of occupants, age, income, climatic condition, building features and systems critically influence energy use.

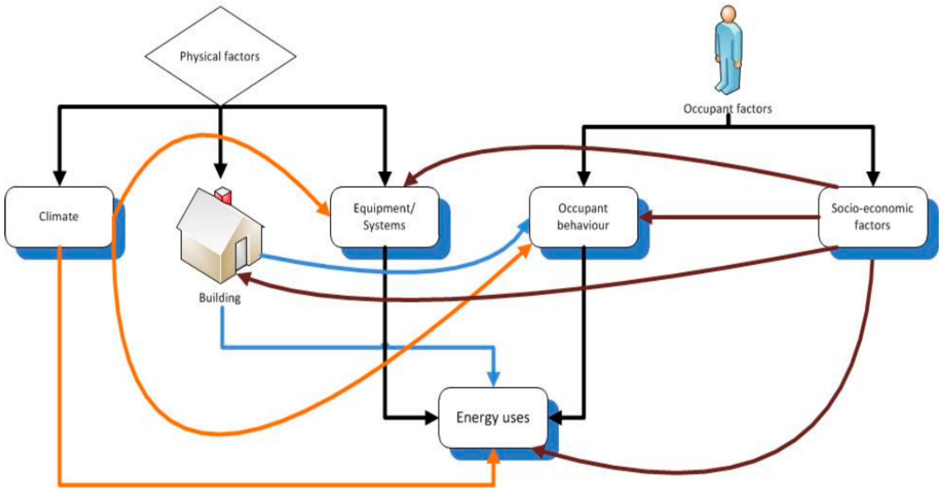


Figure 1.1 Factors influencing occupant behaviour in domestic energy use

(Tam, Almeida and Le, 2018)

Duarte, Budwig and Wymelenberg (2015) and Yan et al. (2018) emphasised that occupant behaviour has a remarkable and critical impact on building prediction and actual energy consumption. According to Wilde (2014), buildings do not perform as predicted during the design stages due to three factors contributing to this phenomenon. One of the most significant factors Wilde (2014) identified was the contradictions between energy prediction and measurements caused by occupant behaviour. The prediction of energy use would not be precise if the behaviour of occupants, such as adjusting the thermostat for comfort, pulling up/down window blinds, moving between spaces, switching lights, and using appliances, gets neglected (Yan *et al.*, 2018).

It has been suggested that occupant behaviour influences energy consumption as equal to mechanical characteristics such as equipment and appliances, resulting in differences in energy consumption between households, even in similar dwellings with identical equipment and appliances. In a study conducted by Santin (2010) in the Netherlands, a significant issue was raised when houses with similar construction characteristics were found not to meet the calculated energy performance criteria and had considerable energy consumption variations. In the same study, it was found that homes with low energy efficiency use only half of the expected energy for heating. However, homes with high energy efficiency consume more energy than anticipated. This may be due to the fact that high-efficiency homes tend to use more appliances compared to low-efficiency ones. Majcen (2016) emphasises that the behaviours of the people who occupy a building significantly influence energy consumption and could account for more than 50% of the variations. The effects of occupant behaviour on a home's energy consumption should be given more attention throughout the calculation and early design stages because they can vary even in homes with the same attributes.

1.2 Problem Areas

Simulation software has been used to estimate the energy consumption of a building which may be evaluated after occupancy. The actual energy use levels are different than the expected or calculated during the design stages due to design stage calculation drawbacks, incorrect construction applications in the implementation stage, and unexpected occupant behaviour (Bedir, 2017). Santin (2010) argued that the variance in energy consumption in residential buildings is caused by the ignorance of occupant behaviour, which is a crucial issue. This research focuses on the factors that may cause the high energy consumption in Saudi's residential buildings, understanding the determinants of energy consumption, and considering the effect of household socioeconomic and building characteristics, weather conditions, and occupant behaviours.

Furthermore, failing to consider the behaviours of the people who occupy a building during the design process, the rebound effect, lack of knowledge on the possible behavioural variations among occupants, and low resolution energy model during the design phase may cause problems on the occupancy of the dwellings (Bedir, 2017). The considerations about human behaviours are usually based on conventional scenarios based on deterministic or static schedules and ignore the stochastic and dynamic schedules. The energy issue becomes complicated because most practises prioritise technological reasoning over social logic, overlooking that such technology exists primarily for human benefit. Eon, Morrison and Byrne (2018) stated that it is essential to consider the possible behaviours of the occupants when assessing energy use in residential dwellings. The energy performance gap is recognised worldwide and defined as the variance between the calculated/theoretical energy performance and the actual energy consumption, which has been discussed in detail in Chapter 3 of this thesis.

1.1.1 Contradictions Among Energy Prediction and the Measurements

The design and construction process for a building incorporates several professions and parameters required for decisions. It is not easy since it takes several professional cross-checks to compile all the detailed and specialised information relating to the entire construction process, from design to post-occupancy. According to Yoshino, Hong and Nord (2017), climate, building envelope, building energy and services systems, indoor air quality, building operation and maintenance, and occupant behaviour and activities all influence energy usage in buildings. While the first five major areas have seen significant progress, scientific and reliable approaches to characterise and predict energy-related occupant behaviour in buildings are still inadequate (Bedir, 2017; Yoshino, Hong and Nord, 2017). The process is complicated by the significant changes in occupant behaviours due to variations at different levels, which requires calibration and optimisation to consider them. The data changes make it impossible to obtain comprehensive data that leads to calculation challenges (Bedir, 2017).

According to Yan *et al.* (2015), occupant behaviour has a major impact on building energy consumption and is a primary source of uncertainty when trying to anticipate building energy use. According to Santin *et al.* (2018) findings, the uncertainty of occupant behaviour makes it difficult to accurately estimate the performance of buildings, particularly zero-energy buildings. Clevenger and Haymaker (2006) used different occupancy schedules and environmental preferences to study different building energy models based on uncertainty in occupant behaviours and found variations of up to 150% when the occupant-related inputs were considered fully, even when the common behavioural patterns of occupants were considered.

1.1.2 Problems Related to Building Construction and Systems

The variation in energy consumption is likely due to the building characteristics and imperfections in its construction. Such defects include mistakes in thermal insulation, changes in plans during the construction, and heating, ventilation, and air conditioning HVAC system installations. Santin, Itard and Visscher (2009) studied 15,000 Dutch dwellings and found that approximately 42% of the variation in energy consumption for heating can be attributed to building characteristics (i.e., insulation, building type, the presence of thermostat, garage, and basement). Alwetaishi (2022) conducted a study to research some building variables, including thermal insulation, window-to-wall ratio WWR, and shading devices to determine their impact on energy consumption to provide a rationale for reducing energy consumption in the Kingdom of Saudi Arabia. One of the major findings of the study was that it is possible to adjust the glazing system size depending on daylight conditions and heating sources used in the regions.

The study further indicated that thermal insulation and window to wall ratio influence thermal comfort and subsequently energy consumption in hot regions. Alwetaishi (2022) found that reducing WWR by 20% leads to a 15% energy consumption improvement. While the findings do not explain the energy consumption variations, they provide the foundation for new fields of energy efficiency.

1.1.3 Occupant Behaviour

Energy consumption based on occupant behaviour depends on their response to interactions with the building systems, discomfort, and presence and movement, which influence thermal comfort, energy consumption, interior air quality, and visual aspects (Bélafi, 2018). The energy use of the occupants depends on occupancy and the actions of the occupants, such as controlling devices that consume energy, such as heating, air conditioning, lighting system, window and blind control, and ventilation (Balvedi, Ghisi and Lamberts, 2018). Laaroussi *et al.* (2019) stated "Even though several definitions of occupant behaviour have been produced, the definition of the occupant behaviour depends mainly on the context of the study, on the objective from the research, and could be defined by different levels of complexity." In this research, occupant behaviour is defined as the residents' patterns of presence in different home spaces (e.g., family living rooms and bedrooms) and the use of air conditioning, lighting, and electrical appliances.

The study considers that occupants differ in their actions and reactions, their drivers for these activities vary, and different environmental conditions may influence them. Laaroussi *et al.* (2019) suggest that there is a need for more comprehensive research on occupant behaviours to understand the many variables that influence their actions and reactions that manifest in the variations in energy consumption. Such an understanding can help in understanding building energy performance better.

1.1.3.1 Availability and Accessibility of Occupant behaviour Data

Modelling the relationship between occupant behaviour and energy consumption is problematic because there is a lack of sufficient data on occupant behaviour that can be used (Mahdavi, 2011). Most of the time, while considering occupant behaviour throughout the design phase, it is common practice to make broad assumptions about patterns that rarely correspond to reality (Mahdavi, 2011; Bedir, 2017). There has been substantial improvement in building form, material qualities, and exterior conditions such as weather. However, input information on occupants' presence and behaviour in buildings are still relatively low, especially in Saudi Arabia. To the researcher's best knowledge, this study is the first attempt at the intensive investigation of the role of occupant behaviour, along with other factors, on residential energy consumption in Makkah City, Saudi Arabia. Gathering and analysing data on occupant behaviour while keeping Saudi Arabian cultures and traditions in mind is challenging. At the same time, it is critical to exert maximum effort to overcome the challenges.

1.1.3.2 Rebound Effect

Most of today's households are outfitted with several high-tech appliances, systems, and pieces of technology used regularly. There are various devices and systems available that to help raise the consciousness of energy use and enable control over it. These include presumed energy-efficient smart control devices, smart meters, and real-time feedback. Most research on occupant behaviour has uncovered a mainstream concept called the "Rebound Effect." This term was defined as improved energy efficiency that lead to energy savings, but that saved energy is used on other activities within the household, such as energy saved from heating used for more thermal comfort (Santin, 2010). Berkhout, Muskens and Velthuijsen (2000) indicated that the rebound effect describes the consumption variations between low and high energy efficient dwellings. Using more efficient technologies reduces energy consumption but increases consumption in other aspects of the dwellings.

Several studies have uncovered data that points to the existence of a rebound effect, which can be exemplified as follows: Haas, Auer and Biermayr (1998) stated that energy efficiency is associated with lowered prices but also a significant increase in energy and service demand. Santin (2010) found that the use of programmable thermostat lead to increased energy consumption compared to the use of manual valves in radiators and manual thermostats. Sorrell *et al.* (2009) indicated that the rebound effect in the Organisation for Economic Co-operation and Development OECD countries is below 30%, which indicated that the 30% energy saved through improved technical improvements of the buildings led to increased energy consumption because of the behavioural changes among the users.

1.1.3.3 Including Occupant Behaviour from the Early Design Stage

The need to include occupant behaviours is problematic since the occupant is not known when the building is being designed. The main consideration made during the design phase is that the system must meet the needs of the users. Considering the characteristics and behaviours of the occupants can increase the chance of the buildings being more energy efficient since there would be a reduction in the energy misused or lost. Many studies highlight the importance of taking occupant behaviour into account during the design phase and later phases to anticipate their impact on energy usage. Abuimara *et al.* (2018) concluded that future occupants should be consulted to provide information on their needs and preferences because of the differences in indoor air quality, thermal comfort, visual comfort, and acoustics comfort. Such an approach would allow the buildings to be designed based on the needs and preferences of the occupants, which would lead to reduced energy consumption and a lower rebound effect.

Although occupant behaviour is a crucial factor among others (i.e., indoor and outdoor climate conditions, household socioeconomic and building characteristics, and energy policies and regulations) influencing the energy consumption of dwellings, the majority of new residential buildings and retrofit projects in Saudi Arabia do not include an accurate representation of occupant behaviour in building energy models during the early design stages. Early engagement with potential occupants can increase the chance of developing better, more comfortable, and more energy-efficient buildings. Bélafi (2022) declared that considering the occupants during the design process could reduce the gap between calculated and actual energy consumption levels.

1.1.4 Occupant Behaviour and Energy Consumption

In the past few years, energy performance laws and regulations and the various implementations in the field have improved significantly and contributed to reducing both buildings' energy consumption and related environmental impact. The reduction in energy consumption may not be as substantial as expected. Occupant behaviour, building quality, and discrepancies between energy predictions and measurements might all compromise the regulations' effectiveness. Little is known about how residents of Makkah City, Saudi Arabia, engage with their homes, what drives them to do so, and how this influences domestic energy consumption. Therefore, instead of using the current conventional way of assumptions about occupant behaviour, we can develop more accurate techniques to model behaviour in energy use predictions by studying and understanding how occupants' behaviour affects energy consumption at home. It would also help integrate occupant behaviour into home energy rules and regulations in Saudi Arabia.

An experiment done by Branco *et al*. (2004) for more than three years showed that the actual gas energy use in multi-family buildings in Switzerland was 50% more than the estimates. It was determined that the variation between actual value and estimated value was because of energy utilisation such as the differences in interior temperature and ventilation rate, the weather conditions, and the actual performance of the system (Branco *et al.*, 2004). Esmaeil, Alshitawi and Almasri (2019) conducted a study to evaluate energy consumption patterns and found that Saudi Arabian residential dwellings consumed more energy compared to similar dwellings in other countries. They claimed that the variations were possibly due to poor insulation of dwellings envelop, occupant behaviours, lowly priced residential electricity tariffs, and metrological conditions (Esmaeil, Alshitawi and Almasri, 2019).

Therefore, making an accurate prediction of energy consumption is essential to architects and designers, policymakers, and energy companies. Smart meters have become more important for energy companies and suppliers to make the users aware of their energy consumption patterns, especially in residential sectors. Such information may give the residents the opportunity to adjust their consumption patterns as needed. Unfortunately, this technology is still new in the context of Saudi Arabia since the smart meter project SMP was launched at the end of 2019 by the Saudi Electricity Company SEC. The use of smart meters makes it possible to determine how occupants use smart meters in their respective homes, but collecting such data at the macro-level remains problematic (Bedir, 2017). Hence, developing more easily accessible explanatory parameters to estimate home energy consumption is possible when we consider the impact of occupant behaviour in addition to the other variables (such as building characteristics, household socioeconomic characteristics, and weather conditions).

1.2 Research Questions

The main question that this thesis explores is: **What are the determinant factors of electricity consumption in Makkah, Saudi Arabia? And to what extent do occupant behaviours impact residential electricity consumption for the use of air conditioners, lighting, and electrical appliances?**

To research this question, the following questions are formulated:

1- What energy resources does Saudi Arabia possess, and in what specific ways are those resources used? How does the energy consumption of Saudi Arabia fit into the bigger picture of the economy as a whole?
  a. What are the most significant environmental challenges that Saudi Arabia is presently facing?
  b. What steps are the Saudi Arabian government taking to reduce the country's overall energy consumption and boost its economy?

2- What direct and indirect underlying causes contribute to excessive energy use in dwellings, according to the available literature?

3- What is the influence of building attributes, household socioeconomic characteristics, meteorological conditions, and occupant behaviours on the total electricity use in Makkah, Saudi Arabia dwellings?

    a. Which factor has a significant impact on the amount of energy used in residential buildings in Makkah City, Saudi Arabia?
    b. What effect do air conditioning systems, lighting, and electrical appliances have on the total residential electricity consumption in Makkah City, Saudi Arabia?
    c. Do households with the same socioeconomic and building attributes characteristics display a difference in electricity consumption for the use of air conditioners, lighting, and electrical appliances?

4- How can electricity consumption in dwellings be effectively modelled in Makkah, Saudi Arabia, and how much of the variation in electricity use can be explained by this model combining building attributes, household socioeconomic characteristics, climate conditions, and occupant behaviours?
    a. What are the most significant predictors of each factor in explaining energy consumption variation in domestic buildings in Makkah City, Saudi Arabia?

1.3 Research Aim and Objectives

The present research aims to investigate the influential factors of residential electricity consumption in Makkah, Saudi Arabia, with a particular emphasis on the influence of occupant behavioural aspects. This research seeks to provide insight into the factors that contribute to residential electricity consumption in Makkah and to highlight the importance of occupant behaviour in shaping electricity consumption patterns.

Various studies have been conducted globally to identify the role of occupant behaviours on the amount of heating/cooling energy consumption or electricity consumption. However, no such studies to determine the influence of occupant behaviours on electricity consumption in Makkah's dwellings, Saudi Arabia have been conducted. This research will help to understand the impact of different factors on energy consumption in dwellings, particularly occupant behaviours factor. As a result, products, systems, and residences can be designed better, and more progressive regulations can be attained, all in pursuit of Saudi Arabia's Vision 2030. The main objectives of this research are:

- To investigate the fundamental causes contributing to the high household electricity consumption in Saudi Arabia and determine the underlying factors responsible for this phenomenon.
- To demonstrate how electricity could be better represented in Makkah's residential buildings and how it could be supported by understanding occupant behaviour.
- To review strategies that can be used to improve occupant behaviours to reduce electricity consumption in residential buildings in Makkah and to understand how buildings attrributes and socioeconomic characteristics affect electricity consumption.
- To pinpoint activities by occupants that consume the highest amount of electricity in residential buildings in Sauid Arabia.

- To propose recommendations and guidelines for policymakers, building designers, and occupants to promote energy-efficient behavior and reduce electricity consumption in residential buildings.

1.4 Research Approach and Methodology

The purpose of this study was to determine the macro-level elements that play a role in determining energy consumption. The many factors that impact energy consumption made it necessary to conduct this research at the macro-level. The goal is to analyse how these factors contribute to the high energy consumption in Makkah dwellings, Saudi Arabia, including household socioeconomic and building characteristics, weather conditions, and occupant behaviours. However, more micro-level information on household characteristics and behaviours and the energy consumption is required to investigate the impact of occupant behaviours on home energy consumption. Analysis of occupant behaviour is improved by using micro-level data on individual households' behaviour and energy consumption patterns (Pachauri, 2004).

It is not a new trend in the architectural and engineering fields to examine the factors that affect residential energy consumption. Government energy subsidies, climate, population growth, HVAC systems, architectural details and building envelope, and occupant behaviour are the most commonly studied factors in the literature (Duarte, Budwig and Wymelenberg, 2015; Delzendeh *et al.*, 2017; Yan *et al.*, 2018). However, occupant behaviour needs to be given greater attention and scrutinised more comprehensively to get more insights and a complete understanding of such phenomenon in Saudi Arabia. Such a phenomenon has been investigated for a long time and has become increasingly complex. Although several studies have been conducted in residential sectors in Saudi Arabia, there is a tangible shortage of studies examining the impact of occupant behaviour on energy consumption.

While there is a need for more research on how occupant behaviours influence energy consumption, it is problematic because of the assumed energy consumption patterns, retrospective data collection methods used by energy companies, uncertainties in collecting and analysing data, and determining the differences between actual and predicted usage (Bedir, 2017). Therefore, a mixed-method design, as described by academics, combines the use of both qualitative and quantitative methods in this study. The main advantage of combining qualitative and quantitative approaches is the ability to obtain more insights regarding the study problem (Creswell, 2014).

This study uses concurrent mixed methods to assess the impact of occupant interactions on energy use as well as building attributes, household socioeconomic characteristics, and weather conditions. There has been no public release of information regarding the energy use of Saudi Arabia residential buildings or individual household data. Therefore, this study used quantitative instruments (questionnaires, electricity consumption records, meteorological data) to examine the association between household socioeconomic characteristics, building attributes, weather conditions, occupant behaviour, and energy usage. On the other hand, qualitative documents technique was used to collect relevant documents (e.g., official government reports) that assist the investigation on residential energy consumption in Saudi Arabia. In order to develop and support the research's aims, questions, and framework, secondary data was also employed. The goal of incorporating quantitative and qualitative data was to obtain a better understanding of the study's problem, answer research questions by combining comprehensive statistical data (quantitative) and detailed perspectives (qualitative), and manage data collection timeframe effectively.

This research reviews the building and household socioeconomic characteristics, climate conditions, and occupant behaviours that determine residential energy consumption. This study also considered occupant behaviours as presence patterns in a space, along with the use of air conditioning, lighting, and electrical appliances. Therefore, correlation analysis, one-way ANOVA, and independent-sample t-test were performed to investigate the factors impacting energy use in Saudi's residential buildings. The main goal was to identify the relationships between factors like household socioeconomic characteristics, building attributes, weather conditions, occupant behaviours and residential energy consumption. In addition, multiple linear regression (MLR) analysis was used to determine the variability in electricity consumption explained by occupant behaviours, building attributes, and household socioeconomic characteristics. The utilization of MLR analysis can greatly benefit various fields, such as energy performance, healthcare, finance, and marketing. It enables professionals to predict outcomes and make informed decisions based on data accurately. The process involves carefully examining and interpreting large data sets to identify patterns and relationships. To achieve success in today's competitive world, an analytical approach is of utmost importance (Freire, Oliveira and Mendes, 2008). The methods employed are discussed in accordance with the objectives of each chapter.

1.5 Thesis Structure

Chapter 1 'Introduction' introduces the research problem and context and presents the research questions, aim and objectives. It also describes the scope and methodology of this thesis and the research outline.

Chapter 2 'Introductory Study on Saudi Arabia and the Energy Consumption Issue' introduces the background of the Kingdom of Saudi Arabia. It explains the significant parts that any nation needs to consider for its development, culture, environment, and economy. It further reviews the future diversification and development in the Kingdom, discussing different issues such as the national transformation and goals, renewable energy projects and efforts to find different sources for energy production.

Chapter 3 'Residential Energy Consumption and Occupant Behaviour: Existing Knowledge' examines what is known about occupant behaviour and how it influences energy consumption. It also reviews the determinants of energy consumption, where the relationship between occupant behaviours along with other factors and energy consumption will be discussed. Following this, the main research assumptions related to occupant behaviour and energy consumption are reviewed. Empirical methods of investigation, data collection, and modelling approaches for energy usage with respect to occupant behaviours are discussed further in this chapter.

Chapter 4 'Research Methodology' explains the research strategy and methodology used to accomplish the goals and objectives set out in this research. This chapter explains the researcher's four key strategies to achieve specific goals and objectives. A mixture of methodology options provides a strong example of the selected technique. The research methods for data collection, such as structured questionnaires, actual electricity consumption records, meteorological data, and relevant documents from government entities, are described and justified. In addition, the implementation of the research methods is explained. This chapter also describes the data analysis steps and the metrics constructed to answer the Research Questions in Chapters 6 and 7. Finally, this chapter describes the main limitations of the research methodology and describes how validity is addressed in this case study and how ethical considerations are considered.

Chapter 5 'Makkah City: Geographical Location and Current Electricity Consumption Scenario' evaluates the energy consumption patterns in residential dwellings in Makkah. The chapter also discusses the significance of choosing and justifying the city and a neighbourhood as a research-investigated area. Finally, it provides simple descriptive statistics and details of households/dwellings in the selected neighbourhood.

Chapter 6 'Results Part I: Influential Factors on Residential Electricity Consumption in Makkah City'. First, it reveals the investigation's findings on the impact of building attributes on residential electricity usage in Makkah. Secondly, it illustrates the analysis results on the influence of household socioeconomic characteristics on the electricity usage of the surveyed homes. Thirdly, it presents the findings related to the influence of meteorological conditions on households' electricity consumption. Lastly, the chapter shows the findings on the impact of occupant behaviours on electricity consumption of residential building in Makkah City.

Chapter 7 'Results Part II: Regression Models for Residential Electricity Consumption' presents the findings of the electricity consumption regression models and identifies the most significant contributors to electricity consumption in the city of Makkah, Saudi Arabian.

Chapter 8 'Discussion' takes all the outcome chapters together and compares the results to the critical conclusions discussed in Chapters 2 and 3. It also compares and justifies the research finding with the available literature.

Chapter 9 'Conclusion' starts with a summary of the thesis and concludes with the key findings, contribution to the knowledge, limitation of the research, and the recommendations for future studies and projects.

Chapter Two:

Introductory Study on Saudi Arabia and the Energy Consumption Issue

Chapter 2: Introductory Study on Saudi Arabia and the Energy Consumption Issue

2.1 Chapter Overview

This chapter is an extensive review of related studies in the literature regarding the Kingdom of Saudi Arabia in terms of culture, environment, and economy, which are the essential pillars of any nation. It starts with a brief discussion of the significance of Saudi Arabia and its geographical location to the Arabian world and the entire world. Following that is a comprehensive discussion of the climate, economic, cultural, and social features of Saudi Arabia. Finally, this chapter discusses the developments and changes in Saudi Arabia and the governmental efforts to support the nation in achieving its objectives. This review helped establish the context and first steps of this research by clarifying the existing scenario in Saudi Arabia.

2.2 Geographical Location and its Importance Globally and Locally

The Kingdom of Saudi Arabia is widely recognized as the centre of the Islamic World. Qattan (2016) emphasised that it is incredibly critical to highlight the significance of Saudi Arabia in both the Islamic society and the world as a whole. It is distinguished from other Islamic nations because it is home to two out of three of Islam's Holy Mosques: *Al Masjid Al Haram* in Makkah City and *Al Masjid Al Nabawi* in Madinah City. The Kingdom of Saudi Arabia is a developing Middle Eastern nation that occupies around 80% of the Arabian Peninsula, as seen in Figure 2.1. The total size of the Kingdom is approximately 2.2 million square kilometres, making it the largest country in the Middle East and the fourteenth-largest country in the world (Industrial Centre, no date). It is in an arid region (Latitude: 16.5^{o} N; Longitude: 33.75^{o} E – 56.25^{o} E). The Kingdom contains three different deserts covering approximately 28 % of the Kingdom’s total area (Saudi Geological Survey SGS, no date). It has a core strategic location within the Arabian Peninsula and the Middle East. It shares the Southern borders with Yemen and Oman, Northern borders with Jordan, Iraq, and Kuwait, Eastern borders with United Arab Emirates, Qatar, and Bahrain, and Western borders with the Red Sea.

Figure 2.1 the location of Saudi Arabia and its borders

(Wikimedia Commons, no date)

An absolute monarchy has governed Saudi Arabia since it was founded in 1932 by King Abdul Aziz Ibn Saud. It is divided into thirteen specific administrative regions, as illustrated in Figure 2.2. These regions are divided into many provinces (Ministry of Commerce and Investment, no date). The Kingdom's constitution is the holy book (*Qur'an*), which means the King makes his decisions under the limitations of a very conservative religious infrastructure (Bowen, 2014). The country is governed by Islamic law, which is the implementation of the *Holy Quran* and *Sunnah* (recorded sayings and behaviour attributed to the Prophet Muhammad) (Qattan, 2016).

Figure 2.2 The administrative regions of Saudi Arabia
(Central Department of Statistics and Information CDSI, 2010)

2.3 The Economic Context of Saudi Arabia

The economic growth of Saudi Arabia can be split into before and after oil exploration main phases. Saudi Arabia's economy was primitive, relying on the Makkah pilgrimage, commerce, fishing, and agriculture for revenue, which has rapidly changed due to the successful commerce of oil (Qattan, 2016). The Kingdom of Saudi Arabia holds the second-largest proven oil reserves in the world that it uses to obtain revenues to fund other sectors. The nation ranks as the largest oil-consuming nation in the Middle East (U.S. Energy Information Administration EIA, 2017). Bahgat (2012) mentioned that “in 2010, the Kingdom produced more than 10 million barrels per day (b/d), 12% of the world’s total production.” However, the report of the EIA in 2017 displayed an increase in petroleum liquids (crude oil and petroleum products) production capacity at approximately 12.4 million b/d in 2016.

Although oil sales are the government's primary source of revenue, the price of oil remains susceptible. Figure 2.3 depicts the price of crude oil over the last five years, from April 2016 to March 2021. The highest price was nearly 180 dollars per barrel in October 2018, and the lowest price was approximately 51 dollars per barrel in April 2020 (Index Mundi, no date).

Even though Saudi Arabia is the largest exporter of petroleum liquids and holds the largest production capacity of crude oil in the world, it is still suffering from the high demand for energy generated from the combustion of crude oil (EIA, 2014). Ozturk, Sozdemir and Ülger (2013) coined some significant global problems caused by using fossil fuels in energy production, such as the climate change caused by greenhouse gas emissions, the breakdown of the ozone layer and the increase in the level of ultraviolet light, acid rains, the decrease in biodiversity, the increase in soil erosion, and the contamination caused by wastes from industry and lifestyles.

Electric power generation and transportation fuel increase the quantity of oil consumption in the country. As a result, seeking new ways to produce electricity rather than relying solely on oil is considered the Saudi Arabian government's top priority, as discussed in Section 2.6. Bahgat (2012) reported that the former Minister of Oil Ali Al-Naimi claimed that using safe and sustainable renewable energy sources would free up more oil for export, reduce reliance on hydrocarbon resources, and retain them as a source of income for a more extended period. According to Awan and Knight (2020), global energy demands are increasing due to the current digital economy, a rapidly growing global population, and the need for better living standards.

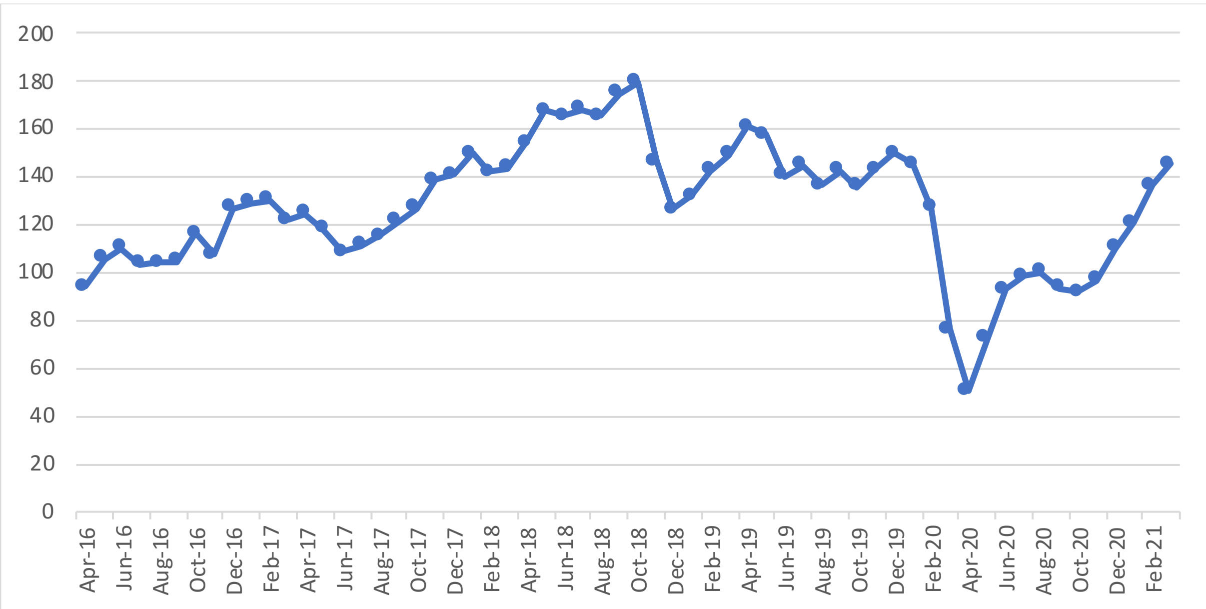


Figure 2.3 Oil Prices ($/barrel) from Apri 2016-March 2021
(Index Mundi, no date)

Whether oil reserves will soon be depleted has been a controversial issue due to the widespread consumption of oil and the less frequency of discovering new oil reserves in Saudi Arabia and around the world. Such a crisis is significant to consider and prepare alternatives because it threatens economic and social life globally. Ozturk, Sozdemir and Ülger (2013) warned that the world would face more catastrophes if proper preparations are not made to continue producing energy when the fossil oils are depleted. If there is a high demand for oil and gas, this tragedy will need a miracle to fix. However, countries should be united and act very quickly to reduce the reliance on oil by finding an appropriate alternative for oil since it is currently still one of the essential elements needed to produce energy. The Energy Bulletin (n.d.) stated,

> "Depletion rates after the peak can vary widely, from about 2% per year for a well-managed onshore field, to 20% or more per year for deep water fields like Mexico's Cantrell field, and other deep water fields in the Gulf of Mexico. Of the 42 largest oil producing countries in the world, representing roughly 98% of all oil production, 30 have either plateaued or passed their peaks."

The global oil demand increased by 1.8 % in 2017, which was an increase of almost 1.7 million b/d. The most significant contributors to the rise in the oil demand were the United States of America in the first place, with nearly 20 million b/d and China in the second, with almost 13 million b/d, whereas Saudi Arabia in the fifth, with nearly 4 million b/d (BP Energy, 2018). Large global conventional oil production investments are also significant, especially in the Middle East. Oil as an energy source is not new since people have been using it for thousands of years. Nowadays, many non-oil-producing countries already purchase oil as a future trade. As Peters and McKay (2015, p. 55) declared, "this contract entitles the purchaser to buy the security at a future date at a specified price. Two broad classes of investors typically trade it. The largest class has interests in the oil industry."

2.3.1 An analysis of the Energy Resources, Supply, and Prices in Saudi Arabia

The study by Howarth *et al.* (2020) highlighted that Saudi Arabia faces a well-known electrical sustainability predicament at two levels, posing a danger to oil export revenues and climatic conditions in the country. Moreover, the quick expansion of air conditioning demand and inappropriate utilisation increased oil consumption for electricity generation. Saudi Arabia relies entirely on natural gas and oil for energy generation. As indicated in Figure 2.4, crude oil and heavy fuel oil account for around 40% of Saudi Arabia's electricity production. In contrast, more than half of the electricity production is from natural gas as of 2019 (ECRA, 2020). In comparison to 2009, natural gas contributed 38%, diesel 22%, and crude oil and heavy oil 40% of electricity production (ECRA, 2010).

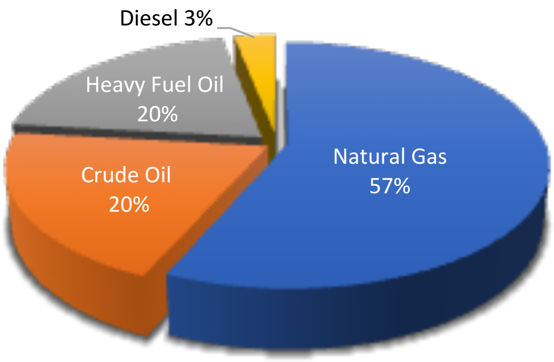


Figure 2.4 Fuel types used in electricity production in 2019
(generated from ECRA, 2020)

According to Lahn and Stevens (2011), a steady increase in domestic oil consumption and stable oil production could make Saudi Arabia to become an oil importer by 2038, resulting in a more difficult deficit in its fiscal and current accounts. This would have happened if the necessary changes to the country's policies did not emerge to change the energy consumption patterns, especially in the residential sector since it is the most energy-consuming sector in Saudi Arabia. Within a decade, from 2009 to 2019, oil consumption increased from 2.8 million barrels to 3.6 million barrels, reflecting a 2.6% annual consumption growth rate. Nevertheless, a visible reduction of 2.5% in 2020 compared to 2019, with 3.5 million barrels, was noted (BP Energy, 2021).

Similarly, the annual growth rate for natural gas consumption was 4.1% for the same period. A total of 111.2 billion cubic meters was consumed in 2019 compared to 74.5 billion cubic meters in 2009. A consumption growth rate of 0.6% was detected in 2020 with 112.1 billion cubic meters (BP Energy, 2021). The historical pattern of energy use in Saudi Arabia compared with the Gulf Cooperation Council (GCC) countries from 1965 to 2020 is shown in Figure 2.5. As observed, the energy consumption patterns were steady until the early1970s when there was a remarkable massive increase in the consumption patterns of oil and natural gas in the Kingdom (BP Energy, 2021).

Saudi Arabia is already one of the Middle East's most significant emitters. Such rapid growth in domestic energy demand has implications for both the global oil market and global emissions (Aldubyan and Gasim, 2021). According to the report by the BP Energy (2021), Saudi Arabia emitted 570.8 million tonnes of carbon dioxide CO_2 emissions in 2020, which was a 1.8% decrease in the emission growth rate from the previous year. Consequently, Saudi Arabia has been declared the country with the greatest CO_2 emissions among the GCC countries. Figure 2.6 depicts the history of CO_2 emissions in the GCC countries from 1965 to 2020 (BP Energy, 2021).

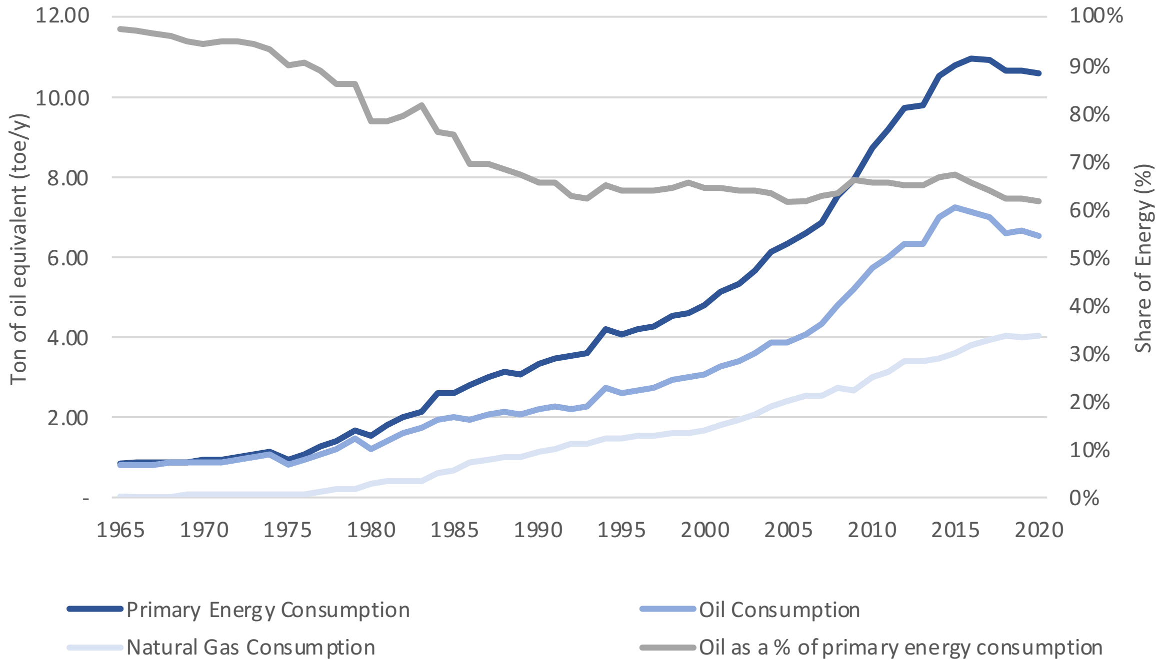


Figure 2.5 Historical pattern of energy use in Saudi Arabia (generated from BP Energy, 2021)

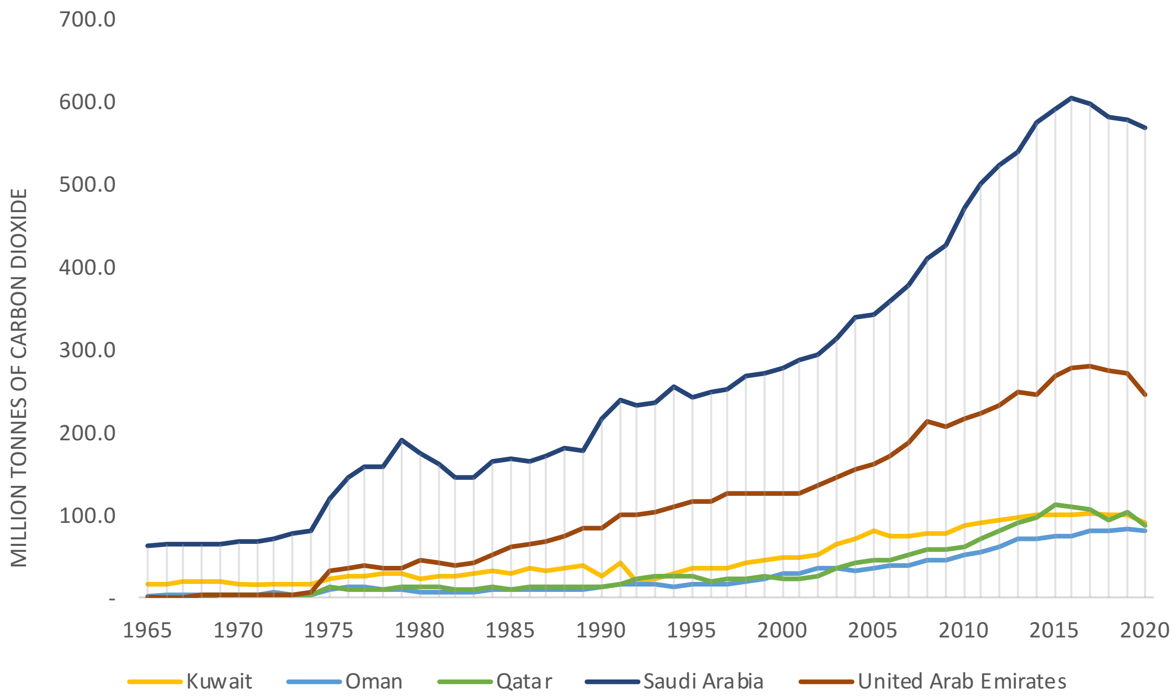


Figure 2.6 Carbon dioxcide emissions in the GCC countries (generated from BP Energy, 2021)

Based on the reports of ECRA (2020), there are over 20 electricity generation licensee companies in the Kingdom, but the SEC produces 65% of the electricity through 39 power plants distributed throughout the nation. The electricity production volume of the SEC in 2020 was 181.8 Terawatt, which accounts for 50.2% of the total electricity used to power the electrical system. At a 37% total efficiency rate, electricity generation used around 315 million barrels of oil equivalent (SEC, 2020). From Figure 2.7, it is evident that the residential sector consumed approximately 46% of the SEC electricity sales. The industrial sector followed at nearly 18%, while the commercial and government sectors accounted for 16.5% and 14.5%, respectively.

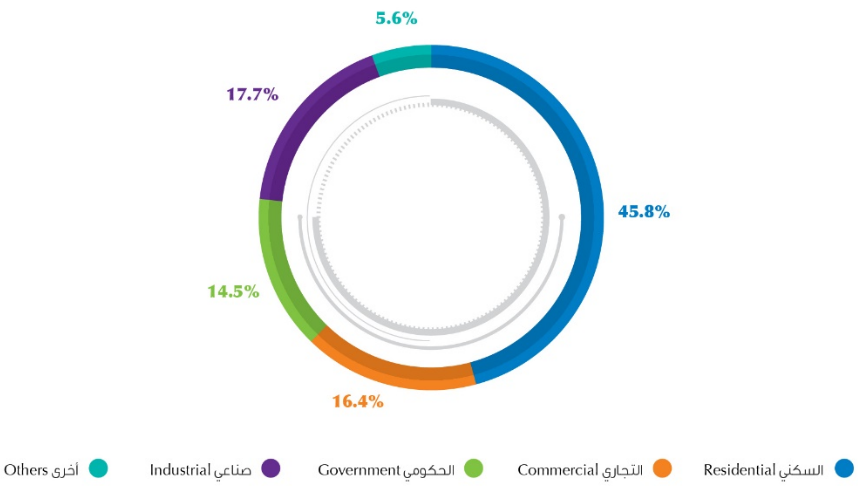


Figure 2.7 SEC electricity sales by sector
(ECRA, 2020)

2.4 An Explanation of the Saudi Cultural/Social Aspects

Culture consists of a set of learned behaviours derived from collective values, beliefs, and attitudes held by the individuals of a community or society. Culture acts as rules dictating behaviour that can be socially enforced to strengthen the shared identity among the group to ensure its survival through collaboration (cited in Alhomoud, 2014). It is well-established that a society's structure must include families. Saudi families are distinct from those in other countries because they are highly cohesive and are intricately linked to their origins, which can be traced back hundreds of years. Individuals also feel responsible for the tribe and not just the family unit. Saudi Arabian culture is divided into three irreplaceable layers: religion, family, and tradition (Long, 2005). The only layer that can be affected by western culture is the top layer, as shown in Figure 2.8.

Loyalty is integral to tradition, religion, and family, which means that imposing change on these layers is hard, even when the change is by Saudis who are educated overseas (Long, 2005). The governance of Islamic teaching characterises Saudi’s highly conservative culture based on the *Holy Qur’an* and the *Sunnah* (the deeds and sayings of Prophet Mohammed), which influence the lives of all Muslims worldwide. Moreover, Rice (2003) explained that “the Arab culture is influenced heavily by the Islamic tradition as well as by *Bedouin* values.” He stated that the Bedouin values impact the behaviour of the Arab individual regardless of their education level, economic status, political philosophy, or religion.

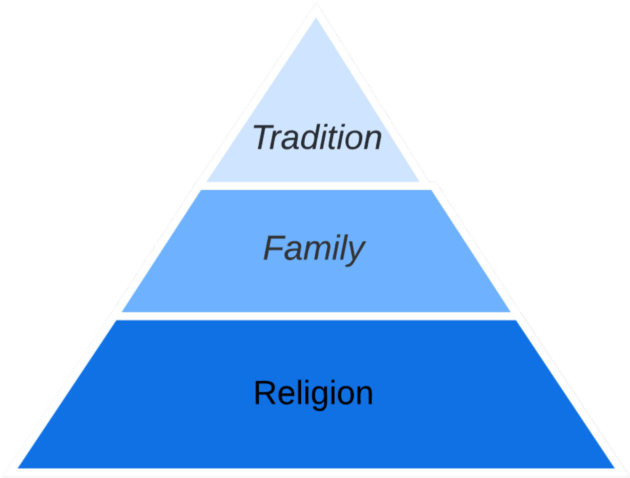


Figure 2.8 Saudi Arabian cultural pyramid

The diversity of Saudi citizens has helped build the country's rich culture and formed the basis for Saudi Arabia's unique identity. Approximately 34 million people live in the Kingdom across 13 regions unified mainly by the Arabic language, yet each has its dialect, traditions, heritage, and culinary identity. Two of the three official annual celebrations of the Kingdom are associated with Islamic holidays. Eid al-Fitr, Eid al-Adha, and the last is the Saudi National Day, celebrated on September 23rd. Saudi people follow many values influenced by Islam, ensuring that the Kingdom's ancient traditions and customs are preserved. The guiding values of the Saudi people include hospitality, and generosity, courage, and strong family ties. Each Saudi region is different based on its topography, environment, and identity, evident in architecture, costumes, and cuisine (*People & Culture*, no date).

The Saudi culture is family-oriented, where two to three generations may live together in one homestead. All other family members respect older adults since they are considered wise family leaders. The fact that a Saudi family often consists of multiple generations makes the size of a Saudi house considerably larger than a Western house in which a single-family life in a unit with two bedrooms or something comparable. It's not only that Saudi Arabian homes are excessively large; there's also a complexity issue with how people use their residences and the various parts and systems within them. The five daily prayers, for example, require ablution multiple times per day, and the country's hot summers mean that air conditioners are used extensively throughout the house.

Saudi Arabia's culture is constrained by the country's real conservatism and the necessity to adhere to Islamic laws. One of the essential principles of Islam is the separation of the genders, especially in public or in the presence of others who are not members of the immediate family, which is a principle that requires reflection in the design of the dwelling. In Saudi reality, segregation between males and females in residences, schools, universities, banks, and other public areas is expected and required to adhere to Islamic lifestyles. It is also customary practice for men and women who are not related to one another to avoid socially engaging in face-to-face conversation without the presence of a "*mahram*." Mahram refers to a man who is related to a woman in some way, such as her father, brother, or another male relative. The Western expatriates and their families used to live in isolated compounds for the opportunity to live their everyday life. Consequently, they can find an open environment in a western style, escaping from the strict cultural restrictions on the other side (Glasze, 2006). There are exceptions, such as healthcare facilities in which opposite genders can mix.

Another significant aspect that influences the lifestyle in Saudi Arabia, which also complies with conservative Islamic culture, is that women must wear the *hijab*. The religious view indicates that Saudi women wear *hijabs* to cover their hair in the presence of a '*non-mahram*' man. Some women also wear an *abaya* (long robe) and a *niqab* (hair and face veil) to veil their face when they are in the public domain, where they are likely to come across men they are not related to. Although non-Saudi women are not mandated to wear an *abaya*, *niqab*, or *hijab*, they must adhere to Saudi cultural norms and customs. The strict Saudi culture is unlike other Muslim nations since some do not mandate women to wear the *abaya*, *niqab*, or *hijab*. This has begun to change in recent years as more females (mainly younger females in urban areas) have decided to reveal their faces in public, creating an environment where visitors can interact with locals and learn about their culture.

People are typically quite attuned to the distinction between what is considered public and what is considered private domains. Therefore, the cultural norms of Saudi Arabian households place a significant emphasis on respecting the privacy of individuals as well as families. A good example is if someone is working on a roof and can view into the neighbour's courtyard or windows, he has a responsibility to tell the neighbour so that the woman can take precautions. However, many things have started to change after oil exploration and extraction since the rapid modernisation and technologies have granted a surprising connection to the outside world (Qattan, 2016). It started after the American oil company executives spread out prospecting for oil. In the middle of the 20th century, the Saudis' social and economic infrastructure development started because of the abundance of oil wealth, which led to the imagination of how life was before the discovery and extraction of oil (Long, 2005). Seeking modernisation has significantly impacted Saudi culture since Saudis have struggled to maintain cultural values. Nonetheless, foreigners respect the culture of Saudi Arabia and Islamic rules and traditions.

There is an excellent opportunity to ameliorate social communication and stop the segregation between citizens and residents in the country. Unlike some arguments that the Americans were the only source of imported western culture and innovation in the country, Saudis have flown abroad to many different nations. They have imported foreign goods, services, and even ideas. The scholarship programme of the Custodian of the Two Holy Mosques is a significant factor that has played an important role in changing citizens' understanding of the differences between cultural aspects, which allows both men and women to witness those differences and share them (Arab News, 2014). Understanding the Saudi cultural and social aspects is incredibly significant in forming this research and realising its complexity.

2.5 Saudi Environment

Saudi Arabia is a developing country and one of the GCC members. Saudi Arabia sometimes encounters regional fluctuation in climate due to its size, with its two coastlines having diverse topography (Holiday Weather, no date). Furthermore, a big part of the Kingdom is covered by three deserts in various parts of the country. These deserts are 780,000 square kilometres, which equals one-third of the Arabian Peninsula (SGS, no date). The biggest desert is the *Rub' al-Khali*, which has covered most of the southern frontier with 550,000 square kilometres. The second desert is *Ad Dahna*, in the central part of the Kingdom, and the last desert is called *An Nafud,* in the northern part of the country. There are two coastlines along the west and east side of the country, and a variation of topographies, such as mountains, hills, plains, and valleys, which creates different climate zones.

Saudi Arabia's topography can be divided into coastal plains, Western heights, the Empty Quarter (*Rub' al-Khali)* desert, and Najd, the Eastern, and the Northern plateaus, as illustrated in Figure 2.9 (Al-Ahmadi and Al-Ahmadi, 2013). The coastal plains are roughly 2,500 kilometres long, with the Tihama coast in the west being approximately 1800 kilometres in length and the Eastern coastal plain on the Arabian Gulf being roughly 500 kilometres long. A notable topographical feature of Saudi Arabia is the Western Heights, which has a length of about 1700 kilometres, a width of between 120 and 200 kilometres, and a height of about 2990 metres, recognized as Hijaz-Asir Scarp. It is narrower on the north and broader towards the central and southern regions. The slopes are steeper on the western side towards the sea compared to the eastern side. The Najd plateau is also a unique topographical feature in Saudi

Arabia. It rises to between 800 and 1100 meters. The Tuwayq mountains are part of the plateau and has a range of approximately 800 kilometres. The Eastern plateau is also unique due to its elevation of between 170 and 400 metres (Al-Ahmadi and Al-Ahmadi, 2013).

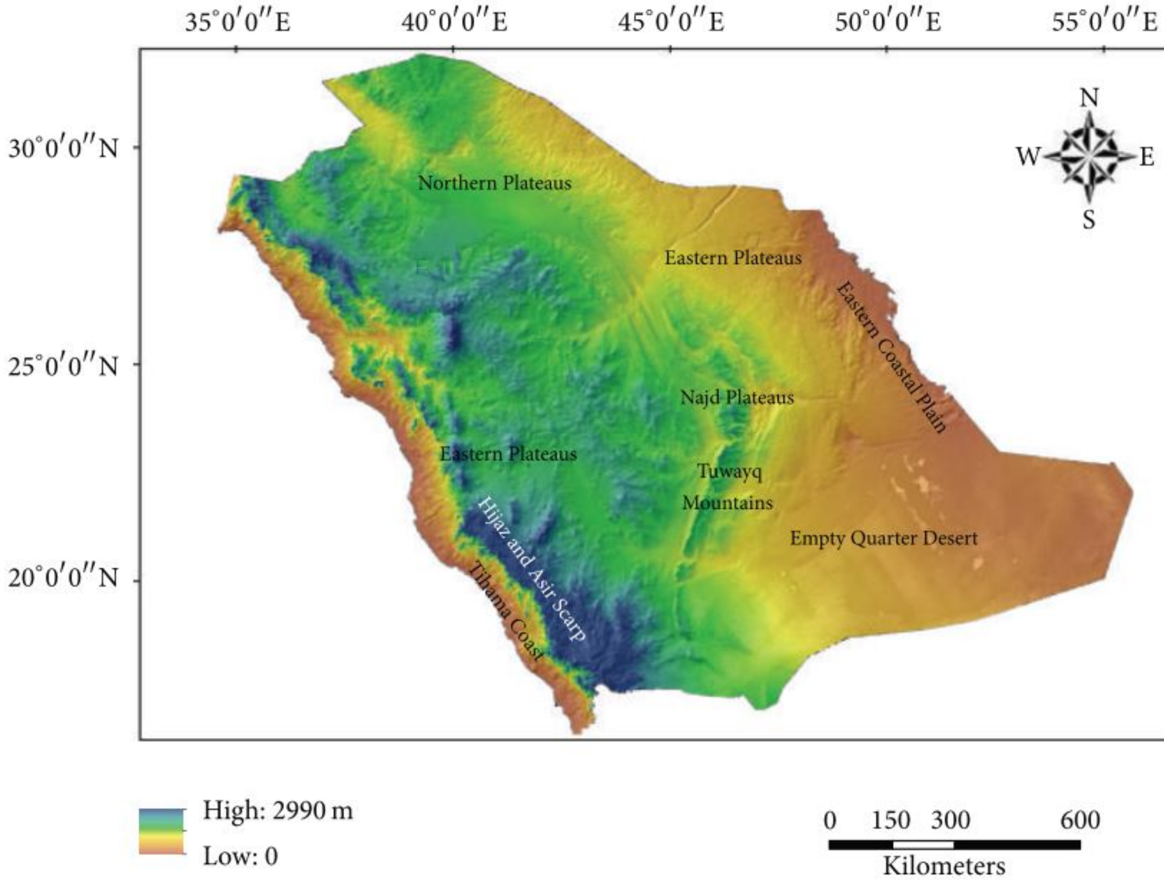


Figure 2.9 topography of Saudi Arabia
(Al-Ahmadi and Al-Ahmadi, 2013)

2.5.1 Climatic Data of Saudi Arabia

Saudi Arabia is described as having an arid desert climate, extreme heat in most parts of the country, and exceptionally low annual rainfall. Saudi Arabia is one of only a few countries where summer temperatures can exceed 45°C. Long (2005) explained that Saudi Arabia experiences intermittent rains despite its relatively arid climate and extremes in temperature (summer temperatures can reach 50 Celsius degrees). Saudi Arabia is characterised as a BWh according to the Koppen-Geiger climate classification (Beck *et al.*, 2018), where "B" represents the land area is an arid, and "W" represents the mean annual precipitation (mm y^{-1}) which mainly falls in winter, and "h" represents the mean annual air temperature (°C) which is hot and dry climate except the southwestern highlands, see Figure 2.10.

Saudi Arabia is in a subtropical high-pressure system that causes significant variations in temperature and humidity. These climatic conditions are influenced by mass air movements, being located near moisture sources, and local topography (Al-Ahmadi and Al-Ahmadi, 2013). The regional topography significantly impacts the rainfall and temperature in different regions. The only region within the nation with high average annual rainfall is the area around the Asir Mountains in the southwestern part of the nation. All other regions experience low and irregular rainfall. The standard climatic features throughout the nation are elevated temperature and low humidity apart from a few strips in the coastal areas.

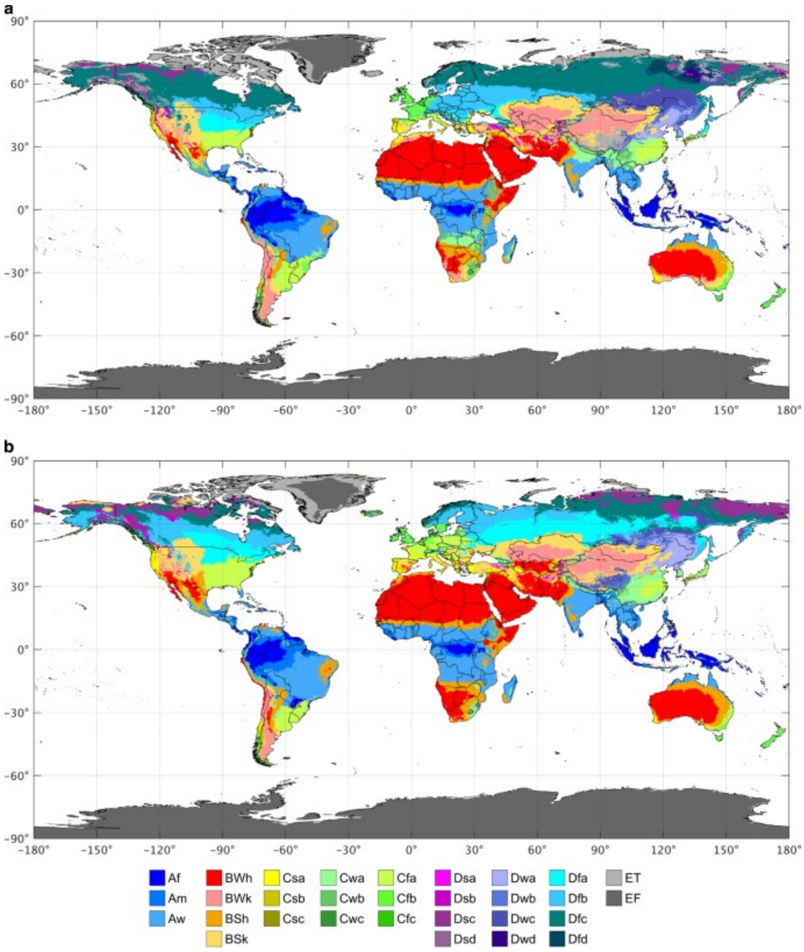


Figure 2.10 New and improved Köppen-Geiger classifications. Part (a) shows the present-day map (1980–2016) and panel (b) the future map (2071–2100)
(Beck *et al.*, 2018)

The Food and Agriculture Organization (FAO) announced that the Kingdom of Saudi Arabia is one of the biggest countries without a single permanent river or lake that can feed the country (Al-Zahrani and Baig, 2011). The low precipitation in the country and the necessity for irrigation and fresh water for its citizens make Saudi Arabia totally depend on desalinating sea water and underground water. However, it there has been a strange phenomenon witnessed in the nation, such as heavy rainfall in 2017 and 2018. Most of the GCC countries are similar to Saudi Arabia, except Oman, and are classified as water-scarce countries by the United Nations (DeNicola *et al.*, 2015).

The architecture, building styles, and materials have been affected by the climatic conditions of the country depending on the location and the region. The western region's most important figure of architecture is called “Rawshan” or “Mashrabia,” which is ornamentation on the wooden screens confronting large-opening windows and balconies. This device has different uses, including improving natural ventilation, sunlight control, and social privacy for occupants (Aljofi, 2005; Al Surf, Susilawati and Trigunarsyah, 2012). The Saudi Arabian climate is hot and dry in the centre, hot and humid in the two coastlines (the Red Sea and the Arabian Gulf), and cold and dry in the north. Finally, the southwestern highlands show moderate summer and cold winter temperatures (Algarni and Nutter, 2013). The unusually hot temperatures across the nation make many individuals spend more time indoors and rely heavily on air-conditioning.

The available literature established interesting studies and research that care about the climatic classifications and conditions in Saudi Arabia. Based on the findings of the study of Alrashed and Asif (2015b), Saudi Arabia can be divided into six climatic zones. One of these climatic zones is an uninhabited region called the Empty Quarter '*Rub' al Khali*', while the other five areas reflect the five habitable climatic zones. Guriat, a cold and dry desert subzone; Dhahran, a hot and dry maritime subzone; Khamis Mushait, a sub-tropical region with a mountainous subtype and Mediterranean subzone; Jeddah, a hot and dry maritime subzone; and Riyadh, a hot and dry region with a desert subzone (Indraganti and Boussaa, 2017).

According to the Saudi Building Code National Committee SBCNC (2018), Saudi Arabian’s climate is divided into three zones, as presented in Figure 2.11. Zone 1 is described as the warmest zone while Zone 3 is the coldest. A detailed explanation of the code is discussed in Section 2.6.4. Therefore, a better understanding of the meteorological conditions in the country and determining how those variables are related to energy usage could help design more energy-efficient buildings.

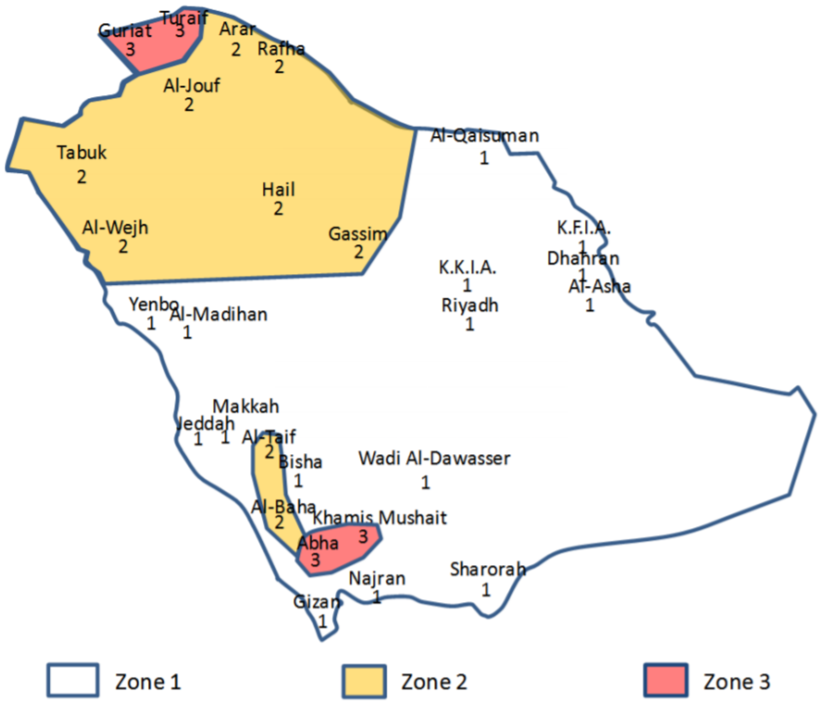


Figure 2.11 Climatic zones in Saudi Arabia
(SBCNC, 2018)

2.5.2 Environmental Challenges in Saudi Arabia

The climate change concerns that emerged in the 1990s made the government devise stringent energy requirements for buildings in the nation. The advanced building codes aim to promote low energy usage and low carbon emissions in short to medium term (IEA, 2013). In the 20th century, climate change was the most significant threat to the world (Thead, 2016). Northon (2017) indicated that the year 2016 is considered the warmest on record globally. According to Arab News (2016), “Climate change has made deadly heat waves and hurricanes, along with droughts and flooding, both more frequent and more intense in recent years, according to a UN report released Tuesday.” Environmental conservation and protection are critical in the fight against environmental challenges. As a result, recognising environmental issues and their effects on the Kingdom of Saudi Arabia has become essential for the government to improve the individual's quality of living while also strengthening the country's economy.

Air pollution in urban areas, CO_2 emission due to the high energy demand and usage, concerns about clean drinking water sources due to a lack of fresh water, industrial pollution, waste management, pollution in coastal areas, and the resulting stress on marine habitats are all major environmental challenges that the Kingdom of Saudi Arabia is facing (Husain and Khalil, 2013). The Unified National Platform (n.d.) observed the most prominent environmental challenges in the Kingdom. Based on that platform, the challenges could lead to a rise in environmental contamination and threats, such as polluted well water, waste from cement factories, increased sulphur dioxide and nitrogen oxide emissions, land degradation, and desertification.

Saudi Arabia has many environmental challenges because of its location and climatic conditions. There is little land that can be used for agricultural purposes, and even then, there is insufficient water for such a purpose. Moreover, no perennial rivers, lakes, or other water bodies exist. There is also the concern that underground water resources will be depleted. The rare coastal oil spills are also a significant concern since they lead to the pollution of water resources (Federal Research Division, 2006). According to Almazroui *et al.* (2012), there has been a significant drop in rainfall in the Kingdom of Saudi Arabia during the wet season to an average of 35.1 millimetres per decade between 1994 and 2009. At the same time, there has been a significant increase in temperature, which has been increasing by 0.51°C per decade in the dry season. This suggests that buildings may consume more energy to fulfil their cooling loads, resulting in higher CO_2 emission rates.

Energy is important in all aspects of human beings, including nutrition, health, education, transportation, and communication. The energy production process has been questioned because of its role in the environment. In addition, there are concerns that the current energy source, fossil fuels, is unsustainable (Ozturk, Sozdemir and Ülger, 2013). As a result, the government of Saudi Arabia takes several actions to protect the environment, as discussed in following section.

2.6 Diversification and Development in Saudi Arabia

Remarkable progress is being made in implementing a sustainable development concept in government, industry, and businesses in the Kingdom of Saudi Arabia. In 2016, the government launched a national transformation called "Vision 2030", emphasising three fundamental pillars, which are the culture, environment, and economy. The government aims to change Saudi Arabia from an oil-based economy to an economy with different revenue generation streams, as indicated in the Saudi vision 2030 (Felimban *et al.*, 2019).

The Saudi Vision 2030 has already prepared the ground and launched some executive programmes, including the Fiscal Sustainability Programme, which was launched as the Fiscal Balance Programme in 2016. The initiative's main objective was to expand non-oil revenues to improve efficiency (*Fiscal Balance Programme: Update*, 2018; *Fiscal Balance Programme: Balanced Budget*, 2020). Some of the inclusions of the Fiscal Balance Programme include energy price reforms, expatriate levies, and value-added tax. The most important initiative of the three is the energy price reform since it is based on linking local prices with international market. “providing subsidies with no clear eligibility criteria is a substantial obstacle to the energy sector’s competitiveness” (*Vision 2030 Foreword*, no date, p. 51).

The National Industrial Development and Logistics Programme (NIDLP) is an important initiative of the Saudi Vision 2030 Programmes, which was launched at the beginning of 2019. The main objective of the programme is to make the Kingdom of Saudi Arabia a leading industrial powerhouse with a global logistics hub based on maximizing the value from the mining and energy sectors to unlock full potential of the nation during the fourth industrial revolution (*NIDLP*, 2020). The NIDLP has been driving diversification of the Kingdom of Saudi Arabia by providing a favourable investment environment. One of the achievements of the NIDLP is the introduction of the "*Saudi Made*" programme as a national project that intends to encourage local products both domestically and globally. Another achievement is the launching renewable energy projects in the Kingdom, as explained in Section 2.6.2.

The main objective of the Housing Programme launched in 2018 is to create a vibrant environment for families and the entire societies. The programme has set new standards in the nation by increasing ownership for the Saudi citizens. It allows the Saudi citizens to have various housing options to increase housing ownership in the nation. The programme has been responsible for increasing house ownership rate from 47% in 2017 to 60% in 2020. The next objective is to increase house ownership to 70% by 2030 (*The Housing Programme Delivery Plan (2021-2025)*, no date). In addition, activating the partnership with private sector like banks and financing institutions is one of the essential achievements of the Housing Programme, which resulted in the development of more than 141 thousand housing units.

The Saudi Vision 2030 exemplifies a forward-thinking perspective that recognises the importance of a high standard of living while respecting the environment and planning for future responsibilities. Subsequently, the government of Saudi Arabia took numerous measures to avoid potential economic and environmental disasters caused by the country's high energy consumption. The SBC, the SEEC, the launch of renewable energy projects, and the establishment of the citizen account programme were all parts of these initiatives. A summary of each initiative and an explanation of its importance are provided in the following sections.

2.6.1 Citizen Account Initiative

The government of Saudi Arabia developed the citizen account programme to assist low and middle-income households respond to the rising energy costs. The government introduced a scheme that funds eligible families using money generated from the oil exports (*Fiscal*

Balance Programme: Balanced Budget, 2020). The combined energy price reform and the citizen account programmes have allowed the government to help the most affected households while not affecting it revenues. These two programmes are consistent with the vision 2030, which has indicated that the main approach is to provide food, water, fuel, and electricity subsidies to those in need (*Vision 2030 Foreword*, no date). Alghamdi (2019) studied the changes in electricity tariffs in Saudi Arabia since 1974-2018 and found that 48% of the Saudi citizens can benefit from the citizen account programme. The government allocated about 2.3 billion SAR to an estimated 11 million beneficiaries by August of 2018. The main objective of the programme was to offset the impact of high energy prices through the provision of some utility costs.

2.6.2 Renewable Energy Projects

Solar radiation is one of the sustainability methods that should be taken seriously in Saudi Arabia because it is an abundant resource in the country and holds immense economic promise. Figure 2.12 shows the highest solar potential in Saudi Arabia and indicates that the annual solar irradiation is more than 2100 kWh/m^2. In addition, the continued use of fossil fuels has many serious environmental impacts. At the same time Husain and Khalil (2013) clarified that the traditional power plants used are associated with air pollution, toxic chemicals, and greenhouse gas emissions. These challenges can be addressed through renewable and energy efficient resources such as solar energy that significantly benefits the environment (Alnatheer, 2005).

Renewable energy must be included as part of diversified energy sources in Saudi Arabia to decrease the price of electricity, which is no longer subsidised, reduce the harmful environmental impacts, and release more barrels of oil for trade. This approach can help the Kingdom reduce its reliance on fossil fuels while improving use of current energy resources. The renewable energy approach can also help Saudi Arabia save billions of dollars that are currently wasted due to the reliance on fossil fuels. Saudi Arabia would be able to use energy more efficiently while becoming more prosperous (Husain and Khalil, 2013).

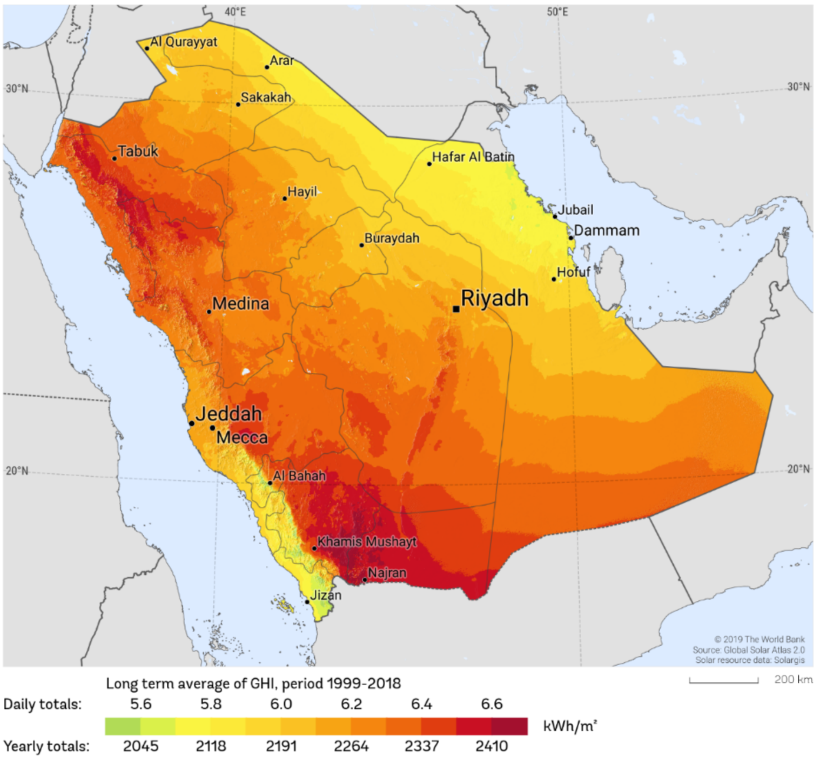


Figure 2.12 Map of Saudi Arabian horizontal solar irradiation
(Global Solar Atlas, no date)

Saudi Arabia started operating the 300-MW Sakaka Solar Power Plant in Al-Jouf region in 2021 and considered it the first of the renewable projects that would be developed in the coming years. The Sakaka Solar Power Plant has 1.2 million photovoltaic technology (PV) solar panels in a 6 km^2. This power plant was put up in a place that was well selected by a specialised Saudi technical team to ensure that it could generate the best possible electric power production (*Vision 2030 Progress & Achievements 2016-2020*, no date). The Sakaka Power Plant set the benchmark for producing electric power using solar systems since it cost approximately SAR 0.08775 per kWh yet it produces sufficient power for approximately 45,000 Saudi households (*Vision 2030 Progress & Achievements 2016-2020*, no date).

The Al-Jouf region also has the 400 MW capacity Dumat Al-Jandal wind energy project that has the lowest tariff of approximately SAR 0.0746 per kWh (*Vision 2030 Progress & Achievements 2016-2020*, no date). This wind power was recognised through the "Deal of the Year" award for the renewable energy sector in the Middle East and Africa yet it was the first in the nation (*Vision 2030 Progress & Achievements 2016-2020*, no date).

The King Salman Energy Park SPARK is another project that shows the seriousness of the Saudi government in diversifying its energy resources. The fully integrated industrial city ecosystem, the first in Saudi Arabia and in the world to receive a silver Leadership in Energy and Environmental Design LEED certification, is strategically located in Saudi Arabia's eastern province. The industrial city provides an opportunity for international investors to invest in water production and water treatment, oil and gas refining, and petrochemicals and energy production (*Vision 2030 Projects*, no date). These projects are just a few examples since there are ten other renewable energy projects still in progress. The expected combined capacity of these projects is approximately 3,600 MW. However, further research studies are needed to explore the factors that affect residential energy consumption in Saudi Arabia, with particular emphasis on occupant behaviour. Disregarding such studies may result in an increase in Saudi Arabia's energy consumption, despite the government's support for environmental issues and attempts to diversify its revenue by using renewable energy.

2.6.3 Saudi Energy Efficiency Centre (SEEC)

The SEEC strives to become a global benchmark for energy efficiency by collaborating with local and international public and private partners and authorities. Their goal is to acquire expertise on the most effective approaches that can be implemented in Saudi Arabia and beyond (SEEC, 2020). The SEEC conducted an awareness campaign to ensure that the citizens understood the importance of lowering energy consumption. The approaches used included leaflets and workshops that emphasised the need to use suitable electrical equipment to ensure that energy costs could be lowered. The SEEC also set conditions that sales outlets needed to follow to reduce energy consumption. The SEEC introduced mandatory Energy Efficiency EE labels that would provide information on energy consumption rates of the electrical appliances, as shown in Figure 2.13. the main objective of the EE labels is to increase awareness on the importance of rationalising energy consumption (SEEC, no date).

The SEEC devised a plan to provide lower- and middle-class citizens with discounted air-conditioning units that they could pay for through instalments. Another helpful initiative is the consumption footprint that is a daily per capita consumption of electrical energy compared to other consumers in the same category. The SEEC has provided Saudi citizens an opportunity to access a website to help them determine their footprint and know the financial saving opportunities that can be achieved by changing the consumption pattern. Consumers also get tips on lowering their electricity use and electricity bills by adjusting their appliance use and behaviour and dwelling insulation and maintenance (SEEC, no date).

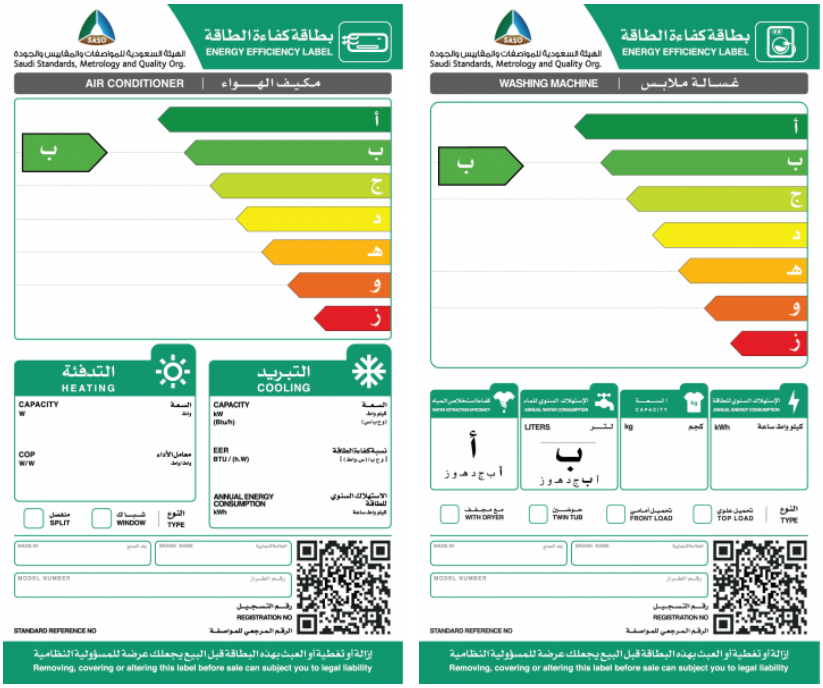


Figure 2.13 Exapmples of energy efficiency lables for domestic machines in Saudi Arabia (SEEC, no date)

2.6.4 Saudi Building and Energy Code

Many governments worldwide have created building construction and energy regulations. The SBC's objective is to improve the standards of living for Saudi citizens while reducing energy by promoting energy-efficient buildings. Energy regulations are provided as codes that must be followed to reduce energy consumption (Aldossary, 2015). Since 2007 the SBC started to be obligated in all building sectors in Saudi Arabia. The SBC was developed by studying and analysing the findings of numerous national studies and international Codes, including the United States of America, Canada, Australia, the Europe, and other Arabian nations.

The SBC comprises legal, administrative, and technical standards that buildings being constructed must meet to be considered safe (SBCNC, 2007). SBC, which was started to be developed by technical committees and sub-committees in April 2003, considered the national social and cultural environment, types of soil, properties of materials that can be used, and the natural climatic regions within the nation (SBCNC, 2007). The first version of the SBC considered the building aspects of construction, including the structural, mechanical, architectural, electrical, energy conservation, sanitary and fire protection aspects, which the public could access by 2007. This research focuses on the Energy Conservation Requirements (SBC 601), which focuses on commercial and residential buildings (SBCNC, 2007). This code was established based on the International Energy Conservation Code IECC.

The SBC 601 development process was done through a methodology that SBCNC approved. It was based on the base code, but the International System of Units were incorporated. The intention was to create a comprehensive code that considered the environmental conditions, the construction practices, and the materials used in the Kingdom (SBCNC, 2007). The first commercial and residential buildings code focused on the mechanical aspects of building equipment and systems, building envelope requirements, service water heating, electrical, lighting, and power, general requirements, and total building performance (SBCNC, 2007).

The initial Saudi Building Code disregarded the energy efficiency of buildings since there was no threat to peak loads at the time (Alaidroos and Krarti, 2014). The nation' population increase spiked electricity consumption in the nation due to the increased number of commercial and residential buildings. These changes necessitated the review of the SBC and change of building requirements with an emphasis on the construction of buildings that could be more energy efficient (Alaidroos and Krarti, 2016). The SBCNC and SEEC updated and released the Energy Conservation Code (SBC 602) that included minimum energy efficiency requirements for low-rise residential buildings in Saudi Arabia (SBCNC, 2018).

SBC 602 provides energy conservation requirements for low-rise buildings in the Kingdom, including lighting, water heating, ventilation, heating, and energy usage by electrical appliances and other building systems. It further provides requirements for exterior envelop insulation, solar heat gain coefficient SHGC ratings, door U-factors, water distribution insulation, duct insulation, and expected power efficiency (SBCNC, 2018). Although SBC 602 is comprehensive, it does not cover some aspects, such as portable electrical heaters, residential electric service, operation, maintenance, and residential buildings' use (SBCNC, 2018).

Abuhussain, Chow and Sharples (2019) conducted a study to assess the effectiveness of the Saudi residential buildings envelope codes for two detached single-family houses (villas) located in a hot and humid climate in Jeddah, Saudi Arabia. It further reviewed the possible impact of climate change in future based on the existing houses and the retrofitted houses to the codes. The study concluded that using the new codes on existing villas decreased colling energy consumption by between 17% and 40%, which indicates that these codes could help to reduce the potential impact of climate change in the future. However, the actual impact of climate change is still not well understood currently. It is known that the demand for cooling energy will increase with climate change. Global warming will increase demand for colling energy by between 22 and 36% (Abuhussain, Chow and Sharples, 2019).

The major drawback, in addition to considering future climate change, is the failure to consider occupant behaviour, especially their perceptions regarding the use of energy in houses when developing Energy Conservation Requirements (SBC 602), which was one of the major technical factors. (Abuhussain, Chow and Sharples, 2019) argued that there is no motivation towards consumption habits becoming more rationalised due to ongoing low electricity bills even with the introduction of the cut subsidies, as the current average price of electricity is minimal. On the other hand, the literature suggests that there is a need for further investigations on the residential electricity consumption rather than concentrating only on electricity bills alone in Saudi Arabia. Factors such as size and type of dwelling, occupant standard of living, poor energy efficiency for the building construction, occupant behaviour and the use of domestic equipment and appliances were found to significantly influence residential energy consumption (Alrashed and Asif, 2015a). Therefore, one of this study's key objectives is to highlight the effect of occupant behaviour on residential energy consumption.

2.6.5 The Introduction of A Value-added Tax

The government introduced a 5% value-added tax VAT on all goods and service supplies on January 1, 2018. The government hopes to make VAT one of the major non-oil revenues in the future. This indirect tax is an important economic diversification strategy since it minimises taxation loss, yet it has low administrative costs. As of the first of July 2020, an increase in the VAT rate from 5% to 15% has become effective. This will have either a positive or negative impact on the country's overall energy usage, which calls for additional research and study of the current situation.

2.7 Summary

This chapter looks at the significance of Saudi Arabia and its geographical location to the Arabian region and the entire world. It also examines the climate, economic situation, and cultural and social features of Saudi Arabia. Finally, it discusses the developments and changes in Saudi Arabia as well as the governmental efforts to reduce energy consumption. The residential building sector is increasing energy consumption and is associated with increased CO_2 emissions, unsustainable use of natural resources, and production of waste. These aspects have changed significantly in the last four decades as the population of Saudi citizens has been increasing rapidly and so has the need for housing. Energy efficiency has become a focal point due to the rising energy consumption and associated environmental concerns in the Kingdom of Saudi Arabia.

Saudi Arabia is the world's largest exporter of petroleum liquids and has the highest capacity for producing crude oil. Yet, it still has problems meeting its energy demands because most of its electricity is produced by burning natural gas and crude oil (EIA, 2014). The largest revenue source for the government of Saudi Arabia comes from oil sales. However, the amount of oil produced domestically and used for energy generation could impact these sales. Moreover, It has been suggested that residential energy demand will double by 2025 (Salam and Khan, 2018), highlighting the urgent need to decrease energy consumption to improve the country's economic prosperity. In 2016, the government launched Vision 2030 to lead the country in a new direction by building a great future for the next generation. As the Crown Prince Mohammed bin Salman said, “all success stories start with a vision, and successful visions are based on strong pillars” (‘*Vision 2030 Foreword*’, n.d., p 06). Vision 2030 is a plan to diversify the country's economy and reduce its reliance on oil. As part of this plan, the government is investing in renewable energy sources, such as solar and wind power. It is also working to improve energy efficiency and reduce energy consumption in all sectors. This vision will help the country to be more sustainable financially, socially, and environmentally.

In Saudi Arabian culture, three pillars remain untouched by Western influence: family, traditions, and religion. The nation remains conservative and upholds the Islamic doctrine as a means of preserving its customs and traditions. However, the discovery and extraction of oil in Saudi Arabia influenced the nation’s architecture and culture to some extent. Nonetheless, it is clear that the citizens of Saudi Arabia have made deliberate decisions to maintain their Islamic customs and values, while deliberately disregarding any external influences that do not align with their beliefs. The nation's main challenge is balancing the traditionally conservative culture and modernisation and technological development. The conservative culture of Saudi Arabia presents some challenges for the government's efforts to promote energy efficiency and renewable energy. For example, the traditional practice of keeping homes cool in the summer by opening windows and doors can lead to increased energy consumption. Therefore, the government is working to educate the public as part of Vision 2030 about the importance of energy efficiency and to promote the use of energy-efficient appliances and lighting.

The Kingdom of Saudi Arabia has an arid desert climate characterised by intense heat and low rainfall most of the time. The nation is among the few that experience summer temperatures of more than 45°C. Saudi Arabia climate has been the subject of many studies due to its uniqueness. The SBCNC indicates that there are three climatic zones in Saudi Arabia, with zone 1 being the warmest and zone three being the coldest and zone being average. The main challenge the nation faces is the increase pollution in urban areas and the increased energy demands associated with carbon dioxide emissions. There are also concerns about industrial waste management since some coastal areas have been polluted and have led to stress on the marine habitats (Husain and Khalil, 2013). These environmental challenges are likely to worsen as the nation continued to develop and its population increasing rapidly. These environment challenges and metrological conditions need further analysis to determine how they relate to energy consumption in the country.

As a starting point for this research, this chapter reviewed several related studies worldwide, including those from Saudi Arabia. It uncovered cultural, economic, and environmental challenges that could be useful in conducting research in the Saudi Arabian context. The following chapter will discuss the determinants of energy consumption in dwellings with special emphasis on occupant behaviour. It will also examine the current situation of residential buildings and energy consumption in Saudi Arabia. The chapter will be discussing the factors that influence energy consumption in dwellings. These factors include the building and household socioeconomic characteristics, meteorological conditions, and occupant behaviour.

Chapter Three:

Residential Energy Consumption and Occupant Behaviour: Existing Knowledge

Chapter 3: Residential Energy Consumption and Occupant Behaviour: Existing Knowledge

3.1 Chapter Overview

This chapter provides an overview of the existing knowledge of determinants of residential energy consumption and provides an overview of home energy usage. The chapter also provides insights into the "energy performance gap" concept and explores the various factors that influence energy consumption, with a particular focus on occupant behaviour. The purpose of conducting this literature review is conducted to identify: (1) significant factors that influence energy consumption locally and internationally; (2) potential methodologies for collecting and analysing energy consumption and its influential factors; and (3) prospective modelling techniques for energy consumption. Moreover, a growing body of literature recognises the importance of occupant behaviours and their role in residential energy consumption (Santin, Itard and Visscher, 2010; Bedir and Kara, 2017; Bélafi, 2018). However, Insufficient research studies have been conducted to thoroughly investigate the correlation between occupant behaviour and household energy consumption in Makkah, Saudi Arabia.

This review aimed to establish a baseline for comprehending the factors that influence household energy usage, with a specific focus on how residents' behaviour, including their culture, attitudes, awareness, and adherence to rules, contribute to varying outcomes of residential energy consumption. A framework was then created based on the reviewed literature showing factors such as household socioeconomic characteristics (education, income, and age), dwelling characteristics (building type, floor area, the type of lighting and air conditioners), and weather conditions (temperature and relative humidity), which all have an impact on energy consumption and occupant behaviour. Insights gained from this evaluation informed the development of the study's survey questions.

3.2 Determinants of Energy Consumption in Dwellings

The purpose of this section is to use existing literature to understand better the determinants of energy consumption in dwellings, including building and household socioeconomic characteristics, meteorological conditions, and, most importantly, occupant behaviours. Humans comprise and modify their physical surroundings to survive and perform their activities comfortably. As a result, their environment experiences gradual but noticeable transformation and deformation. On the other hand, buildings must be designed for occupants so that energy efficiency measures are compatible with their desire for the best living environment. Most of the time, building systems and components, or occupant behaviour, prevent make it impossible to achieve these goals.

3.2.1 Influential Factors on Energy Consumption in Dwellings

Based on the literature review, the factors influencing residential energy consumption are broken down into five categories: lighting and electric appliance ownership and usage, dwelling attributes, household characteristics, economic characteristics, and HVAC system characteristics (Bedir, 2017). In addition, occupant behaviour is a significant predictor of electricity consumption in dwellings.

3.2.1.1 Building Characteristics

Based on the works of literature, several factors of the building proved their influence on energy consumption, such as building type, floor area, number of rooms, number of bedrooms, building envelope, and insulations. The dwelling and insulation types influence how occupants consume energy in their homes according to Santin, Itard and Visscher, (2009) and Bedir, Hasselaar and Itard, (2013). Where the dwelling is located (Yohanis *et al.*, 2008; Lee *et al.*, 2019) and the building's age (O'Doherty, Lyons and Tol, (2008)) are equally important factors that appear to have a significant impact on electricity consumption. The number of rooms (Santin, Itard and Visscher, (2009); Bedir, Hasselaar and Itard, (2013); Bedir, (2017)) and the number of bedrooms (Santin, Itard and Visscher, (2009); Sakah *et al.*, (2018); Awan and Knight (2020)) also emerge as significant predictors of electricity consumption.

According to Bedir (2017), length of residency in the same dwelling, number of bedrooms, number of study/hobby rooms, and building type, among other parameters, are significant determinants of electricity consumption. Santin, Itard and Visscher (2009) research on the impact of occupancy and building characteristics on the Dutch residential stock energy use for space and water heating found that building factors account for 42% of the variance in heating energy consumption. The insulation level and the size of the dwelling were found to have a significant effect on energy consumption. It was further found that newer buildings did not consume much energy compared to those constructed earlier. However these findings are not fully accurate since some new structures, such as non-detached dwellings with thermostat, shed and basement, and garage have higher energy consumption (Santin, Itard and Visscher, 2009).

The type of the HVAC system used plays a role in energy consumption. In 10 Australian residences utilised as embedded Living Labs and monitored for over a year, Eon, Morrison and Byrne (2018) discovered that heating and cooling systems are a primary driver of energy use.

Awan and Knight (2020) suggested that increased energy demand was due to the need for space conditioning in the Punjab domestic sector. The study indicated that future climate change could increase the demand for cooling systems, increasing energy demand in domestic dwellings. Considering the average domestic dwelling demand for electricity is approximately 2401 kWh/year, the demand could increase by between 18 and 23% depending on the number of rooms that would need cooling.

3.2.1.2 Household Socioeconomic Characteristics

Several authors have considered the effects of family size and composition on the energy consumed (Santin, Itard and Visscher, 2009; Motuziene and Vilutiene, 2013; Huebner *et al.*, 2016; Bedir, 2017). The size of a household is among the major determinants of electricity consumption. In comparison to homes with one or two people, Jones and Lomas (2015) discovered that households with three or more occupants tend to be high consumers. Santin, Itard and Visscher (2009) illustrated that the age, tenure, income, household size, and inclusion of heating in the rent were the major factors that influenced energy consumption

The age of a household occupant can determine whether they will use heating and subsequently determined electricity consumption (Santin, 2010; Martinaitis *et al.*, 2015). The authors found that elderly people in households increased electricity consumption because they used more heating and kept the bedroom and living room windows closed for most of the day. Children in households also increased the likelihood of windows remaining closed for longer but there was little use for the heating system. Jones and Lomas (2015) further found that teenagers in households were likely to increase energy consumption. In a study conducted in Hangzhou, China by Chen, Wang and Steemers (2013), it was discovered that the occupant's age had a higher impact on energy use than the occupant's income. Surprisingly, a negative correlation between occupant age and energy consumption was found. Generally, from the perspective of thermal comfort, where the elderly spends more time indoors and require more energy, at least for heating, these results appear contradictory. One possible explanation for this discrepancy is that elderly residents often dress more properly than younger occupants. Another reason is that the elderly occupants set air conditioners at a higher temperature in summer comparing to the younger occupants (Chen, Wang and Steemers, 2013).

Santin and Itard (2010) and Bedir (2017) concluded that higher education influenced occupants to consume less energy but children and older adults used appliances and HVAC systems in a different way. O'Doherty, Lyons and Tol (2008) found that the nature of tariffs influenced energy consumption, with those in low-priced tariff likely to have a 2.1% more energy consumption compared to those on other tariffs. Conversely, Bedir, Hasselaar and Itard

(2013) found that electricity tariff has no significant correlation with electricity consumption. This might be because the electricity tariff does not directly influence electricity consumption, yet it directly affects how residents behave.

The education level of the occupant, household income, employment, lifestyle, tenure type, and length of residency all appear to be strongly associated with energy consumption. This view is supported by Bedir, Hasselaar and Itard (2013) who illustrated a positive correlation between household income and electricity consumption, albeit this correlation was not detectable in the regression model. On the other hand, Sakah *et al.* (2018) showed that household and socioeconomic factors were important attributes in electricity consumption in homes in Ghana. They found that household income, appliance ownership, such as air conditioner, fan, television, refrigerator and freezer, and house floor area determined electricity consumption.

According to Eon, Morrison and Byrne (2018), residents' habits and regular household activities significantly impact energy consumption, and the way households heat and cool their homes can differ greatly, both within a household and between different households. The reason for these differences is that individuals within a household can have different attitudes, beliefs, and motivations regarding energy use. On the contrary, Jones and Lomas (2015) claimed that there should be no much effect on heating energy consumption with differences in lifestyles since they found that there were no major changes in heating energy consumption in their study.

Finally, O'Doherty, Lyons and Tol (2008) and Ardakani, Hossein and Aslani (2018) claimed that the type of tenure influences the behaviour of the occupant and energy consumption. O'Doherty, Lyons and Tol (2008) indicated that own outright homes are likely to have more appliances but at the same time more energy saving features. Occupant characteristic-related factors, which are found to be influencing energy consumption on residential buildings, have also been explored by other authors. Xu, Xiao and Li (2020) found that the householder's age, education level, income, occupancy type, and residency lead to a 10.70% variance in electricity consumption. These authors found that occupancy type had the largest impact on electricity consumption followed by education level, residency length, household size, and household income. In contrast, Bedir, Hasselaar and Itard (2013) discovered that no relationship existed between education level and energy consumption, which would be understandable because the respondents had similar educational qualifications and were from the same nation, 86% Dutch.

3.2.1.3 Weather Related-Factors

Residential energy use can be affected by factors like outdoor air temperature, horizontal global irradiance, wind speed, and humidity. Many studies conducted previously have used weather-data-related variables such as heating degree day (HDD) and cooling degree day (CDD) to estimate electricity consumption based on cooling and heating. The results of the analysis by Fumo and Biswas (2015) conducted a study to analyse the prediction methodologies used to predict residential energy consumption using linear and non-linear regression followed by simple and multiple regression models in June 2013. They used dry-bulb temperature as the independent variable. The results showed a positive regression coefficient, indicating that rising outdoor temperatures were associated with rising cooling energy consumption.

The findings of the study by Lee *et al.* (2019) found that the only factor that influenced electricity consumption was heating regardless of the climatic condition differences. They further indicated that in most cases, cooling energy consumption was not influenced by weather data. On the other hand, a decrease in HDD decreased heating energy consumption, which was an indication that weather influenced heating and subsequent energy consumption. Meteorological data can also influence occupant behaviour regarding energy consumption in dwellings. For instance, occupants adapt their clothing according to the air temperature in various seasons. They maintain the airflow within the room by utilising fans, air conditioners, and shutters or windows (Liu *et al.*, 2017).

A longitudinal study of the effect of seasonal variation of thermal comfort demands on energy needs for heating or cooling purpose by Liu *et al.* (2017) reports that warmer thermal conditions influence people to wear lighter clothes in adaptive zones of between 13 °C and 25 °C. Adapting to clothing becomes problematic with hotter summer temperature of more than 25 °C and colder winter temperature of below 13 °C. In an investigation into the influences of outdoor and indoor environmental variables on occupant behaviour related to window opening and closing using one-year field monitoring data, Park and Choi (2019) found that the daily average outdoor temperature influenced occupants manual control of the windows. They further found that there was higher window opening frequency during the moderate period and low frequency was noted during the heating period. The rationale is that windows are usually maintained open during slight cooling and cooling periods in which windows stay open for longer (Park and Choi, 2019). Further study is required to ascertain and quantify the actual effect of meteorological parameters on heating and cooling energy usage.

3.2.1.4 Occupant Behaviour

The behaviour of lighting and appliances and occupancy patterns are affected by several factors, including the type and size of the home, the time spent in various rooms, the activities carried out there, and the members' personal preferences and habits. It is possible to explain variations in lighting and appliance behaviour among households through factors such as a region's or country's demographics or institutional setting (cited in Bedir, 2017). Several studies have attempted to measure household lighting and appliance usage, but none have been conducted in Saudi Arabia where cultural norms and practices play a significant role.

Electricity consumption is significantly correlated with the number of electrical appliances owned and the length of time they are used in dwellings. Bedir (2017) proposed a model to determine electricity consumption by appliances in terms of minutes per day. The proposed categories included general, cleaning, food preparation, extra ventilation, and hobbies. It was determined that the amount of time an occupant spends in their household influences electricity consumption and was responsible for 37% variance in the amount of energy consumed. Bedir's research further introduced second model based on the number of appliances, such as the number of lamps and other appliance used in the household and the dwelling, household, economic, and system DHES characteristics that was responsible for 52% variance in electricity consumption. Lastly, the final model for electricity consumption estimation combined the total amount of time the appliances were used and DHES characteristics, which led to a 58% variance in electricity consumption (Bedir, 2017).

O'Doherty, Lyons and Tol (2008) used the National Survey on Housing Quality to conduct a study based on housing characteristics, problems, and household members in 40,000 Irish houses. The survey aimed to determine the major electricity consuming appliances and asked information pertaining to the ownership of television, videocassette recorder VCR, washing machine, refrigerator, personal computer, telephone, electric shower, microwave oven, and dishwasher. The survey also asked information regarding the value of the dwelling, the location, ownership, weekly income, household composition, age of the occupant, electricity tariff, and the number of years the occupants have stayed in that dwelling. All the variables considered were found to be statistically significant in determining electricity consumption (O'Doherty, Lyons and Tol, 2008).

Saidur *et al.* (2007) estimated the total and appliance specific energy consumption and savings and GHG emissions and their reduction in Malaysia for a period of 17 years between 1999 and 2005. The main finding was that the refrigerator consumed more energy than any other appliance. The other appliances that consumed more electricity energy include the air conditioner, washing machine, fan, rice cooker, and iron in that order. Sakah *et al.* (2018) provided a thorough analysis of city-scale electricity use in Ghanaian homes. It was found that various factors, including income, household size, floor area, and possession of appliances like air conditioners, freezers, fans, refrigerators, and televisions, have a significant impact on Ghanaian household electricity consumption.

On the other hand, the study conducted by Jones and Lomas (2015) in UK showed that portable electric heating and electric water heating consumed more electricity than other appliances. Eon, Morrison and Byrne (2018) concluded that people have varying cooling and heating practices that dictate electricity usage. Moreover, occupants at the same home may have varying perceptions regarding the use of these appliances and greenhouse gases emissions, which affects their attitudes towards their use. occupants concerned about energy conservation are likely to engage in different practices, such as putting more clothes when it is cooler or putting on lighter clothes and opening windows when it is warmer rather than using cooling and heating systems. On the other hand, those who do not care about energy conservation are likely to switch on cooling and heating appliances or systems at any opportunity when the weather changes. (Eon, Morrison and Byrne, 2018).

According to Yilmaz, Firth and Allinson (2017) research, it is feasible to anticipate occupants' electrical appliance usage by examining the frequency, length, and timing of switch-on events. The study's key discovery was that electricity consumption fluctuates significantly depending on the number of appliance switch-on events. The research also highlighted significant differences in how appliances were utilized. Cold appliances were switched on for an average of 2.8 times per day in one household and 125.3 times in another household. These variations are an indication that the people have varying preferences on how to use their appliances. However, there may be variations on the voltage of the appliances, standby on/off functions, and the use of battery charge, which suggests that there is a need for more research (Yilmaz, Firth and Allinson, 2017).

3.2.1.4.1 Determinants of occupant behaviour

When assessing residential energy consumption, it is important to consider several factors relating to the building's structure and the habits and behaviours of its occupants. One consideration is that a home's energy usage is affected by the occupant's daily routines, such as cooking, sleeping, and watching television. Energy consumption is affected by how the inhabitants react to various changes in the indoor environment, such as temperature changes and food smells (Bedir, 2017). Occupants have varying perceptions of comfort in their homes and how they try to achieve them. Although the determinants of occupant behaviour are not within the scope of this investigation, it is important to understand the motivations and drivers of the behaviours towards energy use in buildings. Moreover, there is a bilateral relationship between occupant behaviour, energy consumption, and other influencing behaviours (Bedir, 2017).

Scholars identified several variables (also denominated as drivers) that may influence directly and/or indirectly the way that occupants use energy. These variables may be deliberated as objective aspects such as temperature, air velocity, accessibility to control building features, noise, time, and activity type. Subjective factors like age, gender, perception of comfort, expectations, values, and social interaction (Tam, Almeida and Le, 2018). Users' actions may also be influenced by external features such as politics, economics, and culture (Tam, Almeida and Le, 2018). The IEA Annex 66 report has also elaborated that occupant actions are influenced by external or internal factors, where the first is connected to the building and building equipment properties, time, and physical environment and, the second one related to biological, psychological, and social aspects (Yan *et al.*, 2017).

Peng *et al.* (2012) made a comprehensive analysis of users interactions in residential buildings. The authors have differently categorised the drivers influencing occupant behaviour and their interactions with building systems and devices: environmentally-related factors, time-related factors, and random factors. They explained that people have varying behaviours that they have developed over time, for instance, opening windows for ventillation or using some equipment to adapt to new conditions. These habits may change depending on the day or nigh, weekdays or weekends, and season. Therefore, there is a need to review the time or periods to determine the effect of habits on energy consumption (Peng *et al.*, 2011). The way people behave depends on the outdoor environment of the dwelling, the educational level and economic status of the occupant and the household characteristics, including the mechanical systems installed, electrical appliances used, and the envelop and mass compsition characterstics (Bedir, 2017).

Delzendeh et al. (2017) added that comfort is one of the most essential aspects that drive the occupants' energy use. They stated, "comfort (specifically thermal comfort) is a state of mind that varies from person to person due to personal (physiological, psychological) and social parameters, which directly affect occupant's energy use" (Delzendeh *et al.*, 2017, pp. 1066). Economic parameter, climatic parameter, architecture and interior design, building type and function, and regulation and policies have also a direct impact on the energy behaviour of the occupant in addition to the socio-personal parameter. As can be seen in Figure 3.1, A summary of all the essential aspects that influence the energy behaviour of the occupants in a building (Delzendeh *et al.*, 2017).

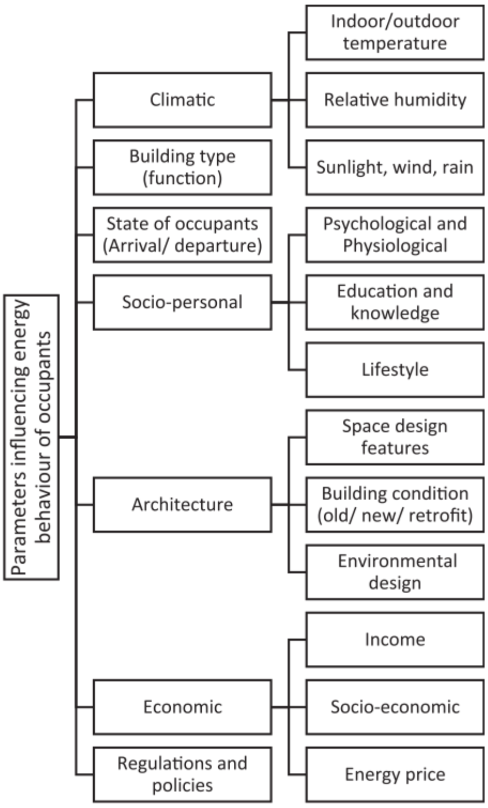


Figure 3.1 Factors and sub-factors influencing Energy behaviour of Occupants
(Delzendeh *et al.*, 2017)

3.2.2 *Influential Factors on Residential Energy Consumption in the Saudi Arabian Context*

Algarni and Nutter (2013) emphasised critical factors that have led to the high energy consumption in residential buildings in Saudi Arabia. The first factor is the government energy support, which has led to the low price of electrical energy resulting in bad attitudes and behaviours toward personal energy usage at home. Therefore, one of the goals of this study is to determine the role that electricity tariffs play in residential electricity consumption. Another factor is the harsh climatic conditions in the country, which require massive space cooling-related energy use, especially during the summer season. Furthermore, the rapid population growth and the family size are very significant factors that have given rise to an average annual increase in electricity usage (Algarni and Nutter, 2013). The annual growth rate of the population in Saudi Arabia is 2.52% whereas almost 50% of citizens own houses in Saudi Arabia, according to the General Authority of Statistics (Arab News, 2018).

Finally, Algarni and Nutter (2013) pointed out that the cooling system used is a significant factor impacting energy use in dwellings, with a very low energy efficiency ratio EER.

Therefore, the consumed energy in dwellings increases annually depending on the increase in the number of air-conditioners installed and their operating hours based on the different behaviours by the occupants. According to a study conducted at the King Abdullah Petroleum Studies and Research Center KAPSARC (2021), substantial population increases, regulated energy prices, and economic growth are crucial factors that influence the high demand for energy in Saudi Arabia.

A significant factor impacting energy use in residential buildings was identified in the literature, which is just as important as the prior components. The behaviour and actions of occupants and how the energy is used play a vital role in household energy consumption. Rapid population growth, industrial development, meteorological conditions, and energy prices have strained Saudi Arabia's present energy supply infrastructures. The following subsections go through each of these characteristics in further depth.

3.2.2.1 Population Growth in Saudi Arabia

Since the discovery and commercial extraction of oil in the 1930s and the rise in market demand in the 1970s, the Kingdom of Saudi Arabia has seen several changes. As such, the nation started getting oil revenues that have been used to transform traditional Saudi society into a modern one similar to developed nations (Sidawi, 2008). The new revenues were evident in the way urban centres started to grow exponentially. Cities in Saudi Arabia are among the fastest growing in the middle east (Al Surf, Susilawati and Trigunarsyah, 2012). Between 1950 and 1992, urbanisation in Saudi Arabia grew from just 10% to more than 75%, which was a significant development in just over four decades (Library of Congress, 2011). The forecasts indicate that the population in the Kingdom of Saudi Arabia is going to increase by 24% by 2030 (United Nation, 2017). Figure 3.2 shows the change in population growth (in thousands) in Saudi Arabia between 1950 and 2100, which also supports the need to diversify energy resources since a growing population will need more energy.

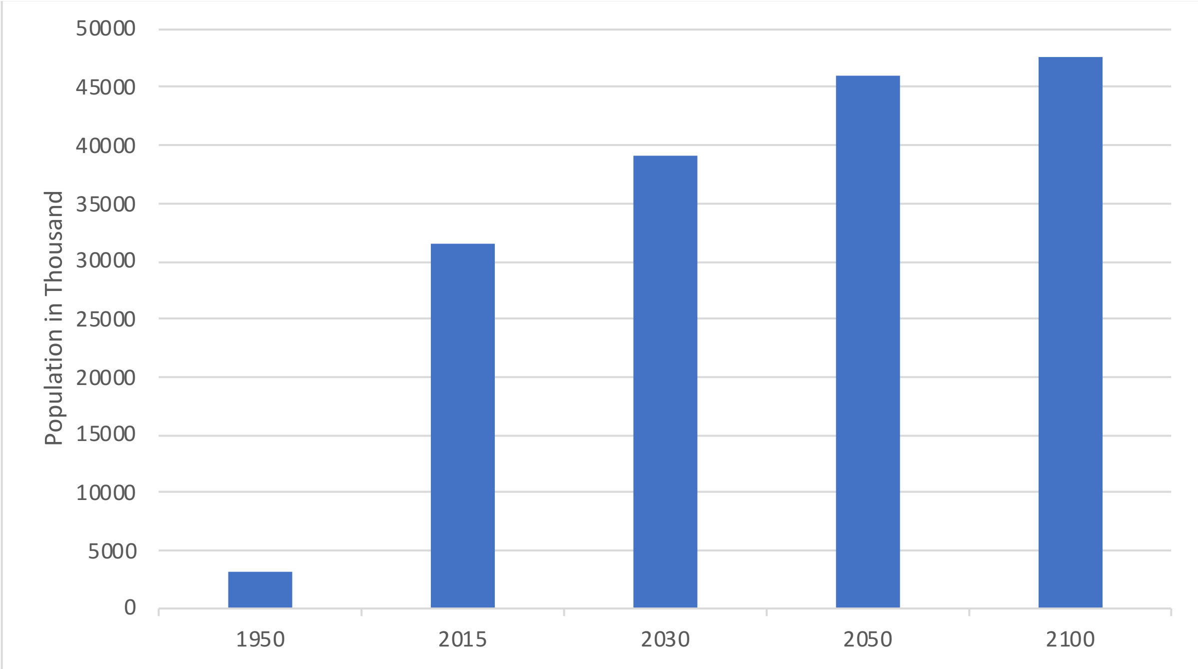


Figure 3.2 Saudi Arabian Population Growth in Thousand
(United Nation, 2017)

The population of Saudi Arabia experienced a 31.75% growth from 2009 to 2020, with an average annual increase of 2.65%. However, as of 2021, the total population has decreased to 34.1 million individuals (SGAS, 2019, 2021). Figure 3.3 presents the demographic breakdown of Saudi Arabia's total population in the middle of 2021, broken down by gender and age group. It is clear from this statistics that more than half of the population (54%) comprises people between the ages of 20 and 49 (SGAS, 2021). Housing demand has increased in Saudi Arabia, leading to an increase in the country's total energy consumption. This is a direct consequence of the population growth in the country. These changes indicate that it is essential to investigate the determinants of electricity consumption and understand the role of occupant behaviour in the effort to promote more energy-efficient residential buildings.

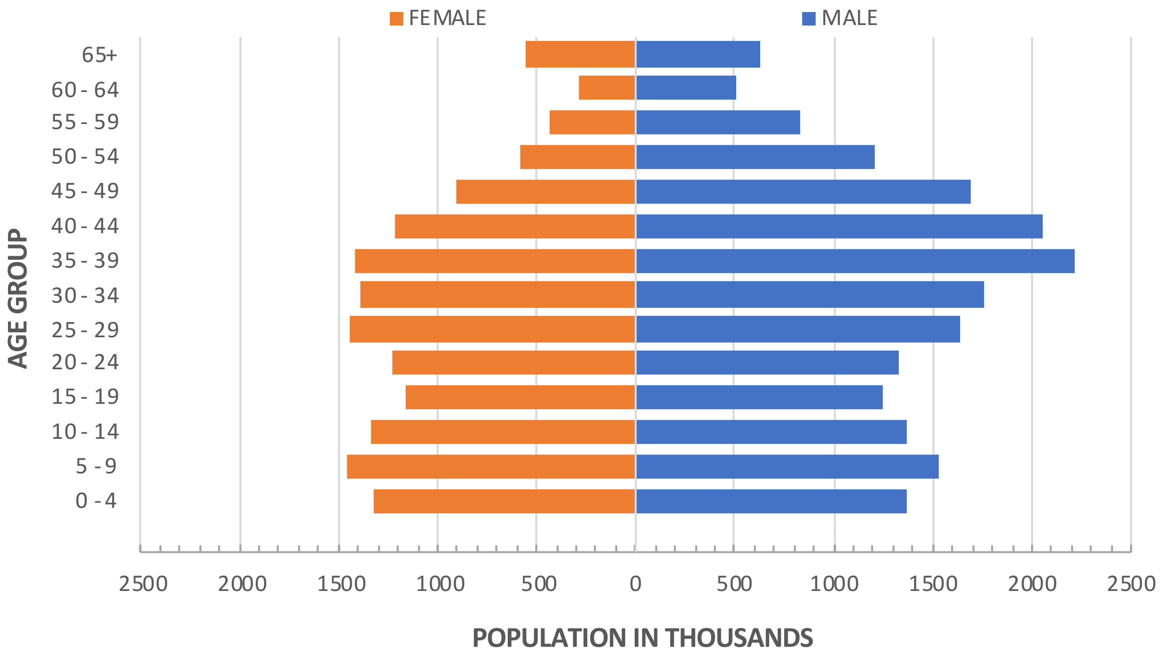


Figure 3.3 Saudi Arabian's population by age and gender
(SGAS, 2021)

3.2.2.2 The Revolution of Energy and Real Estate in Saudi Arabia

Even though Saudi Arabia is the largest exporter of petroleum liquids and holds the largest production capacity of crude oil in the world, it is still suffering from the high demand for energy since it currently generates most of its electricity from the combustion of crude oil and natural gas (ECRA, 2020). The primary energy consumption statistics show that Saudi Arabia was ranked the world's 10th largest consumer in 2017 at 268.3 million tons of oil equivalent, which is increased by 1.7% based on the statistics of the previous year. Saudi Arabia is considered the 9th largest CO_2 emitting country in the world (BP Energy, 2018). In fact, many of the world's most serious air and other pollution problems are caused by excessive energy usage. Urbanisation and industrialisation are the major causes of atmospheric pollution problems in developing countries, resulting in local and international environmental impacts, such as human health effects from air pollution and ecological harm from acid deposition. Global climate change is also a concern for many countries, with developing countries accounting for the majority of greenhouse gas emissions (Alnatheer, 2005).

Furthermore, buildings in their operational phase are widely known to be responsible for steadily rising energy consumption. According to the SEEC (2018), approximately one-third of the electricity produced in the nation is used in the construction sectors. Buildings consume about 29% of the total primary energy in the country, whereas the cooling system represents 50% of the buildings' electricity consumption. These statistics underscore the significance of energy consumption during the operational phase of buildings, particularly in relation to cooling systems. These figures somehow compare to those of the European Union EU building sector that is considered the most significant single energy consumer absorbing approximately 40% of energy (European Commission, 2020).

Although reports of a dropdown in the total energy consumption among building sectors with a total of 288,599 GWh in 2019 compared to the previous four years was reported, it is still a substantial issue in the country, as shown in Figure 3.4. Electricity consumption is based on electricity sales of SEC and Marafiq. Among the highest energy-consuming building industries in Saudi Arabia, the residential sector is considered the highest in the country's energy use (ECRA, 2020). Figure 3.4 illustrates that among all building types in Saudi Arabia, half of the total electricity sold in 2019 is consumed by residential buildings, of which 70% is consumed by air-conditioning. At the same time, commercial, government, industrial and others stand for 16%, 14%, 20% and 6% respectively. (ECRA, 2020).

According to Alshahrani and Boait (2018), retrofitting existing buildings with insulation is a viable option and highly recommended because the majority of current residential buildings are uninsulated, which leads to increased energy consumption. Still, it would take considerable time, effort, and several years to complete retrofitting all existing residential buildings in Saudi Arabia. However, the decision to improve insulating techniques for implementing high energy efficiency in future residential buildings is feasible. Moreover, most new residential buildings in Saudi Arabia are designed to fit the clients' needs, regardless of environmental considerations and other energy-saving measures and actions, according to Almatawa, Elmualim and Essah (2012) and Alshahrani and Boait (2018).

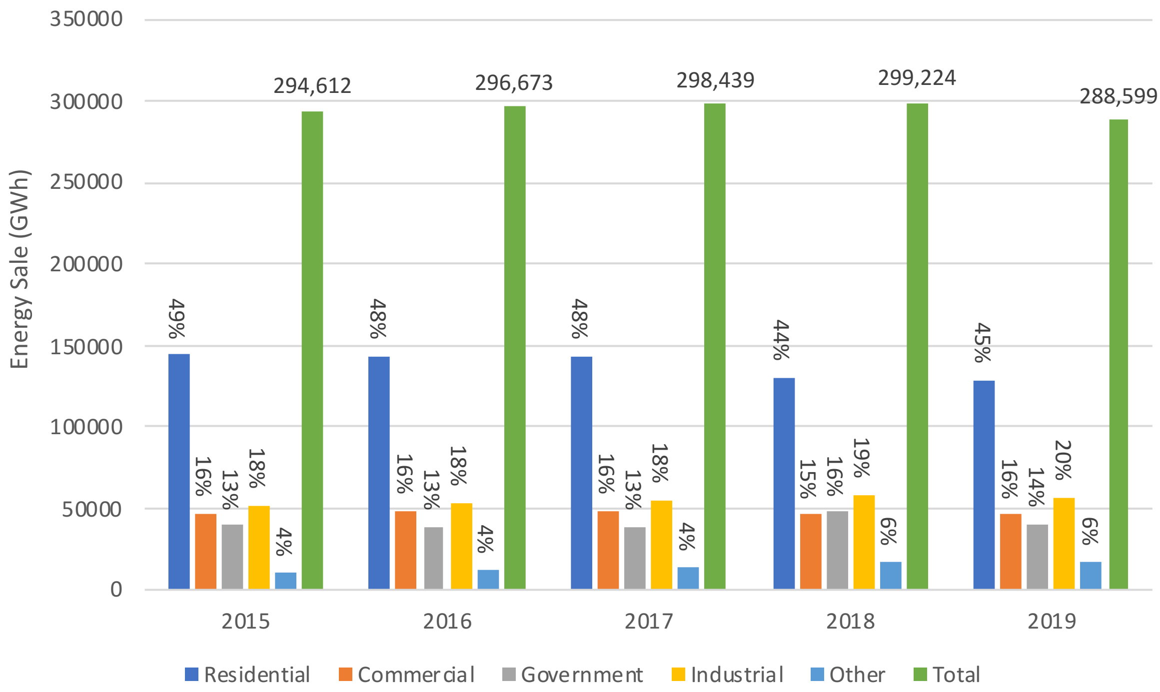


Figure 3.4 Energy sales (GWH) in Saudi Arabia's construction sectors between 2015-2019 (generated from ECRA, 2020)

In a comparison between the GCC countries, which have similar climatic conditions and cultures, Saudi Arabia was the largest country in terms of population and had the highest total electricity consumption in 2020 (The Statistical Centre for the Cooperation Council for the Arab Countries of the Gulf GCC-Stat, 2021; IEA, 2022). However, when dividing this total consumption by the country's population, Saudi Arabia's per capita electricity consumption is lower than other GCC countries, such as Kuwait and Bahrain. According to the IEA (2022), the electricity consumption per capita in Saudi Arabia was 10,310 kWh in 2020, whereas Kuwait and Bahrain were 16,000 and 18,800 kWh, respectively. Table *3.1* compares the GCC countries' electricity consumption, cost, and population.

There are several reasons why this might be the case. One is that Saudi Arabia has a relatively large population, which means that the total amount of electricity consumed is spread out across a larger number of people. Additionally, Saudi Arabia has taken steps to diversify its energy mix and reduce its reliance on fossil fuels. The country has set ambitious targets for renewable energy, with plans to generate 50% of its electricity from renewables by 2030. This includes the development of large-scale solar and wind projects, as well as the construction of a nuclear power plant. These efforts aim to reduce the country's carbon footprint and promote sustainable development.

GCC Countries	Population in Millions in 2020 (%)	Electricity consumption (TWh) in 2020	Electricity consumption (MWh/cap) in 2020	Electricity consumption by residential sector (%) in 2020	Residential electricity price (US/kWh) in 2022
Saudi Arabia	35 (60.8%)	359	10.31	45	0.048
Qatar	2.8 (4.8%)	46.5	16.2	47	0.032
Kuwait	4.5 (7.7%)	68.1	16	45	0.029
Oman	4.6 (8%)	34.4	6.7	47	0.026
Bahrain	1.5 (2.6%)	32	18.8	27	0.048
United Arab Emirates	9.3 (16.1%)	130.3	13.2	34	0.081

Table 3.1 Electricity consumption, cost, and population in the GCC Countries (GCC-Stat, 2021; *Electricity Prices*, 2022; IEA, 2022)

Data from the Ministry of Municipal Rural Affairs and Housing MOMRAH have reported 103,485 construction permits issued in Saudi Arabia in 2018, of which about 90% were issued for residential buildings, as shown in Figure 3.5 (MOMRAH, 2018). Moreover, the residential sector is expected to grow considerably. As displayed in Figure 3.3, approximately 60% of the population were younger than 35 years old, and estimates suggest that in order to meet the needs of a growing population, 75 thousand new development housing units and a 70% increase in homeownership must be provided by 2030 (*The Housing Programme Delivery Plan (2021-2025)*, no date).

The rapid increase in population necessitates a significant need for new residential constructions, which will lead to a rise in the amount of energy consumed. To compensate for these issues, the government focuses on reducing building energy consumption, primarily in the housing sector, due to its effects on the country's total energy consumption. Therefore, in 2018, a new development of building and energy codes was implemented for new construction. Existing buildings are the main cause of the current energy consumption and will remain the case without redevelopment (Felimban *et al.*, 2019).

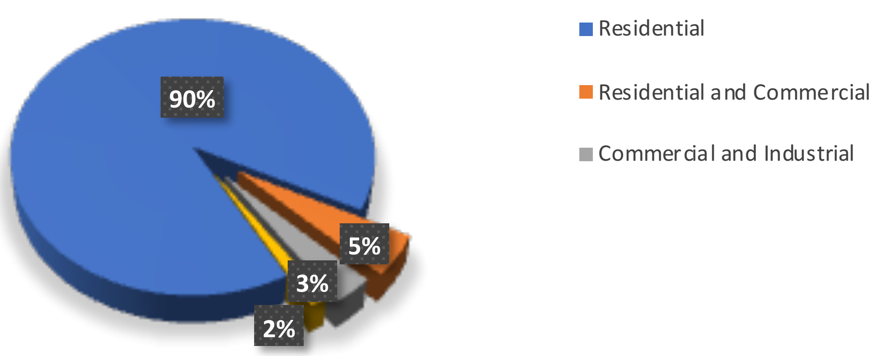


Figure 3.5 Total construction permits in Saudi Arbia in 2018
(MOMRAH, 2018)

3.2.2.3 Electricity Tariff in Saudi Arabia

Excessive reliance on energy has grown in the Kingdom of Saudi Arabia due to its rich oil and natural gas reserves and the government's heavy subsidisation of energy prices during the past several decades. Saudi Arabia's government has supported its citizens by providing fixed domestic energy prices, which have been considered below the international market levels. Subsidised energy helps to keep energy prices consistent and affordable, which is critical for low-income households. According to Aldubyan and Gasim (2021), the result of subsidised energy could be a rapid increase in consumption and wasteful consumption while discouraging investment in energy efficiency. Nonetheless, Lahn and Stevens (2011) and Alyousef and Stevens (2011) identified two arguments favouring Saudi Arabia's government subsidising or lowering energy prices. One case deal with poverty, while the second discusses the benefits of reducing costs for advancing economies other than those dependent on oil.

In 2014, the SEC spent 0.154 SR per energy unit (kWh) for production, transportation, and distribution. Operational and capital expenses, fuel costs, purchased energy costs, and depreciation are all included in the costs. Despite the low fuel prices, which are lower than the international fuel prices with an average unit cost of about 0.80 SR/kWh, and the government's low-interest loans to the SEC, the average unit price received by SEC from consumers in 2014 is still lower than the cost of production (ECRA, 2015). The average unit price collected was 0.138 SR/kWh (ECRA, 2015). However, the government provides it for households in Makkah City as an example, with a price of 0.07 SR/kWh from 1974. In 2000, the government made a further reduction to a price of 0.05 SR/kWh (ECRA, 2015).

Parry *et al.* (2014) revealed that energy price increases are associated with many advantages. It is the most cost-effective and efficient method currently available in terms of managing domestic energy consumption and promoting energy efficiency investments. Furthermore, they asserted that it influences consumer behaviour and prevents the unfavourable environmental impacts of fossil fuel use. Policymakers often turn to alternative energy sources since rising energy prices have a heavy burden on lower-income households. Aldubyan and Gasim (2021) stated that high energy prices are challenged due to their regressive effects in developing countries with a focus of eliminating subsidies and in developed nations where a carbon tax may be the goal. Nonetheless, Saudi Arabia's electricity tariffs, compared to other countries, is still one of the lowest cost in the world (ranking 33 among 230), as can be seen in Figure 3.6 (Cable.co.uk, 2021).

Moreover, Aldossary (2015) suggested several strategies to make changes in the energy policy, which can make a reduction in dwelling energy consumption. The first approach is encouraging homeowners to retrofit their homes by installing solar panels at the expense of the Ministry of Electricity. Installing solar panels might be a viable alternative to subsidising electricity rates. The secondly is increasing public awareness to reduce electricity consumption, which is easily achievable. This could be done by installing an enhanced insulation system or encouraging Saudi citizens to buy high-efficient appliances, which would reduce electricity consumption while ensuring a comfortable living environment. The final strategy is encouraging the Saudi Arabian government to ensure its building stock is sustainable by enacting and enforcing robust policies and regulations to reduce energy consumption and carbon dioxide emissions (Aldossary, 2015).

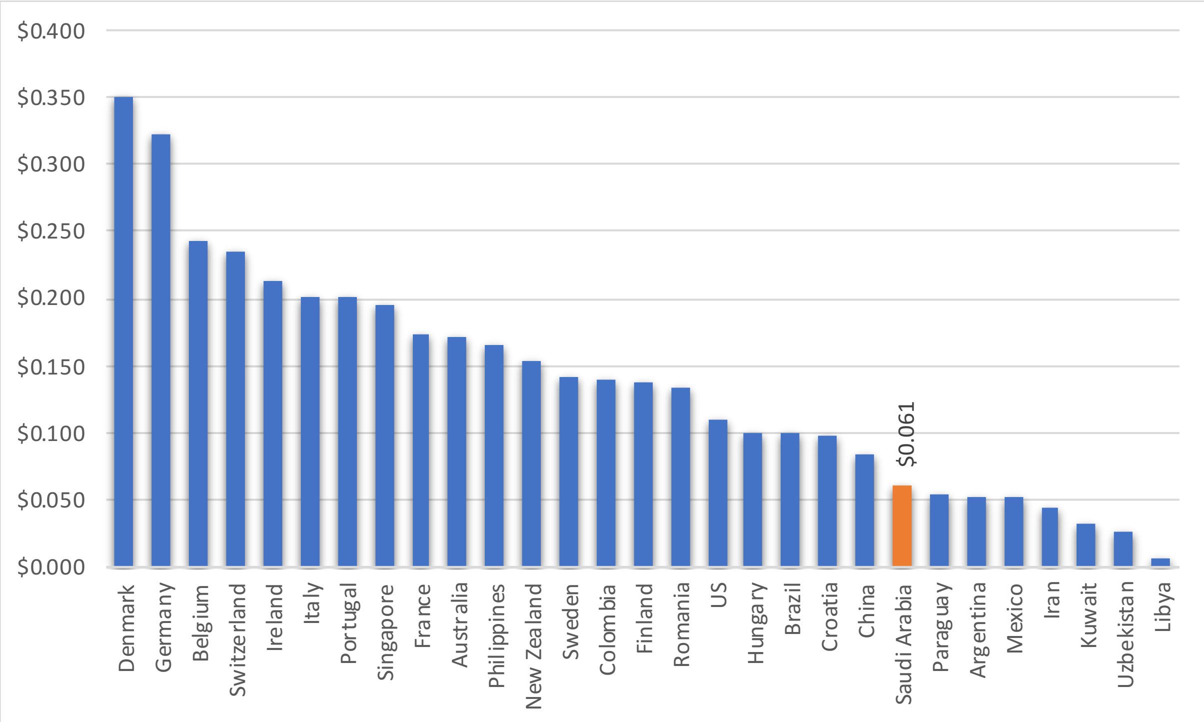


Figure 3.6 Comparing the average price of electricity tariff in Saudi Arbia with a tariff for selected countries in the world
(generated from Cable.co.uk, 2021).

3.2.2.4 Temperature Characteristics of Saudi Arabia and the Need for Cooling

The Kingdom of Saudi Arabia is witnessing some climatic phenomena that were not observed before, such as snow in the Northern and Southern Provinces, the high humidity of the Arabian Gulf, and the irregular heavy rainstorms (Howarth *et al.*, 2020). The harsh climate in Saudi Arabia requires supplementary use of air conditioning, especially during the summer season. It was anticipated by some scientists that Saudi Arabia's weather would grow increasingly severe and hot. Almazroui *et al.* (2014) indicated that temperature in Saudi Arabia has been increasing at 0.65 °C per decade. Alghamdi and Harrington (2019) claimed that there had been about 1338 heatwave events in the nation in just 35 years. According to Almazroui

(2013), the Hijaz on the western region along the Red Sea is one of the locations likely to be affected by extreme rainfall events.

Lelieveld *et al.* (2016) stated that the Middle East and North Africa MENA region will be twice warmer compared to the winter by the end of the current century. The expected temperature increase in Saudi Arabia is about 6 ◦C during the summer months between 2081 and 2100 compared to the average summer months between 1986 and 2005. Indeed, from the beginning of June until the middle of September, when temperatures are at their highest, it is against Saudi labour regulations for outdoor workers to be on the job between 12 and 3 p.m. due to their safety since they can quickly get heat stroke. Hotter temperatures may also have an impact on water demand since many people are likely to get thirsty faster (Howarth *et al.*, 2020).

HDD and CDD degree day found to be significant in energy consumption research. The relative warmth or coolth during the day over a period of a day, month, or year represents the degree day value. The degree day value relates to the outdoor temperature of an area and the indoor temperature design (Indraganti and Boussaa, 2017). Several attempts have been made to evaluate the correlation between temperature and the consumption of energy in the Kingdom to calculate HDD and CDD (Al-Hadhrami, 2013; Indraganti and Boussaa, 2017; Howarth *et al.*, 2020). These authors indicate that approximately 50% of the energy demand in the Kingdom of Saudi Arabia is due to cooling needs. These studies have considered the day's average to be above or below the reference point of 18 ◦C, deemed the average temperature. Equation 3.1 shows how the American Society of Heating and Air-Conditioning Engineers ASHREA methods are used to calculate the monthly heating and cooling degree days.

$$CDD = \sum_{i=1}^{n} (T_m - T_b)^{+} \qquad HDD = \sum_{i=1}^{n} (T_b - T_m)^{+}$$

N = days in the month, T_b = the reference temperature, T_m = Average daily temperature, and the + sign indicates that only positive values are taken into account in the sum.

Equation 3.1 Monthly cooling (left) and heating (right) degree-days
(ASHRAE, 2021)

Indraganti and Boussaa (2017) used three-base temperatures for calculating HDD (14 °C, 16 °C, and 18 °C) and five-base temperature for CDD (18 °C, 20 °C, 22 °C, 24 °C, and 28°C). These base temperatures were the benchmarks used to obtain the regression equations to determine how the heating and cooling energy requirements differed in Saudi Arabian cities, such as Riyadh, Guriat, Khamis, Dhahran, and Jeddah. The study was a challenge since it was impossible to obtain the CDD models for the cities other than Riyadh in Saudi Arabia at base temperature 18 °C (Indraganti and Boussaa, 2017). This could be because of the weak relationship between the dependent variable (CDD18) and the independent variables. Howarth *et al.* (2020) further reported buildings' cooling and heating energy consumption patterns follow a U-curve as shown in Figure 3.7. Riyadh and Jeddah, located in Saudi Arabia, only appear in the cooling degree-days zone on the graph, indicating that Saudi Arabia places a significant emphasis on cooling loads to reach the comfort zone.

Cooling is among the most essential aspects for people living in Saudi Arabia, India, Venezuela, Egypt, Thailand, Brazil, and Indonesia because of the high CDD. In most Saudi Arabian cities, CDD is more than 3000, which necessitates air conditioners for the people to live and work comfortably (Howarth *et al.*, 2020). These estimates of increasing temperature in Saudi Arabia suggest that there is an urgent need to reduce energy consumption. Therefore, investigating the relationship between temperature and residential energy consumption in Saudi Arabis, especially in Makkah City, is one of this research objectives, without ignoring the potential effect of other climatic factors such as humidity and solar radiation.

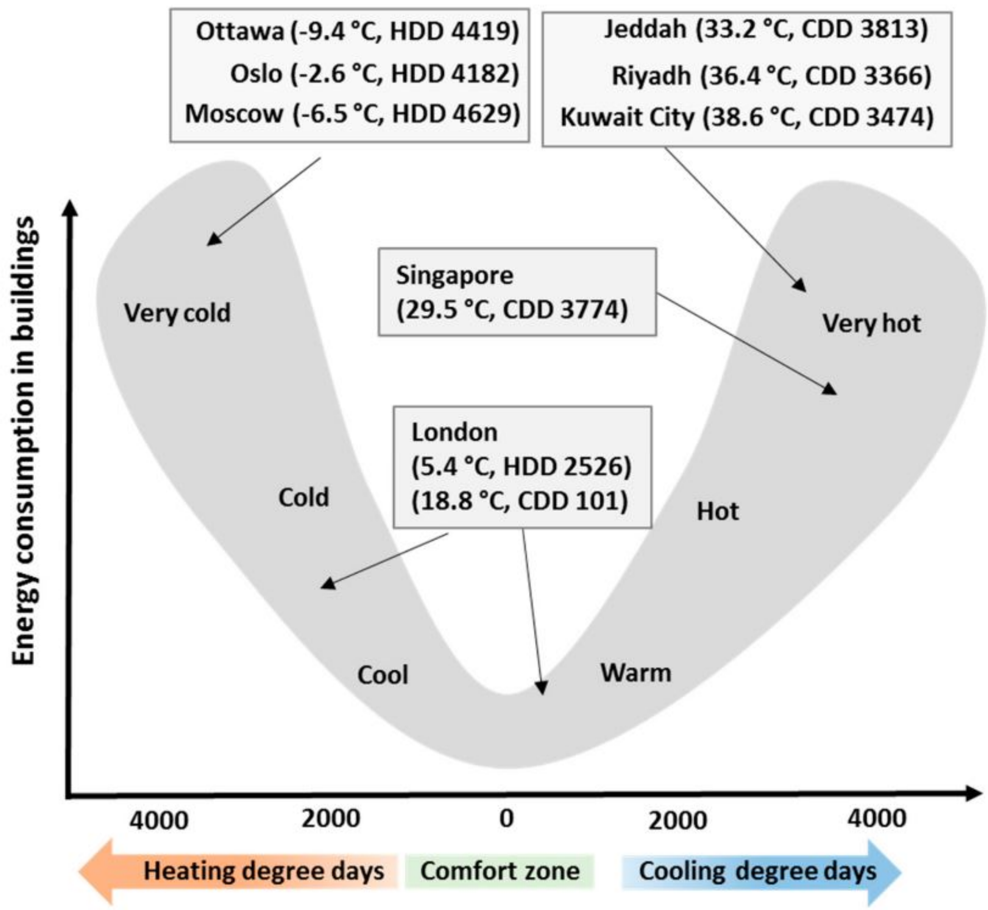


Figure 3.7 U-curve for cooling and heating energy consumption patterns
(Howarth *et al.*, 2020)

3.3 Energy Performance/Consumption

Most countries have issued standard building and energy codes with the primary target of producing more efficient buildings and energy supply systems. This approach may lead to a reduction of the overall energy use associated with building characteristics. However, reducing energy consumption in dwellings is a very sophisticated concept affected by other factors in addition to the building ones. An accurate estimation of the building's energy performance is one of the most fundamental criteria for architects, designers, and researchers to construct and design more energy-efficient buildings. Therefore, if a building's energy performance after occupancy differs from what has been predicted during the design phase, this discrepancy is known as the "*Energy Performance Gap*."

Occupant behaviour, among other factors like building attributes, household socioeconomic characteristics, and weather conditions, play a significant role in residential energy consumption, which is usually neglected during the design stage. There is also a growing demand for energy on a national and international scale, even though the quality of homes and HVAC systems is gradually improving. This research study emphasises the importance of the occupants' behaviour in determining actual energy consumption, which could account for up to 50% of the variance.

3.3.1 Energy Performance gap in Residential Buildings

Energy simulation tools are usually employed during the design process to forecast the energy consumption of a building based on design outcomes. However, several studies, such as Wilde (2014); Romero *et al.* (2013); Hong *et al.* (2017); Tam, Almeida and Le (2018); and Delzendeh *et al.* (2017) showed that there was a major disagreement between the actual energy use (post-occupancy) and the predicted energy consumption of a building. Romero *et al.* (2013 and Delzendeh *et al.* (2017) clarified that the real energy consumption of buildings is sometimes up to 3 times greater than the predicted one, which is referred to as an energy performance gap. According to Wilde (2014), the energy performance gap will remain unresolved until there is a shift in the standard procedures for designing and constructing buildings.

Housing consumption is thought to be highly influenced by the energy-related occupant behaviour factor both globally and locally (i.e., in Saudi Arabia). Efforts to foster energy-efficient buildings have increased over the past few decades. To achieve this goal, a plan must be developed to meet the demand for end-use energy services in cities while drastically lowering primary energy use and its effects on the environment (Bedir, 2017). Occupant behaviour must be included in this plan to reduce the energy consumption, especially in residential sector. The rationale is that there are major variations in the way occupants use electricity and the time they use it more, which are issues that are not captured by the prediction models made (Balvedi, Ghisi and Lamberts, 2018).

Human-building interactions are a very crucial issue to building systems and performance with modelling and simulation tools as well as the design and operation of energy-efficient buildings. There is evidence that the impact of occupant behaviour is over-simplified or under-recognised on the design, construction, operation and retrofit of buildings (Hong *et al.*, 2016; Delzendeh *et al.*, 2017; Yan *et al.*, 2017; Tam, Almeida and Le, 2018). Even if professionals used the appropriate tools to develop energy predictions, the results would still be subject to fundamental uncertainties because of the lack of knowledge about occupant behaviour, particularly with regard to variation in factors like actual weather conditions, occupancy schedule, internal heat gains, and plug loads (Wilde, 2014). Assessing electricity consumption in buildings with similar designs may be most appropriate strategy to investigate energy performance gap (Wilde, 2014), which will be addressed in this study (Chapter 5).

3.3.2 Uncertainties

The energy performance gap usually arises because of the limitations due to the uncertainty of the prediction models. These uncertainties can be due occupant behaviours, or environmental, or workmanship factors. Occupant behaviour has a considerable impact on a building's energy use and is a leading source of uncertainty when attempting to predict energy use, particularly in residential settings (Bedir, 2017).

The climate data uncertainties are concerned with the use of synthetic data files. Climate data is essential to consider since the expected lifespan of buildings makes it possible for them to be under different climates at different times, especially now that global warming is an issue. de Wilde and Coley (2012) showed that it is essential to design buildings that can operate under different climate conditions. The lack of consideration for the extreme weather conditions may lead to variance that may range between 0.5% and 57% when calculating energy demand (Wang, Mathew and Pang, 2012).

The uncertainties are usually due to the underestimation of the role of occupant behaviours, which suggests that occupants may have an influence on energy usage (Bedir, 2017). Lee *et al.* (2019) investigated residential end-use energy consumption for 71 households in Seoul, South Korea, and that there were significant differences in the consumption of cooling energy depending on the operating hours of the air conditioner, as some operated 2 hours or less while others consumed between 2 hours and 12 hours, and others more than 12 hours.

Additionally, the number of refrigerators and televisions displayed a positive relationship with energy consumption with a correlation coefficient of 0.360 and 0.389, respectively. This relationship depends on occupants' behaviours while in their homes (Lee *et al.*, 2019). Clevenger and Haymaker (2006) used different occupancy schedules and environmental preferences to study uncertainty in occupant behaviours and found there was a variance of 150% or more depending on whether the occupant behaviour patterns were minimised or maximised.

Even if the weather conditions, the building envelope, and systems are well-defined, one could still conclude that the presence of occupants and their interaction with the various building systems and components significantly impact the prediction of energy consumed by the building. Residential energy consumption is driven by interactions between occupants and different building systems, as well as other factors such as building envelope and indoor air quality.

3.4 A Brief Overview of the Emergence and Development of Occupant Behaviour Studies

Although numerous studies and research have tried defining occupant behaviour in buildings, all agree that occupant behaviour impacts energy consumption. The definition of occupant behaviour is simply the interactions between occupant and building characterised by the way the occupants control systems and devices that can influence energy consumption, such as windows and their blinds, air conditioning systems, lighting systems, or ventilation (Balvedi, Ghisi and Lamberts, 2018).

Past studies, reports, and research must be reviewed to ensure the development in the field based on the understanding of the impacts of energy-related occupant behaviour on residential buildings. For this reason, Tam, Almeida and Le (2018) conducted a study that reviews the impact of occupant behaviour on buildings energy use. A chronological review method was used to go back in the history of the occupants' behaviour studies, as displayed in Figure 3.8. The first research identified was by Dick, J and Thomas, D in the early 1950s. It focused on the interactions between the occupants, window- opening and ventilation systems (Tam, Almeida and Le, 2018). After the mid-1980s, the revolution of studies in this field begun to grow, which were directed toward stochastic models, adaptive occupant behaviour and indoor thermal comfort. According to Tam, Almeida and Le (2018), researchers had to slow down providing new fields in their studies after 2010. They started to focus on developing innovative approaches of existing fields of research such as the energy performance gap problem.

Some projects on the relationship between occupant behaviours and energy consumption in dwellings were conducted in the early 1990s. These studies showed that considering occupant behaviour matched the energy consumption patterns of the respective buildings between 40 and 70% of the time. They further showed that there were great variations in the different households depending on how the occupants used their electric appliances, family schedules, comfort preferences, and occupancy patterns (Tam, Almeida and Le, 2018). The conclusion was that there was a need to account for these additional factors to minimise energy-related occupant behaviour. The first point was to make the public aware of the impacts of their actions and behaviour on the building energy performance. The second point was to provide a technical manual with each building to make sure that the users are well informed of the proper practices when dealing with building systems. Finally, a real alteration of the existing rating systems is highly recommended due to the lack of consideration for occupant behaviour, which leads to differences in real building energy use (Tam, Almeida and Le, 2018).

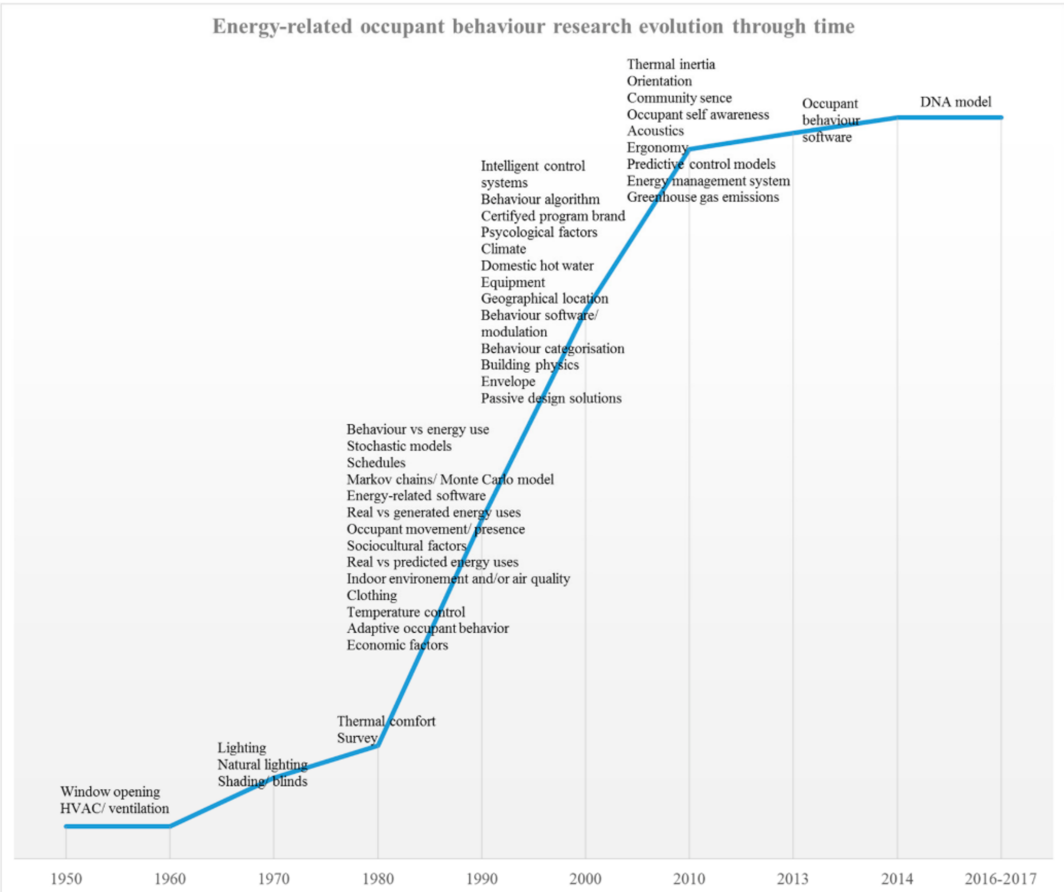


Figure 3.8 Energy-related occupant behaviour time line since 1951
(Tam, Almeida and Le, 2018)

The IEA Annex 53 final report was released in 2013 and has since been used to understand better the factors influencing the occupant behaviour. It allowed better understanding of the total energy use and enhanced a reliable quantitative assessment of energy saving policies, techniques, and measures (Yoshino, Hong and Nord, 2017). The IEA approved Annexe 66 project in November 2013 "*Definition and Simulation of Occupant Behaviour in Buildings*" to help understand, quantify, and model occupant behaviours and their impact on energy consumption and indoor environmental quality (Yan *et al.*, 2017).

The behaviour of occupants when engaging with building's systems and devices and their impact on buildings' energy consumption has been the subject of considerable research in recent decades. However, there is a lack of research studies investigating the impact of occupant behaviour on dwelling energy use in Makkah, Saudi Arabia. Therefore, most of the available works of literature have shown that ignoring the user actions and behaviour is very crucial to the predicted energy model during the design stage as well as the actual energy use during the operation of the building, which represents a clear gap between the actual and predicted energy consumption (Hong *et al.*, 2017; Ruan *et al.*, 2017; Balvedi, Ghisi and Lamberts, 2018).

3.4.1 Classification of Occupant Actions

Several studies have produced different classifications of the occupant attitude in buildings toward energy. One of these categorisations is an active user who adjusts the thermostat setting in order to obtain a more comfortable temperature, a medium user, and a passive user who does nothing and accepts the consequent discomfort (D'Oca *et al.*, 2014 and Delzendeh *et al.*, 2017). Furthermore, the occupant behaviour within residential buildings has another classification depending on their complexity, which is simple, intermediate, and complex users (Chen *et al.*, 2015).

The general tendency of humans is to seek out pleasant and comfortable environments and avoid unpleasant ones. Subsequently, behavioural intentions have a direct impact on intended behaviour. These intentions are the outcome of perceptions, conventions, and attitudes. Beliefs in behaviour, standards and control motivate behaviour. Yan *et al.* (2018) demonstrated that the primary connection between occupant behaviour and the energy consumption is accredited to the pursuit of environmental comfort of occupants.

However, there are various levels of people's activities and reactions to restore their comfort if a change happens. For instance, adding clothing, using fans or air-conditioners, lighting control, window opening/closing, and adjusting window blinds. The occupant behaviour through activities such as watching television, studying, and washing and changes in indoor environment and activities that generate metabolic rate are important considerations since they affect energy consumption (cited in Bedir, 2017).

3.5 Monitoring Energy Consumption and Occupant Behaviour: A Review of Methodologies

Occupant behaviour in residential buildings is monitored by tracking occupant actions, such as occupancy, window and blinds control, lighting control, appliance use, and cooling and heating system management. Occupant monitoring serves a variety of goals that include uncovering the elements that impact occupant behaviour and gaining insight into the ways in which certain behaviours directly or indirectly affect a building's energy consumption. It also helps identify typical patterns of behaviour to develop stochastic models for occupancy and interactions with building systems (Santin and Tweed, 2015; Yan *et al.*, 2015; Balvedi, Ghisi and Lamberts, 2018). Previous studies monitored occupant behaviour through occupancy along with other activities such as lighting, window, blind, or HVAC systems (Balvedi, Ghisi and Lamberts, 2018).

Much of the occupant behaviour research and studies have focused on having a realistic basis rather than making conventional assumptions about how we would expect occupants to behave. Balvedi, Ghisi and Lamberts (2018) proposed physical monitoring and occupant investigations for monitoring occupant behaviour. Questionnaires, diaries, observations, and interviews have also been used as part of energy consumption and occupant behaviour investigations. On the other hand, physical monitoring relies on equipment to keep track of how many people are in the building and what they're doing, such as switching lights on/off, using appliances, moving between spaces, adjusting the thermostat, and pulling up/down window blinds.

In-situ studies, laboratory studies, surveys, and mixed methods are the main data collection approaches, as shown in Table 3.2. These methods were introduced in the collaborative work of Annexe 66 to monitor occupant behaviour and interactions with building systems and devices (Yan *et al.*, 2018). In-situ studies are those in which the research monitors the occupants in their natural environment. Occupants' behaviour and presence are observed alongside indoor environmental variables, which are all passively monitored with the use of sensors incorporated into building automation system but can also be installed by researchers who want to study some aspects of the occupant (Yan *et al.*, 2018). The use of sensors to research occupants and other environmental variables is a long-term research approach that often has a smaller sample since some are unwilling to participate. There are different types of sensors that can be installed to monitor occupants dwellings such as motion detectors, carbon dioxide sensors, video cameras with computer vision, wearable sensors, security-based systems, and diaries. O'Brien and Gunay (2014) indicated that while there are high hopes that the method is comprehensive, it fails to provide detailed contextual insights about behaviours because of the possibility of privacy implications. In addition, it is a time-consuming process during the data collection phase.

Laboratory studies are another scientific monitoring method that uses a fabricated environment to quantify occupant comfort. The main advantage of the laboratory studies is that they provide data on physiological response to environmental stimuli based on the occupant characteristics, such as age, gender, and culture. These studies may be considered superior to the in-situ ones when different environmental considerations are considered (Yan *et al.*, 2018). Several disadvantages of laboratory studies have been published by Levitt and List (2007) and Yan *et al.*, (2018). One of the identified weaknesses is that behavioural models cannot be developed in laboratory settings due to the lack of longevity and a natural working or living environment. A second challenge to laboratory-based behaviour studies is the generalisability of the results, including how hard it is to reproduce a realistic environment, such as social constraints and dynamics, the absence of stressors, and the unfamiliarity with the environment and available adaptations (Yan *et al.*, 2015).

Surveys and interviews are widely used to monitor occupant behaviour (Yan *et al.*, 2017). Researchers have successfully used this method because they can understand the predominant behavioural characteristics of occupants and how they interact with building systems (Santin and Tweed, 2015; Feng *et al.*, 2016; Alshahrani and Boait, 2018). However, despite the wide use of surveys and interviews, previous researchers in the field of occupant behaviour identified fundamental issues including: (1) participants misrepresenting behaviour knowingly and unknowingly (Gunay *et al.*, 2014), (2) inability to recall behaviours by some participants in cases of discomfort (Gunay *et al.*, 2014; Yan *et al.*, 2015), (3) participants responding in unexpected ways during the data collection process (Yan *et al.*, 2015).

The main advantage of these methods is the fact that it is possible to determine logic and rationale of the occupant habits and behaviours. In addition, it is possible to work with a large sample, making it easier to understand the phenomenon being studied better, including the hard-to-study ones, such as thermal comfort sensation and clothing level (Yan *et al.*, 2018). Surveys are popular among researchers due to their cost-effectiveness. However, researchers need to be cautious when observing human interactions and behaviour in residential buildings. The relationship between the researcher and the subjects being studied can influence the study's results. Questionnaire responses may also be subjective, influenced by the direct communication between the researcher and the respondent. Balvedi, Ghisi and Lamberts (2018, p.469) stated “monitoring with equipment allows the researchers to distance themselves from the occupant, diminishing the subjectivity of the monitored results.”

Most of the available technological equipment that monitors occupant behaviour has inherent uncertainty, which might be due to its position in spaces, or even a restriction in its efficiency. Another critical problem with monitoring using the equipment approach is that it needs proper maintenance and attention and its visual appearance for occupants (e.g., cable placement), which might make occupants to adjust their behaviour. According to Balvedi, Ghisi and Lamberts (2018), visible cabling and devices may influence occupant behaviour, as it reminds occupants that their actions are being monitored.

Lastly, (Yan *et al.*, 2018) explained that researchers can use different methods simultaneously to achieve their research goals. Although a researcher may use the mixed method approach, they may place more emphasis on one approach, either qualitative or quantitative, depending on their focus. They may also consider that each approach should have equal weight in the research process. The mixed methods approach can be exploratory sequential, embedded, convergent parallel, or exploratory sequential (Creswell, 2009). Mixed methods in this study refer only to the type of data collected for analysis, whether it may be quantitative (e.g., measured data) or qualitative (e.g., documents and official reports). In Chapter 4, there is a further discussion regarding the research design and its methodologies.

Monitoring Occupant Behaviour Methods		
In-situ Studies	Laboratory Studies	Survey Studies
Use natural environment	Use fabricated environment	Use natural environment
Use of sensors	Use of sensors	No equipment needed
Long-duration data collection	Long-duration data collection	Short time frame
Limited sample size	Limited sample size	Large sample size
Expensive costs	Expensive costs	Cost-effective

Table 3.2 Comparison of available data collection methods for monitoring occupant behaviour

The investigation of occupants requires asking about the users’ activities within the building and compiling subjective data. There are several methods to collect occupant data, but Santin and Tweed (2015) emphasised that the most popular method used in occupant investigation studies is the questionnaires. Feng *et al.* (2016) investigated tenants' air-conditioning behaviour in residential buildings in Chengdu, China during the summer of 2013. They utilised a questionnaire technique that was distributed in 287 districts by the local survey team to acquire a broad sample of data on residents' air-conditioning behaviour patterns, demographics, and essential building characteristics; 1426 legitimate responses of the questionnaire were conducted. In addition, Alshahrani and Boait (2018) conducted a questionnaire that reached 451 participants, in which 383 of these completed and returned the forms. Their research aimed to find viable solutions to the problem of high energy demand related to the KSA's air-conditioning requirements in residential buildings.

Santin (2011) and Bedir, Hasselaar and Itard (2013) used a household survey carried out by the OTB Research Institute in the Netherlands. The main objective of the survey was to obtain information that could provide insights on the behaviours of the occupants. There were 323 cases covered, which considered some household characteristics such as the composition, years the occupant(s) have stayed in the same house, and household composition change, economic characteristics such as ownership, income, and electricity tariff, and individual characteristics such as education level, age, hours spent outside homes, and occupation. They also covered dwelling characteristics that included the number, type, and function of rooms and appliance use such as number of appliances in the household, appliance labels, appliance size, standby appliances, chargers, the type and number lighting devices, and the duration of use of the different appliances.

3.6 Integrating Occupant Behaviour in Energy Consumption Models

Residential buildings are consuming massive energy in Saudi Arabia. The total energy consumption of a house usually refers to the amount of energy required to support all energy-consuming end-uses, including the losses caused by the efficiency of appliances and systems (Swan and Ugursal, 2009). There is a need to present effective residential energy consumption models that consider the effect of all inter-related factors in homes, such as building characteristics, household socioeconomic characteristics, weather conditions, energy economic policy, and occupant behaviour. This section reviews the available literature on residential energy consumption models, which begins with an overview to the modelling techniques, provides examples of the published literature, and concludes with an evaluation of the strengths and shortcomings of the introduced methods.

Energy consumption modelling of buildings quantifies energy needs as a function of input factors. Models are often used to ascertain macro-scale energy supply needs for a region or country and micro-scale changes in energy consumption for a single residence due to a technological update or addition (Swan and Ugursal, 2009). Such modelling can inform policy decisions regarding energy demand and energy conservation in the residential sector. It can also help to detect consumption trends in specific household energy end-uses and address questions about the implications of the various influential factors on energy use. Swan and Ugursal (2009, p. 1821) demonstrated that "by quantifying the consumption and predicting the impact or savings due to construction/demolition, retrofits and new materials and technology, decisions can be made to support energy supply, retrofit and technology incentives, new building codes, or even demolition and re-construction".

The end-use energy consumption models have been categorised as either top-down or bottom-up models according to the vast majority of studies (Swan and Ugursal, 2009; Min, Hausfather and Lin, 2010; Fumo and Biswas, 2015; Matsumoto, 2015; Lee *et al.*, 2019). This terminology is used to indicate the relative importance of the data inputs (Swan and Ugursal, 2009). The uniqueness of the top-down models is that their focus is overall energy consumption and changes that take place in consumption in the long-term while considering macro level variables such as number of residential units, gross domestic product GDP, appliance ownership estimates, climatic conditions, the rate of construction or demolition of houses, and employment rates (Swan and Ugursal, 2009). On the other hand, bottom-up models focus on the individual household consumption in a certain region within a country. This approach must define individual households or end-use energy consumption while considering micro-level variables such as envelop performance, socio-economic conditions of the occupants, and the number of occupants in the households considered (Lee *et al.*, 2019). These top-down and bottom-up approaches and their categorisations for modelling home energy consumption are depicted in Figure 3.9.

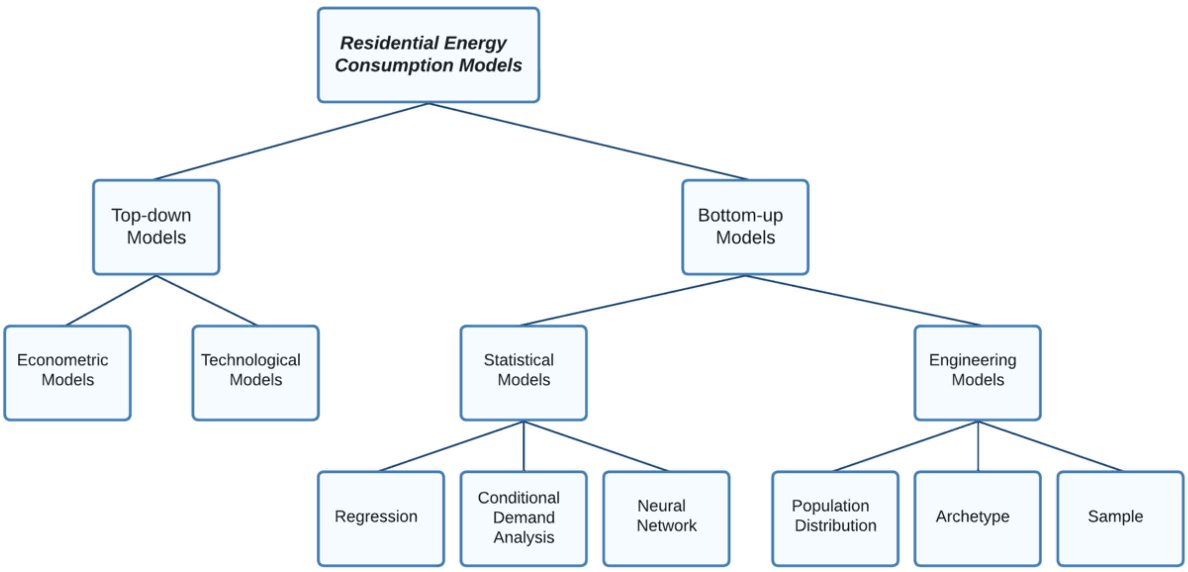


Figure 3.9 Classification of residential energy consumption models
(Swan and Ugursal, 2009)

The bottom-up model focuses on some households individually or a group and can be used to determine the energy consumption patterns in a certain region and used as a representative sample at the national level. The high level of input detail (micro-level variables) of bottom-up models is a strength since it is possible to model technological choices. The main disadvantage of this model is the requirement of a vast data input, which is not always possible in some cases. In addition, simulation models and calculations done in bottom-up approaches are exceedingly complicated compared to the top-down approaches (Swan and Ugursal, 2009). Nonetheless, bottom-up approach is preferred because it is possible to understand the effect of occupant behaviour on the aspects being researched. According to Swan and Ugursal (2009), bottom-up modelling can be divided into engineering and statistical models.

Engineering models can be used to calculate energy consumption based on the dwelling characteristics, the way appliances are used, and energy rating. They can also be used to effectively develop energy-consumption models even in cases in which there are no historical energy consumption data. On the other hand, statistical models focus on energy consumption data, the behaviour of the occupant, and dwelling characteristics. This model can be used to determine the relationship between household characteristics and energy consumption (Lee *et al.*, 2019). Fumo and Biswas (2015) concluded that the statistical models can be a worthwhile approach to predict energy consumption in residential buildings reasonably and accurately. Even though occupant behaviour must be included in the energy estimation models, it is considered exceedingly difficult practically as behaviour has been shown to vary widely and in unpredictable ways.

Utilising the statistical method has some drawbacks that researchers need to keep in mind. It relies on historical information to estimate future usage, which may be inaccurate when considering the present energy usage. The method is time-consuming since it requires a large sample size that can be a challenge to obtain in some cases (Al Qadi, Sodagar and Elnokaly, 2018). Previous studies indicate that forecasting energy consumption in various sectors has relied heavily on regression technique. Fumo and Biswas (2015) emphasised that linear regression analysis is a highly effective prediction tool that boasts reasonable accuracy and straightforward implementation. Based on regression analysis, the model's coefficient is determined based on input parameters, and the residential energy consumption is aggregated into parameters or groups of parameters believed to have an impact on energy consumption. In addition, input variables considered simple are removed because there is the assumption that they cannot have a significant effect, which may make the model to lack physical significance (Swan and Ugursal, 2009).

3.6.1 A Review of Regression Models for Determining the Variance in Electricity Consumption

The findings of existing research on electricity consumption in dwellings differ based on the fuel type used for heating and cooling space and heating water, as well as the existence and usage of air conditioning. A review of previous research and studies is presented here to demonstrate the usefulness of regression models for determining the variance in electricity consumption in Makkah City, Saudi Arabia.

Fumo and Biswas (2015) conducted a comparative study through simple linear regression, multiple linear regression, and nonlinear regression methods and analysed the results of simple and multiple regression analysis and a BEopt simulation through a case study house recorded by the TxAIRE Research and Demonstration. The recorded data includes information on energy consumption (dependent variable) and meteorological characteristics (independent variable). The finding of the study showed that the quality of the models improved as the time interval of observed data increases. When solar radiation is included as a second predictor variable along with the outdoor temperature in the multiple regression model, the coefficient of determination improves, but root mean square error decreases. This emphasises the need of evaluating the model's quality using both parameters. However, the results show that these two predictors explain 74% of the variation in electricity consumption (Fumo and Biswas, 2015).

Bedir, Hasselaar and Itard (2013) developed three regression models for predicting residential energy consumption in the Netherlands houses. The first model was based on the duration of appliance use and presence while the second model was based on the number of appliances and DHES characteristics. The third model was based on the total duration of appliance use and DHES characteristics. It has been found that the first model explained 37% of the variance in electricity consumption. The second model explained 42% of the variance in electricity consumption, and the last model explained 58% of the variance in electricity consumption. A conclusion can be drawn that the building and household characteristics and the duration of appliance use are significant predictors of energy consumption.

Huebner *et al.* (2016) used data from 845 households collected between 2011 and 2012 to compare several regression models to determine the factors that influenced energy consumption. They found that the significant factors that influenced energy use included the ownership and use of distinct types of appliances, such as lighting, which explained the reason for the 34% variability in energy consumption. The socio-demographic characteristics of the occupants accounted for 21% variability while building variables did not have a major impact. Combining all these factors showed a 39% variability while including some information on the appliances. The conclusion of the study was that the size of the dwelling and the nature of appliances influenced electricity consumption.

Al Qadi, Sodagar and Elnokaly (2018) reported that the type and age of dwelling, construction materials and wall insulation, the nominal heated area, monthly income, tenancy length, settlement type, number of months heated, and heating system type are the influential factors that influence how much energy is consumed. The heating energy consumption in Hebron, Palestine, was estimated using regression technique that explained 60.6 % of the variance. Al Qadi, Sodagar and Elnokaly (2018) suggested that it was possible to simplify the model to make it more user-friendly for policymakers, professionals, and building industry to estimate the heating energy Palestinian households in Hebron consumed. The effect of local climate and the outdoor temperature was not included in the analysis, which could provide an adequate improvement to the model.

In Seoul, South Korea, Lee *et al.* (2019) established six end-use models: heating, cooling, domestic hot water DHW, lighting, appliance, and cooking using multiple linear regression models. Regarding the ventilation end-use, regression analysis was not applied because the energy consumption proportion was extremely low. Instead, a calculation formula was derived for average bathroom and kitchen ventilation. The results showed that the variance in electricity consumption between the proposed regression models and actual usage ranged from 40.6 % to 70.3 %, depending on the end use. These regression models were validated with a different test group consisting of ten apartment units. The maximum error between the measured and predicted values was around ±30%. Lee *et al.* (2019) found that heating, cooling, and DHW error rates were much greater than lighting, ventilation, electrical appliances, and cooking error rates because they are affected by the weather conditions, and the latter end-use had less variation in energy usage throughout the year.

The study conducted by McLoughlin, Duffy and Conlon (2012) explores the influence of housing and occupant variables on residential electricity consumption patterns by analysing smart metering data from 4200 Irish homes. Multiple linear regression was used to total electricity consumption, load factor, maximum demand, and time of use of maximum electricity demand for several dwelling and occupant socioeconomic variables (McLoughlin, Duffy and Conlon, 2012). The findings show that the first model, which considers housing and occupant factors, does not explain much about electricity usage, but it may explain the underlying reasons for various energy use patterns. The second model, which looks at specific appliances, provides a better forecast of power usage patterns but does not explain the underlying reasons. The number of bedrooms, the age of the head of household, the social classes of the family, electric water heating and cooking, as well as the number of appliances and their usage patterns (i.e., tumble dryers and dishwashers), were the independent variables most strongly correlated to electricity consumption (McLoughlin, Duffy and Conlon, 2012). The conclusion of the study was that it was possible to reduce energy consumption among households when non-high priority home tasks are not done during peak hours.

For predicting Turkey's annual gross electricity demand, Günay (2016) used multiple linear regression and artificial neural networks models based on population, GDP per capita, inflation rate, and average seasonal temperatures. Results indicate that population and GDP per capita were critical determinants in electricity consumption. Chen, Wang and Steemers (2013) found that socio-economic characteristics and behaviour variables can explain 28.8% of the variation in heating and cooling energy consumption. Unlike the study of Santin, Itard and Visscher (2009), they discovered that building factors contributed to almost 42 % of the variation in heating energy consumption in the Netherland, whereas household characteristics and occupant behaviour account for only 4.2 % of the variation. In addition, Xu, Xiao and Li (2020) studied the effect of occupant characteristic-related factors OCRF on energy usage in dwellings. The results showed that energy consumption in dwellings can be influenced by OCRF and could explain 10.70% of the variance in electricity consumption. The age of the residents, size of the family, income, level of education, type of occupancy, and period of residence all play a significant role in this variability (Xu, Xiao and Li, 2020).

3.7 Key Findings of the Literature Review

Understanding household energy consumption is a complex matter, influenced by several factors such as building attributes, household socioeconomic characteristics, climate conditions, and occupant behaviour. All these aspects can impact the amount of energy a household consumes. When it comes to buildings, their attributes such as age, size, and design play a significant role. It's commonly known that older buildings tend to be less energy-efficient compared to newer ones, while larger buildings consume more energy than smaller ones. Table 3.3 summarises the global literature on building attributes that impact energy consumption and occupant behaviour. It outlines the studies' authors and dates, locations, and the various building factors identified as crucial in shaping household energy consumption, providing a concise yet informative overview of the most significant determinants.

Variables	Reference	Location
Floor area of the house	Yohanis *et al.* (2008)	Northern Ireland
	Lee *et al.* (2019)	Seoul, South Korea
	Sakah *et al.* (2018)	Tema city, Ghana
	Awan and Knight (2020)	Punjab, Pakistan
	Jones and Lomas (2015)	Leicester, UK
	Chen, Wang and Steemers (2013)	Hangzhou, China
	Aldossary (2015)	Saudi Arabia
Building type	Santin, Itard and Visscher (2009)	The Netherlands
	Yohanis *et al.* (2008)	Northern Ireland
	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Huebner *et al.* (2016)	England
	Jones and Lomas (2015)	Leicester, UK
Number of rooms and bedrooms in the house	Santin, Itard and Visscher (2009)	The Netherlands
	Yohanis *et al.*, 2008	Northern Ireland
	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Aldossary (2015)	Saudi Arabia
Building design	Santin, Itard and Visscher (2009)	The Netherlands
	Eon, Morrison and Byrne (2018)	City of Fremantle, Australia
	Aldossary (2015)	Saudi Arabia
Number of air conditioners and light bulbs	Lee *et al.* (2019)	Seoul, South Korea
	Chen, Wang and Steemers (2013)	Hangzhou, China
	Huebner *et al.* (2016)	England
Number of baths and showers	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Santin, Itard and Visscher (2009)	The Netherlands
	Aldossary (2015)	Saudi Arabia
The type of HVAC system	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Jones and Lomas (2015)	Leicester, UK
	Fumo and Biswas (2015)	Texas, USA
Building insulations	Santin, Itard and Visscher (2009)	The Netherlands
	Aldossary (2015)	Saudi Arabia
Dwelling age	Santin, Itard and Visscher (2009)	The Netherlands
Presence of thermostat	Santin, Itard and Visscher (2009)	The Netherlands

Table 3.3 International reference for building attributes that affect energy consumption and occupant behaviour

The socioeconomic status of a household encompasses factors such as income, education level, and employment status. Generally, households with higher incomes consume more energy compared to those with lower incomes. Moreover, households with a higher level of education tend to be more aware of their energy use. Table 3.4 provides a brief summary of the worldwide studies conducted on the correlation between household socioeconomic characteristics, energy usage, and the behaviour of its inhabitants.

Variables	Reference	Location
Income	Santin, Itard and Visscher (2009)	The Netherlands
	Yohanis *et al.* (2008)	Northern Ireland
	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Sakah *et al.* (2018)	Tema city, Ghana
	Huebner *et al.* (2016)	England
	Jones and Lomas (2015)	Leicester, UK
	Chen, Wang and Steemers (2013)	Hangzhou, China
	Ardakani, Hossein and Aslani (2018)	Nordic countries
	Xu, Xiao and Li (2020)	USA
Age and gender	Santin, Itard and Visscher (2009)	The Netherlands
	Yohanis *et al.* (2008)	Northern Ireland
	Lee *et al.* (2019)	Seoul, South Korea
	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Huebner *et al.* (2016)	England
	Chen, Wang and Steemers (2013)	Hangzhou, China
	Ardakani, Hossein and Aslani (2018)	Nordic countries
	Xu, Xiao and Li (2020)	USA
	Aldossary (2015)	Saudi Arabia
Number of occupants in the house	Santin, Itard and Visscher (2009)	The Netherlands
	Yohanis *et al.* (2008)	Northern Ireland
	Lee *et al.* (2019)	Seoul, South Korea
	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Sakah *et al.* (2018)	Tema city, Ghana
	Martinaitis *et al.* (2015)	Lithuania
	Huebner *et al.* (2016)	England
	Jones and Lomas (2015)	Leicester, UK
	Chen, Wang and Steemers (2013)	Hangzhou, China
	Xu, Xiao and Li (2020)	USA
Presence of children, teenagers, and the elderly	Eon, Morrison and Byrne (2018)	City of Fremantle, Australia
	Santin (2011)	The Netherlands
	Chen, Wang and Steemers (2013)	Hangzhou, China
	Jones and Lomas (2015)	Leicester, UK
Tenure type	Santin, Itard and Visscher (2009)	The Netherlands
	Yohanis *et al.* (2008)	Northern Ireland
Length of residency	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Xu, Xiao and Li (2020)	USA
Employment status	Jones and Lomas (2015)	Leicester, UK
	Ardakani, Hossein and Aslani (2018)	Nordic countries
Education level	Jones and Lomas (2015)	Leicester, UK
	Xu, Xiao and Li (2020)	USA
Electricity tariffs	Aldubyan and Gasim (2021)	Saudi Arabia
	Parry et al. (2014)	Saudi Arabia
	Aldossary (2015)	Saudi Arabia

Table 3.4 International reference for household socioeconomic characteristics that affect energy consumption and occupant behaviour

Furthermore, to design and operate energy-efficient homes, it is crucial to take into account the impact of climate variables on energy consumption and occupant behaviour. Table 3.5 provides a summary of the global literature on this topic. The findings indicate that local climate plays a significant role in determining the design of homes. For instance, in hot climates, minimizing solar heat gain should be a priority, while in cold climates, retaining heat is essential. It is important to note that the findings of these studies are only applicable to a specific set of locations. Further research is necessary to fully understand how these factors affect household energy usage in other regions of the world.

Variables	Reference	Location
Outdoor temperature	Fumo and Biswas (2015)	Texas, USA
	Akara et al. (2021)	Abidjan, Cotonou, Lomé (west African cities)
	Kang & Reiner (2022)	Ireland
	Howarth *et al.*, 2020	Saudi Arabia
Cooling and heating degree days	Akara et al. (2021)	Abidjan, Cotonou, Lomé (west African cities)
	Fikru & Gautier (2015)	Texas, USA
	Indraganti and Boussaa (2017)	Saudi Arabia
Solar radiation and Rain	Fumo and Biswas (2015)	Texas, USA
	Fikru & Gautier (2015)	Texas, USA
	Kang & Reiner (2022)	Ireland
Humidity	Akara et al. (2021)	Abidjan, Cotonou, Lomé (west African cities)
	Fikru & Gautier (2015)	Texas, USA

Table 3.5 International reference for climate conditions that affect energy consumption and occupant behaviour

Finally, occupant behaviour has been proven to have an important role on energy consumption. The term "occupant behaviour" pertains to the choices and actions made by individuals in their households, including the usage of appliances, temperature settings, and lighting. These behaviours can significantly influence energy consumption. If windows and doors, for instance, are left open while the HVAC system is running, the thermostat is set too high, or the insulation is inadequate, more energy will be used for heating and cooling. Table 3.6 summarises a number of occupant behavioural factors affecting residential energy usage, along with study references and geographic areas.

Variables	Reference	Location
Household appliances ownership	Yohanis *et al.*, 2008	Northern Ireland
	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Sakah *et al.* (2018)	Tema city, Ghana
	Eon, Morrison and Byrne (2018)	City of Fremantle, Australia
	Awan and Knight (2020)	Punjab, Pakistan
	Huebner *et al.* (2016)	England
Occupancy patterns	Santin, Itard and Visscher (2009)	The Netherlands
	Yohanis *et al.* (2008)	Northern Ireland
	Bedir, Hasselaar and Itard (2013)	The Netherlands
	Eon, Morrison and Byrne (2018)	City of Fremantle, Australia
	Awan and Knight (2020)	Punjab, Pakistan
Daily use of lighting	Lee *et al.* (2019)	Seoul, South Korea
	Huebner *et al.* (2016)	England
	Jones and Lomas (2015)	Leicester, UK
Temperature setting	Santin, Itard and Visscher (2009)	The Netherlands
	Lee *et al.* (2019)	Seoul, South Korea
	Chen, Wang and Steemers (2013)	Hangzhou, China
Daily use of air conditioners	Lee *et al.* (2019)	Seoul, South Korea
	Chen, Wang and Steemers (2013)	Hangzhou, China
Number of TVs	Lee *et al.* (2019)	Seoul, South Korea

Table 3.6 International reference for occupant behaviour that affect energy consumption

3.7.1 Determinants of Energy Consumption in Dwellings: A Framework of Occupant Behaviour Integration

The available literature categorised the factors that affect household electricity use as HVAC system features, dwelling characteristics, socioeconomic characteristics of the household, and appliance ownership and use. According to the findings of this review, only a small number of studies addressed these aspects in correlation. Most of the studies concentrated on only one or two of these aspects. Table 3.7 categorises the household socioeconomic and building characteristics, meteorological conditions, and occupant behaviour that influence energy consumption discussed in the relevant literature. The data conducted in this study in the quest to investigate the determinants of household energy consumption include (1) building characteristics, (2) household socioeconomic characteristics, (3) weather conditions, (4) and occupant behaviour.

It is important to underline that long-term monitoring of both winter and summer behaviour in terms of energy usage and comfort and validation are essential in Saudi Arabia. There is a need to modify the behaviour of the occupants or implement modern technologies that can allow reduced energy consumption. The building designers also need to have information about the user behaviours, so they devise ways to ensure effective energy usage. In addition, more information is required for developing legislation on a global and local scale, particularly incorporating occupant behaviour into energy conservation regulations. The significance of occupant behaviour in relation to building attributes, household socioeconomic characteristics, or meteorological conditions cannot be overlooked when evaluating the impacting factors on energy consumption. As shown in Figure 3.10, it is of equal importance and should be given the appropriate consideration.

Occupant Characteristics		**Building Characteristics**			**Meteorological**	**Occupant Behaviour**
Household	**Economic**	**Building envelope**	**Mass composition**	**Mechanical systems**	**Site & climate**	**Energy Consumption**
Age range	Tenure	Material use	Floor area	Cooling	Location	Appliances
Gender	Income	Insulations	Building type	Heating	Temperature	Lighting
Education level	Length of residency	Air tightness	Window design	Water heating	Solar radiation	Culture
Family size	Electricity tariff		Design elements		Wind	Lifestyle
Presence of elderly					Humidity	Hobbies
Presence of children						Habits
Occupation						Occupancy patterns

Table 3.7 Characteristics affecting energy consumption and occupant behavior
(Interpreted from literature review)

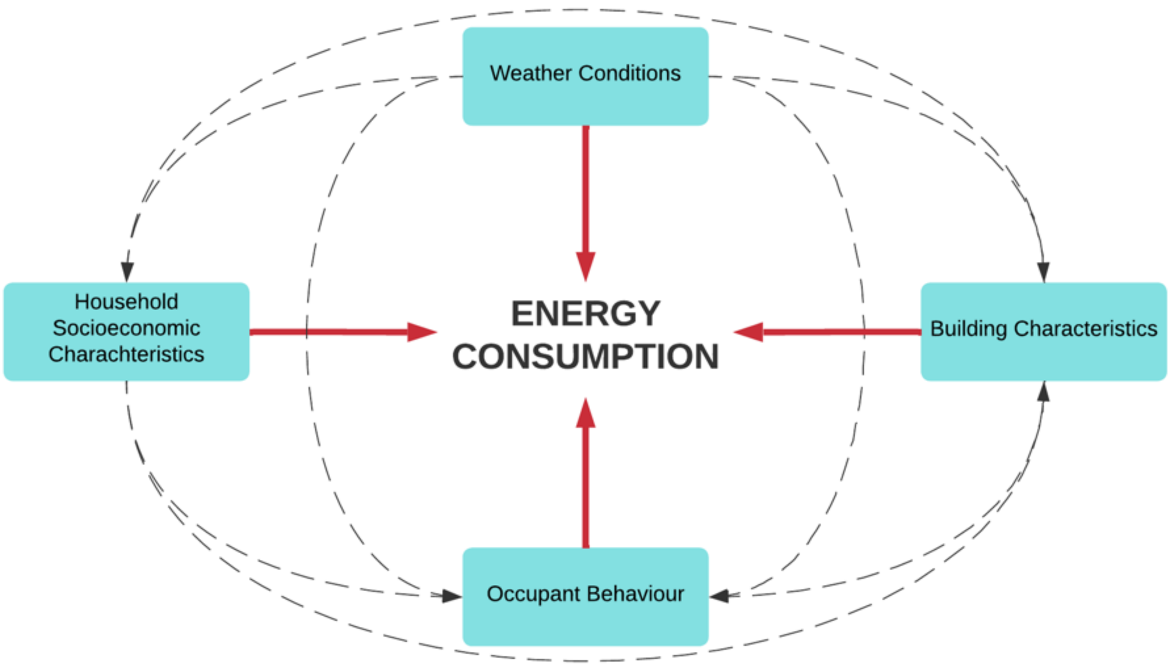


Figure 3.10 Framework to evaluate the influence of occupant behaviour and the other influential factors on residential energy consumption

3.8 Summary

This chapter displayed the findings of existing research and studies concerning energy consumption and its determinants conducted in various locations worldwide, including Saudi Arabia. The increasing contribution of the building industry to total energy consumption and environmental depletion is made clear by factors such as industrialization, population growth, rising energy consumption and CO_2 emissions, and the excessive use of natural resources and fossil fuels. Therefore, energy efficiency improvements across all sectors and the provision of more energy-efficient buildings, particularly residential buildings, have been a primary priority in the Saudi Arabian context. However, improvements in energy efficiency require an interdisciplinary strategy that considers all factors impacting energy consumption, including household socioeconomic characteristics, building attributes, occupant behaviour, and meteorological condition. The purpose of this study is to determine the factors that affect energy consumption in Makkah dwellings in Saudi Arabia and to clarify the impact of occupant behaviour on energy consumption.

Numerous factors impact energy consumption in residences, including building design and construction materials, household demographics, occupants' behaviour, and economic and climate conditions. The characteristics of a building can have an impact on its energy consumption as they can affect the amount of energy required for lighting, heating, and cooling. Additionally, the choice of construction materials plays a significant role in energy efficiency, as some materials are more efficient than others. Household demographics can significantly impact energy consumption; as a general rule, the more individuals living in a household, the more energy they consume. Furthermore, the way occupants behave in their homes plays a crucial role in determining energy consumption. Leaving lights on when leaving a room, for instance, can lead to a significant increase in energy usage. The climate can also affect energy consumption, as dwellings in colder climates require more energy for heating, while dwellings in warmer climates require more energy for cooling.

Nevertheless, inadequate research studies have been conducted to thoroughly examine the factors influencing the household electricity consumption in Makkah, Saudi Arabia, specifically regarding occupant behaviour. The next chapter will discuss the methods used to collect and analyse data for this study. A questionnaire will be administered to residential buildings in Makkah, Saudi Arabia to acquire the necessary data. The survey will cover topics such as the building attributes, household socioeconomic characteristics, and occupants' behaviour and energy consumption habits. Furthermore, actual household energy consumption records and actual weather data will also be obtained. By utilizing statistical analysis methods, this research will identify the factors that affect energy consumption, identify the extent to which each factor contributes to the overall variance in residential energy consumption, and provide suggestions for minimizing energy consumption in residential buildings. This would assist in the improvement of energy efficiency legislation as well as the energy efficiency of residential buildings Saudi Arabia.

Chapter Four:

Research Methodology

Chapter 4: Research Methodology

4.1 Chapter Overview

This chapter provides a comprehensive explanation of the methodology that was designed throughout the research process to guarantee that it properly addressed the questions and objectives of the study. However, due to a lack of data and resources regarding occupant behaviour in Saudi Arabia, one of the most significant challenges was assigning the best methods and techniques for the research. Figure 4.1 shows the chapter structure as follows: (1) Overview, (2) Research Design, (3) Research Stages and descriptions and ends with the research flowchart and conclusion. The first section will describe and clarify the fundamental concepts and terms related to the methodology that is applied in studies. The second section will outline the approach used to answer questions and achieve the primary aim of the research, as well as the established research roadmap. The third section will examine the methods or strategies employed at each stage together with their applicability and outcomes.

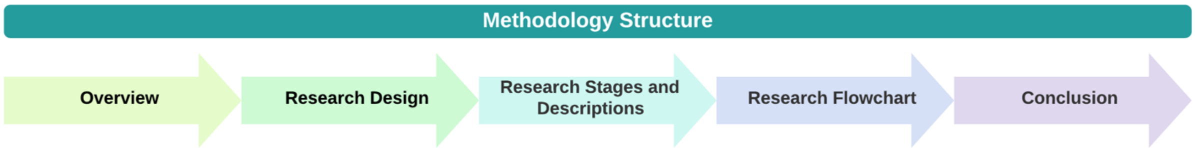


Figure 4.1 Methodology Structure

At this stage, it is important to distinguish the difference between a research methodology and research methods. All strategies and techniques used to conduct research are referred to as research methods. However, Kothari (2004), describes the research methodology as "a way to solve the research problem systematically. It may be understood as a science of studying how research is done scientifically". In other words, the process and procedures used by the researcher to analyse the research problem, as well as the logic behind them, are referred to as the research methodology. Furthermore, the researcher seeks to contribute to the available literature within its discipline by way of searching for the truth via (1) study, (2) comparison, (3) observation and (4) experimentation, which is the basic definition of research (Kothari, 2004). To develop a reliable study, the researcher also must be aware that specific steps must be taken. Nevertheless, the dilemma that typically confronts a researcher is that they may often be unacquainted with these steps, how they are related to one another and the fact that a number of these decisions must be made in advance with the aim of creating an appropriate design (Figure 4.2). Therefore, Jonker and Pennink (2010) proposed a research pyramid that the researcher needs to understand. The pyramid is classified into the following four levels (Jonker and Pennink, 2010):

1- The research paradigm: how the researcher views 'reality'. A paradigm is expressed in his/her 'basic approach.
2- The research methodologies: 'a way' to conduct the research that is tailored to the research paradigm.
3- The research methods: specific steps that need to be completed in a certain (stringent) order.
4- The research techniques: practical 'instruments' or 'tools' for generating, collecting and analysing data.

The researcher is guided by the theoretical principles and beliefs that significantly impact the research process and can be organised into a research paradigm. A research paradigm, according to Johnson, Onwuegbuzie and Turner (2007, p. 129), is "a set of beliefs, values and assumptions that a community of researchers has in common regarding the nature and conduct of research". Jonker and Pennink (2010) also clarified that a research paradigm that is a set of beliefs and assumptions concerning how the world is viewed that informs and directs the researcher's behaviour. Therefore, adopting a research paradigm requires the researcher to give careful consideration to several critical practical considerations (Saunders, Lewis and Thornhill, 2019). As discussed above and illustrated in the diagram (Figure 4.2), the researcher must make a series of informed decisions steered by a clear view of the relationship between knowledge and the research process itself. These decisions include the research philosophy, reasoning approaches, strategies, techniques and procedures that are most appropriate for the study and subsequently justify them (Saunders, Lewis and Thornhill, 2019).

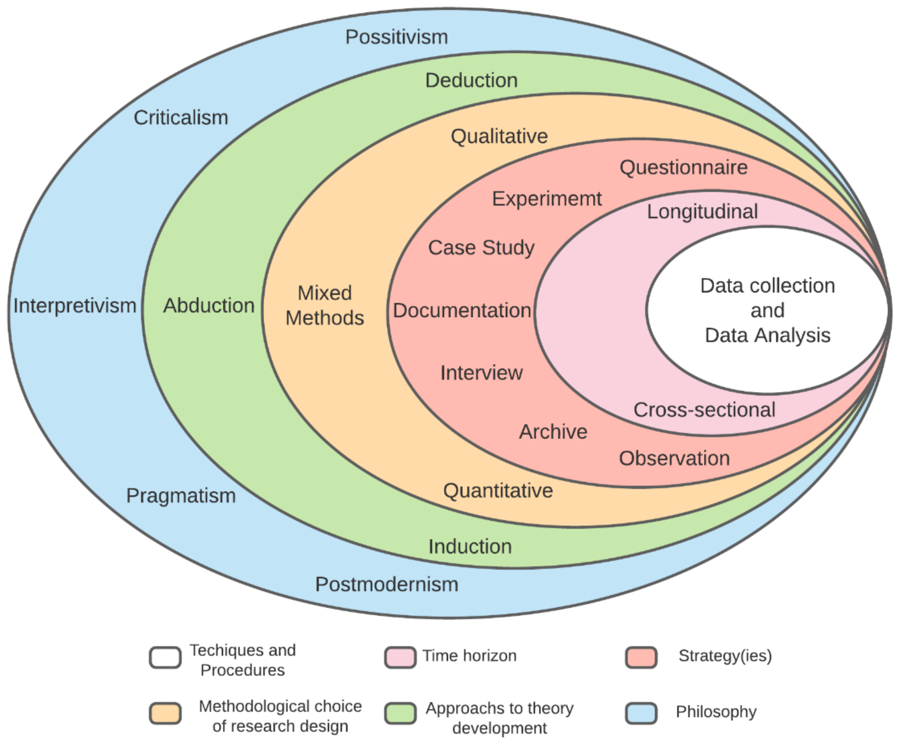


Figure 4.2 Research philosophy
(Saunders, Lewis and Thornhill, 2019).

This chapter also includes a detailed description of the methods and techniques employed for the data collection, as well as data analysis. Likewise, this chapter provides an explanation of the data analysis process used in this research. The research focuses on identifying the determinants of residential energy consumption in Makkah, Saudi Arabia and investigating the effect of occupant behaviours on energy consumption used for air conditioning, lighting and electrical appliances; specifically, how people regularly use their homes as a way of life. The research seeks to demonstrate the way occupants behave as regards the level of energy consumption in houses. It also concentrates on discovering the relationship between energy use and household socioeconomic characteristics, building characteristics and climate conditions. Hence, one of the benefits of this research is collecting, compiling and examining the realistic and current situation regarding the use of energy as well as occupant behaviours for dwellings in Makkah, Saudi Arabia.

4.2 Research Design and Justification

With respect to the fields of architecture, engineering and technology, it is not a novel idea to investigate the factors that influence the amount of energy that is used in the residential sector. The most widely recognised factors in the literature are government energy support, climate conditions, population increase, HVAC systems, construction details and building envelop, along with occupant behaviour (Duarte, Budwig and Wymelenberg, 2015; Delzendeh *et al.*, 2017; Yan *et al.*, 2018). However, occupant behaviour needs to be given greater consideration and scrutinised in order to acquire more insight and a complete understanding of such phenomena both globally and locally. While occupant behaviour can have a significant impact on energy consumption, it is challenging to monitor and accurately model and incorporate it into energy models. There are several reasons for this (Balvedi, Ghisi and Lamberts, 2018; Yan *et al.*, 2018):

1- Complexity: Occupant behaviour is influenced by a wide range of factors, including personal preferences, routines, cultural background, and environmental conditions, making it difficult to predict and model accurately.
2- Lack of data: There is limited data available on occupant behaviour, particularly in terms of how they interact with building systems such as lighting and HVAC systems.
3- Uncertainty: Even with available data, there is significant uncertainty in how individuals will behave in a specific building, making it challenging to make accurate predictions.
4- Dynamic nature: Occupant behaviour is dynamic and can change over time, making it challenging to model in a static simulation.

Overall, while the consideration of occupant behaviour in energy models is limited, efforts are being made to improve their accuracy and incorporate this essential factor into building energy modelling. Despite these challenges, some research has shown that occupant behaviour can have a significant impact on building energy consumption, particularly in terms of lighting and HVAC usage. As such, there is a growing interest in developing methods to model and incorporate occupant behaviour into energy models accurately. This could help building owners and occupiers make more informed decisions about energy-saving measures and improve the efficiency and sustainability of their buildings.

Over the years, the number of studies focusing on the influence of occupant behaviour on energy consumption has increased. Thus, papers with various research designs are now regularly published in a number of the highest-ranking journals in order to both qualitatively and quantitatively interpret occupant behaviour, boost energy efficiency, as well as reduce the gap between predicted and actual energy consumption. Several of these studies investigated the impacts of occupant behaviour on energy consumption in buildings focusing on one type of human action, such as window opening (Park and Choi, 2019), heating and thermostat usage (Santin, Itard and Visscher, 2009; Santin and Itard, 2010), cooling system (Feng *et al.*, 2016), electrical appliances (Yu *et al.*, 2015), and occupancy pattern (Martinaitis *et al.*, 2015; Buttitta, Turner and Finn, 2017). Furthermore, further studies explored occupant behaviour on numerous types of human activities such as occupancy, use of appliances, and window operation (Chen *et al.*, 2015), everyday practices for heating and cooling systems (Eon, Morrison and Byrne, 2018), and lighting and appliances usage (Huebner *et al.*, 2016).

Despite the fact that many studies have been conducted as regards residential buildings, there is a dearth of research exploring the impact of occupant behaviour on residential energy consumption in relation to Makkah, Saudi Arabia. The field of occupant behaviour needs further evidence concerning the impact on energy consumption and usage in Saudi buildings, especially in dwellings. Consequently, this research incorporated qualitative and quantitative approaches, resulting in a mixed methods design, as defined by researchers. The primary premise of mixed methods research is that combining qualitative and quantitative approaches yields better insights into the research problem than either approach alone (Creswell, 2014). "The mixed methods approach is becoming increasingly articulated, attached to research practice and recognised as the third major research approach or research paradigm, along with qualitative research and quantitative research" (Johnson, Onwuegbuzie and Turner, 2007).

Generally, numerical and textual forms of data can be reached by combining both qualitative and quantitative approaches into studies on the determinants of residential energy consumption, such as household socioeconomic characteristics, building attributes, weather conditions, and, particularly, occupant behaviour. Nevertheless, in a broader perspective, the term "methods" in mixed methods refers to the combination of various strategies and techniques relating to data collection (such as surveys, observations, interviews, documents, official reports, etc.), research tools (such as experimentation and ethnography), and philosophical issues (such as ontology, epistemology, and axiology) (Johnson, Onwuegbuzie and Turner, 2007).

The aim of this research is to identify the influential factors of residential energy consumption with particular emphasis on occupant behaviour for the use of air conditioning, lighting and electrical appliances in Makkah, Saudi Arabia. This will be achieved by utilising simple descriptive and advanced analysis and developing multiple regression models that can explain the variability of energy consumption between each factor. Consequently, this particular research will provide more extensive data and analyses of the study objectives and questions. More importantly, it is strongly recommended that different research techniques, including qualitative and quantitative approaches, can be used.

4.2.1 Type of Mixed Methods Approach Adopted in the Research

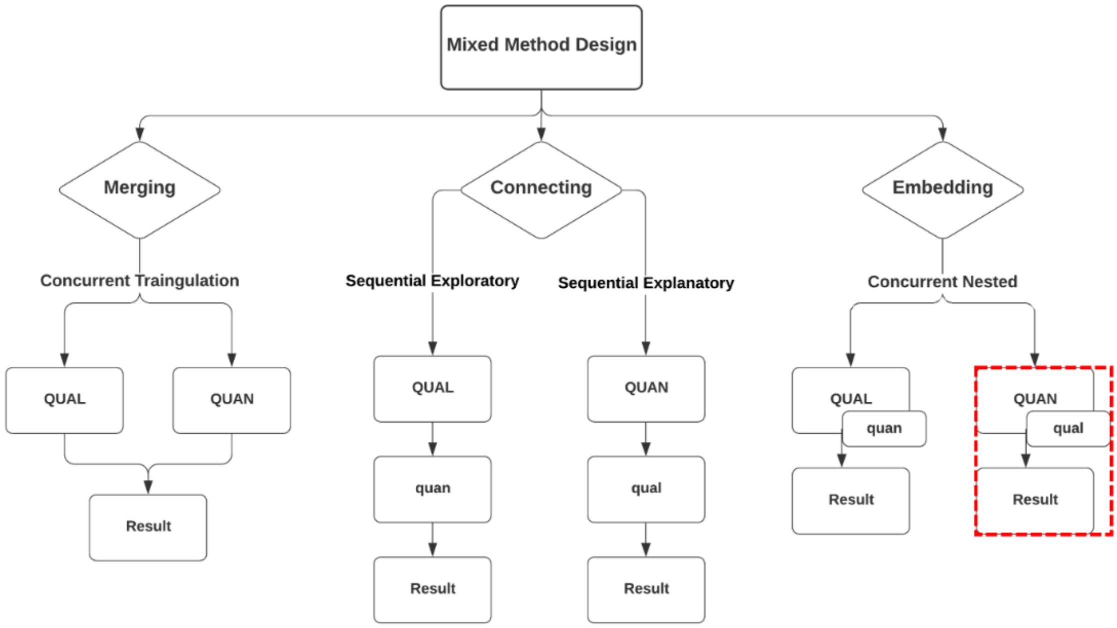
Strategies and processes for research that cover all decisions from general assumptions to precise data collection and analysis methods are the most straightforward definition of the research design methods. The nature of the research problem or topic being addressed, the researchers' personal experiences, besides the study's target audience all play a role in choosing a research design. Creswell (2009), classified study designs into three main categories: qualitative, quantitative and mixed methods. The author added that the easiest way to differentiate between qualitative and quantitative is to use words or open-ended questions (qualitative approach) rather than numbers or close-ended questions (quantitative approach). Over the years, researchers have provided several definitions for mixed methods that incorporate various aspects of methods, the research process and research purpose, as well as the philosophy (Creswell and Zhang, 2009). In this particular work, the research focuses on mixed methods as a methodology and sees the data collection, analysis and incorporation of quantitative and qualitative data as a valuable and tangible tool that helps to understand the process. From a method viewpoint, Creswell and Zhang (2009), rationalised that mixed methods research has various important characteristics. These are listed below:

- The researcher is required to collect and analyse both qualitative and quantitative data regarding the research questions and hypotheses.
- The researcher has to integrate, mix or combine the two forms of quantitative and qualitative data and their results.

- The researcher has to organise the procedures into specific research designs that provide the logic and process for conducting the mixed methods study.
- The researcher has to frame these procedures within theory and philosophy.

There are three different ways to combine qualitative and quantitative data, as shown in Figure 4.3: by merging where the results from both data types are compared or related; by embedding, which means explaining one data type results by the other; or by connecting which means building one data type on the other (Creswell, 2009; Herrera, 2017). Herrera (2017, p. 159) stated that "embedding data supports concurrent nested designs where a predominant data collection is extended by adding a second data collection to gain a broader perspective." Based on the four criteria indicated, the researcher used the concurrent strategy, which is one of several mixed methods designs presented by Creswell (2009).

The researcher could not regularly visit the data collection site for this study because it was gathered in a different country (Saudi Arabia) from the researcher's study country (the UK). Therefore, the concurrent strategy was chosen because it enables the researcher to collect data simultaneously, specifically both quantitative and qualitative data. To answer diverse questions in this study, the qualitative technique was embedded in the quantitative framework, a cross-sectional survey (see Figure 4.3). The researcher employed a combination of qualitative techniques, such as analysing documents and official reports, along with quantitative tools, such as household questionnaires, actual electricity records, and actual weather data. This approach yielded useful insights into household energy consumption patterns in Saudi Arabia. Additionally, qualitative documents and reports assist in constructing the overall framework for this research. Thus, the implementation of concurrent mixed methods in this study intends to consider the implication of occupant interactions for the actual energy use as well as the other influential factors. The purpose of combining quantitative and qualitative data was to gain a deeper understanding of the study problem, answer the research questions and manage the timeframe for the fieldwork (data collection).



* The letters "qual" and "quan" stand for qualitative and quantitative, respectively. Capital letters signify high importance or weight, whereas lower case letters denote lower priority or weight.

Figure 4.3 The most used concurrent designs strategy in research
(Generated from Creswell, 2009)

Accordingly, research undertaken by Bedir (2017) stressed that the methodology for investigating and modelling the impact of occupant behaviour on the energy consumption of buildings follows two main approaches: the deductive and inductive approaches. The difference between these expressions is that the deductive approach aims to test theory while the inductive approach is concerned with generating a new theory emerging from the data. Specifically, according to Saunders, Lewis and Thornhill (2019), the deductive approach, is utilised when a study begins with a theory, which is frequently derived from a person's reading of academic literature, and then a research strategy is developed to test the theory (Table 4.1). Inductive research, on the other hand, begins with data collection to investigate a phenomenon and ends with the generation or construction of theory (typically in the form of a conceptual framework). Due to the time constraints, limited resources and funds, besides the COVID-19 pandemic, this research only employed the deductive approach to test the theories available in the literature regarding the determinants of energy consumption; most importantly the effect of occupant behaviour and test them in the context of Saudi Arabia.

	Deductive approach	Inductive approach
Logic	When the premise of a deductive argument is correct, the conclusion must likewise be true.	Inductive reasoning uses a known presumption to generate unproven conclusions.
Generalisability	Using broad generalisations to describe specifics	generalising by moving from the specific to the broad
Use of data	Collected data is utilised to assess claims or hypotheses connected to an existing hypothesis.	Collected data is used to investigate a phenomenon, find themes and patterns, and develop a conceptual framework
Theory	Tests that either prove or disprove a theory	Creating and developing theories
Data Requirement	Cross-sectional data	Longitudinal data

Table 4.1 Deduction and induction: from reason to research
(Saunders, Lewis and Thornhill, 2019)

4.3 Research Stages and Descriptions

After presenting an overview of the research design and its rationale, this section will provide a detailed examination of the research procedure to fulfil the research aim and answer its questions. Stage one of this research provides the first step (Chapters 2 and 3), to explore and review the essential pillars of any nation, which are the economy, environment, and culture in Saudi Arabia and identify the factors influencing energy consumption in residential buildings, including occupant behaviour by means of the available literature. Stages two and three of the research were added to explain the research methods and techniques for data collection and data analysis. Stages four and five will provide the analysis of the results and the factors influencing residential energy consumption in Makkah and identify the most significant contributor, using several statistical techniques to meet the research objectives. The last two stages present and consider the findings and conclusion.

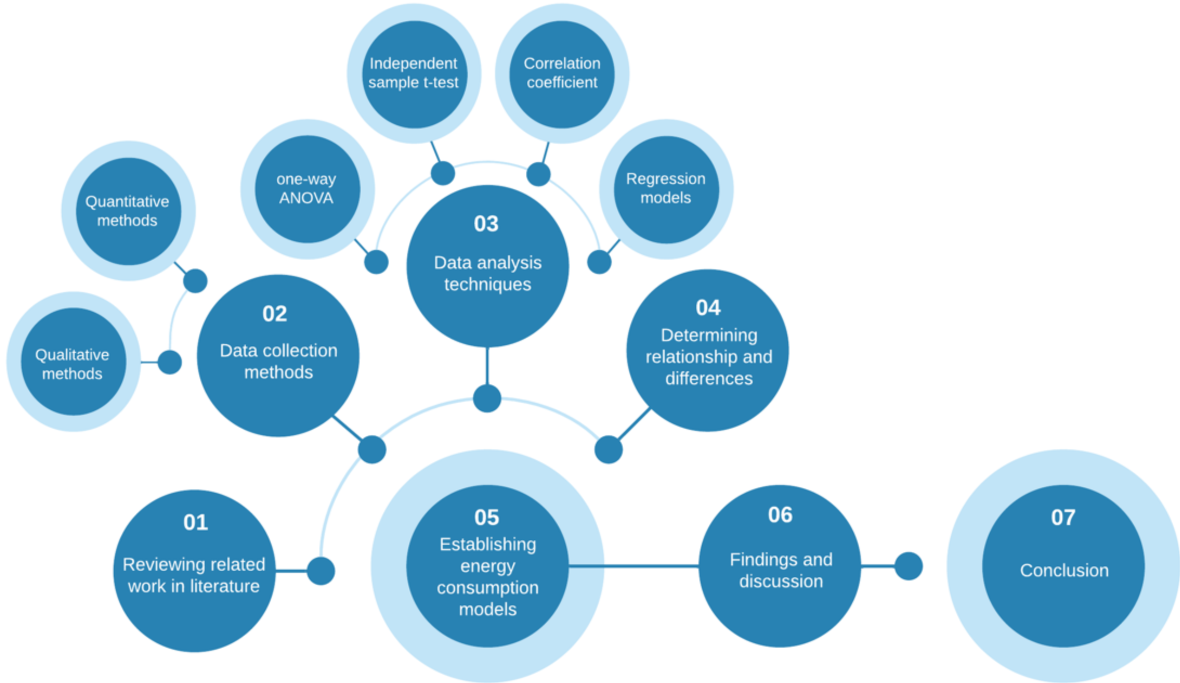


Figure 4.4 Research stages diagram

4.4 Data Collection Methods

This research aims to investigate the determinants of residential energy consumption in Makkah, Saudi Arabia and identify the role of occupant behaviours on energy consumption used for air conditioning, lighting and electrical appliances. The research also aims to identify the contribution of each factor, e.g., building attributes, household socioeconomic characteristics, meteorological conditions, and occupant behaviours, in the overall variation in electricity consumption. This section explains the data collection methods applied in this research and justifies why these methods were selected and how they were designed. The data collection stage for this study started in January 2020 and lasted for four months. Based on the research questions, five particular research instruments were utilised. In addition, this section offers insight into the data analysis methods utilized in this study, along with an explanation of why these methods were chosen and how they were implemented. It also discusses the data cleaning and preparation prerequisites, particularly quantitative data, that must be accomplished prior to the analysis.

4.4.1 Qualitative Techniques

According to Creswell (2014), qualitative research allows for the selective use of participants, places, documents, or visual materials to help the researcher better grasp the problem and the study topic. This does not necessitate using a large sample size or a random selection of people and places, as is common in quantitative studies. This research adopted the qualitative approach, such as secondary data and documentary data, to obtain a comprehensive understanding of the challenges and issues surrounding construction development and energy consumption in Saudi Arabia, with a specific focus on the Makkah region and the targeted neighbourhood. Mohajan (2018) argued that qualitative approach can assist with developing the research aim and objectives, besides the questions and theoretical frames. Incorporating the cultural and climatic contexts of Saudi Arabia into the research framework was an essential consideration throughout this study. These factors can play a significant role in shaping the occupant behaviours in Makkah and, in turn, how energy is consumed.

4.4.1.1 Secondary Data

Secondary data refers to previously gathered, analysed and published data by other researchers and organisations, as opposed to new data that must be collected through fieldwork. Using secondary data, the researcher can analyse and understand the results of data obtained from many sources and make reasonable conclusions about the research framework. Published books, journal articles, government statistics, dissertations, websites, and local and national newspapers all qualify as secondary data sources in this study. Using secondary sources is beneficial due to the abundance of information they provide. Governments conduct large-scale national studies (longitudinal data) that would be difficult for individual researchers to obtain. This enables researchers to examine trends and changes in phenomena over time. Insights gained from these sources, which were used in the preliminary stage of this research, helped the researcher better comprehend the social, cultural and economic norms of Saudi Arabia (Chapter 2) and identified the determinants of electricity consumption in different countries with particular reference to the impact of occupant behaviour that can be included in this study (Chapter 3).

4.4.1.2 Documentary Data

Document analysis is indeed one of the most common qualitative research methods, and it can be a valuable tool for gaining insights and in-depth information about a research subject. Creswell, John W. and Poth (2016) and Grant (2018) argued that when paired with other methods, documentary data can yield more in-depth insights and more information for an investigation. Accordingly, Grant (2018, p. 11) defined documents data as “content or objects which include written, graphical or pictorial matter, or a combination of these types of content, in order to transmit or store information or meaning”.

Documents data, for instance official reports, documents and maps include relevant information about Saudi Arabia, in general, and Makkah and the targeted neighbourhood specifically. The data was collected through several government entities, such as the Holy Makkah Municipality, Saudi Electricity Company, Saudi Energy Efficient Centre, and the Saudi Central Bank. Table 4.2 provides a summary of the collected data. The process of gathering the required documents was challenging, primarily because of the compulsory need for approvals. Therefore, using the researcher's social and personal networks in Makkah (the researcher's hometown) was essential to connect with people who could provide the necessary documents. It is important to acknowledge that the documentary data mentioned were collected concurrently with the quantitative data collection outlined in Section 4.4.2.

Organization	Collected Data
Electricity & Cogeneration Regulatory Authority (ECRA)	Annual reports in 2009, 2011, 2014, 2018, and 2019.
Ministry of Municipal Rural Affairs and Housing (MOMRAH)	Building permits in Saudi Arabia by region and type of permit from 1987 to 2019.
Holy Makkah Municipality	The Master plan of the Al-Iskan neighbourhood (the study area) and the digital architectural drawings
Real Estate Development Fund (REDF)	A guide to expanding villas in Al-Iskan neighbourhood for future development.
Makkah Region Development Authority (MRDA)	The comprehensive schemes of Mecca in 2011.
Saudi Energy Efficiency Centre (SEEC)	Annual Report in 2020.
Saudi Electricity Company (SEC)	Annual Report in 2020. The report provides an overview of the company's performance and accomplishments in 2020 and presents future objectives. It also provides statistics of electricity distribution and customer services.

Table 4.2 A summary of the documentary data collected from different government entities

4.4.1.3 Qualitative Data Analysis

*4.4.1.3.1 **Documents from the ECRA***

The ECRA regulates the electricity and water desalination industry by issuing licenses to individuals engaged in these activities. Its primary objectives include safeguarding the public interest and consumer rights, promoting consumer-centric services that allow for a choice among competing providers, and encouraging private sector investment in the Saudi electricity and water desalination industry while protecting their interests and ensuring fair economic returns on their investments. Additionally, the ECRA aims to establish a transparent and non-discriminatory regulatory framework for the industry and create an environment that fosters legitimate and fair competition among providers and suppliers (ECRA, 2010).

A collection of annual reports spanning five years, namely 2009, 2011, 2014, 2018 and 2019, have been gathered. These reports offer a wealth of information for those seeking to gain insight into the electricity industry in Saudi Arabia. The report provides a detailed outline of the regulatory framework, performance metrics, obstacles, and future objectives. Policymakers and planners can harness the reports as valuable resources to develop and implement policies that will advance this industry in Saudi Arabia. Below are some of the key findings outlined in the reports:

- The electricity sector in Saudi Arabia is growing rapidly. The total electricity generation capacity in the country reached 51,195 MW in 2009, to which various producers, including SEC, contributed. However, the capacity increased by 66% in 2019, which reached 85,185 MW.
- The electricity sector in Saudi Arabia is growing rapidly. The total electricity generation capacity in the country reached 51,195 MW in 2009, to which various producers, including SEC, contributed. However, the capacity increased by 66% in 2019, which reached 85,185 MW
- Electricity demand in Saudi Arabia is experiencing rapid growth, with the country's total consumption increasing by 49% in 2019 compared to 2009, with residential as the biggest consumer sector.
- In 2009, natural gas and crude oil were responsible for 72% of the energy production. However, by 2019, this figure had increased to 77%. The remaining fuels employed were diesel and heavy fuel oil (HFO).
- The rising demand for electricity is placing a burden on the nation's power grid. Despite the government's significant investments in the electricity sector, meeting the growing demand remains a challenge.
- The Saudi Arabian government strives to expand the range of electricity generation sources within the country. In this regard, the government is incentivizing the private sector to invest in developing renewable energy sources, including solar and wind power, as a means of promoting sustainability in the Kingdom.
- Several initiatives, such as the Smart Grid Project, have been launched by the government to increase the grid's reliability and hence the reliability and quality of energy supply in Saudi Arabia. Efforts have also been made to enhance the quality of the electricity supply, resulting in fewer blackouts.

The efforts of ECRA have contributed significantly to establishing a robust, productive, and dependable electricity industry in Saudi Arabia. The organization remains dedicated to sustaining its efforts to meet the escalating electricity demands in the country.

4.4.1.3.2 ***Documents from the MOMRAH, REDF, and the Holy Makkah Municipality***

The MOMRAH has provided valuable information regarding the construction industry in Saudi Arabia for three decades (from 1987 to 2019). Over the span of 33 years, Saudi Arabia has seen a significant increase in the total number of building permits issued. In 1987, a total of 15,678 building permits were issued, but by 2019, this number had increased to 103,485 permits. The average annual growth rate is 8.9% when we add up yearly growth rates and divide by 32 years. Furthermore, most building permits were for residential and commercial use. In 2019, a staggering 95% of all permits were issued for these purposes. The remaining permits were distributed among industrial and commercial use (3%), social and governmental use (1%), and educational, health, and mosque use (0.5%).

Based on the data collected, the Makkah Province issued the most building permits in 2015 and 2016, followed by Riyadh and Eastern Regions. This is likely due to the region's development and enhancement, particularly the Holy Mosque projects and its surroundings, creating demand for new housing and commercial buildings. In the years following 2016, Makkah Province has demonstrated a notable trend of consistently ranking as the second most active issuer of building permits. This suggests a sustained level of growth and development within the region's construction industry. The data also shows that residential buildings are the most common type of construction in Makkah Province, with over 90% of all constructions recorded during the given period, followed by commercial and industrial buildings. Figures are presented in Section 5.2.

In addition, the Master plan and architectural drawings for Al-Iskan, an area designated for conducting this research, have been provided by the Holy Makkah Municipality. Al-Iskan neighbourhood's Master Plan is a detailed document demonstrating the current situation for the area under investigation. The plan encompasses various elements, including the street and road layout, the location of parks and open public spaces, schools, hospitals and mosques, and the constructed areas. The architectural drawings offer more details of the building's design, providing detailed floor plans, elevations and sections, and other essential details drawings. Furthermore, the REDF has provided a guide to expanding villas in Al-Iskan neighbourhood for future development. The guide is an indispensable resource that provides residents with critical information and relevant details necessary for planning the future expansion of their housing. Its primary objective is to assist residents in understanding the current facilities available and help them prepare effectively for future expansion by providing detailed plans and strategies designed to ensure a seamless and successful expansion process. With this guide, residents can navigate the complexities of housing expansion and make informed decisions that will benefit them and their families for years to come.

Accordingly, the information gathered from the MOMRAH, REDF and the Holy Makkah Municipality is an essential asset to guarantee the successful completion of this thesis. This data offers detailed statistics on the Saudi Arabian construction industry from 1987 to 2019, as well as a comprehensive guide for future villa expansion in the study area. Additionally, it includes master plans and architectural drawings for the Al-Iskan neighbourhood, allowing for well-informed decision-making throughout the research process.

4.4.1.3.3 ***Documents from the MRDA***

The MRDA was established in 2000, aiming to advance the task of development and enhancement in the Makkah Al-Mukarramah Region. Its tasks include preparing structural, regional and strategic development plans for the region, conducting development studies and programs, and implementing major development projects. The comprehensive schemes of Makkah and the Holy Sites in 2011 have been collected. The comprehensive schemes are plans that thoroughly consider various themes and factors related to community planning, such as housing, the environment, transportation, economy, and infrastructure. The distinguishing feature of a comprehensive scheme is its ability to offer a diverse range of solutions to problems while also evaluating those solutions in the context of other scheme factors (MRDA, 2011).

The vision of these comprehensive schemes for Makkah and the Holy Sites was to balance the city's spiritual, natural and urban elements to provide long-term benefits to permanent residents and pilgrims. The comprehensive schemes showed how large permanent residents and pilgrims can be served through improvements to infrastructure and humanitarian services. They also show how to achieve a more harmonious relationship with the surrounding natural environment through interventions aimed at reducing dependence on non-renewable resources and improving the quality of life in a way that preserves human and environmental health.

The scheme proposed to change the shape of the Central District of Makkah and its means of transportation towards the Holy Sites to ensure the diversity of pedestrian movement to reduce congestion and pressure points. The Holy Mosque and its surroundings and urban streets were expanded as one of the scheme initiatives to improve the pilgrimage quality by designing a new multi-use urban fabric for the public transport facilities and new pedestrian paths to the Holy Sites through Jabal Khandama. Another initiative was the expanded pedestrian paths inside the Holy Sites corridor and the new accommodations and services for pilgrims, which is going to help accommodate the significant increase in the number of pilgrims during the next thirty years. In order for the scheme to be successful, suggestions have been made regarding housing and energy. These recommendations include:

- Establishing 250,000 housing units over the next ten years through cooperation between private sector development processes and public-private partnership development processes. The housing supply is recommended to replace structures that have deteriorated naturally or were demolished during redevelopment projects, as well as new structures to accommodate future residents.

- Establishing 920,000 housing units over the next 30 years to accommodate the estimated future population of 3,806,000.
- An assessment by the SEC for the waste-to-energy project. Therefore, the plant's construction must be initiated once the project's feasibility is confirmed.
- An evaluation from the SEC for the solar energy generation project, and if its feasibility is proven, initiate the plant's construction.

The comprehensive schemes of Makkah are a major undertaking that will significantly impact the city. The schemes can potentially make Makkah a more efficient, enjoyable, and accessible place for its residents and pilgrims worldwide.

4.4.1.3.4 ***Documant from the SEEC***

The esteemed Council of Ministers Resolution No. 363 established the SEEC in November 2010 but started functioning in March 2018 after the announcement of the Saudi Vision 2030 (SEEC, 2020). The objective of the SEEC is to be an energy efficient reference point internationally by working with related local and international public and private stakeholders and authorities to develop knowledge on best practices that can be applied in the Kingdom of Saudi Arabia and worldwide (SEEC, 2020). It also aims to ensure that the national energy resources are used sustainably for the benefit of the nation.

The report highlights the Centre’s efforts and challenges in promoting energy efficiency in all sectors in the Kingdom of Saudi Arabia. For instance, there have been ongoing efforts to decrease energy consumption in building sector by implementing energy efficiency standards. These efforts aim to increase the minimum energy performance coefficient for air conditioners to 57%, decrease the energy consumption of freezers and refrigerators to 22%, and reduce the energy consumption of domestic washing machines by 60%. Additionally, there is a focus on improving home and street lighting efficiency to 80% (SEEC, 2020). There are continuous attempts to increase public awareness about energy efficiency through various initiatives, including:

- The launch of focused campaigns on specific topics and messages, which are presented intensively and for about a month or more, through which multiple awareness messages are injected using various means of media communication channels to reach a wide segment of society members, such as:
    - A campaign aimed to increase awareness about the importance of purchasing energy-saving water heaters and how to identify them: it also provided guidance on the best practices to save energy while using them.
    - A focused campaign was implemented to promote energy-saving practices related to air conditioner usage before and after purchase. The campaign emphasized the benefits of selecting the most efficient air conditioner and

adopting proper consumption habits, which ultimately lead to reduced energy consumption and financial savings for the consumer.
    - A focused campaign was conducted to promote energy-saving habits in lighting consumption, both pre and post-purchase. The campaign emphasized the benefits of using more efficient lighting and adopting correct consumption behaviours, leading to reduce energy consumption and financial savings for the consumer.
- Organizing coordination meetings, interactive workshops, and insightful lectures Awareness programs through coordination meetings, interactive workshops, and insightful lectures tailored for specific audiences such as students from schools, universities, and technical colleges, regardless of gender.
- Participation in awareness pavilions in national festivals and events, and specialized local, regional and international conference exhibitions.
- Coordinating with government agencies to prepare and implement programs to educate their employees on rationalising energy consumption.
- The High-Efficiency Air Conditioners initiative was launched in April 2019, targeting all regions of the Kingdom to achieve the following objectives:
    - Stimulating local content and the private sector by raising the percentage of market competition in local factories.
    - Motivate citizens to buy high-efficiency air conditioners.
    - Rationalization of energy consumption in the Kingdom.
    - Protecting natural resources and reducing the burden on the government from producing electric power.

Overall, the 2020 annual report by SEEC shows that the Centre has made notable advancements in advancing energy efficiency in Saudi Arabia. Nevertheless, there are still some obstacles require attention to fulfil the Kingdom's high energy efficiency targets.

4.4.1.3.5 Document from the SEC

By order of the Council of Ministers in 2000, the SEC was established by merging existing regional electrical firms in Saudi Arabia's Central, Eastern, Western, and Southern regions into a single joint-stock corporation, which constitutes about 33,437 employees (SEC, 2020). The SEC's 2020 annual report provides a detailed and comprehensive description of all the company’s accomplishments in the year of the report, completed and ongoing projects, human resources, and financial performance and financial investments. The following summary presents some of the key findings outlined in the reports.:

- With a goal of installing 10 million smart meters by the end of 2020, the SEC managed to install 8.8 million meters despite the challenges posed by the COVID-19 pandemic.
- Installing 497 power-generating units at 40 power plants distributed throughout the Kingdom.

- The generating business line has significantly boosted its electrical power production to 181.8 Terawatt, representing 50.2% of the total electricity feeding the electrical system.
- Reducing generating plants' diesel use by over 69 million barrels, saving SR 2.305 billion at domestic prices and SR 11.424 billion at international prices from 2015 until 2020.
- The number of transmission substations reached 1,150 substations by the end of 2020.
- Delivering electricity services to 385,000 new customers across various sectors, including residential, commercial, industrial, agricultural, and governmental, increasing the number of customers to 10,122,895 at the end of 2020.
- Al-Fadhili plant commercial operation started in March 2020 under a cogeneration partnership between the SEC and Saudi Aramco. The plant is capable of producing both electricity and steam with a capacity of 1,504 MW.

The SEC's 2020 Annual Report clearly indicates that the company is primed for long-term success. With a sturdy financial position, a clearly defined strategic plan and business development, and a steadfast commitment to innovation, the company is well-equipped to thrive in the future. In addition, investors seeking to gain exposure to the expanding Saudi Arabian economy may find the SEC to be a favourable investment option.

4.4.2 Quantitative Techniques

4.4.2.1 Questionnaire

Cross-sectional surveys are an important technique employed to collect data pertaining to energy consumption and occupant behaviour, as discussed in Section 3.5. The questionnaire's reliability has been demonstrated in the previous literature. For example, Feng *et al.* (2016) considered occupants' air-conditioning behaviour in Chengdu dwellings, China during the summer of 2013. They employed a questionnaire that was disseminated across 287 districts by the local survey team. They aim of acquiring a broad sample of data on building characteristics, residents' air-conditioning behaviour patterns, and demographics. As a result, 1426 responses were received. Likewise, Alshahrani and Boait (2018) conducted a questionnaire that reached 451 participants. Of this number, 383 people completed and returned the questionnaire. The aim of their research was to ascertain possible solutions to the issue of high residential energy demand related to Saudi Arabia's air-conditioning requirements. As a result, the researcher used questionnaires to address the research's questions, aim and objectives, which investigate the determinants of residential energy consumption in Makkah, Saudi Arabia, concentrating on the impact of occupant behaviour on energy consumption.

Generally speaking, questionnaires are often utilised in descriptive and explanatory research. Descriptive research is concerned with surveys that explore attitudes and opinions and which investigate organisational practice, allowing researchers to identify and characterise the variability in various phenomena. On the contrary, explanatory or analytical research allows researchers to investigate and explain relationships between variables, especially cause-and-effect interactions (Saunders, Lewis and Thornhill, 2019). Therefore, prior to designing the questionnaire, researchers should carefully review the literature, have a comprehensive discussion about the concepts and to conceptualise their research correctly. Prior to designing the questionnaire, the researcher also must define the theories that need to be tested based on the preceding literature. Saunders, Lewis and Thornhill (2019) highlighted that the researcher, in particular, must be clear about the relationships he or she believes are likely to exist between variables, such as the dependent variable, independent variables, mediating variable and moderating variable.

One of the fundamental reasons to utilise the questionnaire in the current study is because each individual (respondent) is asked to answer similar questions; the researcher used a questionnaire to gather responses from a broad sample before analysing quantitative data (Saunders, Lewis and Thornhill, 2019). The questionnaire also presents an unbiased method of gathering information consistent with the respondents' knowledge, opinions, perceptions and behaviours (Creswell, 2009; Neuman, 2012; Saunders, Lewis and Thornhill, 2019). Nonetheless, Saunders, Lewis and Thornhill (2019) raised a cautionary point that researchers should consider before employing the questionnaire technique. They asserted that designing a suitable questionnaire is significantly more complicated than expected. Researchers must ensure that the questionnaire will capture the precise information required to answer the research question(s) and meet its goals.

Different methods could be used to conduct a questionnaire, such as face-to-face, internet, mail questionnaires, etc. There are also several ways to produce questionnaires, such as paper-based or web-based surveys. Conversely, researchers tend to rely on survey techniques that make use of new technology, including telephone, computer-assisted or internet-web based questionnaires (Neuman, 2012). Alternatively, questionnaire design varies depending on whether a respondent or a researcher completes it, as well as how it is distributed, returned or collected. Figure 4.5 depicts this variation in questionnaire methods (Saunders, Lewis and Thornhill, 2019).

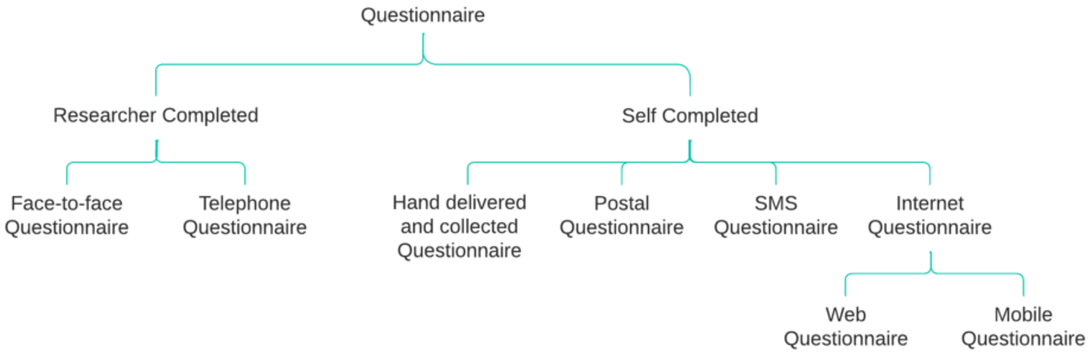


Figure 4.5 Questionnaire methods of data collection
(Saunders, Lewis and Thornhill, 2019)

Face-to-face questionnaires were combined with the internet questionnaire and used in this study (see the following Subsections for more details about the questionnaire design and implementation). The face-to-face technique refers to those questionnaires in which a researcher or a research assistant meets with respondents in person and asks them pertinent questions. Furthermore, the face-to-face technique has various advantages and disadvantages, which was taken into consideration during the fieldwork, as illustrated in Table 4.3. Unlike telephone or self-completed surveys, face-to-face questionnaires are ideal for lengthier questionnaires and they can include more sophisticated questions (Neuman, 2012). More importantly, understanding the countries and cultures where researchers collect research data is essential for international or cross-cultural research. It should be stated that it is easy to make mistakes, such as using incorrect terminology or language and collecting irrelevant data if the researcher fails to consider this (Saunders, Lewis and Thornhill, 2019).

Pros	Cons
It has a high response rate	Costs are more substantial than other questionnaire methods
More complex questions can be clarified as the interviewer is present	Consumes more time and money, besides the cost of transport, food, and the interviewer's preparation time.
It could be very convenient for respondents' cooperation and motivation	Can result in the respondent's answers and behaviour being influenced
Ability to incorporate visual stimuli into the questionnaire	Participant responses may be affected by "interviewer bias"
It can take a long time to collect the information	Face-to-face questioning may raise privacy and anonymity concerns. Less honesty on sensitive questions
It can involve participants who are difficult to engage fully in different survey techniques (e.g., elderly people, illiterate people, etc.)	Time and budget constraints, and limit the area that can be covered.
It provides more opportunities for the interviewer to observe and examine the surroundings	

Table 4.3 Face-to-face technique advantages and disadvantages
(Neuman, 2012)

In terms of the overall structure of the questionnaire, it can be either structured or unstructured. Kothari (2004, p. 101) stated that structured questionnaires comprise definite, concrete and pre-determined questions. Each respondent receives a questionnaire with questions that are exactly the same and in the same order. This kind of standardisation is employed to guarantee that all respondents answer the same set of questions. If any of the above features are missing from the questionnaire, it is referred to as an unstructured or non-structured questionnaire. For the purpose of this study, the researcher used structured questionnaires to collect pre-determined data, which proved to be an effective tool in the data analysis process.

Overall, different occupant behaviour questionnaires from the literature (the OTB survey which was utilised by Bedir, 2017 and Santin, 2011; Alshahrani and Boait, 2018; and the household energy survey from the General Authority for Statistics in Saudi Arabia were reviewed, adopted and modified in order to generate a questionnaire suited to the study's objectives and questions. To begin with, the researcher provided a specific review of literature on the influence of occupant behaviour on the energy consumption of dwellings, with the focus being on three significant aspects related to the domestic sector in Saudi Arabia: cooling system (air-conditioners), use of lighting and appliances, besides occupancy patterns.

4.4.2.1.1 Questionnaire Design

Saunders, Lewis and Thornhill (2019) remarked that to replicate or compare findings to those of another study, the researcher may need to adapt or adopt questions, which allows for evaluation of the reliability. It is also more efficient and faster than having to develop questions, as long as the researcher is able to collect the data required to answer the research question(s) and achieve your goals (Saunders, Lewis and Thornhill, 2019). Nevertheless, to obtain as many responses as possible, the length and detail of the questionnaire were considered. Furthermore, the questions were not in-depth, in order to not discomfort the respondents and violate their privacy.

In the beginning, the questionnaire was designed using 'Survey Monkey', a well-known online survey designer. The questionnaire included 67 questions. The questions comprise all three types of data, e.g., interval, ordinal and nominal. The questionnaire was written in English and subsequently translated into Arabic. Both versions were available during the data collection period. Saunders, Lewis and Thornhill (2019) emphasised that when translating questions and instructions into another language, care should be taken to ensure that the respondents answer the questionnaire correctly. Thus, concerning international research, the researcher must make certain that the survey questions have the same meaning for each respondent. To ensure this, it was tested in a pilot study, as discussed in the following subsection. Furthermore, the questionnaire was constructed in such a way that respondents were unable to skip any questions. Nevertheless, a technique known as skip logic was utilised for several questions depending on the respondents' responses. The time it takes to complete a questionnaire is one of the goals that can be accomplished via the application of the skip logic method. Also, the questionnaire was created to apply a duplicate prevention mechanism, which prevented multiple responses from the same IP address.

In the questionnaire for this study, the researcher employed variables that proved their significance from prior research findings, as well as new variables that were crucial to the culture and context of Saudi Arabia. Five sections stemmed from the 67 questions, including household socioeconomic characteristics, building characteristics, energy consumption and occupant behaviour (Table 4.4). It is crucial to clarify that the survey was specifically aimed at a single adult from each household, aged nineteen or older. This member is able to provide information for both themselves and on behalf of other family members.

CHARACTERISTICS			**ACTUAL BEHAVIOUR**				**ENERGY USE**
Dwelling	Household	Individual	Presence	Cooling	Appliances	Lighting	Energy use
Dwelling type	Family Size	Age range	# of occupants	Use of AC	# of appliances	Use of lighting	Electricity use
Total number of rooms	Presence of children & elderly	Gender	Presence of each room	Use of AC in Summer	Duration of use	Duration of use in bedrooms	Electricity bills
# of bedrooms	Presence of teenagers	Education level	Presence weekday	Use of AC in Winter	Location of appliances	Duration of use in living rooms	Gas use
# of bathrooms	Presence of housemaid & driver	Employment status	Presence weekend			Duration of use in bathrooms	Awareness of energy use
# of family living rooms	Length of residency					Duration of use in kitchens	
# of kitchens	Tenure Type						
AC type	Total Income						
Bulb type	Social habits						

Table 4.4 Variables included in the questionnaire

Section One focuses on the household socioeconomic characteristics, such as family size, gender, age, employment status, education level, total household monthly income, length of residency and tenure type. The information collected encompasses details regarding the participant as well as all individuals residing in the household. Furthermore, because housemaids and drivers are generally present in the homes of numerous Saudi families, it appears to be an important variable that the researcher should include in the questionnaires.

Santin and Tweed (2015, p.201), stated that “given the influence of occupant specificities in occupant behaviour (and therefore energy consumption), demographics and other socioeconomical questions can be added to a questionnaire”.

Section Two aimed to gather information pertaining to the building characteristics, which describe the physical parameters and fixed systems, despite the identical design of buildings in the targeted neighbourhood (discussed in Chapter 5). It includes building type, the total number of rooms in the house (excluding family living rooms and kitchens), the number of bedrooms, family living rooms, kitchens, bathrooms and guest living rooms, the use of solar panels, and air conditioning and lighting type. In addition, participants were asked to provide information about their presence and other household members in specific areas of their homes to gain insight into household occupancy patterns. These areas included family living rooms, bedrooms, and kitchens, and the questionnaire asked about time spent in these spaces on weekdays (Sunday-Thursday) and weekends (Friday and Saturday). The information provided is crucial in studying the correlation between occupancy trends and energy usage. It also helps in pinpointing areas that have a higher consumption rate during particular four-hour periods. However, it is important to note that the reported household presence in these areas was based on the estimations of the participants.

Section Three aimed to collect information about energy consumption comprising two subsections, e.g., electricity and gas consumption. The electricity consumption subsection includes meter reading check, an average electricity bill in the last 12 months and satisfaction with electricity bills. The gas consumption subsection covered the reason for gas use, delivery of gas, monthly gas consumption, if applicable, either gas cylinders or tanks. Section Four is dedicated to gathering information about occupant behaviour regarding the use of air conditioning, lighting, and electrical appliances. The questionnaire consists of inquiries regarding the usage frequency of air conditioning, natural ventilation, and electric fans in summer and winter seasons, as well as methods for controlling temperature. This research takes into account common practices in Saudi Arabia, which involve leaving the air conditioning and lights on while no one is present in the room/space and leaving lights on when no one is in the house, and the use and type of heating systems, if applicable.

As discussed in Chapter 3, accurate estimates of electricity use require knowledge of the voltage and amount of time each appliance is used; yet, this information is challenging for researchers to obtain, especially when studying a large sample. It is, therefore, necessary to seek out other obtainable information with high explanatory power. Thus, the questionnaire also includes gathering information on a provided set of electrical appliances' ownership, estimation of use duration (daily or weekly), and estimation of lighting usage duration in family living rooms, bedrooms, kitchens, and bathrooms. The questionnaire distributed is displayed in Appendix B.

4.4.2.1.2 Sampling Approach

Selecting the sampling for mixed methods research (quantitative and qualitative) is significant because it influences the conclusion at the end of the study. Similarly, the mixed methods sampling design is based on two dimensions which are time orientation (concurrent vs. sequential) and the relationship between the qualitative and quantitative samples (identical, parallel, nested or multilevel) (Herrera, 2017). The methods employed to collect data for a concurrent embedded design is executed by collecting quantitative data, e.g., questionnaires, energy consumption records, and meteorological data and qualitative data, such as documents and official reports, in parallel.

This research aims to identify the determinants of residential energy consumption and define the contribution of each factor to the energy consumption variance in dwellings. According to the researcher's knowledge, there is a gap in research regarding the impact of occupant behaviour, household socioeconomic and building characteristics, and meteorological conditions on residential electricity consumption in Makkah, Saudi Arabia. Although some studies have been conducted overseas, more research is needed in this specific area. Makkah in Saudi Arabia was selected to conduct this research because the researcher was born and raised there and thus has personal connections that may be leveraged during the gathering of important data. Furthermore, this was not the only reason for selecting this city; other reasons, which will be addressed in Chapter 5, were involved in the decision. Therefore, there is a real need to investigate the determinants of electricity consumption as regards residential buildings in Makkah and determine the contribution of each factor to the energy consumption variance.

A crucial step in the data collection process relates to identifying the participants and the location of the study. In this research, the broader selected samples are residents in Makkah, whereas the narrower level sampling is the households from the selected neighbourhood in the city. In regard to choosing a random sample, each resident in the population has an equal probability of participating. With randomisation, a representative sample from a population provides the opportunity to generalise to a population, remembering that selecting a random sample may be difficult if the list of participants is lengthy (Creswell, 2014).

Given that survey research is based on a sample of the population, the success of the research is contingent upon the representativeness of the sample in regard to the target population (Hu *et al.*, 2017). Based on the results of previous research and assessing the reliability of responses, the following equation was applied to establish the sample size at a 99% confidence level. The minimal number of samples required for analysis was calculated to be 530.

$$Sample\ Size = N \times \frac{Z^2 \times p \times (1-p)/e^2}{[N - 1 + \frac{Z^2 \times p \times (1-p)}{e^2}]}$$

where N is the population size; p is the sample proportion, which is 0.5; e is the margin of error, which is 0.05; and z is the z-score, which is 2.58 at a 99% confidence level.

Equation 4.1 Sample size calculation formula
(Hu *et al.*, 2017)

4.4.2.1.3 Questionnaire Implementation

Prior to presenting the completed questionnaire, the researcher had to examine whether each of the participants would read the questions in the same way and grasp the same meaning. Kothari (2004) explained that the pilot study is a rehearsal of the main survey. This method brings to light the flaws (if any) of the questionnaire and the survey techniques, which help with the survey improvements. Therefore, a pilot study was conducted with 26 individuals. However, only 13 surveys were completed. Following the completion of the pilot study, many participants from both groups, completed and uncompleted questionnaires, were interviewed. The primary reason was to ask how they perceived the questions and what could be done to improve the questionnaire. The questions were generally simple to understand. The respondents could answer them and easily follow the instructions, although most of the respondents expressed dissatisfaction with the survey's length (range from 60 to 80 mins), especially with the face-to-face technique. Therefore, the researcher made significant changes to the questionnaire in order to lower the number of questions and duration of the questionnaire.

The researcher also circulated leaflets around the targeted neighbourhood, to various places such as medical clinics, grocery stores, mosques, public areas and private residences. Over 1000 leaflets were distributed. The leaflet design can be found in appendix A. The reason this technique was employed was to motivate volunteers and emphasise the importance of their contributions to the community, city and country. Using the face-to-face technique, the researcher was able to complete approximately 63 questionnaires. As previously stated, only one individual who is 19 years or older per household was permitted to participate in the survey. Surveys were undertaken in different places, such as a respondent house, on the street, mosques, respondents' workplaces and coffee shops located in the targeted area. The face-to-face technique, in fact, took more time than the researcher expected. Hence, the time taken to complete the questionnaire was reduced from 30 to 45 mins**.** In addition to the random sampling methods, the researcher used the snowball sampling approach where participants who completed the survey could refer other participants, either relatives, friends or neighbours from the same targeted neighbourhood.

However, as a result of the prolonged time spent collecting the questionnaires using the proposed technique to cover all the sample and the lockdown that occurred because of the global pandemic, the researcher was forced to change the technique to continue working as planned. Therefore, invitations along with the link to the questionnaire were sent via 'WhatsApp'. The researcher also added the research information sheet with the invitation that explained the significance of the research and provided sufficient information to allow participants to make an appropriate (fully informed) decision concerning their participation. Thus, out of a total of 183 surveys, 80 questionnaires were completed.

The questionnaire was targeted at 530 households, with a response rate of about 27% (143 completed cases). Including the factors stated above, the length of the questionnaire, the essential details it required and the fact that respondents felt uncomfortable disclosing confidential information regarding their behaviours and personal belongings possibly was a factor in the low response rate.

4.4.2.2 Actual Electricity Consumption Records

In the targeted neighbourhood, most dwellings are powered by public networking provided by SEC except for cooking fuel which the questionnaire will establish. This means the residents are unable to switch their energy supplier as the entire city is powered by SEC. Furthermore, data pertaining to electricity records are not accessible to the general public and are difficult to obtain due to the client confidentiality. Therefore, the researcher participated in several meetings with the SEC executives to explain why it was important to collect the data.

Due to the considerable interest in residential energy consumption in this study, the researcher had to search for significant data related to the households' electricity consumption. The SEC provided data for a five-year period (January 2017 to December 2021) for each household in the targeted area. The data included actual electricity consumption (kWh/month), meter readings and subscription numbers for each household. To protect the confidentiality of the customers, their names were redacted from the data that was obtained. A total of 3,760 households electricity records were collected.

Every month, at the start of the billing cycle, the SEC takes metre readings to keep track of electricity consumption and compares them to the previous month's measurement in order to determine the price of the bill. The electricity tariff for residential buildings, on the other hand, has two different rates, either 0.18 SR/kWh for households that consume from 1-6000 kWh of electricity per month or 0.30 SR/kWh for those who consume more than 6000 kWh of electricity per month (see Table 4.5).

Consumption categories (Kwh)	Residential (Halalah / kwh)	Commercial (Halalah / kwh)	Agricultural & Charities (Halalah / kwh)	Governmental (Halalah / kwh)	Industrial (Halalah / kwh)	Private educational facilities, private medical facilities (Halalah / kwh)
1-6000	18	20	16	32	18	18
More than 6000	30	30	20			

Table 4.5 Electricity tariffs in Saudi Arabia according to the type of building

4.4.2.3 Weather Data

As noted in Chapter 3, weather conditions can impact not only the amount of energy consumed but also the behaviour of individuals. Therefore, meteorological data was collected through a weather station located in Makkah owned by the Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research. In the two-year period between 2020 and 2021, the data obtained was recorded hourly. The data relating to meteorological conditions include key parameters like outdoor temperature, relative humidity, rainfall, wind speed and direction, as well as solar radiation.

4.4.2.4 Data Analysis

4.4.2.4.1 Data Cleaning

The reliability and accuracy of the data analysis results are commonly established by means of data quality. Consequently, data preparation should be undertaken prior to data analysis (Xiao and Fan, 2014). The data preparation predominantly consists of three distinct tasks, specifically, data cleaning, data transformation and data reduction. Although raw data may comprise missing and error data and outliers data cleaning can be employed with the aim of solving this dilemma (Liang, Hong and Shen, 2016). Regarding the data error, an online survey generator was used to create the questionnaires, which then generated a link that could be texted to respondents or accessed via the researcher's iPad. Compared to conventional survey forms, this method eliminates the possibility of data transfer errors. Furthermore, the construction of the questionnaire, as mentioned in Section 4.4.1, guaranteed that there was no missing information on the data set. At this point, any questionnaires that were either incomplete or invalid were disregarded.

According to Xu *et al.* (2020), outliers can sometimes be error data and therefore, should be treated as such. Nevertheless, outliers indicate a few specific situations. Conversely, data coding, aims to change data from text format to code, so it can be analysed very easily. For instance, the questionnaires collected data concerning household demographics like employment status, where answers are in text format, such as retired, full-time and part-time employees, etc. Text format can be converted to number format by way of value assignment like 1 for retired, 2 full-time and 3 for part-time employees.

4.4.2.4.2 Data Preparation

a) Questionnaires

Using the example above as a guide, the first step in the preparation of questionnaire data was coding the data by giving each category in the text questions a unique number. A total of 31 out of 67 questions were coded. The second step was extracting information based on the respondents' answers. For instance, the presence of the elderly, teenagers and children in households has been extracted due to their high relevance in investigating determinants of energy consumption. Lastly, the questionnaires collected data on sets of electrical appliances, which was then combined into groups based on the appliances use. Subsequently, the number and total use of each group (mins/day) was calculated (discussed in Section 4.4.2.4.4).

It should be noted that although questions related to gas consumption and the duration of air conditioner use were included in the survey, they were excluded from the analysis due to the unsatisfactory responses. Regarding gas consumption, most families do not track their use. In actual fact, the researcher struggled to keep track of householders' gas supplies because there are numerous gas suppliers in the city and different methods of delivery, e.g., gas tanks and gas cylinders. Regarding the duration of air condition usage, all respondents chose "most of the time". The researcher anticipated this possibility and included a simple follow-up question about how often air conditioners are used, natural ventilation and electric fans.

b) Electricity Consumption Data

Data on electricity consumption comprises actual electricity use (kWh/month), meter readings and subscription numbers for a total of 3,760 households for a five-year period 2017 to 2021, as described in Section 4.4.1. Regarding the surveys, there are no names to establish which records belong to which households. Therefore, the researcher contacted the respondents who had filled out the questionnaire to obtain their subscription numbers so they could be cross-referenced with the SEC electricity data. Then, the monthly electricity bills of the households were calculated, taking into account all of the necessary costs, e.g., a monthly meter fee and

VAT. Additionally, monthly electricity consumption averages and electricity bills were computed. Only the electricity data related to the time period for which the questionnaires were gathered were taken into consideration during the course of the analysis (July 2019 to June 2020). Two out of 143 houses in the sample had high electricity consumption records. Subsequent checks revealed no data entry errors. Thus, these cases were included in the analysis.

c) Meteorological Data

The first step in preparing the hourly-based climate data was computing daily, monthly and yearly averages for all variables, such as outdoor temperature and relative humidity. Monthly and yearly CDD and HDD were also calculated using ASHREA equations described in Section 3.2.2.

4.4.2.4.3 Normality Distribution

Non-normality is measured on the shape of the violating distribution and the sample size. Several methods for assessing normality have been identified; these methods can be roughly categorised as graphical or statistical (Hair Jr. *et al.*, 2019). One of the significant statistical tests for normality is using skewness and kurtosis measures (available as part of the basic descriptive statistics for a variable computed by SPSS software). Skewness can be described as a measure of the asymmetry and kurtosis as a measure of the peakedness or flatness of a distribution. Positively skewed distributions have relatively few large values and long right tails, while those negatively skewed have relatively few small values and long left tails. The skew value of a normal distribution is zero, which typically indicates symmetric distribution. Alternatively, a positive value signifies a moderately peaked distribution and a negative value denotes a moderately flat (Hair Jr. *et al.*, 2019).

Concerning the normality test, skewness and kurtosis are applied to determine a z-value. It is important to mention that the distribution is non-normal if either calculated z value exceeds the specified critical value specified in the literature. The critical value emanates from a z distribution and is dependent on the desired significance level (Hair Jr. *et al.*, 2019). The z-value is calculated by dividing the skewness and kurtosis values by their standard error value, as illustrated in Equation 4.2, (Hair Jr. *et al.*, 2019). Therefore, skewness and kurtosis values and their standard errors are provided in most statistical packages, e.g., SPSS. Field (2017) and Hair Jr. *et al.* (2019) presented the most critical values that are regularly used for rejecting the null hypothesis taking into account the sample size as follows:

1- For a small sample size (N < 50), if the z-value for either skewness and kurtosis is out of the range, between -1.96 and 1.96 which corresponds to a .05 error level, then reject the null hypothesis and conclude the distribution of the sample is non-normal.
2- For a meduim sample size (50 ≤ N < 200), if the z-value for either skewness and kurtosis is out of the range, between -2.58 and 2.58 (.05 significance level), the researcher is able to simply assess the degree to which the skewness and peakedness of the distribution vary from the normal distribution.
3- For a large sample size (N ≥ 200), if the z-value for either skewness and kurtosis is out of the range, between -3.29 and 3.29 (.05 significance level), the researcher must analyse the shape of the distribution visually. Then, a decision was made as regards the degree to which the skewness and kurtosis of the distribution vary from the normal distribution.

$$Z\ value = \frac{\text{skewness}}{SE_{skewness}} \qquad Z\ value = \frac{\text{kurtosis}}{SE_{kurtosis}}$$

Equation 4.2 The calculation of the z-value for skewness (left) and kurtosis (right)
(Hair Jr. *et al.*, 2019)

4.4.2.4.4 Description of the Data

a) Transformed variables

Regarding the electrical appliances, respondents were asked about the ownership of several electrical appliances as well as the duration of use (min/day or h/week) in the questionnaires. These appliances were then converted into groups based on the appliances use and the number and total use of each group calculated (mins/day) (see Table 4.9). Five categories were established: general appliances, food preparation appliances, cleaning appliances, hobby appliances and extra ventilation appliances. Moreover, because most households have a refrigerator and washing machine, they were classified as general appliances rather than food preparation or cleaning appliances. The several sorts of home electrical appliances, together with the categories to which they belong, are summarised in Table 4.6.

Appliances group	Types of appliances
General appliances	TV, desktop, stereo/radio, refrigerator, washing machine, wireless telephone, hair drier, hair straightener, water-heater and shaver
Food preparation appliances	Freezer, coffee machine, electric kettle, toaster, electric grill/oven, microwave, electric cooker, cooker hood, water-cooler, juice blender and dough mixer
Cleaning appliances	Dishwasher, tumble drier, iron, and vacuum
Hobby appliances	Video game, broadband, home cinema set, DVD player and video recorder
Extra ventilation appliances	Extractor fans
Battery charge appliances	Mobile phones, laptops

Table 4.6 Electrical appliances groups by appliance type

Regarding occupancy, the data was obtained on a four-hour basis in the family common spaces, e.g., bedrooms, family living rooms, and kitchen. It was then transformed into dichotomous variables, as seen in Table 4.9. Additionally, occupancy data for each bedroom (according to the number of bedrooms in households) was gathered. However, only the primary and secondary bedrooms were included in the analysis because two-bedroom was the minimum number of bedrooms in the sample and contained no missing data. The justification for the comprehensive examination of parameter occupancy is that the presence in each room may deliver more information than the presence in the entire house, given that the activities that produce electricity consumption may be connected with rooms that have specific functions. In the Saudi Arabian context, bedrooms may use for several functions, such as sleeping, studying and hobbies.

b) Types of Variables

Generally, there are two different types of variables, namely numeric and categorical variables. Variables that cannot be quantified are referred to as categorical variables, for instance, employment status) and variables that can be quantified are called numeric variables, such as electricity consumption. Categorical variables can be either nominal or ordinal, while the only distinction between them is the importance of ranking in ordinal variables. Dichotomous variables are also considered categorical, yet they consist of only two-category levels. In contrast, a numeric variable can be either continuous or a discrete variable. A variable is continuous if it can assume an infinite number of real values within a given interval, whilst a discrete variable can assume only a finite number of real values within a given interval. The following tables provide information about the variables collected via the questionnaires and the variable type.

Variable	Variable type	Unit
Household size	Discrete	
Length of residency	Ordinal	“Less than 5 years, 5 to 10 years, 11 to 20 years, more than 20 years”
Education level	Ordinal	“Lower Education, Middle Education, Higher Education”
Age Range	Categorical	“Child (0-12 years), Adolescence (13-18), Adult (19-59), Senior (60+)”
Gender	Categorical	“Male, Female”
Employment status	Categorical	“Full-time, Part-time, Retired/Unemployed, Student, Housewife, Household Activities”
Tenure type	Categorical	“Owner-occupied and Tenant”
Yearly Household income	Ordinal	Less than 10K SR, 10K – 29,999 SR, 30K – 49,999 SR, over 50K SR
Presence of elderly people	Dichotomous	“Yes, no”
Presence of children	Dichotomous	“Yes, no”
Presence of housemaid	Dichotomous	“Yes, no”
Presence of driver	Dichotomous	“Yes, no”
Electricity tariff	Dichotomous	“6000 kWh or less, More than 6000 kWh”

Table 4.7 Variables related to household socioeconomic chatacteristics

Variable	Variable type	Unit
Building type	Categorical	“One-storey, Partial two-storey, Full two-storey, Excess two story, Apartment/Flat”
Change in building	Dichotomous	“Extended, Nonextended”
Floor area	Continuous	Square metre
Number of rooms	Discrete	
Number of bedrooms	Discrete	
Number of family living rooms	Dichotomous	“One family living room, two family living rooms”
Number of kitchens	Dichotomous	
Number of guests living rooms	Discrete	
Number of bathrooms	Dichotomous	“3 bathrooms, more than 5 bathrooms”
Air conditioners type	Categorical	“Window AC, Ductless AC, Central unit AC”
Type of temperature control	Categorical	“Manual control, Automatic control, Remote control”
Type of light bulb	Categorical	“LED, Halogen, Fluorescent, No Idea”

Table 4.8 Variables related to building chracteristics

Variable	Variable type	Unit
Presence in main bedroom	Ordinal	"Less than 12 hrs, more than 12 hrs", weekdays and weekend
Presence in bedroom 2	Ordinal	
Presence in main family living room	Ordinal	
Presence in family living room 2	Ordinal	
Presence in main kitchen	Ordinal	
Presence in kitchen 2	Ordinal	
Number of general appliances	Discrete	
Number of food preparation appliances	Discrete	
Number of cleaning appliances	Discrete	
Number of hobby appliances	Discrete	
Number of extra ventilation appliances	Discrete	
Number of batteries charger's appliance	Discrete	
Number of air conditioners	Discrete	
Duration of use, general appliances	Continuous	Minutes / day
Duration of use, food preparation appliances	Continuous	
Duration of use, cleaning appliances	Continuous	
Duration of use, hobby appliances	Continuous	
Duration of use, extra ventilation appliances	Continuous	
Duration of use, battery chargers' appliance	Continuous	
Duration of use, bedrooms lighting	Ordinal	"Less than 2 hours, 2 to 4 hrs, 4 to 6 hrs, More than 6 hrs"
Duration of use, living rooms lighting	Ordinal	
Duration of use, kitchens lighting	Ordinal	
Duration of use, bathrooms lighting	Ordinal	"Less than 2 hours, 2 to 4 hrs, 4 to 6 hrs, Always in use"
Air conditioning usage	Ordinal	"Never, rarely, sometimes, usually, always" / Summer and Winter
Natural ventilation usage	Ordinal	
Electrical fans usage	Ordinal	
Use of AC in unoccupied spaces/rooms	Categorical	"Yes, no, sometimes"
Use of light bulbs in unoccupied spaces/rooms	Categorical	"Yes, No, sometimes"
Use of light bulbs in empty house	Categorical	"Yes, No, sometimes"
Duration of guests' visits	Categorical	"Less than 2 hrs, 2 to 4 hrs, 5 to 8 hrs, more than 8 hrs

Table 4.9 Variables related to occupant behaviours in relation to the use of air conditioning, lighting and electrical appliances

4.4.2.4.5 Data Analysis Procedures

Several methods and strategies for modelling and analysing the impact of occupant behaviour on dwelling energy consumption were described in the literature review. The main objective of this research was to investigate the determinants of energy consumption and identify the influence of occupant behaviour on residential energy consumption for the use of air conditioning, lighting and electrical appliances in Makkah, Saudi Arabia. This section of the chapter is dedicated to describing how to transform the collected data into usable data for analysis purposes.

Concerning the analysis of data in mixed methods research, it comprises independently analysing the quantitative data by means of using quantitative methods and the qualitative data using qualitative methods (Creswell and Clark, 2018). It also entails merging both databases using approaches that mix or integrating the quantitative and qualitative data and the results. In this study, quantitative methods (questionnaires, energy consumption records and weather data) primarily use statistical methods. In contrast, the qualitative methods (documents and official reports) help to provide an explanation of the current situation in Saudi Arabia, particularly in the city of Makkah, which is the subject of this investigation.

The quantitative data were collected via a questionnaire, actual electricity consumption records and meteorological data in Makkah, Saudi Arabia in January 2020. The data collection period lasted for four months. The data set of 143 completed household surveys included information on a wide range of household socioeconomic characteristics (family size, composition, tenure, household income etc.); dwelling characteristics (dwelling type, total number of rooms, air conditioning type, etc.); occupant behaviour regarding the presence in the family living rooms, bedrooms and kitchens), electrical appliances (number, duration and place of use), and the use of lighting; electricity and gas consumptions. Generally, analysing data manually can be difficult and time-consuming, which is why data analysis software is often utilized. For this research, the Statistical Package for Social Sciences (SPSS 28) was selected over other software programmes due to its practicality, capabilities, and popularity, despite other programmes having similar features for data analysis.

This research's data analysis was separated into multiple stages to meet the research requirements. Each stage comprised different tasks to answer several research questions and satisfy certain research objectives. In the first stage, descriptive statistics were used to provide basic information about the dataset's properties. This involved summarizing the sample distribution and data measurements, which included the mean, standard deviation, variance, minimum, maximum, and percentages. The purpose of this stage was to gain a better understanding of the current situation of the sample and the area of investigation.

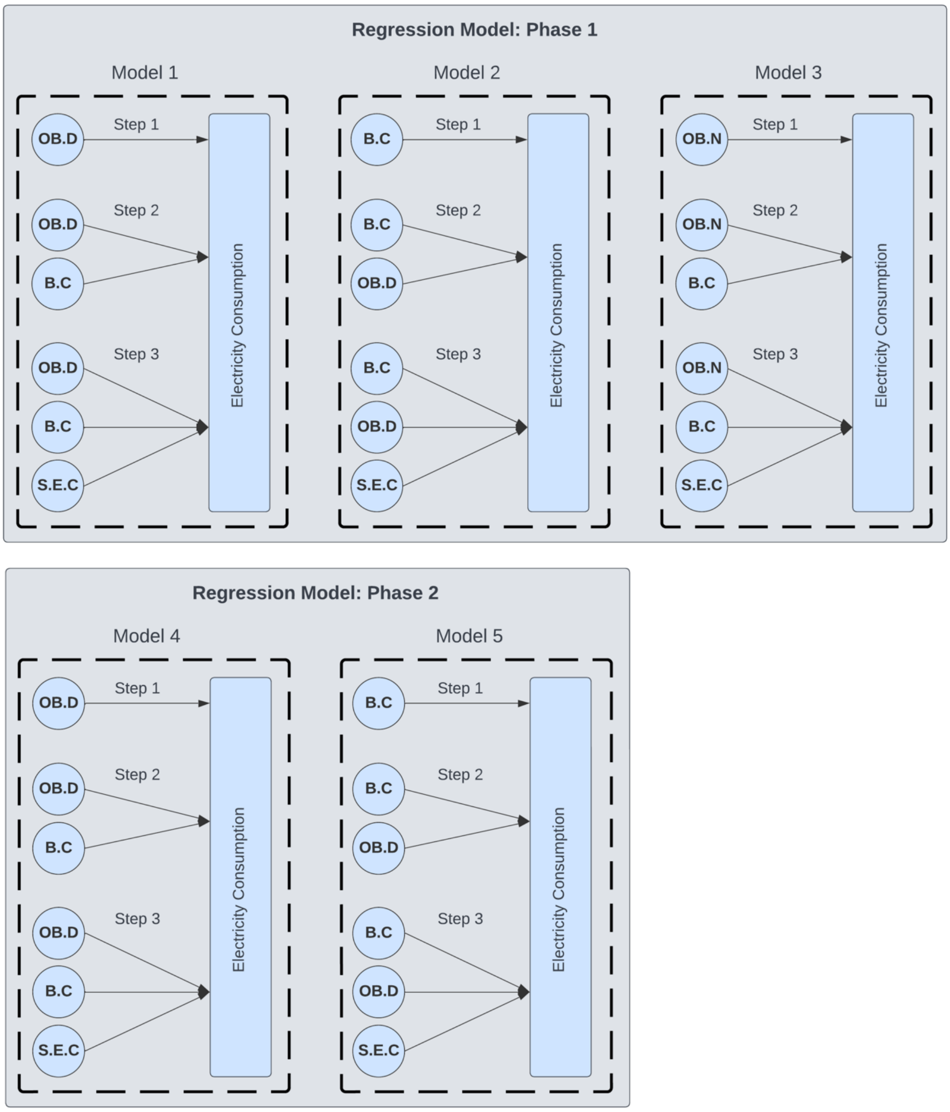
Following this, the relationships and differences between each variable and electricity consumption and the strength of any such relationship were conducted using advanced statistical analysis methods. Based on the variable's type (refer to Section 4.4.2.4.4), continuous variables were analysed using Pearson's correlation coefficients (for normally distributed variables) and Spearman's correlation coefficient (for non-normally distributed variables), categorical variables using one-way analysis of variance (ANOVA), and dichotomous variables using an independent-sample t-test. Correlation coefficient analysis was used to determine the relationships between electricity consumption (dependent variable) and variables, for instance family size and daily use of appliances, while one-way ANOVA and independent-sample t-test were utilised to determine whether there were any statistically significant differences between the means of the independent groups. Therefore, the variables in Table 4.7 to Table 4.9 were examined to discover if a relationship existed and how robust its connection was with electricity consumption. However, these analysis techniques only explored how much a single parameter could account for the variation in energy consumption. This was not enough to establish the causal relationship between groups of factors; hence, regression analysis was used.

Multiple linear regression (MLR) was utilised to determine the influence of household socioeconomic characteristics, building attributes and occupant behaviour on energy consumption. Meteorological conditions were omitted from the regression analysis because all households in the sample were located in the same area of investigation (Makkah). Numerous studies have used this approach to determine the total effect of the determinants on electricity consumption and establish electricity prediction models. Four regression models were built using occupant behaviour, households socioeconomic and building characteristics to further analyse the effect of these factors on electricity consumption and evaluate their level of influence.

The process of conducting regression models involved two distinct phases. In phase 1, only variables that showed statistical significance through correlations, ANOVA, and independent-sample t-tests were included in the regression analysis conducted through the backwards method. Then, the variables that emerged as significant together were combined in standard regression models, resulting in Model 1, Model 2, and Model 3 (see Figure 4.6). The distinction between Model 1 and Model 2 lies in their respective controlling parameters (entered first in the model process). Occupant behaviour variables control Model 1, whereas building characteristic variables control Model 2. However, the difference between Model 1 and Model

3 is that Model 1 is controlled by occupant behaviour concerning air conditioning, lighting and daily use of appliances, while Model 3 is controlled by occupant behaviour pertaining to air conditioning, lighting and the number of appliances.

On the other hand, Model 4 and Model 5 were built using all variables in the regression analysis using the backward technique, then combined with the variables that appeared as significant in standard regression models (phase 2). The difference between the two models lies in their respective controlling parameter as seen in Figure 4.6. The best-fit model was determined after careful consideration of all available options. More information about the models is provided in Chapter 1.



* OB.D refers to occupant behaviour with the duration of appliances, OB.N to occupant behaviour with the number of appliances, B.C to building characteristics, and S.E.C to household socioeconomic characteristics.

Figure 4.6 Regression models for phase 1 and phase 2

4.5 Limitation of the Data Collection Methods

Mixed methods research requires the researcher to be acquainted with several preliminary considerations. First, the researcher needs to gain more experience in both quantitative and qualitative approaches before considering mixed methods design. Subsequently, the researcher should understand how the mixed methods design works with quantitative and qualitative approaches including collecting and analysing data, integrating the data and results, using a particular mixed methods design, and framing theory and philosophy (Creswell and Clark, 2018). Second, the researcher needs to be certain that the research problem can best be considered using mixed methods. Moreover, mixed methods require more effort and time to collect extensive information for both qualitative and quantitative data sets.

However, the researcher was aware that there might be various consequences and limitations during the fieldwork stage of this research and the data collections process. One possible limitation was related to the cultural barriers and that an obstacle might arise while conducting the questionnaire with female participants. Therefore, while collecting the questionnaires, the researcher was accompanied by his sister to overcome this issue and ensure that all relevant data was obtained. Another limitation was related to the translation of the questionnaire into a different language, e.g., Arabic. The questionnaire was evaluated during the pilot study and participants were generally satisfied with the translation provided. Moreover, Saudis occasionally mix languages when using Arabic and English. Therefore, the researcher was defining any English expressions during the collection of the questionnaires if participants decided to complete them in English. Additionally, using sensors and cameras to monitor electricity consumption and occupant behaviour was not employed because of cultural sensitivity and constraints. Similarly, these techniques were not considered due to the limited time available to complete this research and the fact that they required a long-term study based on the available literature.

4.6 Research Flowchart

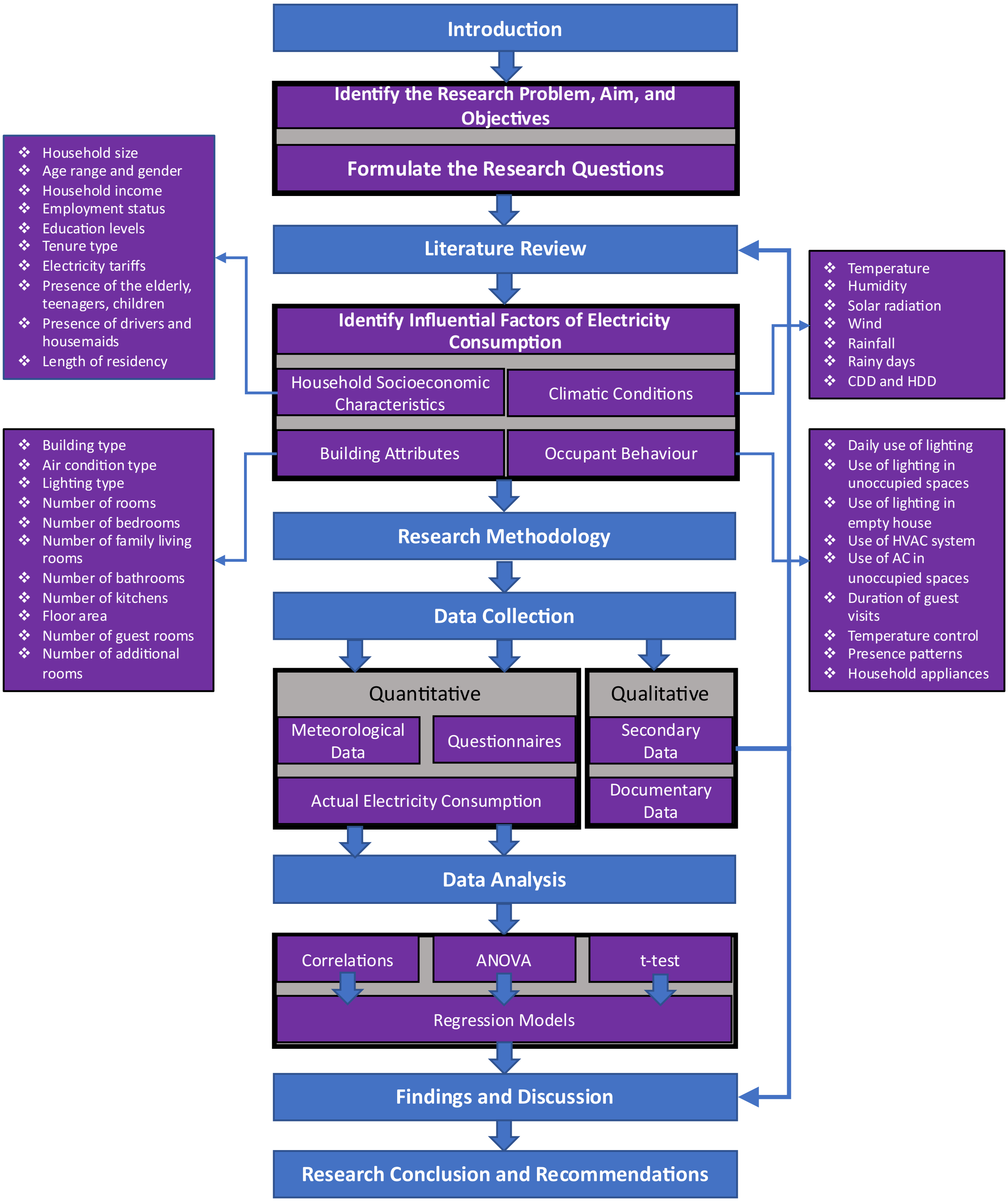


Figure 4.7 Research process flowchart

4.7 Summary

This thesis employed a combination of qualitative and quantitative approaches to investigate the determinants of residential electricity consumption in Makkah, Saudi Arabia. The research focused on analysing building attributes, household socioeconomic characteristics, meteorological conditions, and occupant behaviours as contributors to electricity consumption.

The methodology chapter presented a clear research flowchart (Figure 4.7) outlining the seven stages undertaken to ensure the achievement of the main aim and address related objectives. Each stage was approached using corresponding methods and techniques, which were comprehensively described and justified. Data collection and analysis methods were carefully selected to provide robust insights into the research questions. The methodology presented in this chapter provides a comprehensive investigation of residential electricity consumption in Makkah, Saudi Arabia. It exhibited a highly methodical and stringent approach to the research.

This combined methods approach has involved: (a) data collection and analysis through household questionnaires, which sought to identify key building attributes, household socioeconomic characteristics, and occupant behaviours related to the use of air conditioning, lighting and electrical appliances. (b) An additional quantitative approach was employed to gather actual electricity consumption and weather conditions. This information was not available to the public and therefore the researcher was required to attend several meetings to gain approvals for obtaining such data from governmental entities such as the SEC. (c) A qualitative approach through examining secondary and documentary data to help gather general information regarding Saudi Arabia, along with Makkah and the targeted neighbourhood in particular.

In the upcoming chapters, the study's outcomes will be presented in comprehensive detail. Examining these findings will lead to an exploration of their implications, allowing for a thorough understanding of their significance. Additionally, the chapters will delve into the study's limitations, providing insight into how the outcomes can be leveraged to improve energy efficiency in Makkah dwellings. Overall, this in-depth analysis will offer valuable insights into the study's outcomes and how they can be used to drive positive change.

Chapter Five:

Geographical Location and Current Electricity Consumption Scenario in the City of Makkah

Chapter 5: Geographical Location and Current Electricity Consumption Scenario in Makkah

5.1 Overview

This research aimed to investigate the real effect of the occupants' behaviour on energy consumption as regards the use of air conditioners, lighting and electrical appliances in Makkah's domestic buildings, along with other influential factors, such as building attributes, household socioeconomic characteristics and weather conditions. It also sought to define the contribution of each factor to the energy consumption variance in dwellings. This study defines behaviours as the user's presence pattern and the use of air conditioners, lighting and electrical appliances in the house that can influence energy consumption. As mentioned, there is a lack of research in Makkah, Saudi Arabia, investigating the effect of influential factors, most significantly occupant behaviour, on energy consumption. Therefore, it is important to briefly introduce Makkah to gain a better understanding of the socio-cultural backgrounds of the city, then narrow it down to select a specific residential area based on clear criteria relevant to the research aim and objectives.

5.2 The Selection of Makkah as the Focus Study Area

Makkah is a city in Makkah Region of Saudi Arabia. It is considered the most sacred city in Islam and holds the Ka'ba, a holy site that approximately two billion Muslims face five times a day while praying. The Ka'ba is located inside the Holy Mosque in Makkah. According to the teachings of the *Holy Qur'an*, no Muslim is an authentic Muslim if they do not pray, which is the second pillar of the Islamic Five Fundamental Pillars (Hussain, 2012). Makkah is also a major commercial centre, and it is home to a vast number of pilgrims from all over the world. Making a pilgrimage to Makkah and performing Hajj once in a lifetime, for those able to do so, is, in fact, the fifth pillar of the Islamic pillars. Performing *Hajj* is the world's most significant Islamic event, gathering Muslims from over 140 nations each year (Gatrad and Sheikh, 2005; Shafi *et al.*, 2008; Raj and Bozonelos, 2015).

Makkah, in western Saudi Arabia, is not only the holiest city in Islam, but it is also the administrative capital of the Makkah Al-Mokarramah Region (see Figure 5.1). It is located 70 kilometres (43 miles) from Jeddah on the Red Sea and is situated in a narrow valley at an altitude of 277 metres (909 feet) above sea level. Among the 13 regions, the regions of Makkah and Riyadh, comprise the largest percentage of the total energy consumption, accounting for half of the country's dwelling units, according to a study undertaken by the geospatial representation of residential energy use in Saudi Arabia (Algarni and Nutter, 2013).

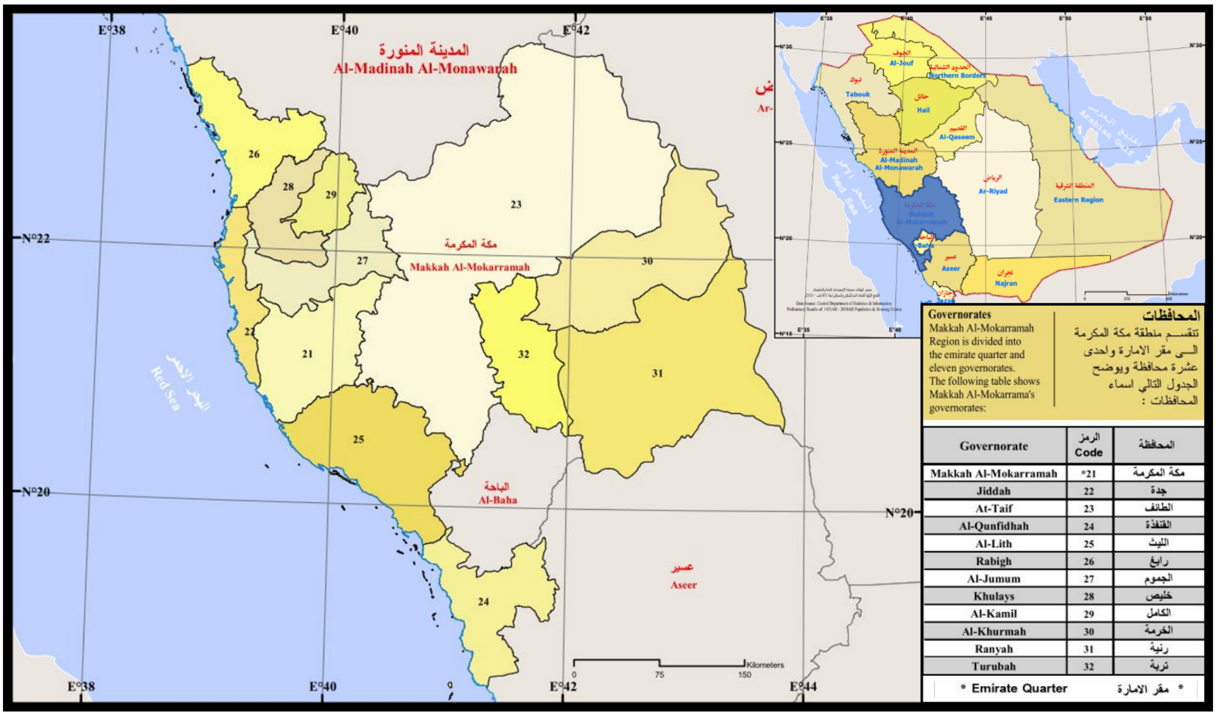


Figure 5.1 Makkah administrative region and its provinces
(CDSI, 2010)

For centuries, Makkah has been regarded as a deeply significant holy site, with its origins dating back to the time of the prophet Abraham (Page, 2014). Its designation as a place of worship and pilgrimage has firmly established its status as a revered destination for Muslims worldwide. The impressive history and religious importance of Makkah make it an extraordinary place that consistently inspires and draws millions of visitors annually (Page, 2014). In addition to its historical and cultural significance, Makkah is presently experiencing a period of substantial growth and transformation through various development and construction initiatives. These projects are aimed at enhancing the city's infrastructure, facilitating economic progress, and ensuring a more comfortable and convenient experience for residents and visitors alike (Makkah Region Development Authority MRDA, 2011). Figure 5.2 shows the location and name of the proposed development projects in the proposed Master Plan for Makkah in 2011.

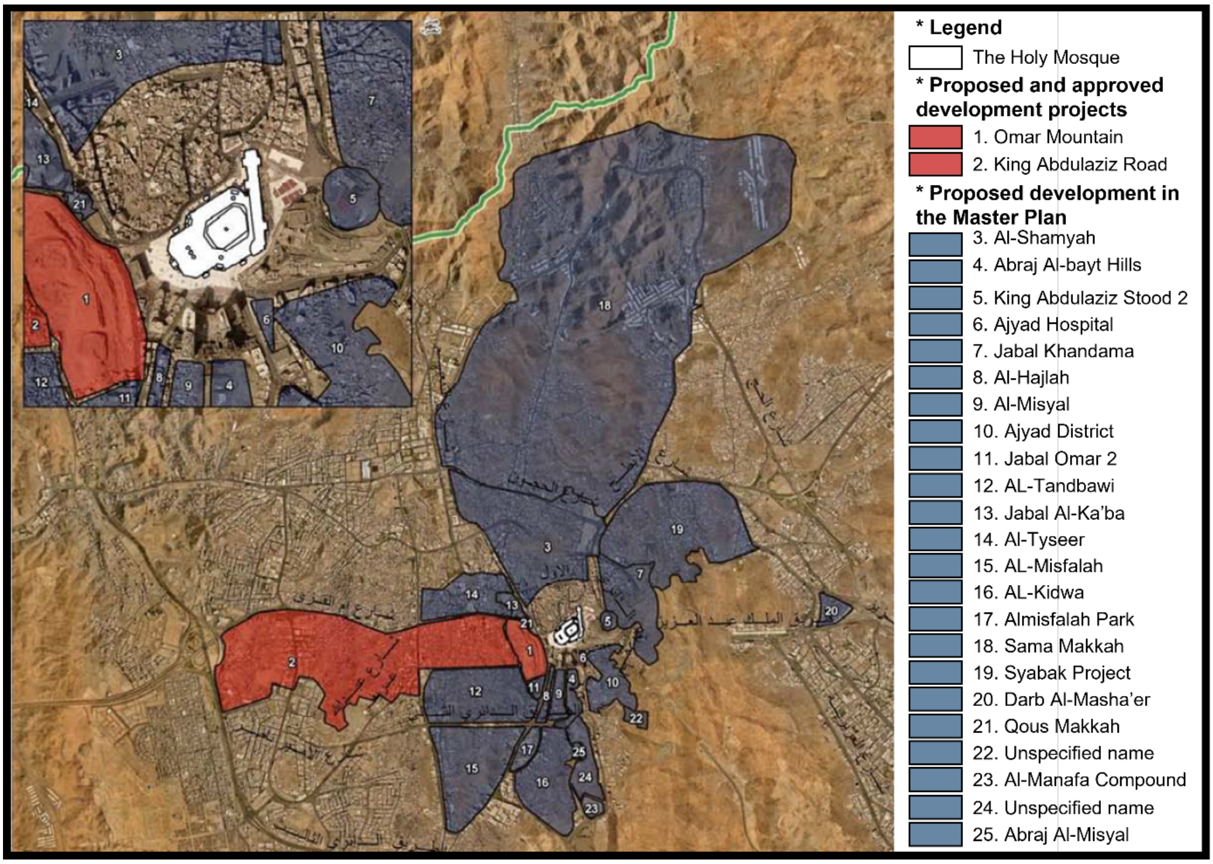


Figure 5.2 Locations of proposed development projects in the Master Plan for Makkah (MRDA, 2011)

An example of a construction initiative is the ongoing expansion of the Holy Mosque in Makkah, as seen in Figure 5.3 and Figure 5.4. This expansion holds great importance for the worldwide Muslim community as it aims to accommodate the increasing number of pilgrims who visit the holy site every year. The demolitions near the Holy Mosque caused a significant displacement of numerous residents from their homes, particularly those residing in the Makkah Central District (MRDA, 2011). As seen in Figure 5.5, there has been a significant increase in the number of constructions permits in the Makkah Region since 2010. This coincides with the start of the new expansion of the Holy Mosque on its northern side. It is important to note that the Makkah Region took the lead in issuing the highest number of construction permits in both 2015 and 2016. Even larger administrative regions like Riyadh and Eastern Regions were surpassed, with 34,320 and 35,599 permits issued, respectively. This fact cannot be overlooked and serves as a testament to the region's commitment to growth and development. Furthermore, housing and commercial buildings accounted for over 90% of the overall construction permits issued in Makkah Region since 1987 (see Figure 5.6 for further information).

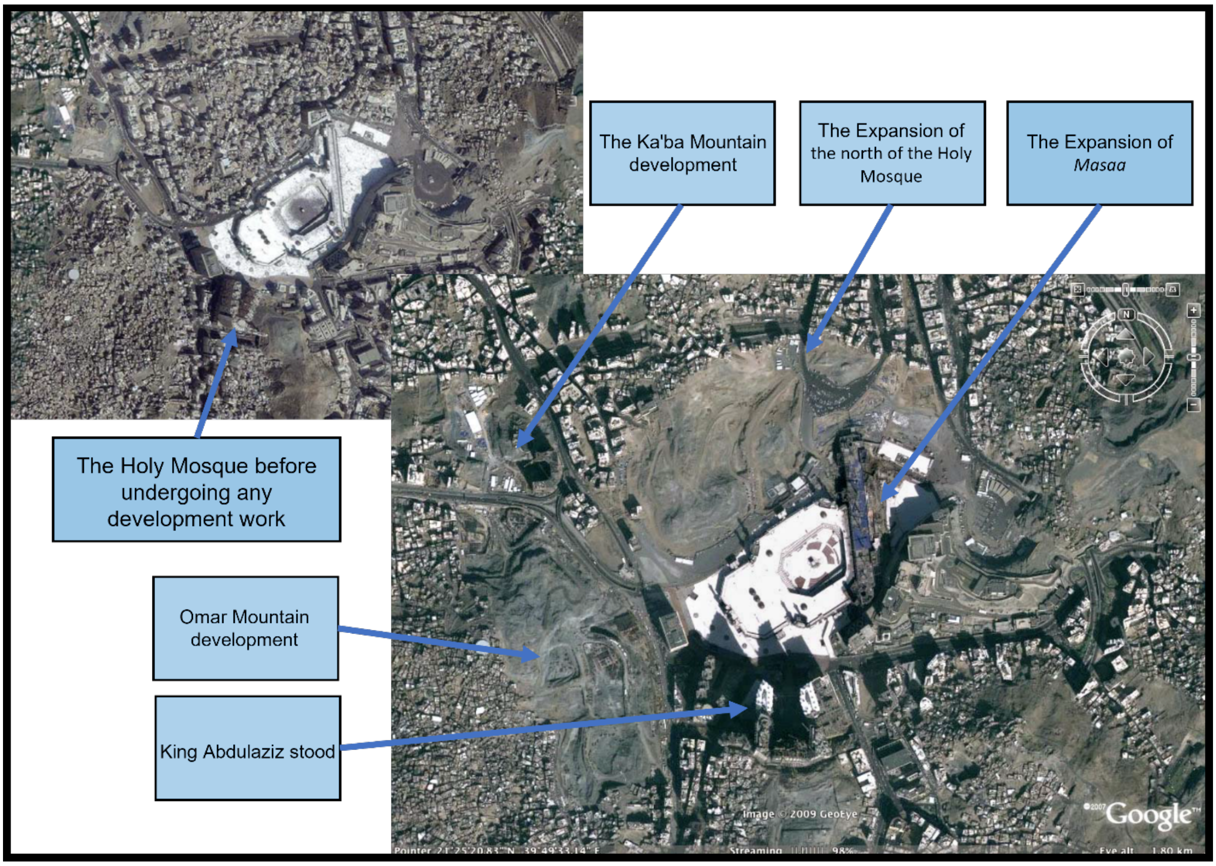


Figure 5.3 The Holy Mosque before and after development
(MRDA, 2011)

Figure 5.4 An aerial view of the ongoing construction of the Holy Mosque and the surrounding demolition work
(TIME, no date)

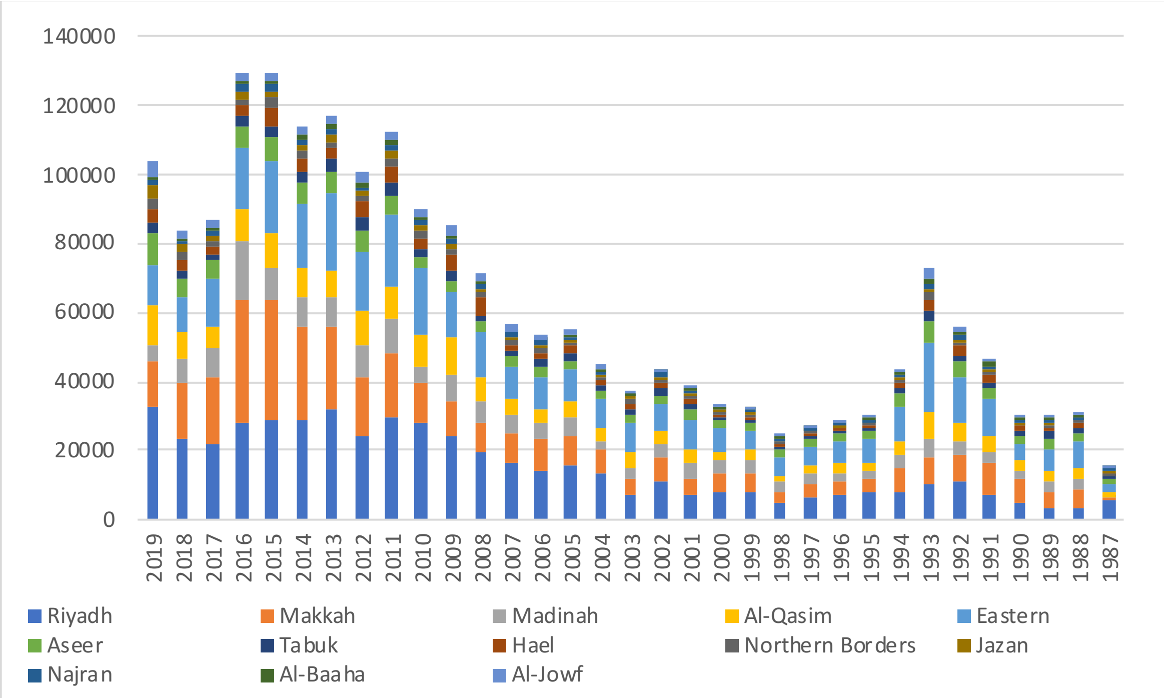


Figure 5.5 Building Permits Issued by Municipalities by Regions from 1987 to 2019
(generated from the data collected from MOMRAH)

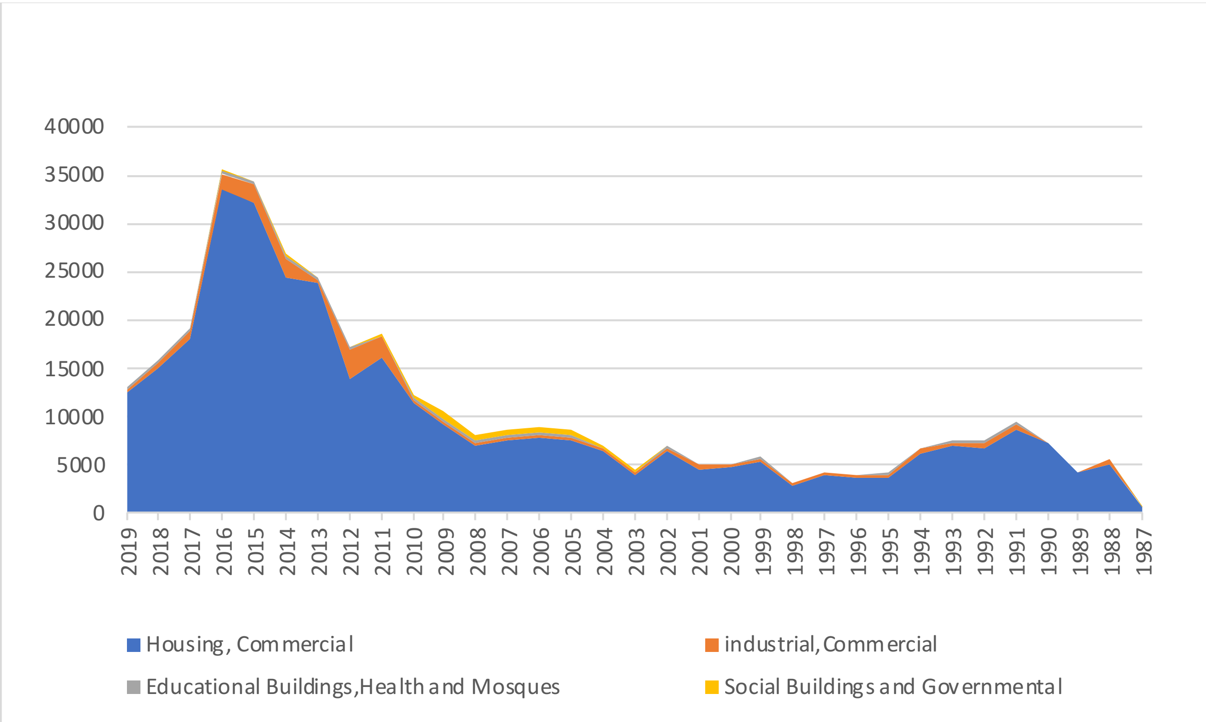


Figure 5.6 Building permits issued by the Holy Makkah Municipality by type of permit for Makkah Region from 1987 to 2019
(generated from the data collected from MOMRAH)

In addition, the city's continuous development and construction projects have resulted in the alteration of certain aspects of the city's culture. In the past, for instance, individuals used to assemble at the Holy Mosque in order to celebrate wedding agreements. Currently, however, individuals attend different mosques in the city to make these agreements due to the massive construction projects and crowding around the Holy Mosque. A further element that contributes to the transformation of culture is the fact that the city of Makkah is a destination for a large number of Muslims from across the world who come to perform the pilgrimages of Hajj and Umrah. Due to this, the locals have been exposed to a variety of cultures and have been able to incorporate aspects of those cultures into their traditions.

The conservative culture of Makkah also has an impact on electricity consumption. In the city, there is a dress code in place that requires women to cover their heads and bodies. Consequently, they are inclined to use air conditioning more frequently. In addition, it is worth noting that due to the city's policy of only allowing Muslims to enter the city, most of the community shares similar cultural practices influenced by the Islamic faith. However, cultural diversity can still exist based on regional, ethnic, and national backgrounds. It is a common practice in Makkah, for instance, for extended family members to reside together in one household, influenced by the Islamic value of upholding strong family bonds. When households have more people living in them, there is a greater need for electricity to meet the demands of multiple family members, as discussed in Chapter 3.

According to recent data, the Makkah Administrative Region's population grew to 8 million people in 2022 from 6.9 million in 2010, indicating an annual growth rate of 1.33%. This significant increase demonstrates the impressive progress and expansion of the region over the years. (SGAS, 2017b, 2022). As shown in Table 5.1, the total population in Makkah City reached 2,4 million based on the population census in 2022, roughly 30% of the administration's population live in Makkah (SGAS, 2022). Moreover, The results of the Saudi Census 2022 showed that the percentage of the non-Saudi population in the Makkah Region amounted to 28.9% of the total non-Saudi population in the Administrative Regions, equivalent to 3.9 million people. The population of non-Saudis makes up 48.2% of the total population in the Makkah Region, making it the most diverse among all regions with 192 different nationalities represented (SGAS, 2022).

	Saudis			Non-Saudis			Total (Saudis and Non-Saudis)		
	Male.	Female	Total	Male	Female	Total	Male	Female	Total
Makkah	548,443	538,467	1,086,910	984,875	356,166	1,341,041	1,533,318	894,633	2,427,951
Jeddah	858,357	850,420	1,708,777	1,434,047	608,898	2,042,945	2,292,404	1,459,318	3,751,722
Al-Taif	325,923	334,837	660,760	189,238	63,376	252,614	515,161	398,213	913,374
Al-Qunfudah	77,071	82,463	159,534	39,592	6,062	45,654	116,663	88,525	205,188
Al-Lith	28,968	30,597	59,565	12,384	1,804	14,188	41,352	32,401	73,753
Rabigh	32,242	31,841	64,083	41,483	6,817	48,300	73,725	38,658	112,383
Al-Jumum	32,870	33,428	66,298	19,321	3,956	23,277	52,191	37,384	89,575
Khulays	19,578	20,334	39,912	9,506	1,920	11,426	29,084	22,254	51,338
Al-Kamil	5,539	5,730	11,269	2,700	401	3,101	8,239	6,131	14,370
Al-Khurmah	14,803	15,600	30,403	7,407	934	8,341	22,210	16,534	38,744
Ranyah	19,698	20,212	39,910	8,565	1,379	9,944	28,263	21,591	49,854
Turubah	16,493	17,579	34,072	6,398	1,299	7,697	22,891	18,878	41,769
Bahrah	30,408	30,164	60,572	28,357	5,674	34,031	58,765	35,838	94,603
Al-Muwayh	12,395	12,597	24,992	3,465	608	4,073	15,860	13,205	29,065
Mysan	11,432	12,383	23,815	4,174	776	4,950	15,606	13,159	28,765
Al-Ardiyat	25,671	28,106	53,777	9,855	1,446	11,301	35,526	29,552	65,078
Adam	13,987	15,087	29,074	3,708	1,176	4,884	17,695	16,263	33,958
Total	2,073,878	2,079,845	4,153,723	2,805,075	1,062,692	3,867,767	4,878,953	3,142,537	8,021,490

Table 5.1 The population distribution at the governorate level by nationality and gender in Makkah Region from the 2022 General Census
(SGAS, 2022)

Furthermore, due to the harsh weather conditions found in the Western Province, Makkah is one of the most challenging cities in Saudi Arabia in terms of domestic energy consumption. The temperature in Makkah is ranging from warm to hot throughout the year. Temperatures in the winter range from 19 °C at night to roughly 29 °C (84.2 °F) in the afternoon. On the other hand, summers are characterised by extreme heat, with afternoon temperatures often exceeding 38°C and evening temperatures falling to around 32 °C (Nayebare *et al.*, 2018). Makkah experiences minimal rainfall, with an annual average precipitation of only 7.4 inches (189 mm). The humidity levels in the area vary from 46.3% to 67.2% (Khan and Alghafari, 2018). Therefore, the most recent update delivered by the SBC places Makkah in climate Zone 1, the hottest among the other two zones, as presented in Section 2.5.1.

The high temperatures and low humidity in Makkah require a lot of energy for cooling. The lack of rainfall means no hydroelectric power in Makkah; therefore, the city, like the rest of the country, relies on fossil fuels for its energy needs. For the aforementioned reasons, Makkah was selected as a representative city for this study to examine electricity consumption and its determinants in residential buildings.

5.2.1 Finding a suitable Neighbourhood in Makkah City

One neighbourhood in the city of Makkah was selected from among 105 neighbourhoods to be the focus of the research, with the aim of exploring the determinants of energy consumption, including occupant behaviours. Bedir (2017) claimed that given that occupant behaviour might vary among homes with similar building attributes, calculations and design should take its influence on energy use more seriously. This claim was investigated by including it as one of several criteria for selecting a neighbourhood in the city of Makkah suitable for this study. These criteria are as follows:

- A non-rural and highly populated area.
- A non-random residential area, and was built and supervised by the government of Saudi Arabia
- Diversity of demographics including economic status (income), gender, age, employment status, level of education.
- Buildings run predominantly by homeowners.
- Mainly consisting of residential units that are identical to one another and were constructed using the same methods and materials (to significantly focus on the influence of occupant behaviour on energy consumption).

Several of Makkah's residential neighbourhoods, such as Al-Shoqyiah, Al-Hamra, Al-Awali, etc., could provide suitable study sites. Nevertheless, the "*King Fahd Housing Scheme*," also known as Al-Iskan, is the only residential neighbourhood that meets the aforementioned criteria. Additional reasons supporting this selection are the familiarity of the area to the researcher, the easy accessibility to the area, mostly populated by Saudis households, and most importantly, it is a governmental project which was implemented by the Real Estate Development Fund (REDF). The REDF is one of several government entities that is concerned about the housing issue in Saudi Arabia. Figure 5.7 indicates the distance from the selected neighbourhood to where the Holy Mosque is located in the centre of the city is approximately two kilometres (1.2 miles). It also presents the Holy Mosque's off-limits perimeter, which non-Muslims are not permitted to enter for reasons related to the Islamic regulations governing the Holy Mosque.

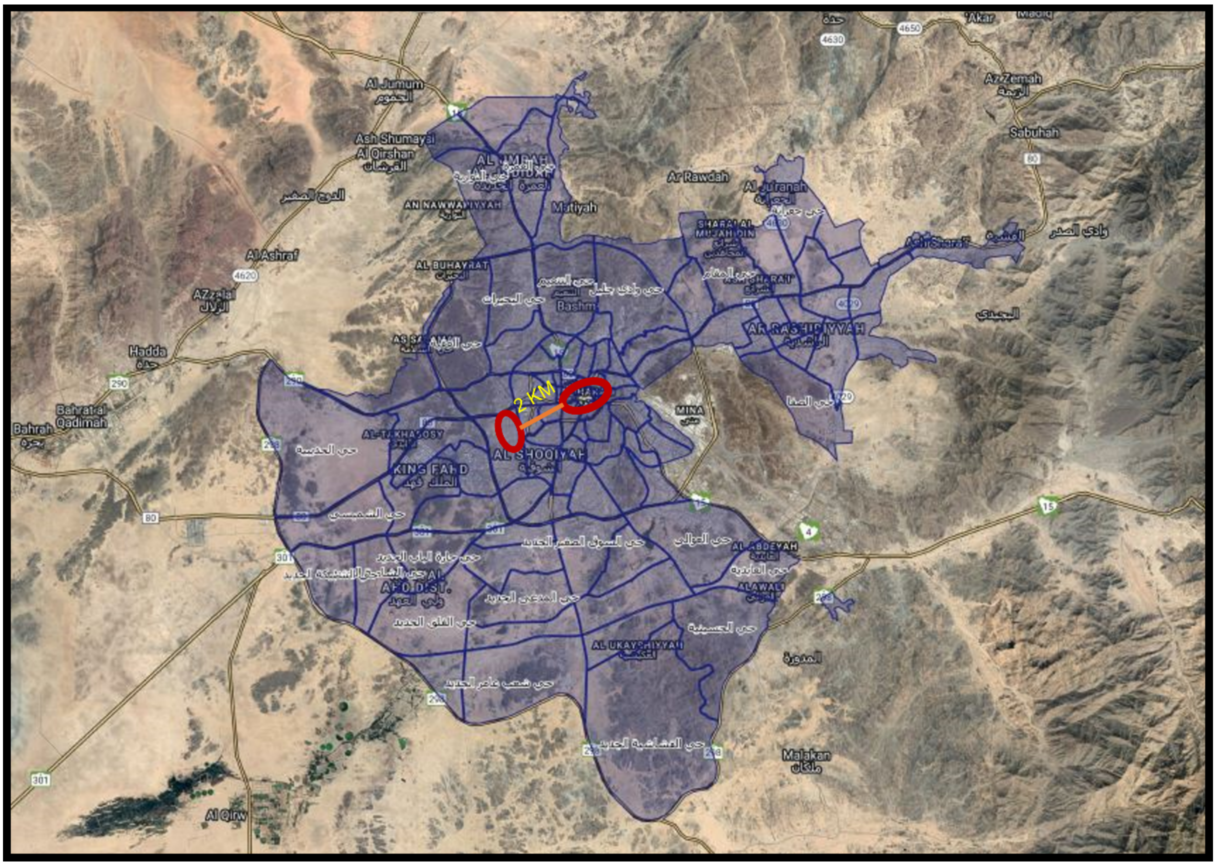


Figure 5.7 The distance from the research study area to the centre city of Makkah

The neighbourhood of Al Iskan, located to the east of the Holy Mosque, was developed in two phases at the beginning of the 1990s. The first phase involved 1456 housing units, while the second phase included 1136. The neighbourhood includes all the necessary facilities and infrastructure, which were implemented under the supervision of the REDF, as mentioned, for example the sewage system, rainwater and torrential water drainage network, the electricity distribution network, etc. (REDF, n.d.). It also contains mosques, schools, shops, parks, a dispensary and a fire station (see Figure 5.8). This neighbourhood was developed to support low-income families. However, during the construction of the second phase, many problems appeared, which caused the postponement of the completion of the project for 22 years. Consequently, in 2012, a royal order was released to complete the infrastructure works and services on the public site. Subsequently, the units were to be sold individually via an auction and the revenue from those units distributed as loans to citizens. This implies all layers of society could be found in the selected neighbourhood instead of the presence of low-income families only.

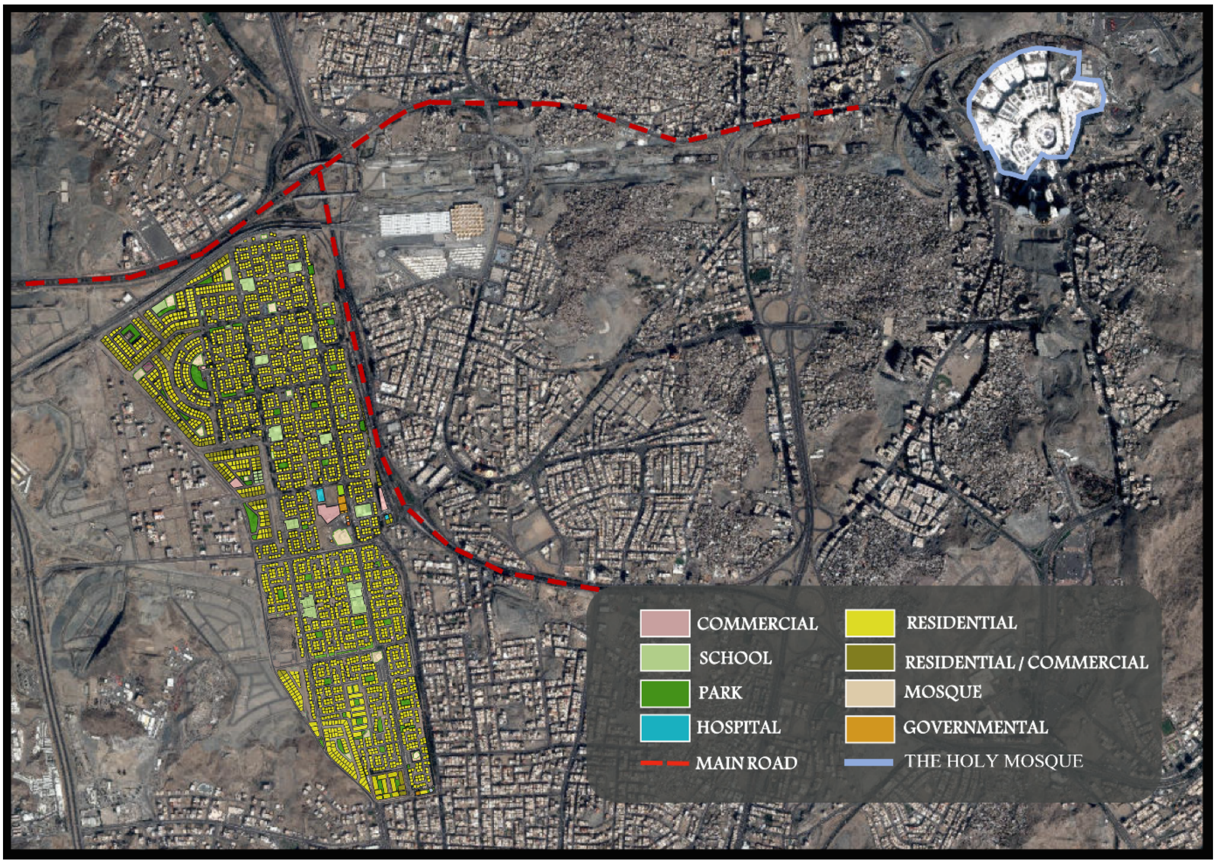


Figure 5.8 The boundary of the targeted neighbourhood
(generated from the data collected from the Holy Makkah Municipality)

Each of the units were designed to include only one of the city's representative building types: one-story semi-detached houses with a total area of land of 400 square metres and a building area of 225 square metres. As seen in Figure 5.9, the original layout of households in the research study area includes three bedrooms, three bathrooms, a family living room, a guest living room and a dining room, and a kitchen. It also presents a perspective of the study's targeted neighbourhood. Additionally, the construction of the building was designed in such a way that it could accommodate future expansion if necessary. Figure 5.10 shows a section layout of an extended building. Several types of cooling system are used in the selected area, such as the Window Air Conditioner, Ductless Mini-Split Air Conditioner or Central Units, with the latter assumed to be the type that is the least used (REDF, n.d.).

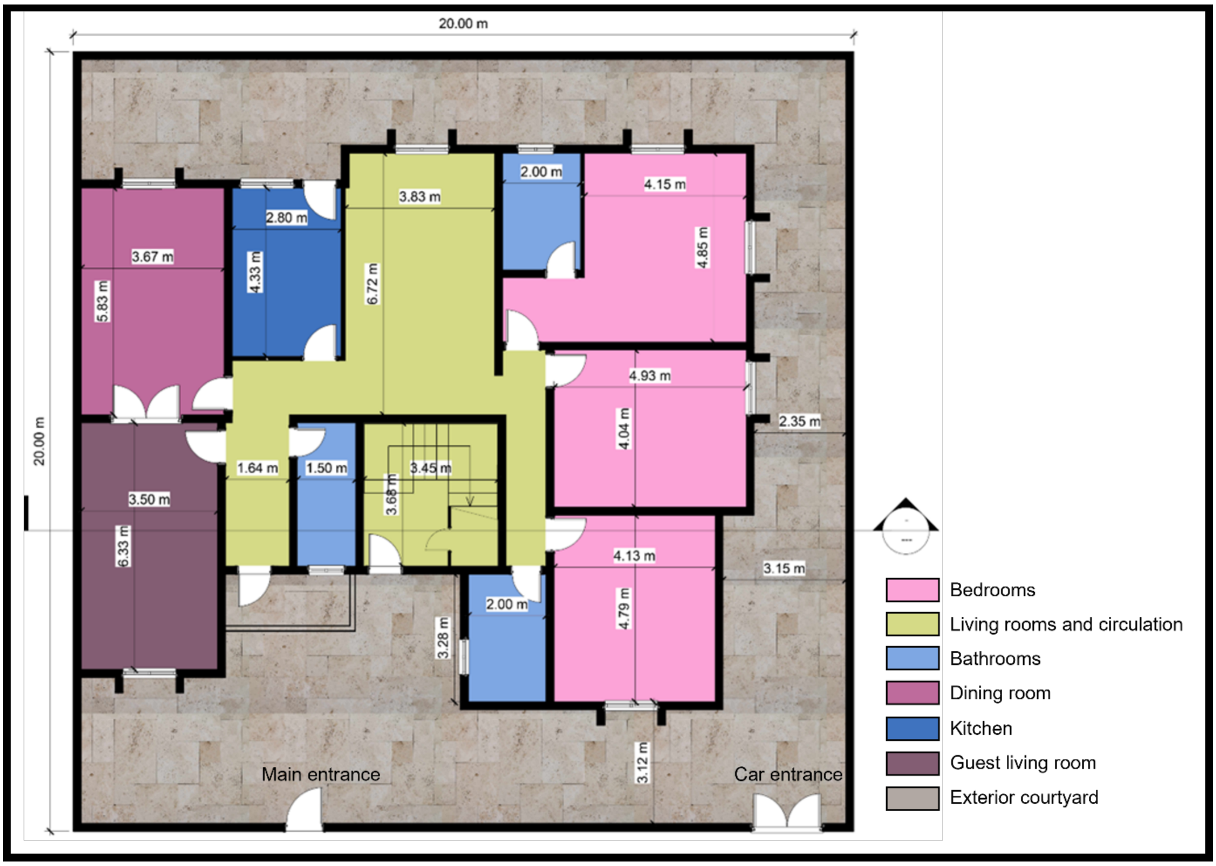


Figure 5.9 Illustration of a villa's ground floor layout and neighborhood perspective in the study's targeted area
(REDF and MOMRAH)

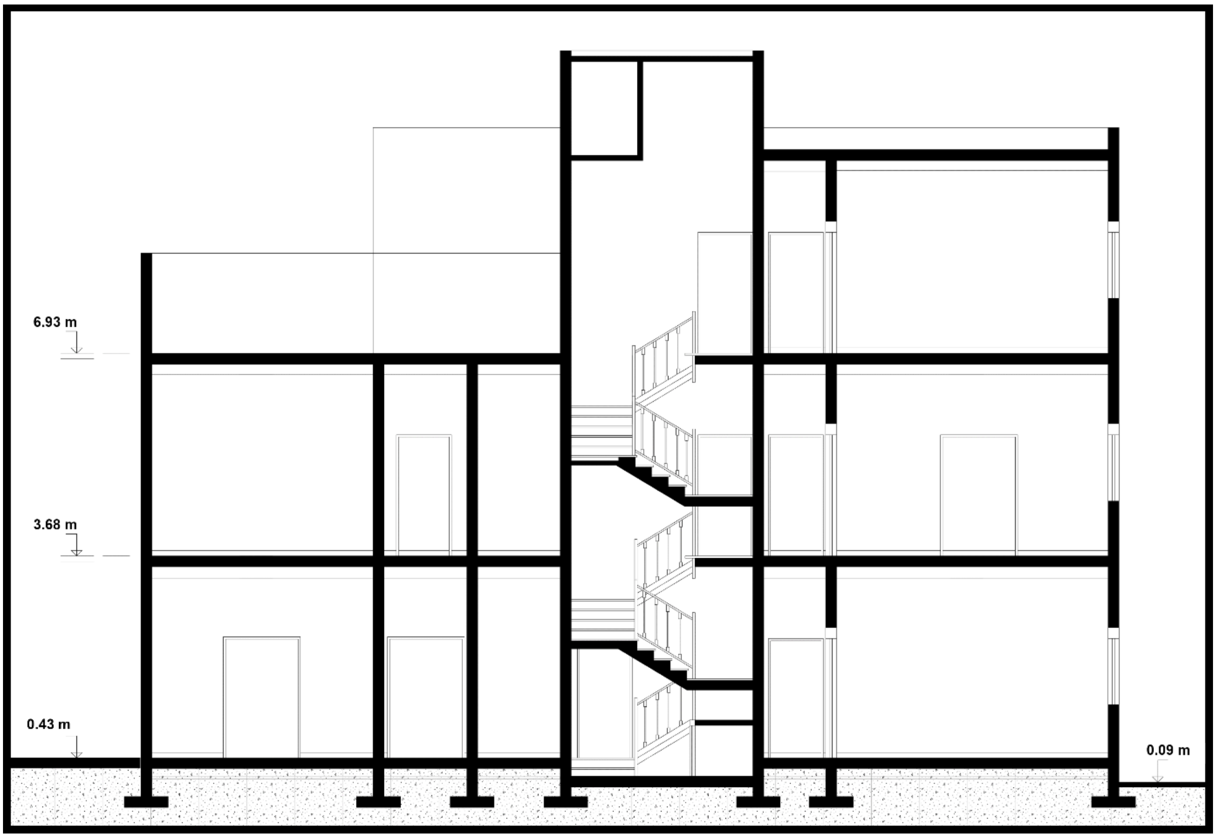


Figure 5.10 Section layout for an extended villa in the research's targeted neighbourhood (REDF and MOMRAH)

5.3 Descriptive Characteristics of the Residence in the Subject Area

This section provides a descriptive statistic of the research neighbourhood. The data on building attributes, household socioeconomic characteristics, as well as occupant behaviours were collected from the questionnaires. Moreover, records of energy use and bills for five years (January 2017 to December 2021) were collected from the SEC because it is the only electricity supplier for residences in the city. The SEC data only covers the area that is the subject of the study. Meteorological data were also collected through the weather station owned by the Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research in Makkah. The data obtained was for the period between January 2020 to December 2021. Moreover, electricity tariffs in Saudi Arabia, as mentioned in Chapter 2, have changed over time. Therefore, it is essential to conduct a review of the history of electricity tariff prices in Makkah. Furthermore, the government of Saudi Arabia recently issued specific laws governing the VAT and their implementing regulations, which took effect at the beginning of 2018. Documents obtained from governmental entities and the questionnaires served as the basis for this section's data.

5.3.1 Building Characteristics

The building characteristics describe the physical parameters and fixed systems of the dwellings. Based on the outcomes from preceding research, dwelling type, insulation levels, building age, floor area, the number of rooms, the number of bedrooms and the number of hobby/study rooms in the house have emerged to be significant predictors of electricity consumption. It should be noted that the age of construction, insulation and U-values were omitted from this study since, as mentioned earlier, all homes in the region under investigation were built during the same period, using the same materials and constructed in an identical manner. Notwithstanding that several cases mentioned that their houses have been developed, this study assumes that the same construction materials were used to undertake the developments on the extended part of the houses.

Due to the house expansions, there are certain variances in building shapes, so building types were not excluded. The survey questions were intended to identify, assess and determine the dwelling features that can cause high energy consumption in domestic buildings in Saudi Arabia. Thus, the key variables in this study include the house's floor area, type of dwelling, the total number of rooms, the number of bedrooms, family living rooms, kitchens, guest living rooms and additional rooms (if applicable), air conditioning type, besides light bulb type due to their significance and variation in the Saudi context.

Figure 5.11 explains that 71% of the surveyed households have vertically extended their houses. This has led to the appearance of different building types in the area, like multi-story semi-detached homes and flats, adding to the typical single-story type. While previous studies confirmed that dwelling type influences energy consumption, participants in the questionnaire were asked to reveal the type of dwelling they live in. Figure 5.12 illustrates specific descriptive information concerning the various types of homes found in the study area. Regarding the use of solar panels, there was not a single response in the study region confirming that solar panels were installed and used in the house.

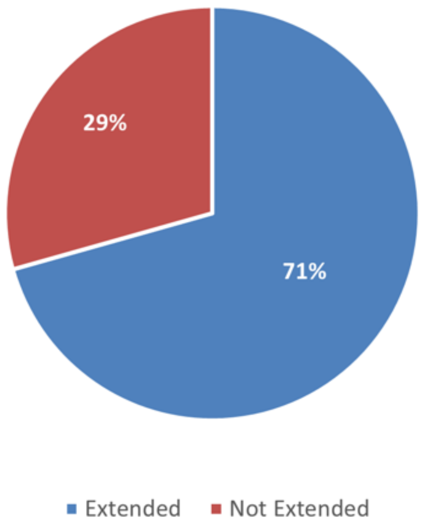


Figure 5.11 Percentages of extended and unextended houses in the surveyed sample

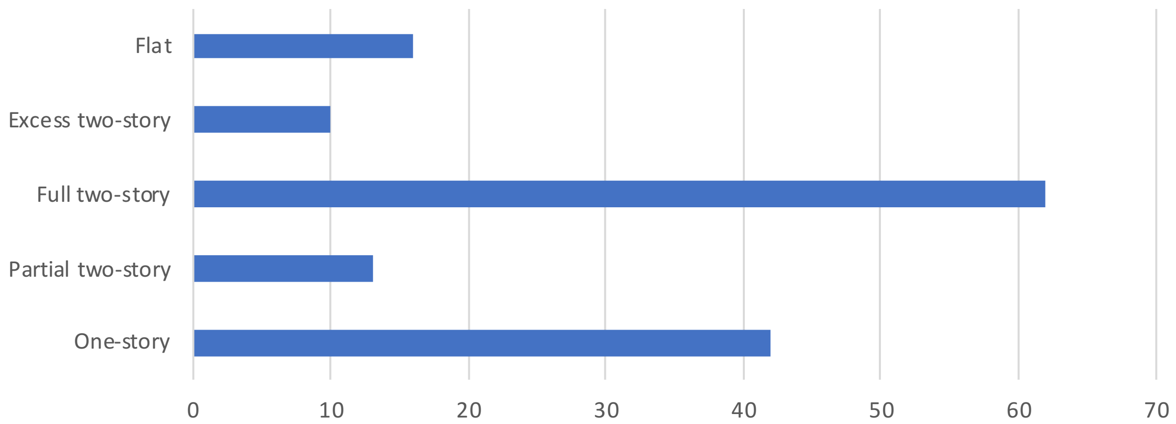


Figure 5.12 Distribution of dwilling type in the sample

In this study, the total number of rooms in the house includes bedrooms, guest living rooms and additional rooms (office or hobby rooms), excluding family living rooms and kitchens. As seen in Table 5.2, the minimum total number of rooms is five, which is the standard number for the typical layout in the study targeted area (Figure 5.9). The maximum number is 15 rooms. In this study, the total number of rooms refers to bedrooms, guests' living rooms, and other rooms, such as storage, office, etc. (called additional rooms), excluding family living rooms and kitchens. Moreover, three-bedroom homes had the highest rate overall (29.4%), followed by four-bedroom dwellings (23.1%). Despite having a maximum of eight-bedroom houses, this category had the fewest occurrences of any in the sample, with only four households accounting for 2.8% of the total. The results also demonstrate that a relatively low percentage of residences have only one guest living room (18.9%), while 81.1% have two or more such spaces, all of which are utilised only for hosting guests and not as additional bedrooms.

	Number of Cases		Minimum	Maximum	Mean	Std. Deviation
	Valid	Missing				
Floor area	143	0	255	675	360.31	126.35
Number of rooms	143	0	5	15	7.29	2.35
Number of bedrooms	143	0	2	8	3.88	1.48
Number of guests' living rooms	143	0	1	5	2.34	0.97
Number of additional rooms	143	0	1	5	1.73	0.76

Table 5.2 Statistical discriptive of the unit floor are, number of room, bedrooms, guests' living rooms and additional rooms

Moreover, this research is interested in the Saudi context in investigating the significance of additional building features because, unlike dwellings in other countries, houses are likely to contain multiple family living rooms and kitchens. Depending on the house size, the sample varied in the number of bathrooms, family living rooms and kitchens, but only two categories were found regarding these variables, as shown in Figure 5.13. According to the data, window units are the most prevalent form of air conditioner in homes (44%), followed by ductless units (34%) and then central units (22%). On the other hand, central unit is the least common type of air conditioner used in Saudi dwellings because of the high installation and maintenance cost. In addition, the distribution of manual, automatic, and remote temperature control of air conditioning systems, which refer to the ways in which the temperature of a building can be set and adjusted, can be seen in Figure 5.13. Moreover, LED lights are the highest bulb type used in the surveyed houses (52 %), followed by the fluorescent type (18%). Surprisingly, almost a quarter of respondents (25% to be exact) said they had no idea what kind of lighting was installed in their homes (see Figure 5.13).

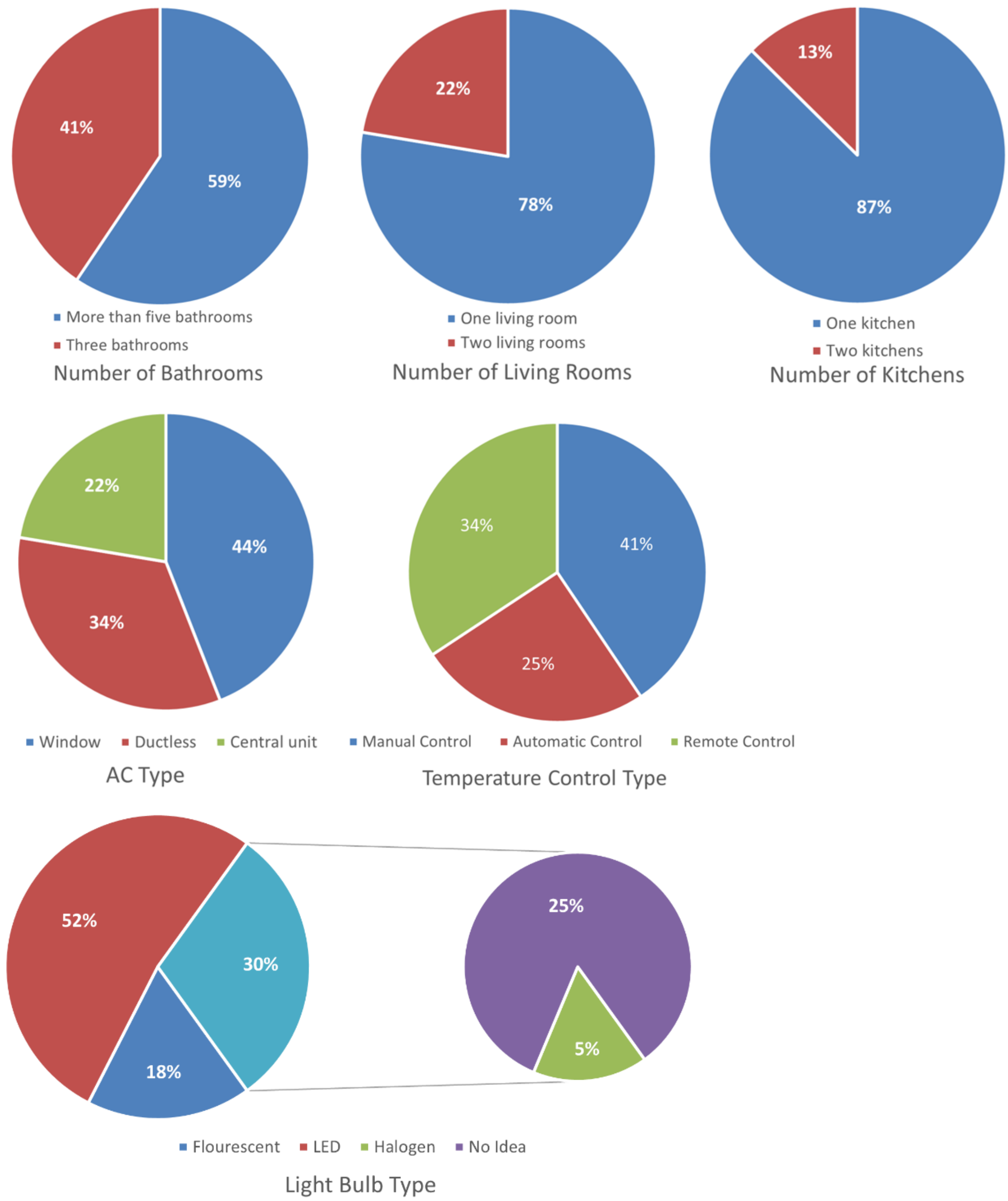


Figure 5.13 Percentages of the number of bathrooms, living rooms, kitchens, and AC and light bulb types in the surveyed houses

5.3.2 Household Socioeconomic Characteristics

The lifestyle and socioeconomic variables of the households in Saudi dwellings formed the basis for the questionnaires' results. Household socioeconomic characteristics that have been found to influence energy use in the literature were investigated: family size, age, the presence of children, teenagers and seniors, education level, income, tenure type, along with the length of residency. Moreover, other variables, which have not been mentioned in previous studies, were added to the investigation because they might be crucial factors in the Saudi

Arabian context. These variables are employment status and the presence of housemaids and drivers.

As mentioned in Section 4.4.2, the questionnaire can only be completed by one adult household member who is 19 years or older. This individual is responsible for providing information for themselves and on behalf of other family members. The respondents were asked to provide their age range of them and all household members including non-relative residents who live in the house like housemaids or drivers. Out of the questionnaires distributed, 143 were completed. The age distribution among the families in the sample is illustrated in Table 5.3. The majority of the respondents were adults, making up approximately 85% of the total responses, while seniors accounted for only 15%. The population of seniors in the whole sample is relatively small at 10.95%, followed by teens at 14.02% and children at 14.64%.

Table 5.4 shows the descriptive statistics for the family size and the age range variables. Based on the data, the largest family had ten members, and the smallest had only two. Furthermore, the highest number of adults in a family was eight, while the lowest had only one adult member. On average, the families had 3.43 adults, with a standard deviation of 1.69. After looking closely at the collected information, it has been noted that there exists a significant variation in the number of children in different families. While some families have as many as eight children, others have only one child in their household.

		Resp.	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Total
Adult (19-59)	Count	122	106	75	63	44	34	14	14	13	6	491
	N %	85.3	74.1	54.7	50.4	45.4	51.5	35.9	45.2	65.0	50.0	60.39
Teens (13-18)	Count	0	7	21	22	27	18	10	5	1	3	114
	N %	0.0	4.9	15.3	17.6	27.8	27.3	25.6	16.1	5.0	25.0	14.02
Child (0-12)	Count	0	5	25	28	19	11	13	10	6	2	119
	N %	0.0	3.5	18.2	22.4	19.6	16.7	33.3	32.3	30.0	16.7	14.64
Seniors (60+)	Count	21	25	16	12	7	3	2	2	0	1	89
	N %	14.7	17.5	11.7	9.6	7.2	4.5	5.1	6.5	0.0	8.3	10.95
Total		143	143	137	125	97	66	39	21	20	12	813

*Note: Resp represents the respondent of the questionnaire, Person 2 represents the second person in the family, Person 3 represents the third person in the family, etc.

Table 5.3 Frequencies and percentages for the age distribution variable

	Number of Cases		Minimum	Maximum	Variance	Mean	Std. Deviation
	Valid	Missing					
Family size	143	0	2.00	10.00	4.60	5.70	2.14
Number of children (0-12)	143	0	0.00	4.00	1.11	0.83	1.05
Number of teens (13-18)	143	0	0.00	5.00	1.12	0.80	1.06
Number of adult (19-59)	143	0	1.00	8.00	2.87	3.43	1.70
Number of seniors (60+)	143	0	0.00	3.00	0.76	0.62	0.90

Table 5.4 Descriptive statistics for Family size and the age range variables in the whole sample

The gender composition of the total households that participated in the survey was as follows: females comprised 54.24% of the population, while males accounted for 45.76% (Table 5.5 and Table 5.6). Regarding the gender composition of the respondents, Figure 5.14 and Table 5.5 reveal that 62.2% are male, of which 73 (82%) are adults and 16 (18%) seniors. Conversely, 37.8% of the gender composition of the respondents are females, of which 49 (90.7%) are adults, and 5 (9.3%) seniors.

		Resp.	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Total
Male	Count	89	55	60	54	41	24	20	18	9	2	372
	N %	62.2	38.5	43.8	43.2	42.3	36.4	51.3	58.1	45.0	16.7	45.76
Female	Count	54	88	77	71	56	42	19	13	11	10	441
	N %	37.8	61.5	56.2	56.8	57.7	63.6	48.7	41.9	55.0	83.3	54.24
Total		143	143	137	125	97	66	39	21	20	12	813

*Note: Resp represents the respondent of the questionnaire, Person 2 represents the second person in the family, Person 3 represents the third person in the family, etc.

Table 5.5 Frequencies and percentages for the gender composition variable

	Number of Cases		Minimum	Maximum	Variance	Mean	Std. Deviation
	Valid	Missing					
Number of males	143	0	0.00	6.00	1.7	2.60	1.32
Number of females	143	0	0.00	8.00	2.4	3.1	1.52

Table 5.6 Descriptive statistics for the gender composition variable in the whole sample

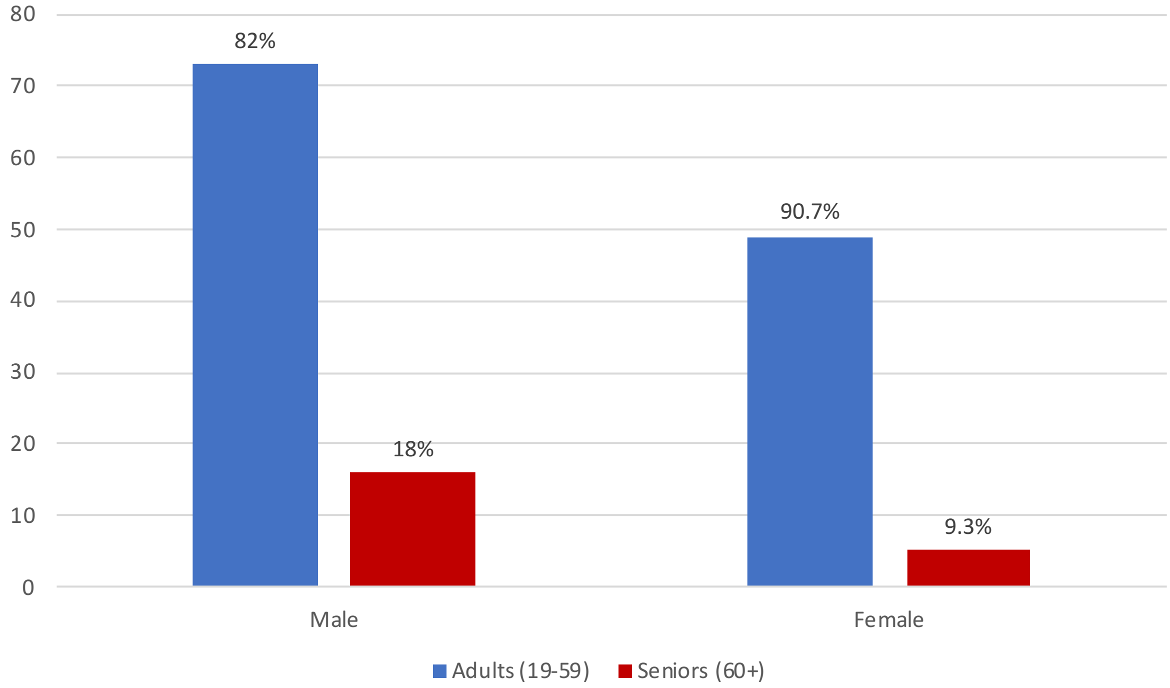


Figure 5.14 The distribution of respondent's age by gender

Considering the education level, Figure 5.15 illustrates that 87.4% of respondents have technical or higher education qualifications, while 12.6% (18 cases) possess middle education qualifications. It also shows the distribution of education levels among the whole population. Accordingly, the average of the technical or higher education group is 2.73 (SD = 1.44). According to the information provided in Table 5.7, 22.76% of the total sample have full-time jobs, 3.20% part-time jobs, 18.33% are retired or unemployed, 11.32% are housewives, whilst 8.98% are involved in household activities (e.g., cleaning and cooking).

It is very important to distinguish between housewives and retired or unemployed groups. Housewives handle their household and family responsibilities without any compensation. The unemployed are actively seeking employment but have not yet secured a job, and they are still considered a part of the workforce and are eligible for benefits. Retirees have left the workforce either due to their age or the length of their service. Moreover, the analysis suggests that the students' group has the highest rate (35.42%) in the surveyed households with a total number of 288 people (M = 2.01, SD = 1.72). According to the findings, the retired or jobless group has an unexpectedly high occurrence of nearly 20% (M = 0.55, SD = 0.91), while the full-time employee group has a mean of 1.28 (SD = 0.90). (See Table 5.7 and Table 5.8 for more information concerning the other employment status groups).

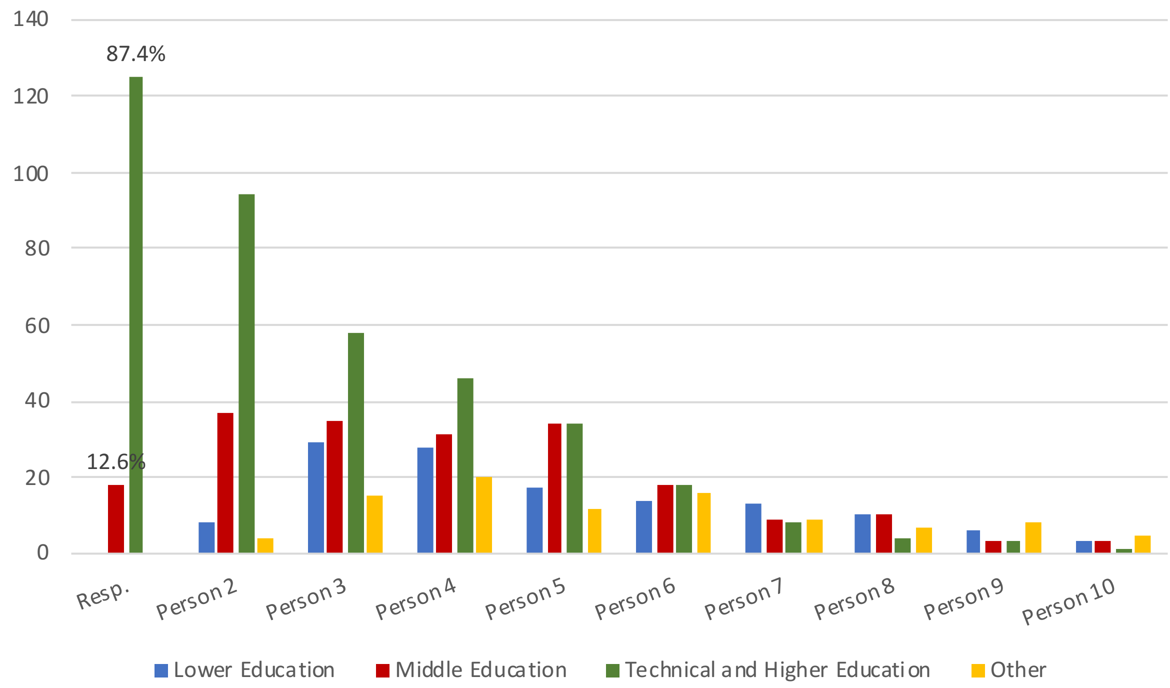


Figure 5.15 Distribution of education levels among the population.

		Resp.	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Total
Full-time employee	Count	80	38	27	19	6	2	3	4	5	1	185
	N %	55.9	26.6	19.7	15.2	6.2	3.0	7.7	12.9	25.0	8.3	22.76
Part-time employee	Count	6	7	5	3	2	2	0	0	1	0	26
	N %	4.2	4.9	3.6	2.4	2.1	3.0	0.0	0.0	5.0	0.0	3.20
Retired or unemployed	Count	28	33	34	22	16	8	4	3	0	1	149
	N %	19.6	23.1	24.9	17.6	16.5	12.1	10.3	14.3	0.0	8.3	18.33
Pupil/ Student	Count	16	15	51	59	60	34	26	15	7	5	288
	N %	11.2	10.5	37.2	47.2	61.9	51.5	66.7	48.4	35.0	41.7	35.42
Housewife	Count	13	47	12	8	6	3	1	1	1	0	92
	N %	9.1	32.9	8.8	6.4	6.2	4.5	2.6	3.2	5.0	0.0	11.32
Household activities	Count	0	3	8	14	7	17	5	8	6	5	73
	N %	0.0	2.1	5.8	11.2	7.2	25.8	12.8	25.8	30.0	41.7	8.98
Total		143	143	137	125	97	66	39	21	20	12	813

*Note: Resp represents the respondent of the questionnaire, Person 2 represents the second person in the family, Person 3 represents the third person in the family, etc.

Table 5.7 Frequencies and percentages for the employment status variable

		Number of Cases		Minimum	Maximum	Variance	Mean	Std. Deviation
		Valid	Missing					
Education level	Number of lower education group	143	0	0.00	4.00	1.004	0.9021	1.00221
	Number of middle education group	143	0	0.00	6.00	1.673	1.3776	1.29356
	Number of technical or higher education group	143	0	0.00	7.00	2.070	2.7343	1.43866
	Other	143	0	0.00	5.00	0.856	0.6713	0.92520
Employment status	Number of full-time employees	143	0	0.00	5.00	0.815	1.2937	0.90252
	Number of part-time employees	143	0	0.00	2.00	0.178	0.1818	0.42187
	Number of retired or unemployed	143	0	0.00	6.00	1.125	1.0420	1.06065
	Number of pupil/students	143	0	0.00	7.00	2.943	2.0140	1.71565
	Number of housewives	143	0	0.00	2.00	0.330	0.6434	0.57416
	Number of household activities worker	143	0	0.00	3.00	0.491	0.5105	0.70078

Table 5.8 Descriptive statistics for education level and employment status variables in the whole sample

Due to the widespread employment of housemaids and drivers in Saudi Arabian households, this study investigated the impact of their presence and absence on residential energy consumption. Notwithstanding, as seen in Figure 5.16, approximately 60% of households reported the absence of housemaids and roughly 90% reported the absence of drivers, statistically significant variations in electricity use were observed.

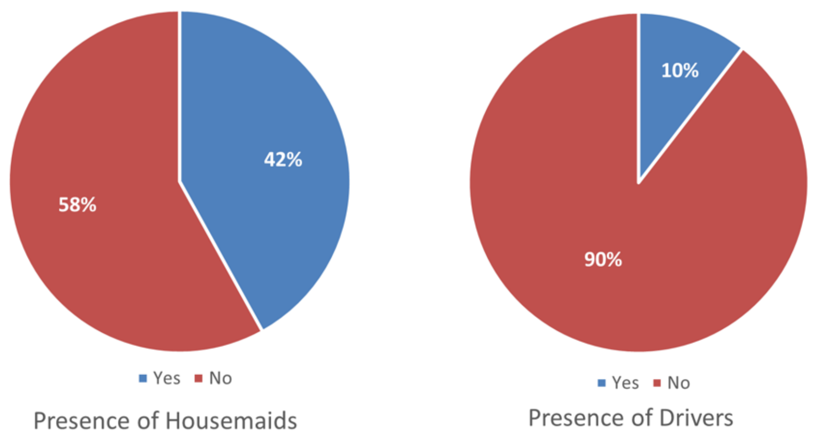


Figure 5.16 Distribution of the presence of drivers and housemaids in households

In terms of monthly household income, Figure 5.17 illustrates the gross household income per month before any deductions. Household income data was collected in Saudi Arabian currency (approximately 5 SR equals £1). It is determined that most of the sample households are low and middle-income. Observably, 23.8% of the households earn less than

10,000 Saudi Riyals per month, whereas 62.2% earn between 10,000 to 29,999 Saudi Riyals per month. Almost 14% of the households are considered as high-income families, although the target area is supposed to be for low-income families.

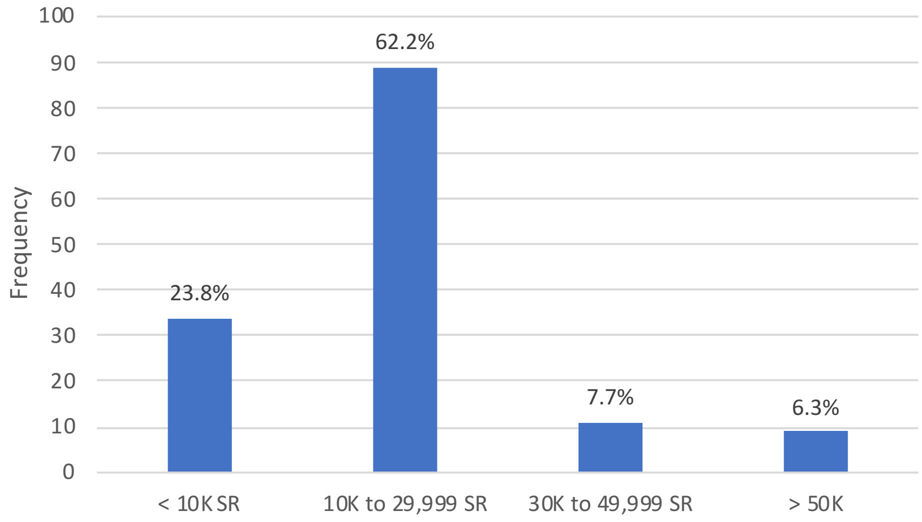


Figure 5.17 Distribution of monthly household income

Homeowners and private tenants are the only two distinct tenure types found in the sample, as seen in Figure 5.18. Compared to tenant groups, the percentage of homeowners in the sample is remarkably high at 88%. Table 5.9 depicts the sample distribution by tenure type and household monthly income. Lastly, the number of years spent in a house is included in this study, Figure 5.19, because it has been demonstrated that it could influence home energy consumption. It is noted that most respondents have lived in their houses for less than ten years (52%), whereas virtually 22% have lived in their homes for more than twenty years.

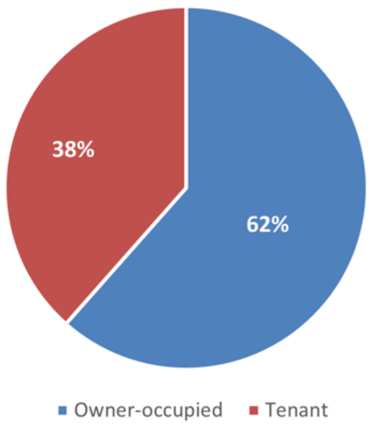


Figure 5.18 Tenure type distribution

			Tenure type	
			Owner-occupied	Tenant
Household Income	Less than 10K SR	Count	23	11
		N %	26.1	20.0
	Between 10K and 29,999 SR	Count	52	37
		N %	59.1	67.3
	Between 30K and 49,999 SR	Count	8	3
		N %	9.1	5.5
	Over 50K SR	Count	5	4
		N %	5.7	7.3

Table 5.9 Household monthly income by tenure type

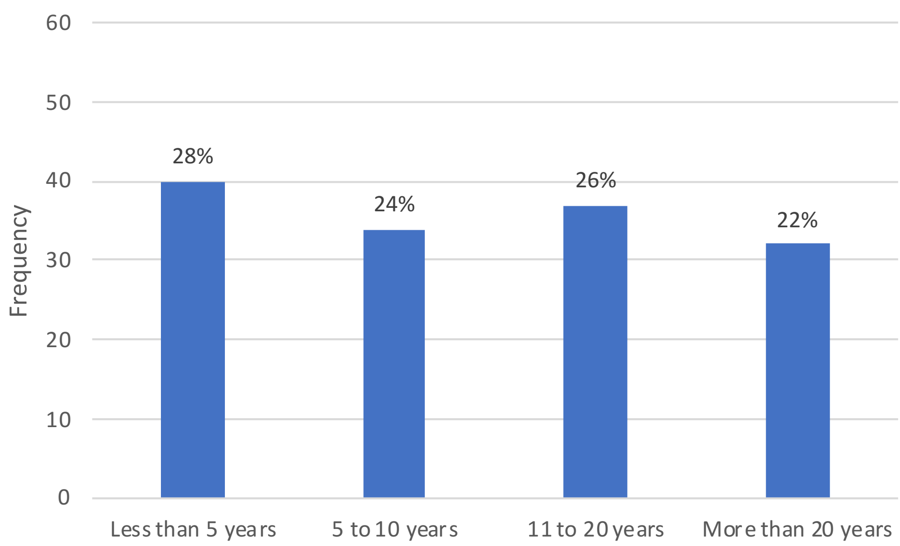


Figure 5.19 Distribution of the length of residency in the house

Saudi Arabia's government has gradually phased out subsidies due to the highly subsidised rate, which means that the cost of producing power is significantly highr than the cost of selling it, as mentioned in Chapter 3. The government has implemented what is commonly referred to as the energy price reform regarding the electricity tariff prices for residential units, in two phases. As of 2016, residents who consume more than 4000 kWh have seen their prices increase by 67%, while residents who use less than 2000 kWh and use between 2001-4000 kWh continued to pay the original rate, 0.05 SR/kWh and 0.10 SR/kWh, respectively. At the beginning of 2018, the minimum rate of power tariffs for households had risen by 260% to 0.18 SR/kWh, up from 0.05 SR/kWh which it had been for almost two decades. Consequently, this posed a substantial challenge to the residential sector. Despite the historical data on the lowest electricity tariff prices in Makkah for 72 years dating back to 1950, the cost of electricity tariffs has been unstable (see Figure 5.20). Moreover, the only factor related to that is the subsidising of electricity by the government of Saudi Arabia.

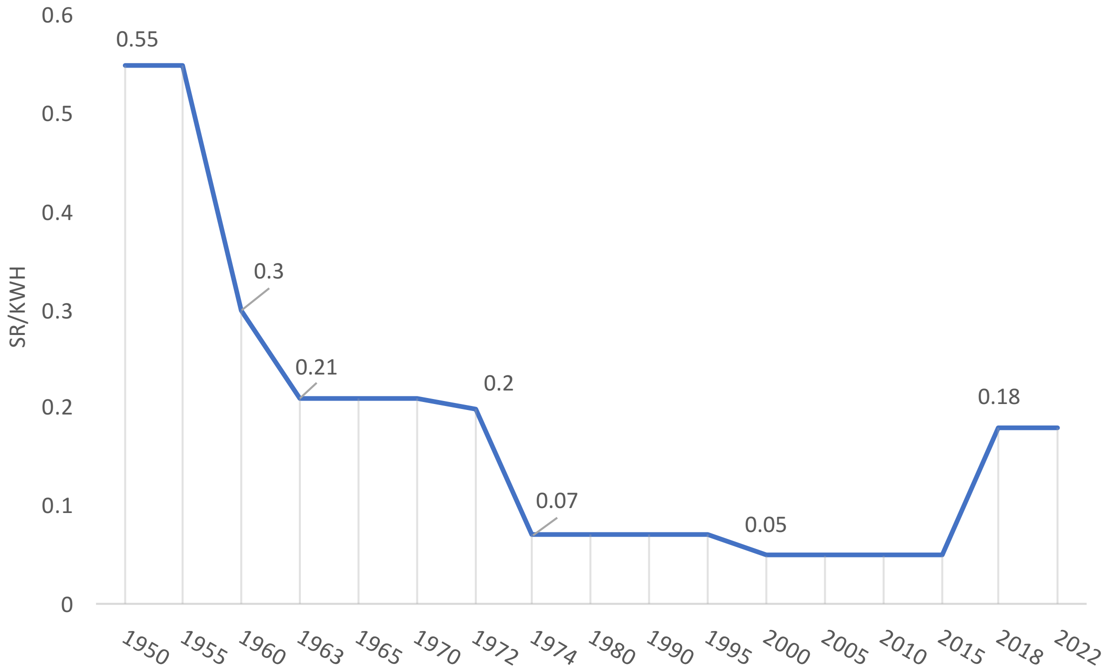


Figure 5.20 Historical data of the lowest electricity tariff prices for residential consumption in the city of Makkah from 1950 to the present
(generated from ECRA, 2015)

As illustrated in Section 2.3, Saudi Arabia's economy depends considerably on oil. Approximately 44% of its GDP and 75% of its exports are oil-dependent. Oil exports are also undoubtedly the largest source of government income, consisting of 68% of government revenues in 2018 (*Fiscal Balance Programme: Update*, 2018). One reason for the country's high domestic consumption is its low controlled fuel prices, which cost the Saudi government somewhere in the region of $61 billion in 2015. Therefore, the Saudi Arabian government has recently launched VAT to be an alternative source of revenue. The government initially imposed VAT of 5% on practically all supplies of goods and services at the beginning of January 2018, and in July 2020, it raised the rate to 15%. Figure 5.21 shows the bill patterns of the surveyed households in July 2017 (no VAT), 2019 (5% VAT), and 2020 (15% VAT). An extreme spike in bill patterns was observed in 2017, while billings decreased in 2019 and 2020, indicating the importance of introducing electricity tariff prices and VAT in relation to investigating residential electricity consumption in Makkah. Additionally, the respondents were questioned within the scope of the survey regarding the level of satisfaction they felt concerning their monthly energy expenses after the recent rise in electricity tariffs and the inclusion of VAT. Using a five-point Likert scale, nearly 81% of the households (116 out of 143) responded to this question. Figure 5.22 shows that a low rate of respondents (23%) was satisfied with their electricity bills, while, in contrast, 47% seem dissatisfied.

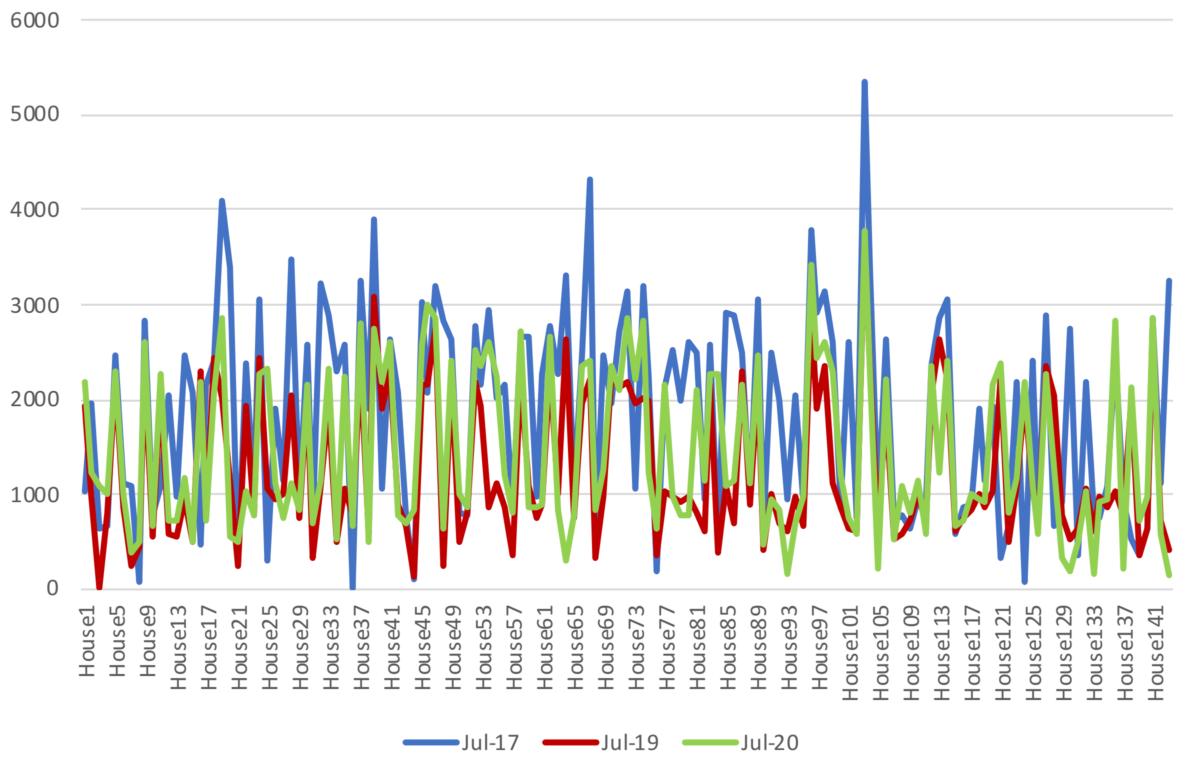


Figure 5.21 Household bill patterns of July 2017, 2019, and 2020

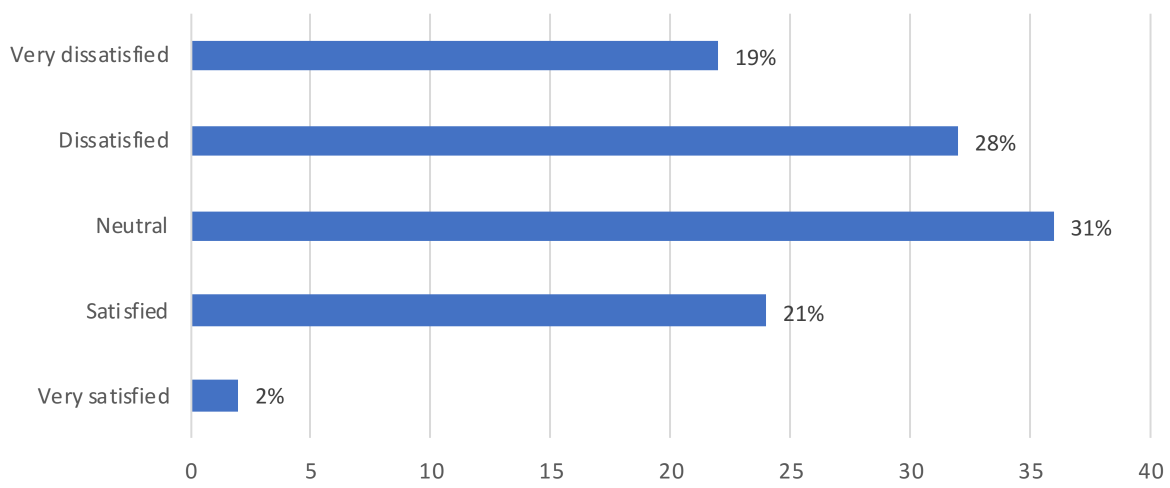


Figure 5.22 Distribution of satisfaction on electricity prices

5.3.3 Meteorological Conditions

Makkah has an exceedingly harsh climate. Therefore, it is too difficult to walk, visit or bike in the city especially in the summer season, which means most activities typically take place indoors. According to Abdou (2014, p. 458), "in Makkah the outdoor temperature may exceed 45°C in summer". Therefore, for the purpose of this study, meteorological data was collected through the weather station owned by the Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research in Makkah. In the two-year period between 2020 and 2021, the following variables were monitored hour-by-hour: outdoor temperature, relative humidity, rainfall, wind speed and direction, and solar radiation. For analysis, the daily maximum and minimum values for all variables were extracted and then monthly average values were computed. The graphs below present a descriptive of each variable.

As shown in Figure 5.23, the monthly average maximum and minimum temperature rises between 2020 and 2021, especially in the beginning quarter of the year. It also portrays that the monthly average maximum temperature was at 42°C (107.6 °F) in June for both years; however, the highest daily maximum temperature of almost 50°C (122 °F) was on the 29th of Aug 2021. In contrast, the monthly average minimum temperature was in January for years 2020 and 2021 at 19 °C and 22°C, respectively, while the lowest daily minimum temperature of 15.5°C was on the 26th of Feb 2020. Despite the fact that February had the highest number of rainy days with a total of eight days for both years (Table 5.10), April had the highest rainfall with a total of 64.76 mm in only two rainy days. In addition, it can be clearly noticed in the graph below that the rainfall was the lowest in June with 0 mm in both years. When comparing the two years, the rainiest months of the year 2020 were September (37 mm) and November (23 mm), whereas the rainiest months of the year 2021 were January (22 mm) and April (64 mm).

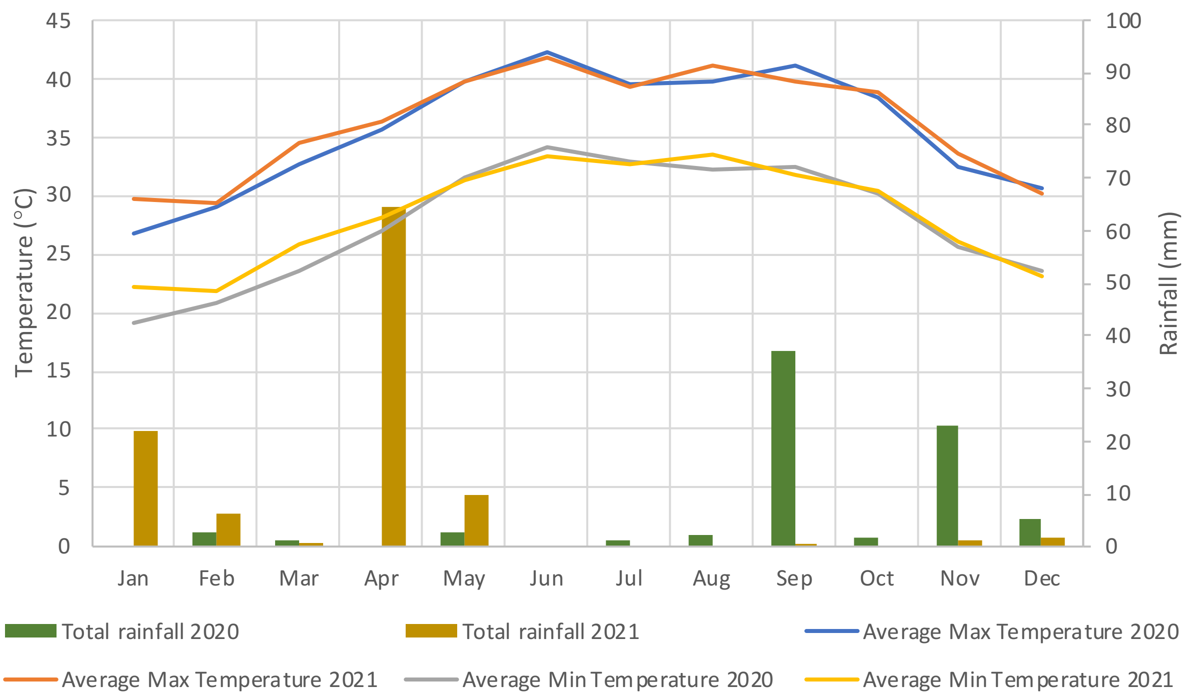
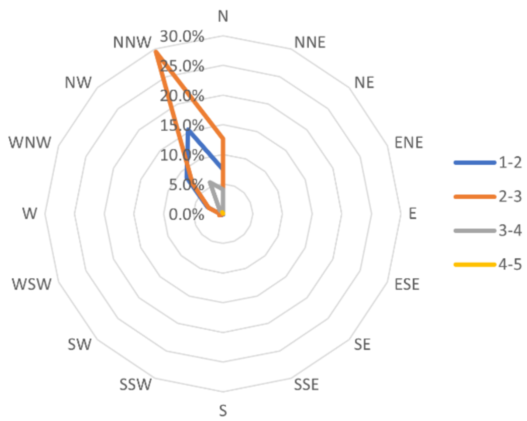


Figure 5.23 Monthly averages for max and min temperature and total reainfall for 2020 and 2021

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2020	0	1	1	0	1	0	1	2	3	1	3	1	14
2021	3	7	2	2	1	0	0	0	1	1	1	2	19
Total	3	8	3	2	2	0	1	2	4	2	4	3	33

Table 5.10 Total monthly and yearly raindays between 2020 and 2021

Figure 5.24, specifically the diagram on the left, shows the maximum wind direction and speed, mostly blowing from the north-northwest, in Makkah during 2020 and 2021. In observing winds from the north-northwest (the long orange spoke), it is determined that they blow at an average speed of 2 to 3 metres per second (29.5% of the time) (See Figure 5.24-right, for more information regarding the minimum wind speed and direction). Furthermore, Figure 5.25 displays that the relative humidity is high during the winter months. However, a wide gap was observed in June when comparing the monthly maximum and minimum relative humidity between 2020 and 2021, while the remainder of the months appear relatively close to each other. According to the data, the monthly maximum higher solar irradiance is April with 823 w/m^2 in 2020 and the highest in 2021 is May with 854 w/m^2.



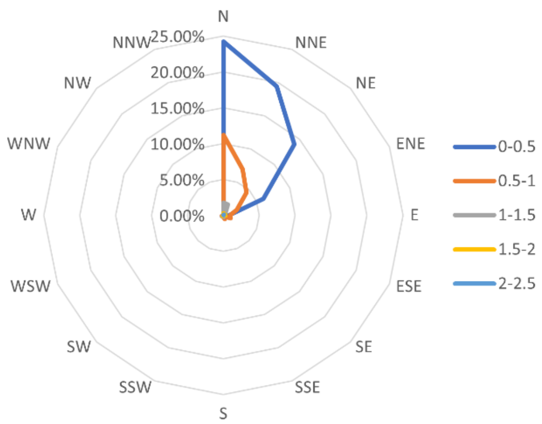


Figure 5.24 Annual maximum wind speed and direction (left diagram) and annual minimum wind speed and direction (right diagram)

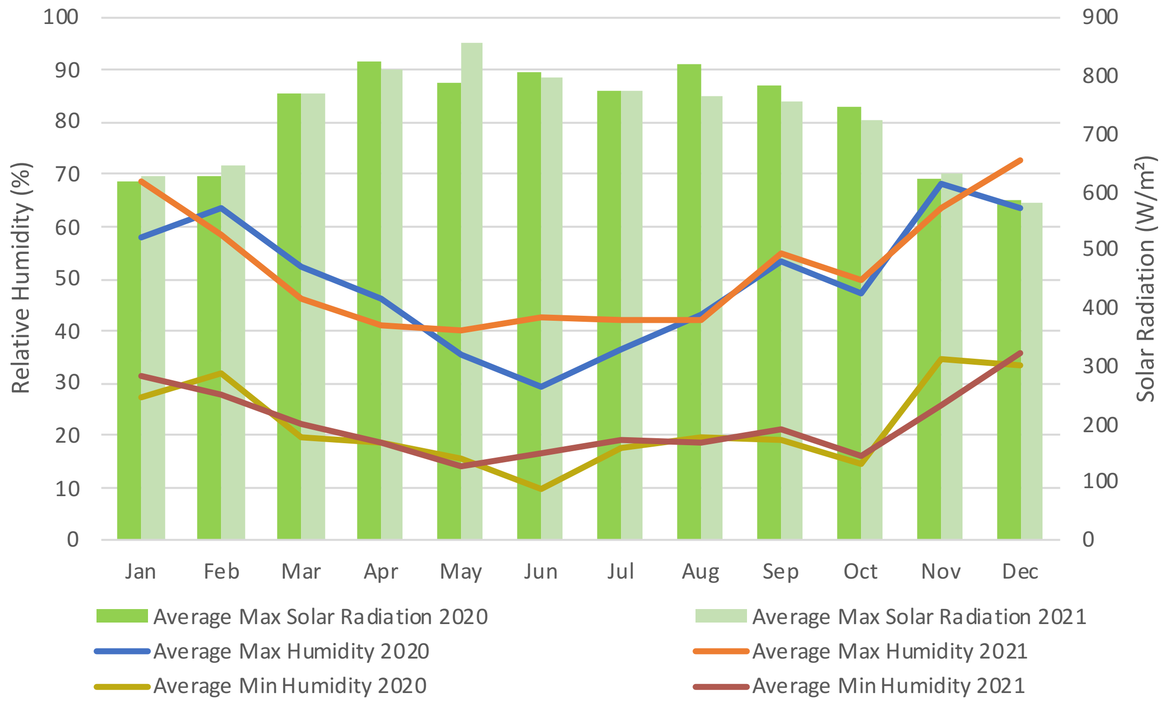


Figure 5.25 Monthly averages for max and min humidity and solar radiation for 2020 and 2021

5.3.4 Occupant Behaviours

The questionnaire used for the survey included questions on the daily use of lighting in bedrooms, family living rooms, kitchens and bathrooms, daily use and number of appliances, the number of air conditioners in the house, as well as the occupants' presence patterns and use of space in dwellings. The respondents were asked to fill out tables in the questionnaires regarding their presence at home, as well as other family members in different spaces, e.g., each room, family living room and kitchen. However, because of the length of the questionnaire, tables were set up with four-hour intervals beginning at six in the morning. Participants were also questioned about their actions throughout the summer prior to the collection of the questionnaire, which was conducted during the winter and spring of 2020. Nonetheless, there are no discernible seasonal changes in Makkah, excluding the summer and winter months. As much as possible, the data from the survey took the form of continuous variables. However, categorical variables must take part of the data since some questions were asked for residents' behaviour.

The respondents were questioned regarding how frequently the HVAC systems were used in the summer and winter. The use of air conditioners, natural ventilation and electric fans was investigated using a Likert scale, where never = 1, rarely = 2, sometimes = 3, usually = 4 and always = 5. Given that the weather in Makkah is hot during most seasons and mild in winter, necessitating mechanical ventilation or air conditioning, cooling loads are rather significant and may represent a major source of electricity consumption. Figure 5.26 shows that air conditioning is used as the primary HVAC system (80% of responses were always and 15% were usually), with little reliance on natural ventilation, e.g., windows and doors, particularly during the summer season. Conversely, approximately 76% (always and usually combined) of households use natural ventilation during the winter season, while 23% of households use air conditioning, as presented in Figure 5.27. Electrical fans had the lowest rate of use in both seasons. Moreover, roughly 95% of respondents reported that their dwellings did not require heating systems.

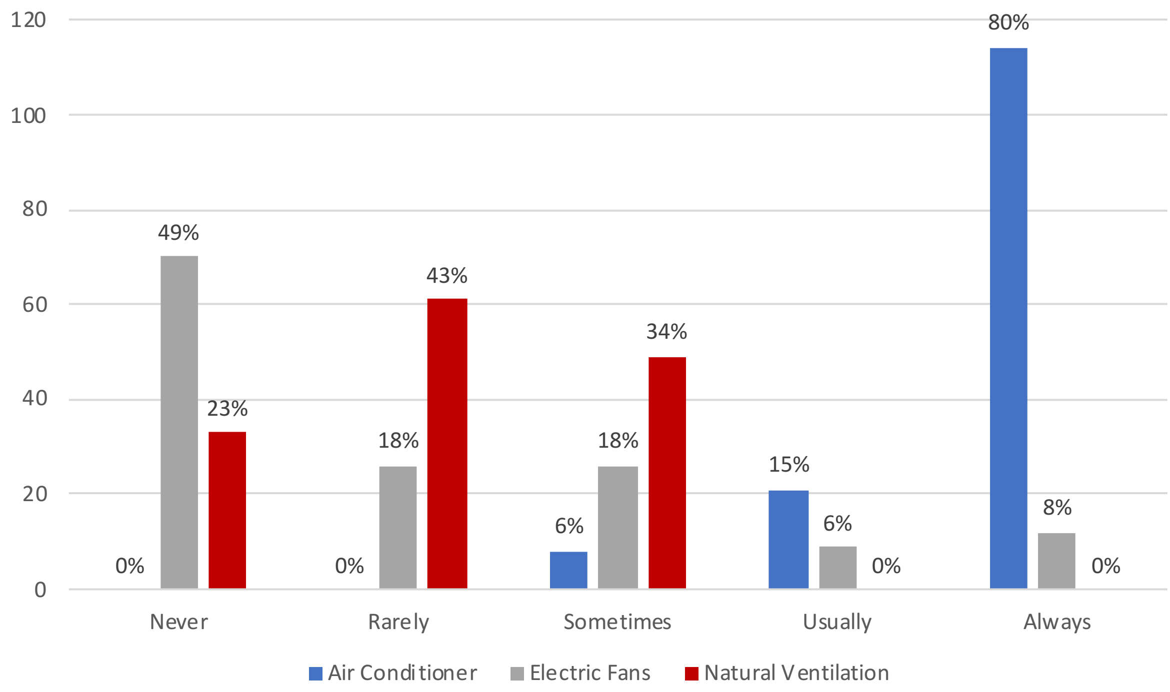


Figure 5.26 Frequency of HVAC systems use during the summer season

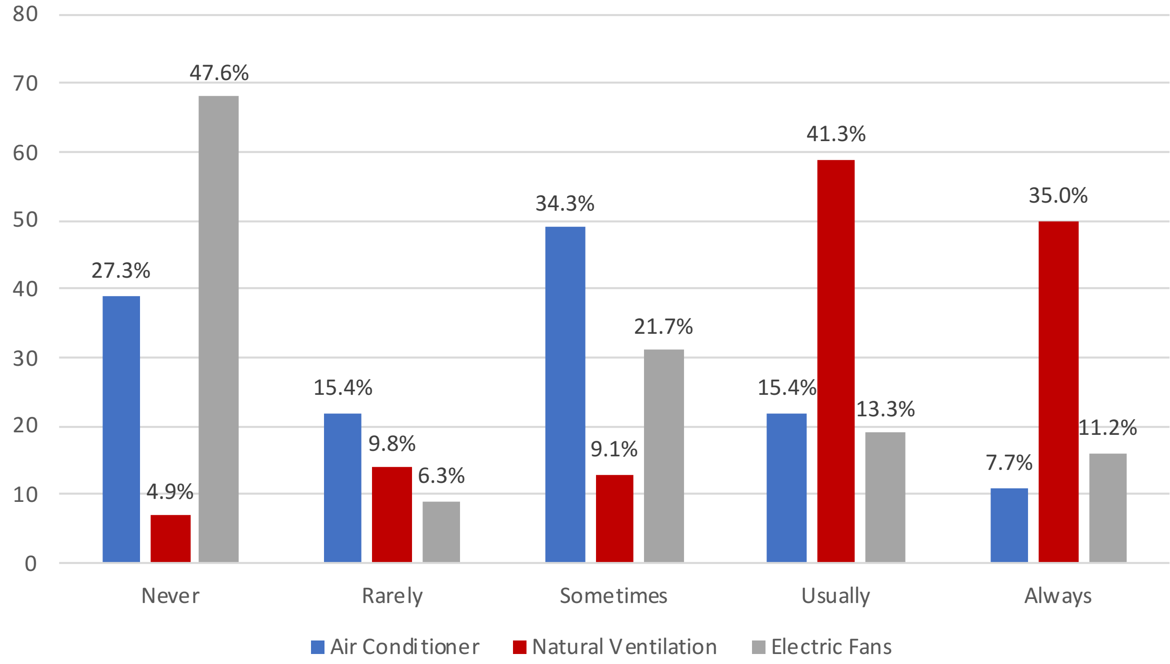


Figure 5.27 frequency of HVAC system use during the winter season

For those residents who use air conditioners in the winter, 63% of residents use them only during the daytime, when the temperature outside rises. In contrast, only 26% use their air conditioners while sleeping (see Figure 5.28). Moreover, the questionnaires covered another behaviour relating to using air conditioners in households. Figure 5.29 describes the residents that keep the air conditioning on while the space or room is unoccupied. A considerable percentage of inhabitants (26%) tend to leave the air conditioner on in an empty room, while a significant rate (63%) does not. This may possibly be for the reason that people forget to turn off the air conditioning or attempt to cool down the indoor temperature of the room.

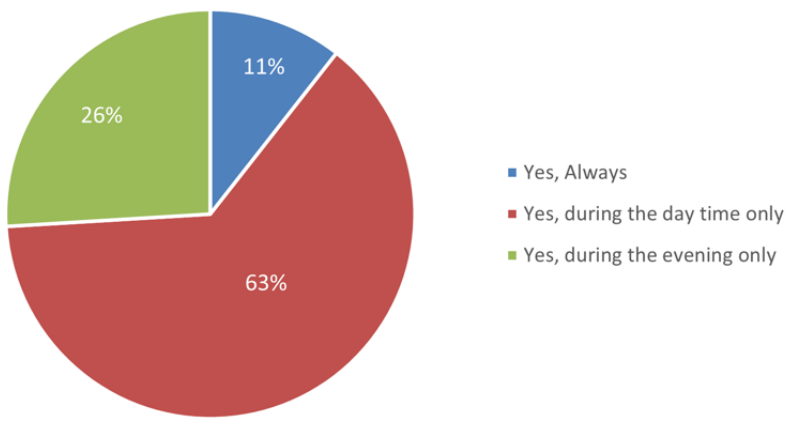


Figure 5.28 Distribution of households using the AC in the winter season

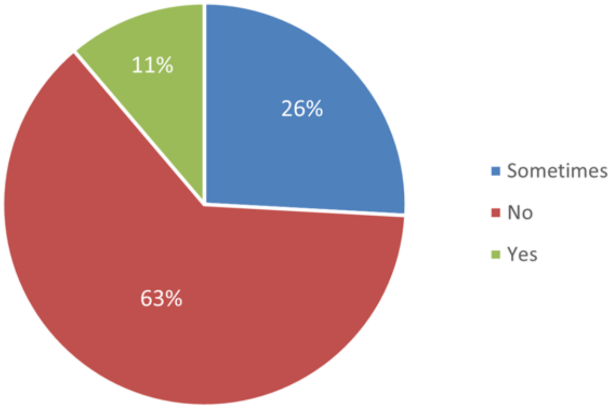


Figure 5.29 Operation of AC in unoccupied space

As mentioned previously, the respondents were asked about occupancy, which is one of the most significant variables in regard to occupant behaviour studies. In this case, respondents were asked to fill in tables that contain intervals of four hours to identify the occupancy of any household member in the most used spaces in dwellings, such as bedrooms, family living rooms and kitchens. It is worth mentioning that bedrooms in Saudi families can be used for other purposes besides sleeping, like studying, hobbies, etc. Figure 5.30 shows the occupancy patterns in four-hour intervals throughout all bedrooms during the weekdays. Regarding responses pertaining to the main bedroom, it is evident that the bedrooms are mostly occupied between the hours of 10 p.m. to 2 a.m. and 2 to 6 a.m., with about 89% and 97%, respectively. For the second bedroom, 76% and 88% were occupied at the same time; roughly 75% and 85% for bedroom three, respectively. It should be noted that number of bedrooms varies between households, as discussed in Section 6.25.3.1. In contrast, at the weekend, the bedrooms are highly occupied between the hours of 2 a.m. to 6 a.m. and 6 a.m. to 10 a.m. (see Figure 5.31).

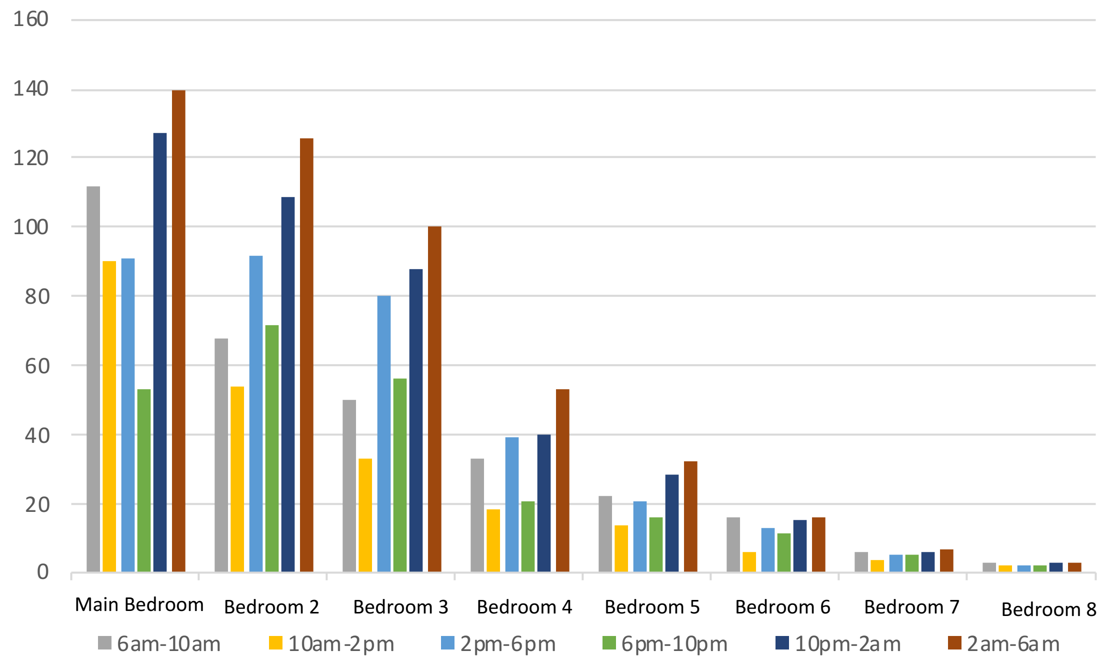


Figure 5.30 occupancy patterns in all bedrooms during the weekdays

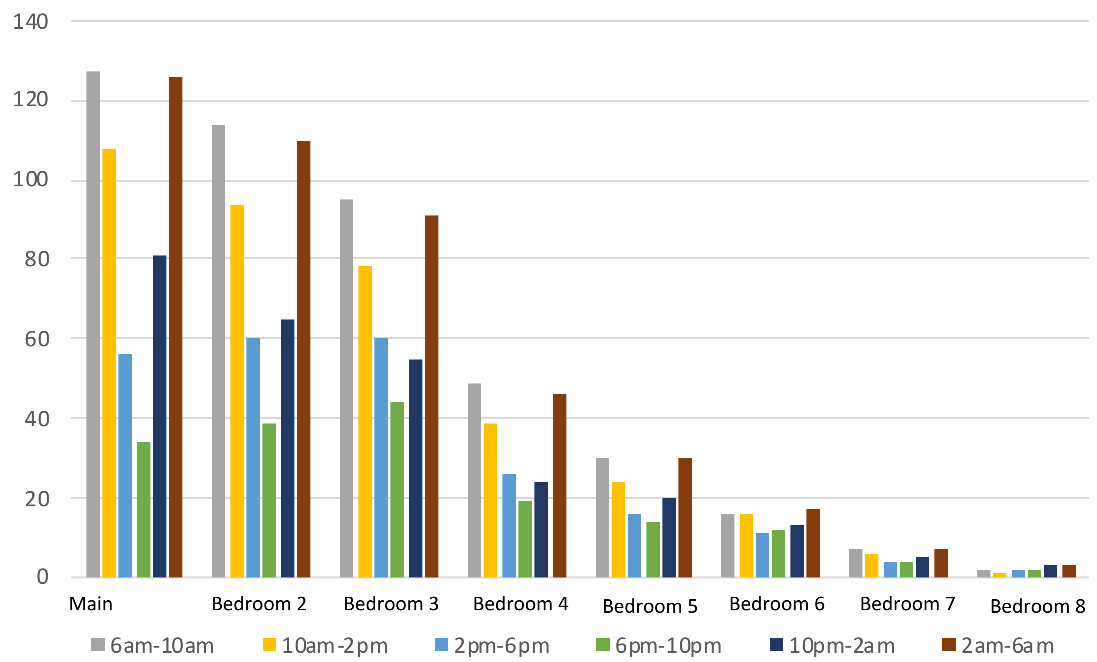


Figure 5.31 occupancy patterns in all bedrooms at the weekend

Similarly, family living rooms and kitchens are significant factors in this research due to the different household practices in both these spaces. Consequently, studying the presence patterns of these spaces would assist in explaining how the electricity is being used in dwellings. Figure 5.32 illustrates the presence patterns in the family living rooms during the weekdays and weekends. It shows that most of the sample (nearly 90%) confirmed the use of the main family living room between 2 p.m. to 10 p.m. during the weekdays. The presence in the main family living room, on the other hand, varies at weekends, with the largest level of households' attendance occurring between 2 p.m. to 6 p.m. and the lowest level occurring between 2 a.m. to 6 a.m. (Figure 5.32). Although some households have two kitchens in their houses, the presence of the family members in the secondary kitchen is almost non-existent (see Figure 5.33).

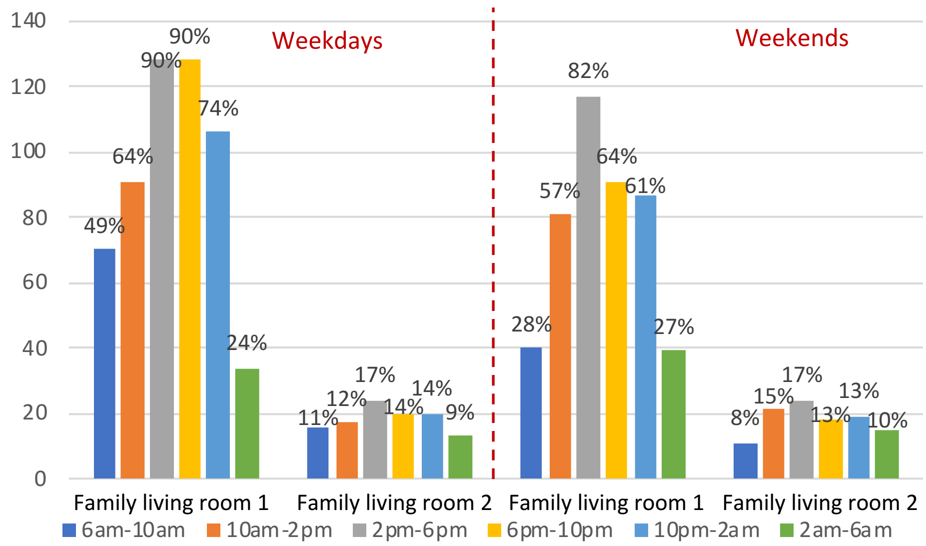


Figure 5.32 Occupancy patterns in family living rooms during the weekdays and weekend

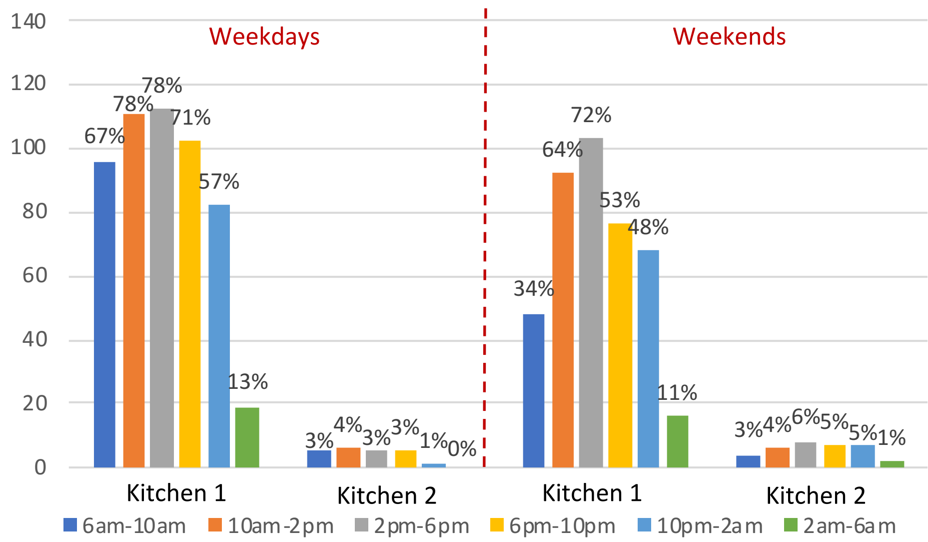


Figure 5.33 Occupancy patterns in kitchens during the weekdays and weekend during the weekdays and weekend

Even though the majority of homes have a large number of guests' living rooms (Section 5.3.1), several are used infrequently. For instance, almost 65% of respondents provide separate guests' living rooms for male and female visitors. This separation of male and female rooms is due to the issue of privacy in Saudi Arabia, as noted in Section 0. Most visitors stayed for two to eight hours, as shown in Figure 5.34, while more than half of the duration was two to four hours. It is possible that this could be associated with the high residential electricity consumption, which will be discussed in the following sections.

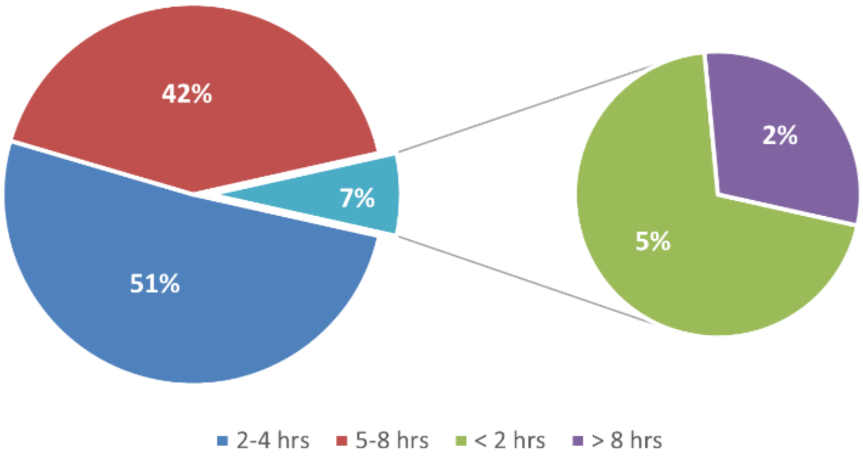


Figure 5.34 Percentages of the duration of guest visits

The data on each one of the appliances were collected independently from the questionnaire, including their number and daily use. Based on the data collected, it can be observed that air conditioners had the highest frequency of electrical appliance ownership of all the appliances included in the sample. This information highlights the significance of air conditioning units in the everyday lives of individuals and emphasizes the need for reliable and efficient cooling systems (Figure 5.35). Furthermore, Figure 5.36 indicates that among the appliances surveyed, refrigerators with built-in freezers and broadband devices are the most frequently utilized appliances by the sample population.

Subsequently, appliances were computed into multiple continuous variables based on the function of the appliances; refer to Section 4.4.2.4.4 for the electrical appliances' details. The number of general appliances in the household ranges between 7 and 24 with an average of 14 appliances, including TVs, phone, etc. Regarding this study, the number and daily use of air conditioners is an important factor. Nevertheless, the number of air conditioners was the only information gathered in the questionnaires for the reason that collecting data relating to the everyday use of each space in the house would require considerable time, effort and equipment, which is beyond the scope of this study. Further details pertaining to the descriptive statistical analysis on the other appliances groups is shown in Table 5.11.

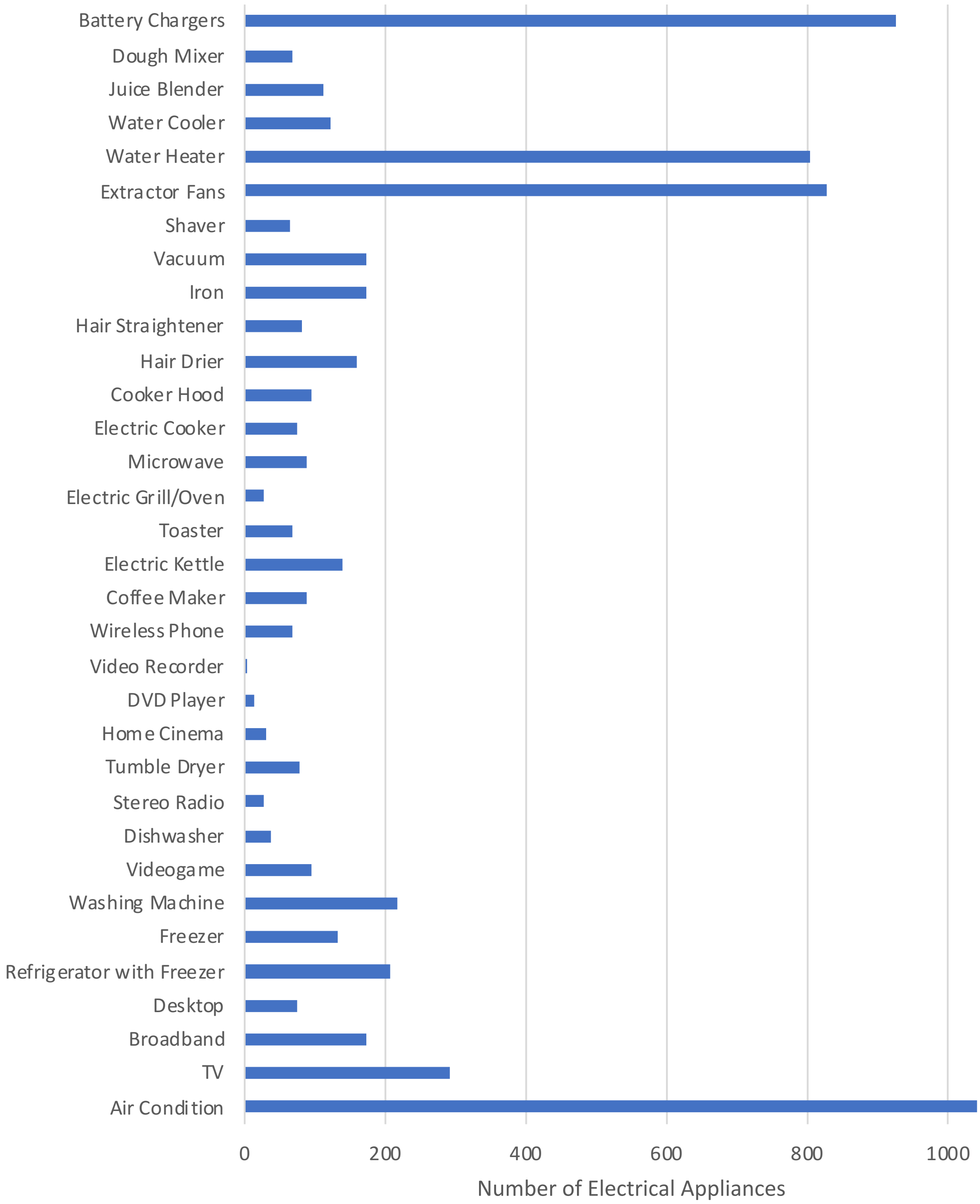


Figure 5.35 Total number of elctrical appliances in the sample

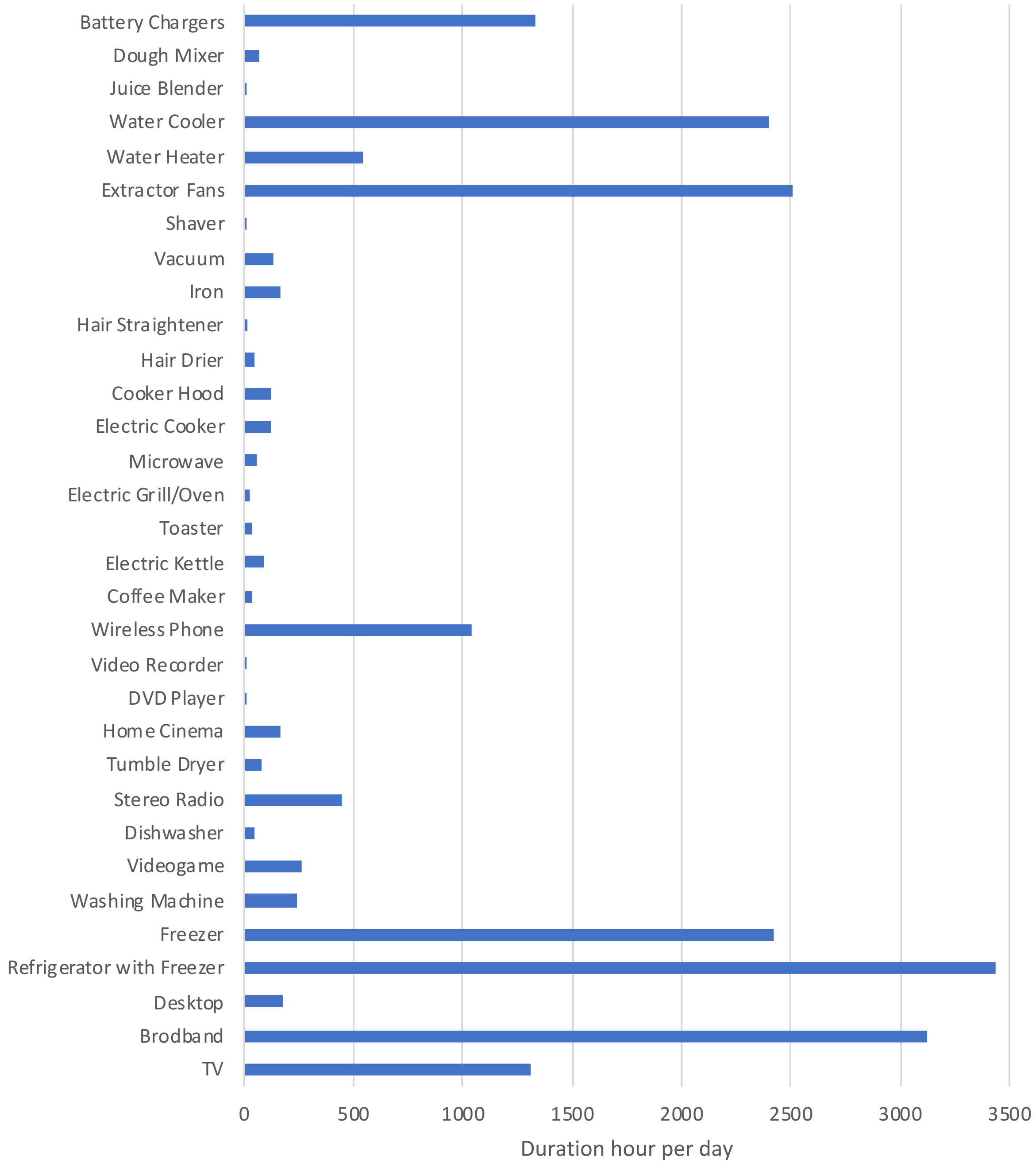


Figure 5.36 Total use of electrical appliances (H/D) in the sample

	N		Minimum	Maximum	Variance	Mean	Std. Deviation
	Valid	Missing					
Number of general appliances	143	0	7	24	14.9	13.83	3.9
Number of cleaning appliances	143	0	2	7	1.38	3.2	1.17
Number of food preparation appliances	143	0	2	13	7.22	7.5	2.7
Number of hobby appliances	143	0	1	6	1.5	2.3	1.22
Number of extra ventilation appliances	143	0	4	9	2.7	5.8	1.63
Number of battery charge appliances	143	0	1	17	13.72	6.41	3.7
Number of air conditioners	143	0	5	15	5.52	7.3	2.35
Daily use of general appliances (duration min)	143	0	1791.43	5725.43	826914.15	3136	909.35
Daily use of cleaning appliances (duration min)	143	0	17.14	381.42	6855.6	168.3	82.8
Daily use of food preparation appliances (duration min)	143	0	111.43	3677.14	979598.5	2416.5	989.75
Daily use of hobby appliances (duration min)	143	0	1440.00	2910	153667.04	1851.4	392.003
Daily use of extra ventilation appliances (duration min)	143	0	42.86	1440.00	306521.38	1804.14	553.64
Daily use of battery charge appliances (duration min)	143	0	60	1080	76202.068	450.21	276.05

Table 5.11 Discriptive statistics of grouped appliances and air conditioners

The use of light bulbs in dwellings was included in this study. Householders were asked about specific behaviour, such as daily use of lighting in different house spaces, use of light when the area or room is unoccupied and use of illumination even when the house is empty. The results obtained from the preliminary analysis of the daily use of bedrooms, family living rooms and kitchens are presented in Figure 5.37. It clearly reveals that family living room lights are used for over six hours while most bedroom and kitchen lights are used between two to four hours. Although most responses to the questionnaires regarding the daily use of lighting in bathrooms were less than two hours, 23 responses reported that they always use lights in bathrooms (see Figure 5.37).

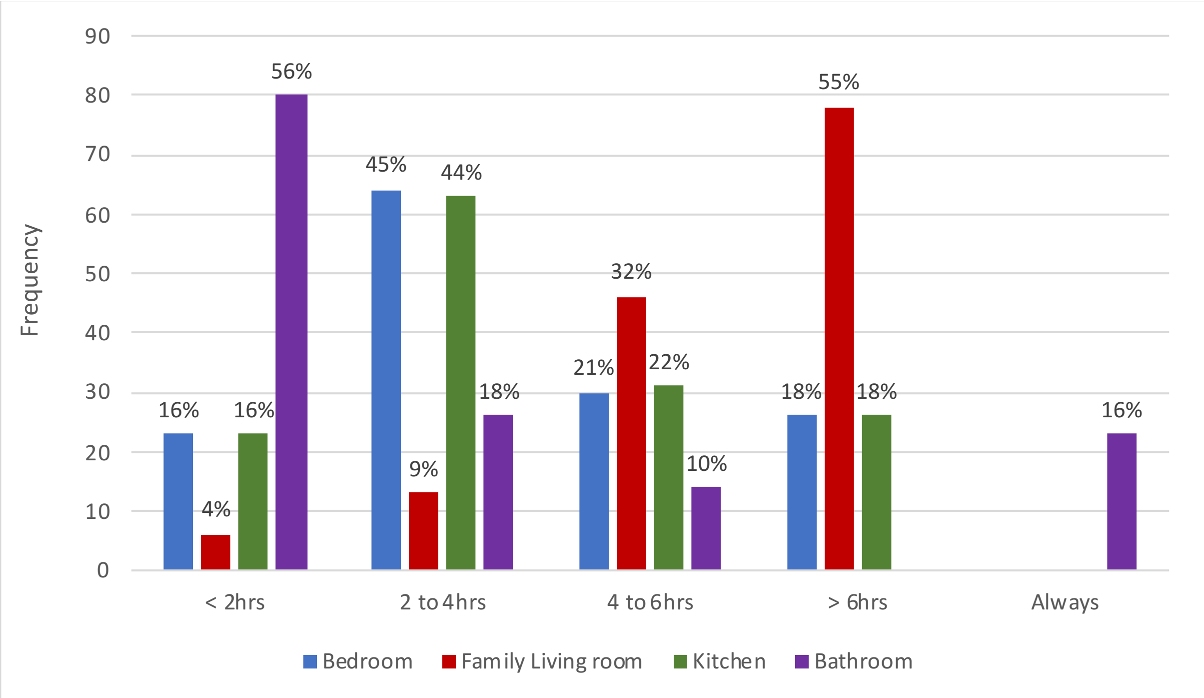


Figure 5.37 Distribution of daily use of lighting in bedrooms, family living rooms, kitchens, and bathrooms

Lastly, another essential behaviour included in this study, as it could seriously affect the amount of electricity use, is how occupants use lights in their houses. Figure 5.38 below presents the breakdown of the use of lighting when the space or room is unused and when the house is empty. The pie chart A illustrates that 42% of householders regularly leave lights on in unoccupied rooms, while the pie chart B shows that 48% of respondents said at least one light bulb might be left on when the house is empty.

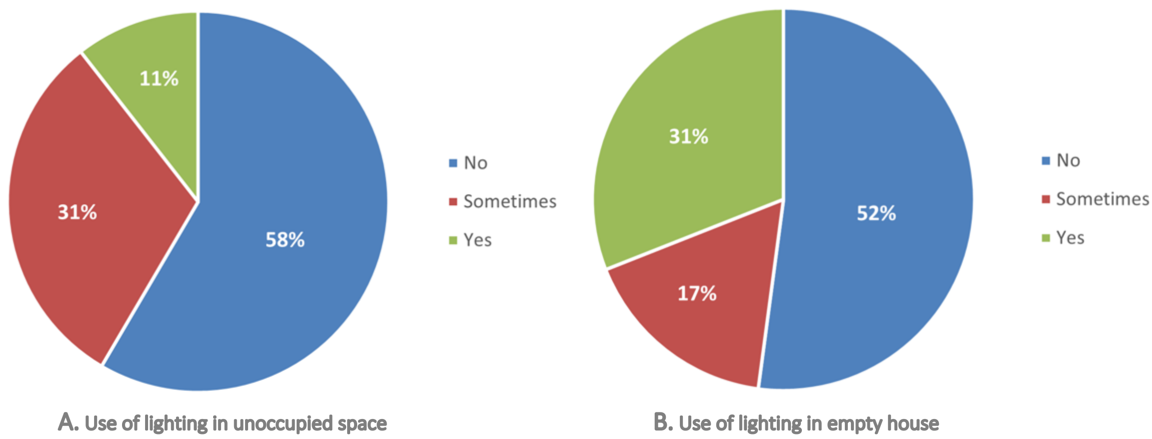


Figure 5.38 Distribution of the behaviour of use of lighting

5.3.5 Electricity Consumption Patterns

A statistical analysis was conducted on the electricity consumption of households surveyed from July 2019 to June 2020. Figure 5.39 depicts a histogram illustrating the monthly electricity consumption by households over the examined period. The average monthly electricity consumption is highest during the summer months (June-August), ranging between 4000-5200 kWh. In contrast, during the winter months (December-February), the average monthly electricity consumption drops to a range of 1700-3000 kWh (Table 5.12). During the summer months, there is usually a higher average monthly consumption, which can be attributed to the increased usage of air conditioning and other cooling appliances. In the winter season, households typically utilize fewer appliances and spend less time at home, leading to a decrease in average monthly consumption.

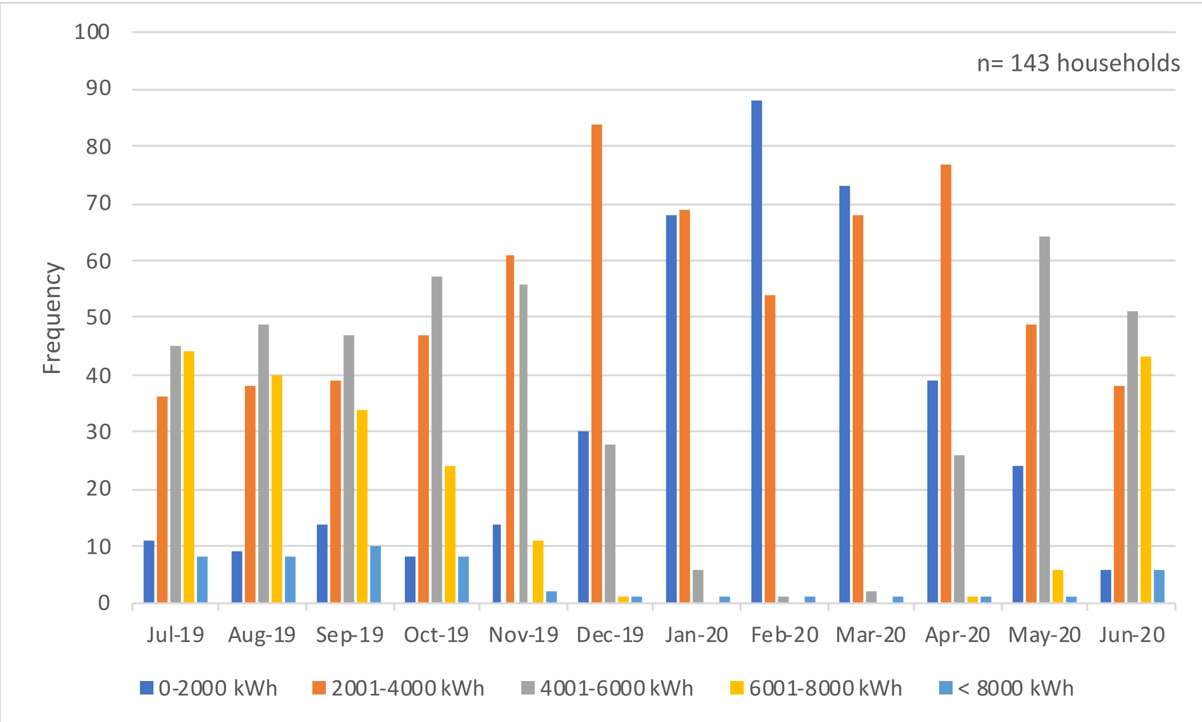


Figure 5.39 Households' monthly electricity consumption (kWh).

	Jul-2019	Aug-2019	Sep-2019	Oct-2019	Nov-2019	Dec-2019	Jan-2020	Feb-2020	Mar-2020	Apr-2020	May-2020	Jun-2020
Minimum	937	893	215	883	343	222	253	354	297	445	669	978
Maximum	11734	12460	11357	10341	8444	6012	4710	4602	4533	6464	7106	10479
Average	5019	4951	4766	4648	3922	3069	2122	1783	1999	2849	3711	5119
Standard Deviations	2001	2037	1998	1828	1503	1182	963	843	878	1223	1513	1850

Table 5.12 Households' monthly minimum, maximum, and average electricity consumption

5.4 Summary

This chapter presents the initial findings of a research study on the determinants of residential electricity consumption in Makkah, particularly the influence of occupant behaviour. This chapter serves as an introduction to the research study, focusing on Makkah as the chosen study area. It's impossible to overstate the significance of Makkah on both an international and national scale. It's revered as the most sacred city in Islam and is home to the Kaaba, which is the holiest site for Muslims. Makkah is also a major economic hub and a popular tourist destination. Additionally, the chapter provides a detailed description of the neighbourhood that served as the study's focal point, determined by various predetermined criteria established to serve the research objectives. Therefore, its conservative culture, harsh climate, and developmental needs position it as a prime choice for the purpose of this study.

The chapter also provides descriptive statistical analysis of the research sample. This analysis sheds light on key characteristics and trends related to residential electricity usage, specifically focusing on building and household socioeconomic characteristics, weather conditions, and occupant behaviour related to the use of air conditioning, lighting, and electrical appliances. Furthermore, a descriptive statistical analysis of the usage patterns and tendencies in household electricity consumption has been provided. Monthly electricity consumption peaks during the summer (June-August), averaging between 4000 and 5200 kWh, while the average monthly electricity consumption drops to a range of 1700-3000 kWh during the winter months (December-February).

The next chapter will use advanced statistical analysis, such as ANOVA, t-test, and correlation, to find the relationship between the following collected variables and electricity consumption:

- Building characteristics (e.g., floor area, number of rooms, type of dwellings)
- Household socioeconomic characteristics (e.g., income, education, household size)
- Weather conditions (e.g., temperature, humidity)
- Occupant behaviour (e.g., use of air conditioning, lighting, electrical appliances)

The findings of this study have important implications for policymakers and stakeholders in Makkah who are interested in reducing energy consumption and improving energy efficiency

Chapter Six:

Results Part I: Influential Factors on Residential Electricity Consumption in Makkah

Chapter 6: Results Part I: Influential Factors on Residential Electricity Consumption in Makkah

6.1 Overview

This chapter investigates the influential factors, i.e., household socioeconomic characteristics, building attributes, meteorological conditions, energy economy policy, along with occupant behaviours on residential energy consumption in Makkah, Saudi Arabia. The results and analysis in this chapter provide a comprehensive discussion of the results obtained from the data collected through questionnaires as well as governmental entities. The relationship and differences between each variable and electricity consumption was examined using various statistical tests based on the variable's data type, specifically continuous, categorical or dichotomous. The analytical procedure is depicted in a flowchart in Figure 6.1.

Pearson’s correlation coefficients were employed for continuous and normally distributed variables, while Spearman’s correlation coefficients were performed for continuous but non-normally distributed variables. These tests were used to determine the effect of each variable on energy use. In addition, the independent-samples t-tests were used for dichotomous variables and one-way ANOVA was utilised for categorical/ordinal variables. These two tests were used to determine whether there are any statistically significant differences between the means of two (t-test) or more (ANOVA) independent groups on electricity consumption. Outliers and normality of all variables were tested. A skewness (a measure of asymmetry) and kurtosis (a measure of peakiness) were checked to calculate the Z-value for normality of distribution, as explained in Section 4.4.2.4.3. The variables including a two tailed value smaller than 0.05 were seen as being statistically significant with a 95% confidence interval.

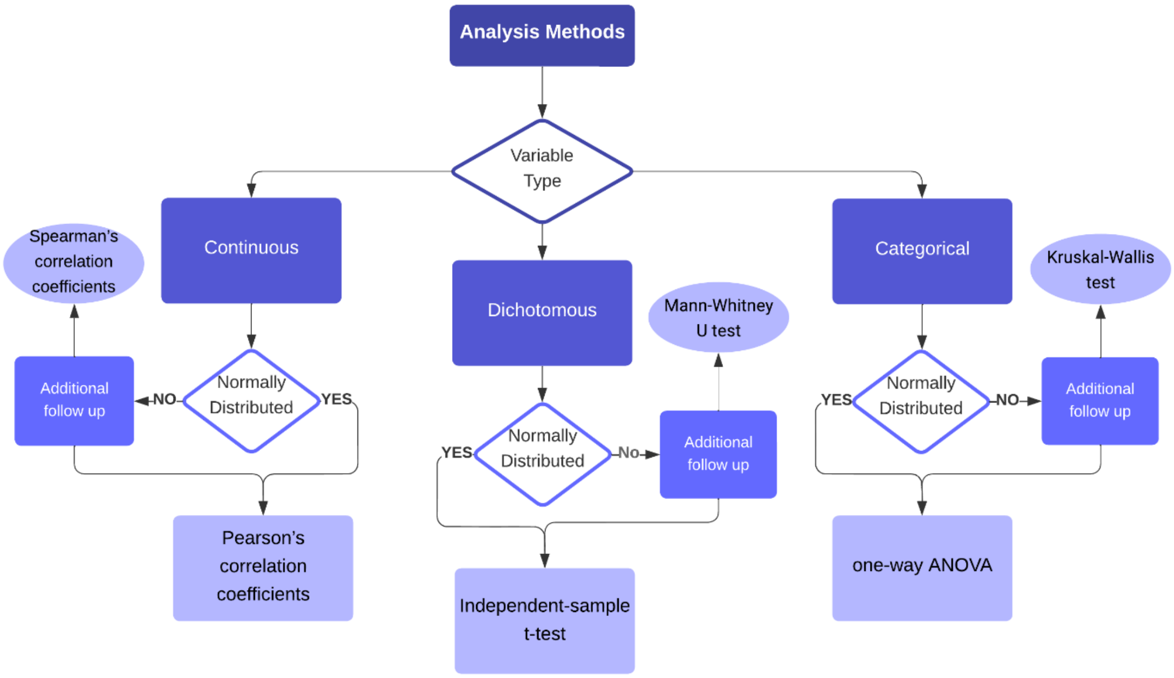


Figure 6.1 Analysis methods of the data collection

6.2 Building Characteristics

The difference in electricity consumption between dwellings variables, i.e., building type, the number of bathrooms, family living rooms and kitchens, in addition to the type of air conditioner, temperature control used for air conditioning and light bulbs, can be seen in Figure 6.2. The electricity consumption of households that have preserved their original building's form and design is lower than that of extended dwellings. Consequently, it is crucial to determine the variances in electricity usage between the various dwelling types. Figure 6.2 illustrates that two-story semi-detached houses consume more energy than other types of dwellings, approximately double the mean of the electricity consumption of apartments. Standard deviations are also included for each dwelling type on the graph, indicating a substantial variation in electricity consumption between dwelling types.

The number of family living rooms, kitchens and bathrooms in the house contribute to electricity consumption, thus, a large dwelling requires more electrical power to meet its functions. (For further information on the differences on electricity consumption and the other building variables, see Figure 6.2). Various statistical analysis was employed to define the relationship between building variables and electricity consumption, as mentioned above. The results are discussed in the subsequent sections.

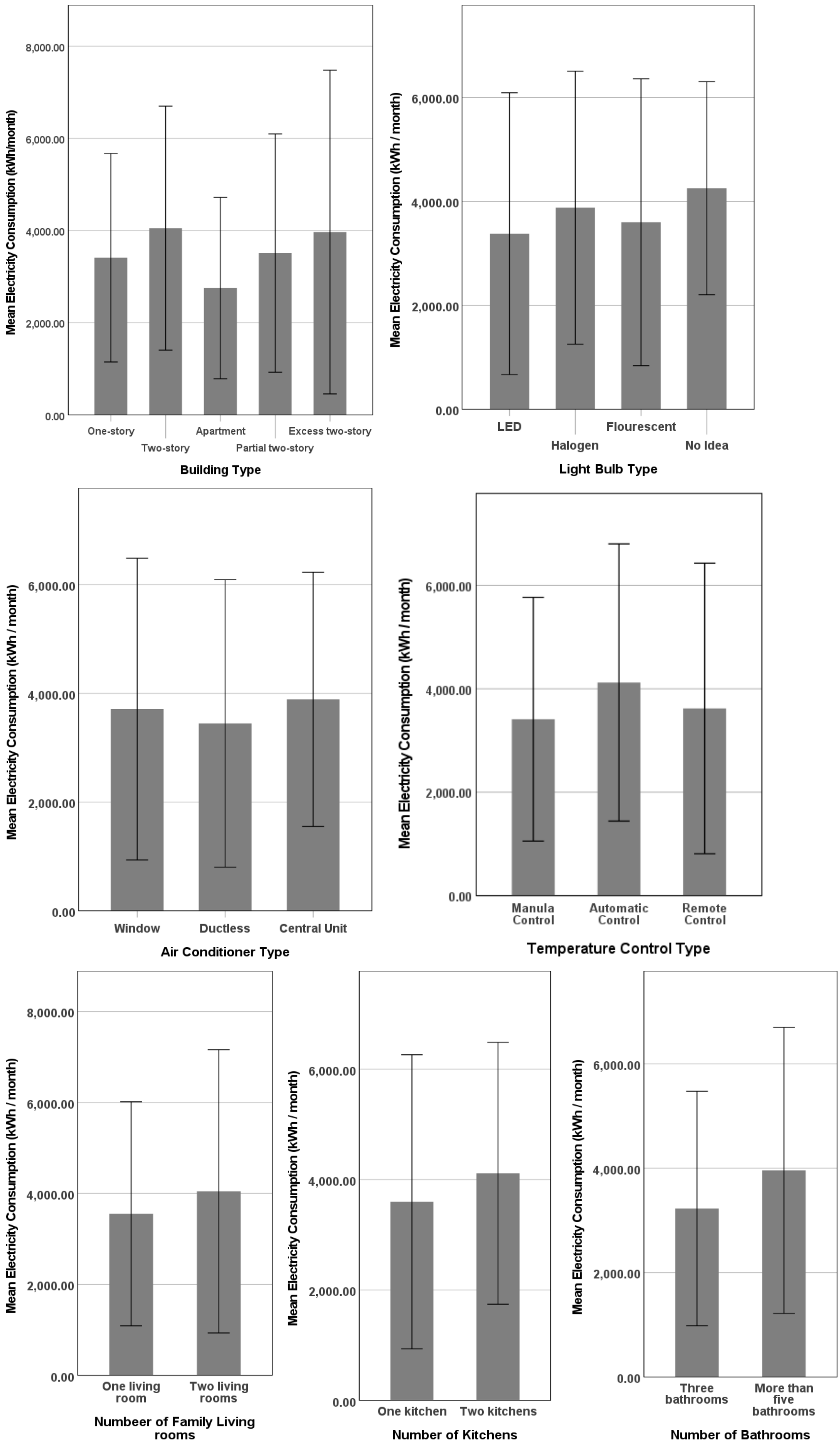


Figure 6.2 Mean and standard deviation for energy use (kWh/month) per building attributes

6.2.1 Relationship between Building Characteristics and Electricity Use

Results of the Analysis of Variance (ANOVA):

A one-way analysis of variance (ANOVA) was performed to determine whether or not the residential electricity use varied according to the building type, the type of air conditioners (central units, ductless and window), and the type of light bulbs (LED, fluorescent, halogen, no idea). The results, as shown in Table 6.2, revealed that there was a statistically significant difference in electricity use between at least two groups of dwelling types.

Light bulb types had a significant effect on electricity consumption (p =.011); statistically significant differences in electricity use were found between light bulb types, which falls between the LED bulbs type and no idea group. Even though more than half of the respondents use LED bulbs, it is determined that the LEDs type group use the least amount of electricity compared to the other groups of illumination bulbs (*M* = 3379.67, *SD* = 1356.30). Figure 6.2 may suggest a noticeable difference in electricity consumption across the various air conditioning types. However, the ANOVA test confirmed that this difference was not statistically significant. In addition, statistically significant differences were observed between the types of temperature control system used for air conditioning and electricity consumption. The findings of the analysis are consistent with those realised in previous research and theoretical frameworks. Table 6.1 illustrates the statistics for the ANOVA analysis.

Results of the Independent-sample t-test Analysis

An independent-samples t-test was performed for dichotomous variables, i.e., number of bathrooms and number of family living rooms and kitchens, so as to determine whether these variables responded differently to electricity consumption. The findings indicate that the number of bathrooms in a dwelling has a statistically significant effect (*p* = .001). Hence, households with more than five bathrooms (*M* = 3959.52, *SD* = 1370.32) were associated with a statistically significantly larger mean electricity consumption than those with three bathrooms. Notwithstanding that the number of family living rooms and kitchens demonstrate some variations in electricity consumption, no statistically significant differences were found in relation to the number of family living rooms and number of kitchens. Table 6.1 presents the statistical results of the independent-sample t-test analysis.

Building-related variables	Statistics (t-test and ANOVA)	Mean (Std. Deviation)
Dwelling Type	*F* (4, 138) = 4.14 *, *p* = .003	One-storey, 3410.21 (1130.40) Partial two-story, 3511.80 (1292.41) Two-storey, 4052.13 (1323.30) Excess two storey, 3967.45 (1755.34) Apartment, 2752.10 (983.60)
Air conditioner types	*n.s.*	Window, 3711.40 (1387.80) Ductless, 3447.70 (1322.52) Central unit, 3891.20 (1169.65)
Light bulb types	*F* (3, 139) = 3.90 *, *p* = .011	LED, 3379.67 (1356.30) Halogen, 3879.98 (1313.62) Fluorescent, 3600.38 (1380.24) No idea, 4254.91 (1321.71)
Number of bathrooms	*t* (141) = -3.363 **, *p* = .001	3-bathrooms, 3228.70 (1123.26) More than 5, 3959.52 (1370.32)
Number of family living rooms	*n.s.*	One, 3552.47 (1231.62) Two, 4046.80 (1556.48)
Number of kitchens	*n.s.*	One, 3598.17 (1331.91) Two, 4113.90 (1185.85)
Temperature control	*F* (2, 140) = 3.356*, *p* = .038	Manual 3412.67 (1178.48) Automatic 4123.31 (1340.04) Remote control 3621.38 (1404.64)

Note: * $p < .05$ level (2-tailed), ** $p < .01$ level (2-tailed), *** $p < .001$ (2-tailed), and *n.s.*, not statistically significant

Dependent variable: electricity consumption (kWh/year)

Table 6.1 Independent-sample t-tests and one-way analysis of variance (ANOVA) tests for variables related to building attributes and energy use

Results of the Correlations Analysis

As previously described, Pearson's correlation analysis was performed to determine associations between electricity use and continuous and normally distributed variables, such as floor area of residences. In contrast, for continuous but non-normally distributed variables like the total number of rooms, number of guestrooms, number of bedrooms and number of additional rooms, Spearman's correlation was employed. To comprehend the relationship between two variables, it's crucial to note that they have a positive correlation when they move in the same direction, either increasing or decreasing simultaneously. Conversely, a negative correlation exists when they move in opposite directions. The results show that a small positive correlation was observed between electricity use and dwellings floor area and the total number of rooms in dwellings. Additionally, a moderate positive correlation was found between electricity use and number of bedrooms. No correlations were found between electricity consumption and the number of additional rooms and guest living rooms in dwellings (for statistics, see Table 6.2).

Building-related variables	Correlation Coefficient	Number of cases
Floor area	*r* = .270 ***	143
Total number of rooms	*p* = .296 ***	143
Number of bedrooms	*p* = .450 ***	143
Number of guestrooms	*n.s.*	143
Number of additional rooms	*n.s.*	92

Note: * $p < .05$ level (2-tailed), ** $p < .01$ level (2-tailed), *** $p < .001$ (2-tailed), and *n.s.*, not statistically significant

Dependent variable: electricity consumption (kWh/year), Pearson's *r* is used for parametric data; Spearman's *p* is used for non-parametric data.

Table 6.2 Correlation coefficient tests for variables related to building and energy use

6.3 Household Socioeconomic Characteristics

This section describes electricity consumption patterns using the questionnaire data collected in residential buildings in Makkah to highlight important aspects of household socioeconomic characteristics. It discusses the variation in electricity consumption by each household socioeconomic factor, namely the respondents' age, gender, education level and employment status, tenure type, household monthly income, length of residency, electricity tariffs, together with the presence of children, teenagers, seniors, housemaids, and drivers).

Figure 6.3 displays the demographics of the respondents, including their age range, education level and gender, as well as the presence of children, teenagers, the elderly, housemaids and drivers. It should be stated that these factors all indicate variation that necessitated further analysis, which is presented in the following section. Regarding the respondents' age range, only residents who are aged nineteen or above can participate in the questionnaire. Although adults and seniors use electricity differently, the graph does not exhibit a considerable difference. However, there appears to be a difference between male and female respondents regarding electricity use.

To compare the difference between the length of residency groups and electricity consumption, Figure 6.4 illustrates that the longer the residents live in the house, the more electricity is used. In addition, the results suggest that there is an increasing trend in energy consumption across income groups. Figure 6.4 reveals that households with over 50K SR per month (over $13K) are the highest electricity consumers despite comprising just 6.3% of the sample population, as illustrated in Section 5.3.2. (For further information on the differences in electricity consumption and the other households' economic variables, see Figure 6.4). After providing an overview of the demographic and socioeconomic variations in energy consumption, the following section employs a variety of tests to statistically investigate the relationship between these factors and residential electricity consumption.

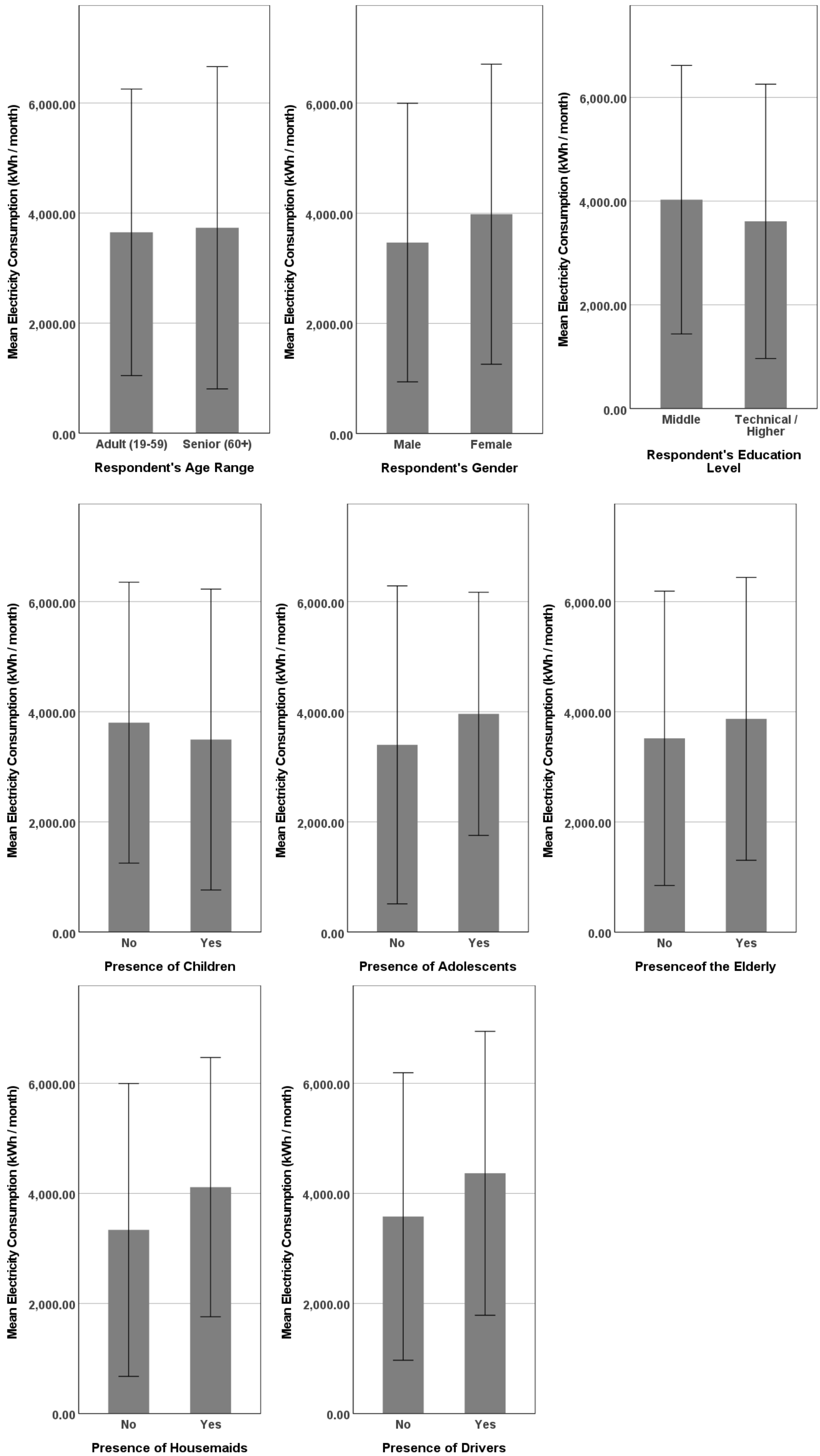


Figure 6.3 Mean and standard deviation for energy use (kWh/month) by the household demographic variables

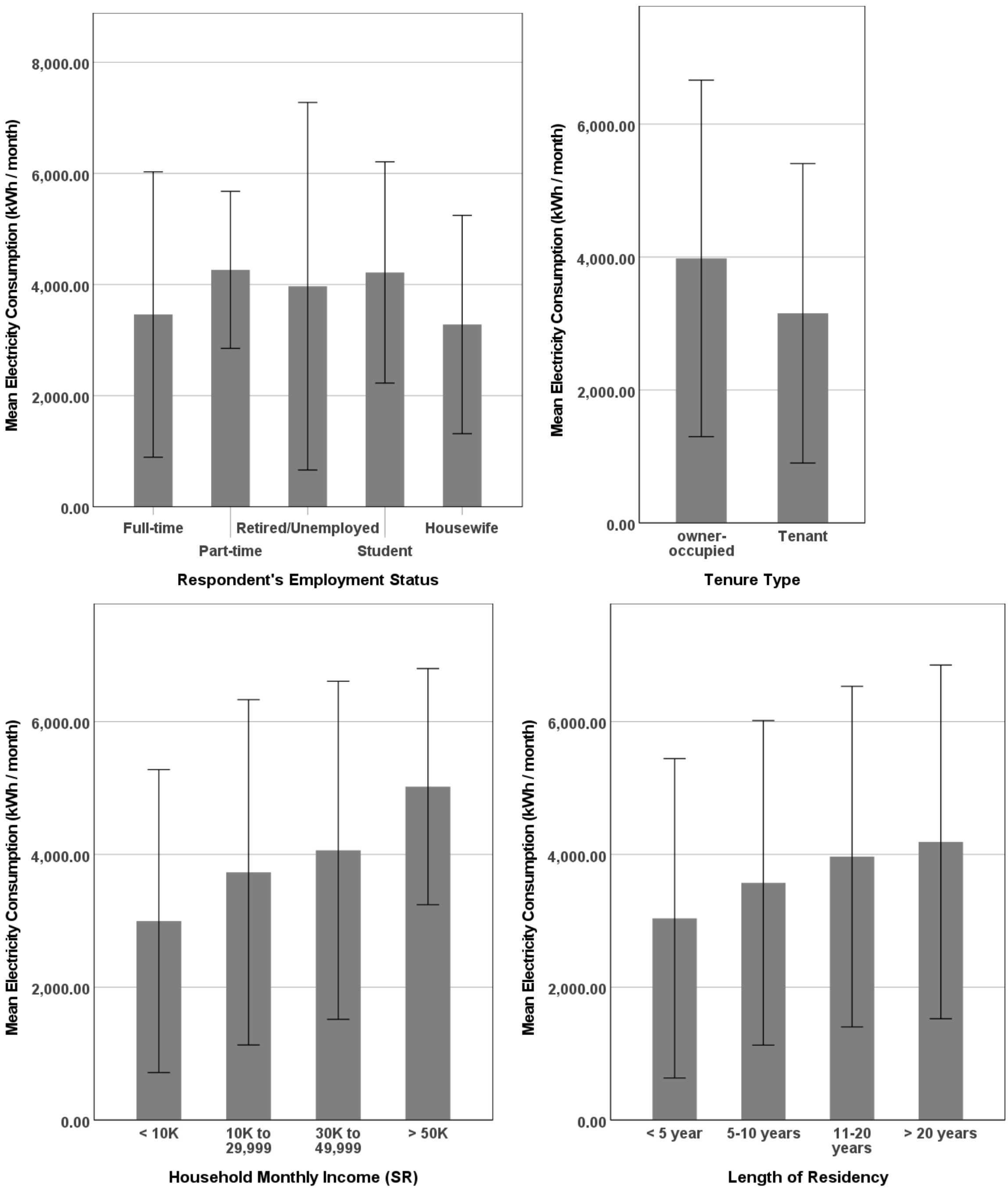


Figure 6.4 Mean and standard deviation for energy use (kWh/month) by the household economiccal variables

6.3.1 Relationship between Household Socioeconomic Characteristics and Electricity use

Results of the One-way ANOVA Analysis

The one-way ANOVA analysis was conducted based on the nature of the variables' data, as mentioned, to determine the variations in electricity consumption between categories of variables. This particular test was utilised for the next categorical variables: length of residency, household monthly income and the respondent’s employment status. It is important to note that roughly 3.75 Saudi Riyal are equivalent to 1 US dollar.

The findings indicate that there is a relationship between the length of residency categories and the level of energy consumed; statistically significant differences were found between the length of residency and electricity use ($p < 0.01$). Furthermore, a relationship was identified between the monthly income of households and variability in their energy use. This relationship is statistically significant ($p < 0.0005$). Statistically significant differences were observed between those who earn less than 10K, between 10K to 29,999 and over 50K in Saudi Riyals.

The findings regarding the analysis of the respondent's employment status revealed that the assumption of homogeneity of variance was violated, as assessed by Levene's test for equality of variances ($p < .05$). Hence, with respect to the results interpreted using Welch's ANOVA; the impact on electricity consumption was statistically significantly different ($p = .026$) for different levels of the respondent's employment status groups. (For more information on statistics, see Table 6.3).

Results of the Independent-sample t-test Analysis

This section provides the results of the independent-samples t-test, which was performed for dichotomous variables, such as tenure type, the presence of children, adolescents, the elderly, housemaids and drivers, respondent's age, gender and education level). In this test, the researcher investigated whether electricity consumption varies between categories within each of these variables. The findings illustrate that there were statistically significant differences in tenure type ($p < .0005$), where owner-occupied homes consumed significantly more electricity than privately rented homes. Additionally, households without children were associated with higher electricity consumption in comparison to those with children. Conversely, houses that did not comprise the elderly were associated with lower electricity use than those where elderly people reside. Nevertheless, the results show that the presence of children and the elderly in houses was not statistically significantly different in regard to electricity use.

The presence of housemaids was statistically significantly related to higher electricity usage compared to households that did not employ housemaids. In contrast, the presence of drivers was related to lower electricity consumption. Moreover, the presence of teenagers was included in this study as well to test their impact on residential electricity consumption. One of the test assumptions was violated: the assumption of homogeneity of variances, as measured using Levene's test for equality of variances ($p = .013$). Welch's t-test (alternative to the standard t-test) was utilised, which indicated statistically significant variations in electricity use between the presence and absence of adolescents' groups ($p = .009$). Thus, the presence of adolescents in houses was established to be statistically significantly related to higher electricity usage compared to their absence.

According to the respondent's age range, as the survey primarily targeted people aged 18 and older, only two appropriate age groups were included, i.e., adults and seniors. No statistically significant variations in electricity consumption were determined between the respondents' age range groups ($p > .05$). Nevertheless, the respondents' gender was statistically significantly varied in electricity use ($p = .023$). In addition, the results show that there were no statistically significant variations in electricity consumption between the respondents' education level. (See Table 6.3 for additional statistical information regarding other variables).

Household Socioeconomic variables	Statistics (ANOVA and t-test)	Mean (SD)
Length of residency	F (3, 139) = 5.94**, p = .001	< 5 years, 3038.02 (1202.61) 5-10 years, 3572.54 (1222.09) 11-20 years, 3967.43 (1282.56) > 20 years, 4188.74 (1331.75)
Household monthly income	F (3, 139) = 7.33**, p < .0005	< 10K SR, 2966.51 (1140.51) 10K to 29,999 SR, 3731.04 (1300.09) 30K to 49,000 SR, 4062.36 (1272.82) > 50K SR, 5021.31 (889.12)
Respondent's employment status	Welch's F (4, 26.88) = 3.26*, p = .026	Full-time, 3461.45 (1284.48) Part-time, 4264.78 (706.45) Retired, 3970.36 (1654.14) Student, 4217.99 (995.95) Housewife, 3281.45 (982.51)
Tenure types	t (141) = 3.81**, p < .0005	Homeowner, 3980.90 (1341.02) Private rent, 3154.43 (1126.17)
Presence of children	*n.s.*	Yes, 3495.93 (1366.18) No, 3802.38 (1275.56)
Presence of the elderly	*n.s.*	Yes, 3873.16 (1283.68) No, 3519.74 (1335.56)
Presence of the adolescence	Welch's t (138.344) = 2.64**, p = .009	Yes, 3962.45 (1104.25) No, 3399.17 (1443.56)
Presence of housemaids	t (141) = -3.62**, p < .0005	Yes, 4114.38 (1330.66) No, 3336.85 (1177.60)
Household Socioeconomic variables	*Statistics (ANOVA and t-test)*	Mean (SD)
Presence of drivers	t (141) = -2.21*, p = .029	Yes, 4365.94 (1289.49) No, 3580.72 (1305.67)
Respondent age range	*n.s.*	Adult, 3650.87 (1301.81) Seniors, 3734.04 (1464.23)
Respondent gender	t (141) = -2.29*, p = .023	Male, 3468.56 (1264.92) Female, 3983.70 (1362.18)
Respondent education level	*n.s.*	Middle Edu, 3948.42 (1288.42) Higher Edu, 3610.53 (1322.33)

Note: * p < .05 level (2-tailed), ** p < .01 level (2-tailed), *** p < .001 (2-tailed), and *n.s.*, not statistically significant

Dependent variable: electricity consumption (kWh/year), Pearson's r is used for parametric data; Spearman's p is used for non-parametric data.

Table 6.3 Independent-sample t-tests and one-way analysis of variance (ANOVA) tests for variables related to household socioeconomic characteristics and energy use

Results of the Correlation Analysis

Recent studies suggest that including all family members in the analysis would be beneficial. Therefore, Spearman's correlation has been conducted for non-normal variables, for instance family size, number of children, teenagers, adults and seniors in the house, number of males and females in the house, number of respondents with a lower education, middle education, technical and higher education, and others (illiterate person and no idea) in the house, number of full-time employees, part-time employees, retired/unemployed, students, housewives and household activities workers in the house and electricity tariffs, in order to determine the relationships between these variables and electricity consumption in residential buildings. Understanding the relationship between two variables is essential. It's important to note that they have a positive correlation when they move in the same direction, either increasing or decreasing at the same time. On the other hand, a negative correlation exists when they move in opposite directions.

Table 6.4 presents Spearman's correlation coefficient matrix for the above-stated variables. There are statistically significant, strong positive correlations between electricity consumption and electricity tariffs, family size and the number of adults and the number of females in the house. There are also moderately positive correlations between electricity use and the number of middle and higher educational levels, number of students and number of household activities workers in the house. Additionally, there are weak positive correlations between electricity consumption and the number of teenagers, number of males and number of part-time workers in the home.

	Electricity Consumption	Family size	# of children	# of teens	# of adults	# of seniors	# of males	# of females	# of lower education	# of middle education	# of higher education	# of other education	# of full-time	# of part-time	# of retired/ unemployed	# of student	# of housewife	# of household activities	# of housemaid	# of driver	Electricity tariff
Electricity Consumption	1																				
Family size	.508***	1																			
# of children	-0.134	.242**	1																		
# of teens	.219**	.572***	0.032	1																	
# of adults	.543***	.740***	-.172*	.187*	1																
number of seniors	0.088	0.027	-.323***	-.214*	-0.146	1															
# of males	.227**	.701***	.271**	.432***	.479**	-0.065	1														
# of females	.513***	.791***	0.104	.426***	.620***	0.092	0.118	1													
# of lower education	-0.017	.298***	.790***	0.154	-0.095	-.228**	.360***	0.106	1												
# of middle education	.370***	.596***	0.005	.735***	.311***	-0.041	.444***	.448***	0.050	1											
# of higher education	.366***	.529***	-.229**	0.108	.695***	0.094	.341***	.444***	-.218**	-0.037	1										
# of other education	0.105	.332***	0.051	-0.040	.298***	.221**	0.077	.396***	-0.126	-0.019	-0.045	1									
# of full-time	0.116	.402***	0.097	0.070	.469***	-0.127	.324***	.282**	0.071	0.049	.408***	0.150	1								
# of part-time	.219**	0.111	-0.137	0.115	0.155	-0.003	0.030	0.128	-.174*	.196*	0.057	0.082	-0.086	1							
# of retired / unemployed	.164*	0.133	0.025	-.256**	0.154	.307***	0.113	0.089	0.011	-0.083	.183*	0.129	-0.145	-0.127	1						
# of student	.337***	.758***	.293***	.765***	.403***	-.209*	.588***	.550***	.394***	.642***	.287**	-0.019	0.157	-0.013	-.256**	1					
# of housewife	-0.134	0.086	0.063	0.019	-0.043	.194*	0.071	0.058	0.098	0.107	-0.141	0.162	-0.109	-0.021	-.241**	-0.002	1				
# of household activities	.306***	.338***	-0.112	0.084	.376***	0.134	0.031	.444**	-0.139	0.104	.191*	.489***	-0.083	0.089	-0.020	0.058	-0.034	1			
# of housemaid	.309**	.394**	-0.086	0.073	.427**	0.152	0.024	.528**	-0.052	0.079	0.145	.632**	0.121	0.106	-0.009	0.082	0.018	.780**	1		
# of driver	.183*	.211*	-0.119	-0.107	.304***	.202*	0.156	0.160	-0.058	0.006	.207*	.221**	.243**	0.015	0.116	-0.016	-0.106	.273**	.189*	1	
Electricity tariff	.804***	.383***	-.176*	0.084	.501***	0.079	0.113	.437***	-0.091	.217**	.393***	0.071	0.054	.230**	.211*	.188*	-0.120	.280**	.273**	.193*	1

Note: * $p < .05$ level (2-tailed), ** $p < .01$ level (2-tailed), *** $p < .001$ (2-tailed).

Table 6.4 Spearman's correlation matrix for continous variables related to household socioeconomic characteristics and energy use

6.4 Meteorological Conditions

This section explores the differences between weather conditions, e.g., outdoor temperature and relative humidity and electricity consumption, as these two variables demonstrate considerable relevance. In addition, based on the temperature data collected, degree-day values were calculated. Degree-days is a numerical representation of the relative warmth or coolness of the weather over a specific period, such as a day, a month, or a year The number of degree-days is a metric for calculating the amount of heating and cooling energy a building will use based on the weather.

As can be seen from Figure 6.5, average electricity consumption rises, particularly when the outdoor temperature increases. For example, while June is typically the hottest month, Makkah reached the highest average electricity consumption in June 2020. This could be attributable to causes other than temperature, as compared to 2021 when an evident reduction is shown in the same month. The lockdown of the city due to COVID-19 might be the biggest contributor to the variation in electricity consumption between these two years. Regardless of the pandemic, the influence of temperature on electricity consumption requires further investigation. Therefore, this will be discussed in the following section. Conversely, when there is an increase in the relative humidity, there is a decrease in the amount of electricity used (see Figure 6.6). In contrast, when there is an increase in the relative humidity, there is a reduction in the amount of electricity used. (Figure 7.6 below illustrates this sort of scenario).

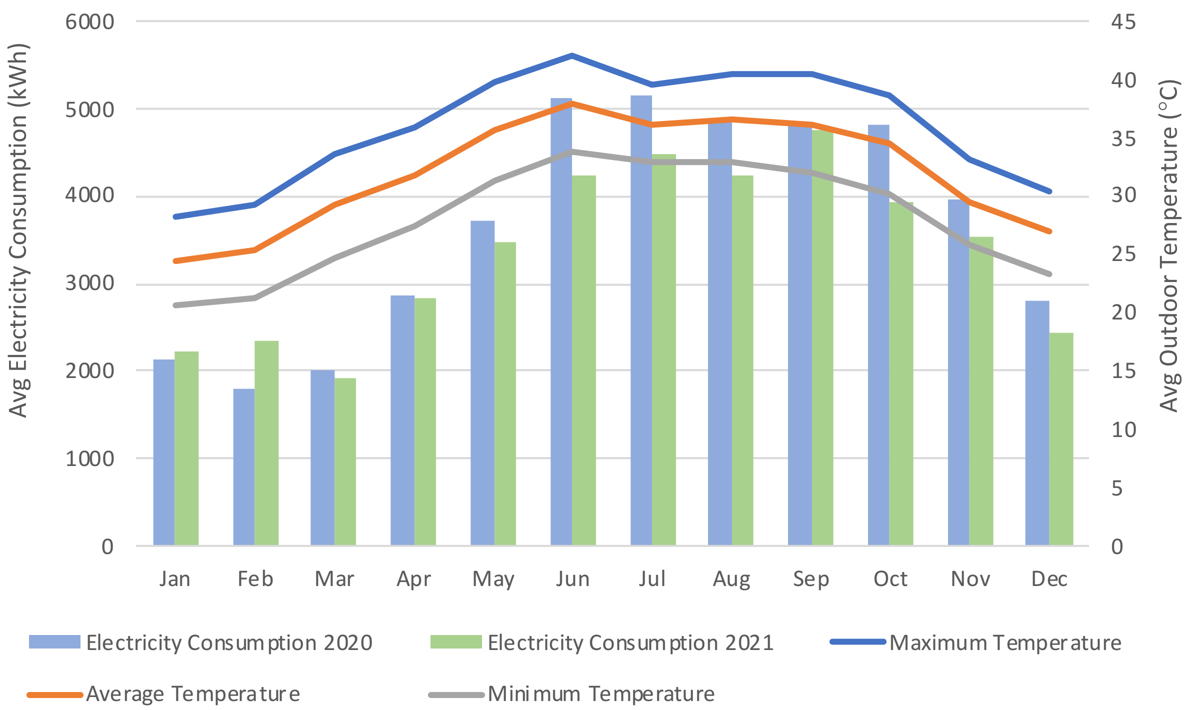


Figure 6.5 Average household energy use monthly in kWh against the difference between the monthly average outdoor temperature

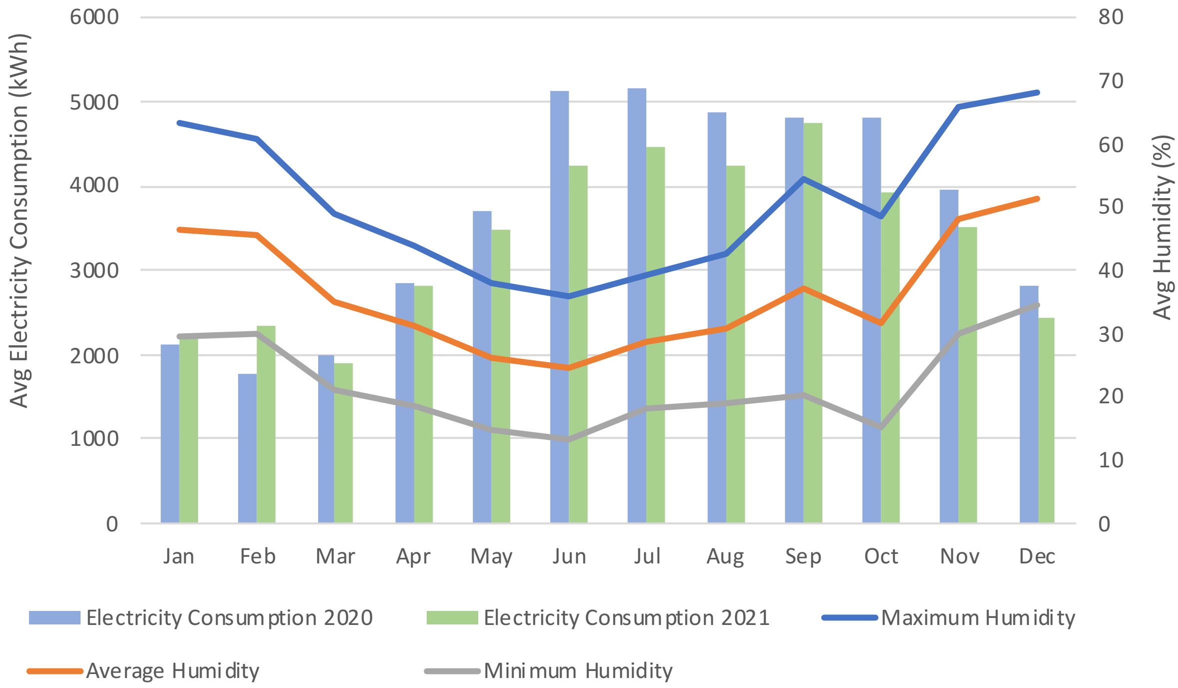


Figure 6.6 Average household energy use monthly in kWh against the difference between the monthly average humidity

Moreover, using the ASHRAE Heat Balance method (Equation 3.1), the monthly and annually CDD and HDD have been calculated for the entire set of nine base temperatures stated in Chapter 3. The data related to temperatures in Makkah over a two-year span was used as the input for the calculations. Table 6.5 presents the HDD values for base temperatures of 14°C, 16°C and 18°C and the CDD values with the base temperatures of 18°C, 20°C, 22°C, 24°C and 28°C. Observably, with an increasing base temperature, the HDD values are always equal to zero, demonstrating that buildings in Makkah do not need to turn on heating systems. On the contrary, even though the CDD values reduced due to the increasing base temperature, differences are noticeable between 2020 and 2021, indicating an increase in buildings cooling demand over the years.

	2020									2021								
	HDD			CDD						HDD			CDD					
	14	16	18	18	20	22	24	26	28	14	16	18	18	20	22	24	26	28
Jan	0	0	0	153	93	47	16	1	0	0	0	0	245	183	121	60	16	0
Feb	0	0	0	201	143	88	42	10	0	0	0	0	213	157	104	58	25	2
Mar	0	0	0	314	252	190	128	69	25	0	0	0	380	318	256	194	133	80
Apr	0	0	0	398	338	278	218	158	99	0	0	0	426	366	306	246	186	127
May	0	0	0	545	483	421	359	297	235	0	0	0	544	482	420	358	296	234
Jun	0	0	0	606	546	486	426	366	306	0	0	0	589	529	469	409	349	289
Jul	0	0	0	565	503	441	379	317	255	0	0	0	561	499	437	375	313	251
Aug	0	0	0	557	495	433	371	309	247	0	0	0	599	537	475	413	351	289
Sep	0	0	0	562	502	442	382	322	262	0	0	0	531	471	411	351	291	231
Oct	0	0	0	504	442	380	318	256	194	0	0	0	513	451	389	327	265	203
Nov	0	0	0	332	272	212	152	93	41	0	0	0	355	295	235	175	115	59
Dec	0	0	0	285	223	161	99	38	3	0	0	0	268	206	144	84	39	6
Total	0	0	0	5022	4292	3579	2890	2238	1667	0	0	0	5223	4493	3767	3049	2378	1771

Table 6.5 Monthly heating and cooling degree-days for different base temperatures in Makkah

As presented in Table 6.5, the annual CDD for the base of 18°C, which is the most usable base temperature in the literature, is 5022 and 5223 in 2020 and 2021, respectively. The monthly maximum CDD is virtually over 600 degree days in June 2020**,** while the mean monthly minimum CDD is almost 150 in January 2020. However, Figure 6.7 explains that the CDD in May is practically similar in both years. In addition, the graph below demonstrates that for most of the year, air conditioning is essential to ensure a pleasant living environment in the home. Therefore, finding the relationship between the weather condition variables and energy consumption is fundamental in this study. Hence, it is discussed in the next section.

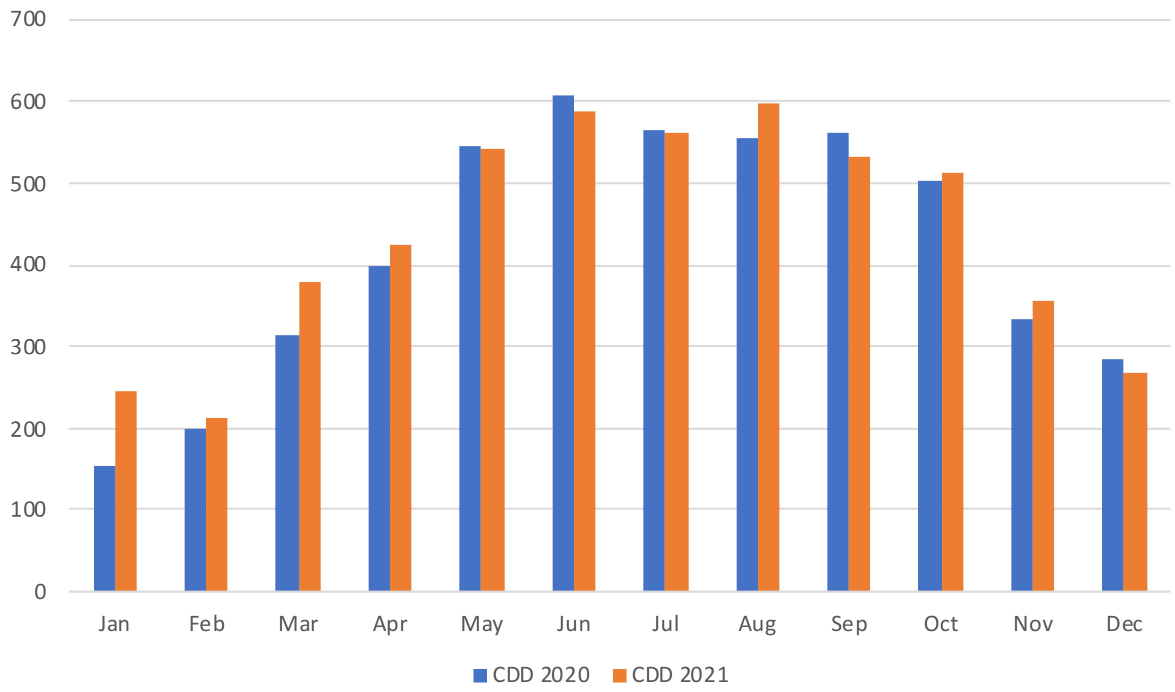


Figure 6.7 The average monthly CDD values for 2020 and 2021 in Makkah

6.4.1 Relationship between Weather Characteristics and Electricity Use

Obtained weather condition variables are classified as continuous variables (variables measured in numerical values). Therefore, correlation coefficients were applied to determine the effect of weather conditions on energy use. For parametric variables (normally distributed such as monthly maximum and minimum temperature, humidity, and wind speed and maximum solar radiation), Pearson's correlation coefficients were employed. Additionally, monthly cooling degree days for all base temperatures were included in the analysis using Pearson's correlation coefficients. Alternatively, Spearman's correlation coefficients were used for continuous but non-normal variables like monthly rainfall and rainy days. Understanding the connection between two variables is of utmost importance. If both variables increase or decrease simultaneously, there is a positive correlation, while a negative correlation is present when they move in opposite directions.

The outcomes show no correlations at a significance level of 0.05 for the monthly total rainfall, monthly total rainy days and monthly minimum wind speed. The results of the Spearman's correlation coefficient analysis are presented in Table 6.6. In addition, the results in Table 6.7 indicate a strong positive correlation between electricity use and monthly minimum and maximum temperature, monthly minimum and maximum relative humidity, monthly maximum wind speed, besides monthly maximum solar radiation. Furthermore, CDD at base temperatures of 18 °C were found to be statistically significantly correlated with electricity consumption. The total CDD with the base temperature of 18°C (the most common base temperature for cooling degree days) for 2020 and 2021 is 4868 and 5148, respectively. Heating degree days were also calculated. However, these always ended up being zero. Consequently, it was not included in the analysis.

	Electricity Consumption	Monthly minimum Temperature	Monthly maximum Temperature
Electricity Consumption	1		
Monthly total Rainfall	-.076	1	
Monthly Rainy Days	-.285	.371	1

Note: * $p < .05$ level (2-tailed), ** $p < .01$ level (2-tailed), and *** $p < .001$ (2-tailed).

Table 6.6 Spearman's correlation coefficient tests for variables related to meteorological

	Electricity consumption	Minimum temperature	Maximum temperature	Minimum humidity	Maximum humidity	Minimum wind speed	Maximum wind speed	Maximum solar radiation	CDD 18 °C	CDD 20 °C	CDD 22 °C	CDD 24 °C	CDD 26 °C	CDD 28 °C
Electricity consumption	1													
Minimum temperature	.880 ***	1												
Maximum temperature	.835 ***	.990 ***	1											
Minimum humidity	-.586 **	-.786 ***	-.840 ***	1										
Maximum humidity	-.528 **	-.763 ***	-.789 **	.915 ***	1									
Minimum wind speed	0.113	0.069	0.020	-0.049	-0.250	1								
Maximum wind speed	.503 *	.552 **	.539 **	-.544 **	-.680 ***	.593 **	1							
Maximum solar radiation	.487 *	.764 ***	.818 ***	-.892 ***	-.881 ***	0.155	.588 **	1						
CDD 18 °C	.855 ***	.997 ***	.995 ***	-.816 ***	-.781 ***	0.031	.537 **	.792 ***	1					
CDD 20 °C	.856 ***	.997 ***	.995 ***	-.816 ***	-.782 ***	0.035	.539 **	.793 ***	1.000 ***	1				
CDD 22 °C	.858 ***	.997 ***	.996 ***	-.820 ***	-.786 ***	0.046	.549 **	.794 ***	1.000 ***	1.000 ***	1			
CDD 24 °C	.861 ***	.996 ***	.995 ***	-.827 ***	-.795 ***	0.068	.569 **	.795 ***	.998 ***	.998 ***	.999 ***	1		
CDD 26 °C	.862 ***	.991 ***	.989 ***	-.830 ***	-.800 ***	0.102	.598 **	.791 ***	.992 ***	.992 ***	.994 ***	.998 ***	1	
CDD 28 °C	.857 ***	.979 ***	.976 ***	-.824 ***	-.799 ***	0.134	.635 ***	.775 ***	.978 ***	.979 ***	.983 ***	.989 ***	.996 ***	1

Note: * $p < .05$ level (2-tailed), ** $p < .01$ level (2-tailed), *** $p < .001$ (2-tailed).

Table 6.7 Pearson's correlation coefficient tests for variables related to meteorological conditions and energy useOccupant Behaviour

6.5 Occupant Behaviour

6.5.1 Relationship between Occupant Behaviour and Electricity Use

In this section, the relationship between occupant behavioural variables and electricity consumption is explored. In relation to this study, the occupant behaviour is concerned with the utilisation of lighting and electrical appliances and occupancy patterns in residential houses in Makkah, Saudi Arabia. The following sections will present the findings from the three statistical analyses, namely one-way ANOVA, the independent-sample t-test and correlation coefficients).

Results of the Analysis of Variance (ANOVA)

The variables included in this test were categorical variables, such as daily use of lighting in bedrooms, family living rooms, kitchens and bathrooms (category 1 = less than 2 hours, category 2 = between 2 to 4 hours, category 3 = between 4 to 6 hours, category 4 = more than 6 hours, and category 5 = always on), usage frequency of HVAC systems during the summer and winter seasons, for instance, air conditioning, natural ventilation and electric fans using Likert scale (always, usually, sometimes, rarely, and never), duration of guests' visit, the use of heating system, the use of lighting and air conditioning in unoccupied spaces, besides the use of lighting when house is empty.

The results show that daily lighting use in the family living room, bedrooms and bathrooms affects energy consumption. Likewise, the results indicate that energy consumption is influenced by occupant behaviour, where leaving lighting on in unoccupied spaces was determined to be statistically significantly different. Statistically significant differences were also observed in using lighting when the house is empty ($p = .044$). The duration of guests' visit was found to be statistically significantly different.

An investigation into the HVAC systems in the targeted neighbourhood indicated that air conditioners are the preferred choice for cooling, particularly during the summer season. The results show statistically significant differences in using air conditioning in both seasons, as seen in Table 6.8. The use of natural ventilation was also found to be statistically significantly different during the summer season ($p = .044$). It's worth noting that relying on air conditioning for cooling during both the summer and winter can have negative impacts on energy efficiency and indoor air quality. Overuse of air conditioning can increase energy consumption and contribute to indoor air pollution if proper ventilation is not provided. The analysis of using air conditioners in unoccupied spaces was determined to be statistically significantly different ($p = .004$) (for statistics, see Table 6.8).

Occupant behaviour variables		Statistics (t-test and ANOVA)	Mean (Std. Deviation)
Daily use of lighting in bedrooms (h)		Welch's F (3, 55.508) = 3.757*, p = .016	< 2 hrs: 3029.93 (1310.75) 2-4 hrs: 3508.73 (1102.38) 4-6 hrs: 4201.81 (1586.23) > 6 hrs: 3981.54 (1243.38)
Daily use of lighting in family living rooms (h)		F (3, 139) = 5.849**, p = .001	< 2 hrs: 2444.32 (1041.61) 2-4 hrs: 3242.53 (1182.85) 4-6 hrs: 3309.08 (1383.47) > 6 hrs: 4035.70 (1205.58)
Daily use of lighting in kitchens (h)		*n.s.*	
Daily use of lighting in bathrooms (h)		Welch's F (3, 45.602) = 4.100*, p = .012	< 2hrs: 3485.08 (1318.75) 2-4 hrs: 3877.21 (1577.39) 4-6 hrs: 3212.45 (763.09) Always: 4201.47 (1093.17)
Use of lighting in unused spaces		Welch's F (2, 36.581) = 6.537**, p = .004	No: 3383.94 (1125.93) Yes: 4978.63 (1742.02) Sometimes: 3711.28 (1223.14)
Use of lighting in empty house		F (2, 140) = 3.184*, p = .044	No: 3452.46 (1249.08) Yes: 3713.44 (1415.18) Sometimes: 4218.13 (1238.16)
HVAC usage in Summer	Air condition	F (2, 140) = 4.759*, p = .010	Sometimes 2595.32 (1096.76) Always: 3817.81 (1301.89) Usually: 3229.92 (1271.41)
	Natural ventilation	F (2, 140) = 9.871*, p = .044	Never: 4177.68 (1336.29) Rarely: 3492.49 (1241.52) Sometimes: 3137.36 (1126.79)
	Electric fan	*n.s.*	
HVAC usage in Winter	Air condition	F (4, 138) = 3.509**, p = .009	Never: 3249 (1112.78) Rarely: 3727.15 (1368.85) Sometimes: 3747.22 (1399.9) Usually: 3552.09 (1052.14) Always: 4850.27 (1464.11)
	Natural ventilation	*n.s.*	
	Electric fan	*n.s.*	
Use of AC in unused space		F (2, 140) = 5.772**, p = .004	No: 3506.02 (1147.18) Yes: 4680.19 (1481.34) Sometimes: 3605.32 (1482.56)
Temperature control		F (2, 140) = 3.356*, p = .038	Manual 3412.67 (1178.48) Automatic 4123.31 (1340.04) Remote control 3621.38 (1404.64)
Duration of guests' visit		F (3, 139) = 3.088*, p = .029	< 2 hrs: 3818.27 (1593.17) 2-4 hrs: 3421.45 (1291.01) 4-8 hrs: 3852.80 (1270.78) > 8 hrs: 5386.36 (1013.92)

*Note: * p < .05 level (2-tailed), ** p < .01 level (2-tailed), *** p < .001 (2-tailed), and n.s., not statistically significant*
Dependent variable: electricity consumption (kWh/year).

Table 6.8 One-way analysis of variance (ANOVA) tests for variables related to occupant behaviour and electricity condumption

Results of the Independent-sample t-test Analysis

To analyse the effect of heating systems since most households either use air conditioning for heating during the winter or have no need for heating, an independent-samples t-test was employed due to the variable's data type. The result highlights that only a small number of households (17.5 %) are using air conditioning as a heating system in winter. Nevertheless, no statistically significant differences were found between electricity use and use of a heating system in winter.

There were also statistically significant changes in electricity use between the weekday and weekend occupancies of the second bedroom, the weekend occupancies of the main family living room, in addition to the weekend occupancies of the main kitchen. The presence of residents in the main family living room and kitchen during the week has no impact on the amount of energy used, nor does the presence of occupants in the main bedrooms during the week and weekends (for statistics, see Table 6.9).

Occupant behaviour variables	Statistics (t-test and ANOVA)	Mean (Std. Deviation)
Use of air conditioners (heating)	*n.s.*	
Presence in the main bedroom (weekdays)	*n.s.*	
Presence in the main bedroom (weekend)	*n.s.*	
Presence in bedroom 2 (weekdays)	t (141) = -2.106*, p = .037	Occupied 12h or less 3444.04 (1262.01) Occupied more than 12h 3904.68 (1352.94)
Presence in bedroom 2 (weekend)	t (141) = -2.732**, p = .007	Occupied 12h or less 3397.27 (1221.52) Occupied more than 12h 3991.20 (1375.57)
Presence in the main family living room (weekdays)	*n.s.*	
Presence in the main family living room (weekend)	t (141) = -2.168*, p = .032	Occupied 12h or less 3459.02 (1284.45) Occupied more than 12h 3937.41 (1331.77)
Presence in the main kitchen (weekdays)	*n.s.*	
Presence in the main kitchen (weekend)	Welch's t (101.768) = -2.213*, p = .029	Occupied 12h or less 3510.12 (1375.44) Occupied more than 12h 3996.22 (1440.88)

*Note: * p < .05 level (2-tailed), ** p < .01 level (2-tailed), *** p < .001 (2-tailed), and n.s., not statistically significant*
Dependent variable: electricity consumption (kWh/year).

Table 6.9 Independent-sample t-tests for variables related to occupant behaviour and electricity consumption

Results of the Correlations Analysis

The correlation analysis was used for continuous variables to determine the influence of occupant behaviour on energy consumption. Pearson’s correlation coefficients were applied for parametric variables (normally distributed); Spearman’s correlation coefficients, on the other hand, were used for non-parametric variables (non-normally distributed). Understanding the correlation between two variables is essential. If both variables move in the same direction, whether up or down, it signifies a positive correlation. Conversely, if they move in opposite directions, it indicates a negative correlation.

A small positive correlation was found between energy use and the daily use of general appliances, the number and daily use of cleaning appliances, the number of hobby appliances, the number and daily use of food preparation appliances, and the number and daily use of extra ventilation appliances. Furthermore, a moderate positive correlation was observed between electricity consumption and the number of general appliances, the number and daily use of battery charge appliances, and the number of air conditioners. No correlations were observed at a significance level of 0.05 for the daily use of hobby appliances (for statistics, see Table 6.10).

Occupant behaviour variables	Correlation Coefficient	Significance (2-tailed)
Number of general appliances	r = .346 **	*p-value* < .0005
Daily use of general appliances	r = .190 *	*p-value* = .023
Number of cleaning appliances	p = .283 **	*p-value* = .001
Daily use of cleaning appliances	p = .234 **	*p-value* = .005
Number of hobby appliances	p = .195 *	*p-value* = .019
Daily use of hobby appliances	*n.s.*	*n.s*
Number of food preparation appliances	r = .239 **	*p-value* = .004
Daily use of food preparation appliances	p = .273 **	*p-value* = .001
Number of extra ventilation appliances	p = .231 **	*p-value* = .005
Daily use of extra ventilation appliances	p = .207 *	*p-value* = .013
Number of battery charge appliances	p = .349 **	*p-value* < .0005
Daily use of battery charge appliances	p = .340 **	*p-value* < .0005
Number of air conditioners	p = .296 **	*p-value* < .0005

*Note: * p < .05 level (2-tailed), ** p < .01 level (2-tailed), *** p < .001 (2-tailed), and n.s., not statistically significant*
Dependent variable: electricity consumption (kWh/year), Pearson's r is used for parametric data; Spearman's p is used for non-parametric data.

Table 6.10 Correlation coefficient tests for variables related to occupant behaviour and electricity use

6.6 Summary

This chapter aimed to determine the relationships and differences between residential electricity consumption and building attributes, household socioeconomic characteristics, meteorological conditions and occupant behaviour. The data used in the survey were collected via questionnaires completed by 143 dwellings in a selected neighbourhood in Makkah, Saudi Arabia. In the questionnaire designed for this study, the researcher made use of variables that demonstrated their significance from prior research findings, as well as new variables that were important in regard to the culture and context of Saudi Arabia. Based on the types of variables, three different statistical tests were performed: an independent-sample t-test for dichotomous variables, a one-way ANOVA for categorical variables and correlation coefficients for continuous variables. From the data analysis above, key findings emerge in the building attributes that building type and light bulb type significantly affect electricity consumption. The number of bedrooms appeared to be an important factor influencing electricity consumption. In addition, the total number of rooms and bathrooms in the house and the dwellings' floor area appear to influence electricity consumption. Generally, the energy consumption of a building is directly related to its footprint. This theory was proven in this study, where large houses consume more electricity than small ones. It was also determined that the number of guests' living rooms did not affect electricity use, nor did the type of air conditioners. Nevertheless, the typical length of guests stay during their visits was statistically significant and affect electricity consumption, as seen in Section 0. Another crucial finding in this research is that no household in the sample reported using solar panels.

Furthermore, this chapter sheds light on the role of household socioeconomic characteristics in influencing electricity consumption in dwellings. The results show that the length of residency in the same house, household monthly income, tenure type, respondents' employment status, respondents' gender, along with the presence of adolescents were all significantly affecting electricity consumption. Unlike other studies, the presence of children and the elderly did not affect electricity use in residential buildings. Interestingly, the presence of housemaids and drivers, who live in the house, was observed to have a significant impact on electricity use. The most prominent result from the socioeconomic data is that family size emerged as the most influential factor, which has a strong positive correlation with electricity consumption.

Regarding weather conditions, monthly minimum and maximum temperature, monthly minimum and maximum humidity, monthly maximum wind speed and CDD for all temperature bases were statistically positively correlated with electricity consumption. Moderate positive correlations were found between monthly maximum solar radiation and electricity consumption. Additionally, the amount of energy used in residential buildings was unaffected by the amount of precipitation.

The key finding of the impact of occupant behaviours on electricity consumption can be summarised as follows:

1- The number and daily use of electrical appliances significantly affect electricity consumption, except for the daily use of appliances used for a hobby. This may be related to the relatively small number of children and teenagers (15% and 14%, respectively) in the sample.
2- The daily use of lighting in everyday use spaces, e.g., family living rooms, bedrooms, and bathrooms, excluding kitchens, was discovered to have a significant influence on electricity consumption. This could be because the majority of households spent more time in the kitchen during the daytime, where artificial lighting is not needed, as shown in Section 5.3.4.
3- It was ascertained that natural ventilation, for instance windows or doors only affects electricity use in the summer. In contrast, air conditioning was established to be used during the summer and winter and significantly impacted electricity use. This could be because of the high summer temperatures, which force households to keep windows permanently closed and rely only on air conditioners for air circulation. Furthermore, since most homes do not use electric fans, their use does not affect electricity consumption.
4- Occupant behaviours, which were only examined in this study, were found to have a significant impact on power usage. These behaviours involve leaving the air conditioning and lights on while no one is present in the room/space and leaving lights on when no one is in the house.

From these results, it is apparent that building attributes and household socioeconomic characteristics, weather conditions, and occupant behaviour have influenced the amount of electricity consumption in dwellings. It should be mentioned that the results presented above demonstrate the influence of each variable on electricity consumption independently. Thus, a follow-up analysis using the regression analysis technique is crucial to determine whether or not building factors, household socioeconomic characteristics, and occupant behaviour as sets of parameters have the same influence. The following chapter addresses this issue in more detail.

Chapter Seven:

Results Part II: Regression Models for Residential Electricity Consumption

Chapter 7: Results Part II: Regression Models for Residential Electricity Consumption

7.1 Overview

The results shown in the previous chapters described how each variable relating to building and household socioeconomic characteristics, weather conditions and occupant behavioural factors affect the residential energy consumption in Makkah, Saudi Arabia. This chapter is devoted to providing further analysis using multiple linear regressing models and validation to determine the factor that contributes the most to electricity consumption in the context of dwellings in Makkah, Saudi Arabia. SPSS 28 was chosen as the software for conducting regression models for this study due to its practicality, vast capabilities, and widespread usage. The chapter is divided into two main sections. The first section discusses the energy model type chosen in this study and explains the rationale behind using this type of model. Furthermore, it presents the mathematical equation and the techniques employed to build the energy regression models and provides the essential assumptions to produce accurate results. The second part of the chapter discusses the modelling phases and the applied techniques and also provides results.

7.2 Procedures and Prerequisites for Regression Analysis in Models of Electricity Consumption Models

It is utilised to describe variability in dependent variables using one or more independent or control variables and to analyse relationships among variables. This is done to answer the following question about how much dependent variables change with changes in each of the independent's variables. Furthermore, it is used to forecast or predict the value of dependent variables based on the values of the independent's variables (Zaid, 2015). Hence, multiple linear regression (MLR) analysis was made use of with the intention of determining the respective influence of building characteristics, household socioeconomic characteristics and occupant behaviour on energy consumption. However, since all households in the sample were located in the same region, climate data were excluded as independent variables in the regression model.

In the multiple linear regression, all the available predictors (variables) are utilised together with the appropriate slope to quantify the impact of each predictor. Moreover, R square (R^2) is a crucial indicator when assessing the regression model. It is the coefficient of determination that denotes the fitness of the model and can be understood as the amount of variation of the dependent variable explained by the regression equation (Fumo and Biswas, 2015). Generally, the value of R^2 varies between 0 and 1. The preferred model include a R^2 value close to 1. Hence, if for instance, the value of $R^2 = 0.70$, this signifies that 70% of the total variability of the dependent variable is characterised by the predictor variables in the model. Mathematically, the multiple regression model is denoted by the subsequent equation:

$$y = \beta_0 + (\beta_1 \times X_1) + (\beta_2 \times X_2) + \ldots + (\beta_p \times X_p) + \varepsilon.$$

* Note: y is the response variable, X_1; X_2; …X_p are the predictor variables with p as the number of variables, β_0; β_1; … $\beta_p$are the regression coefficients, and ε is an error to account for the discrepancy between predicted data and the observed data.

Equation 7.1 Multiple linear regression model

Stepwise, forward and backward are the three most important methods related to the selection of multiple linear regression variables. The stepwise technique is applied to recognise the highly relevant predictors in the model among other variables, whereas the forward method increasingly combines new variables using the highest p-value as a guide. The backward technique removes variables individually once all variables are entered in the order of the lowest p-value. In this study, the backward technique was employed after entering each parameter, e.g., building characteristics to eliminate insignificant variables from the regression analysis. Regression analysis also requires all variables to be continuous variables to obtain reliable results. Therefore, categorical variables were transformed into dummy variables, with each group in a categorical variable being coded to have a value of 0 and 1. Furthermore, the quality of regression models can be verified by ensuring the following assumptions are met:

a) One dependent variable only measured at the continuous level.
b) Two or more independent variables that are measured either at the continuous or nominal level.
c) Should have independence of observations (i.e., independence of residuals). Durbin Walton's criteria values should be between 0 to 4.
d) There needs to be a linear relationship between the dependent variable and each of your independent variables, besides the dependent variable and the independent variables collectively.
e) Data needs to show homoscedasticity of residuals (equal error variances).
f) Data must not show multicollinearity, i.e., independent variables are not highly or perfectly correlated. Using an examination of correlation coefficients and Tolerance/VIF values.
g) There should be no significant outliers, high leverage points or highly influential points.
h) The residuals (errors) are approximately normally distributed in the standardized residuals histogram.

Accordingly, developing the regression models was divided into two phases. The first phase deals with the variables that affect electricity consumption significantly, as presented in Chapter 6. The second phase entails incorporating all variables in the regression model, regardless of their significance, as some variables do not directly affect electricity consumption but may have a noticeable effect when combined with other variables. Figure 7.1 diagrammatically depicts the proposed analytical method for developing the electricity use models across the two phases.

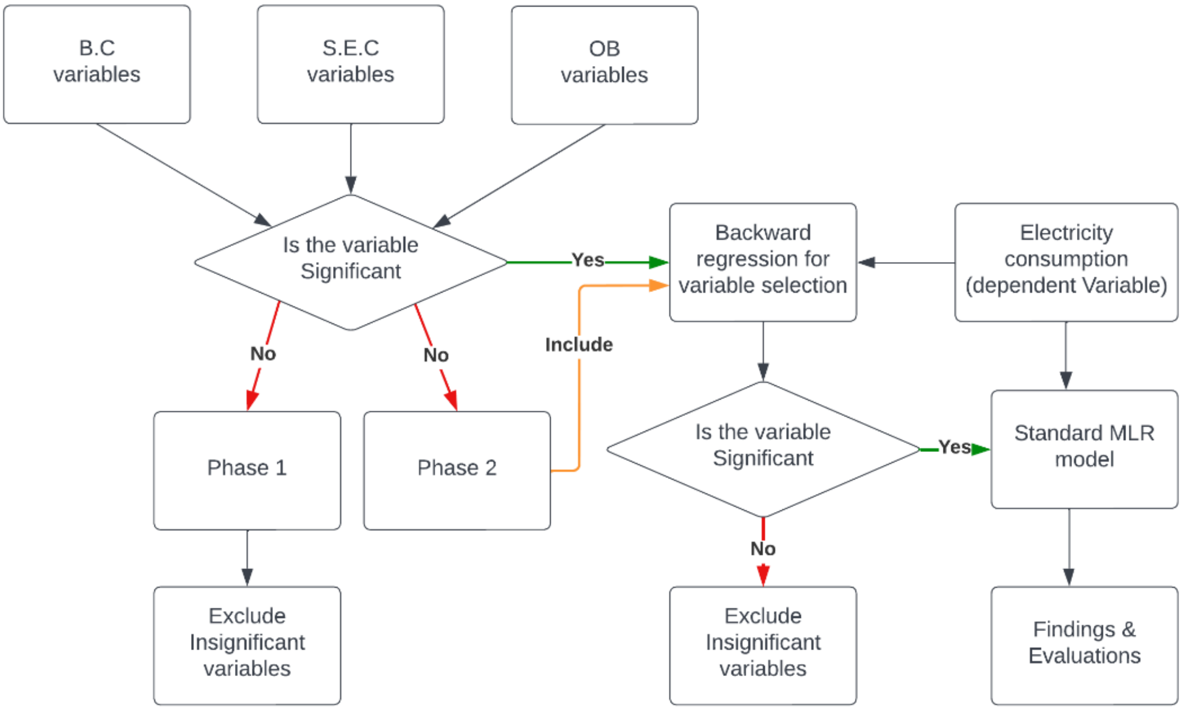
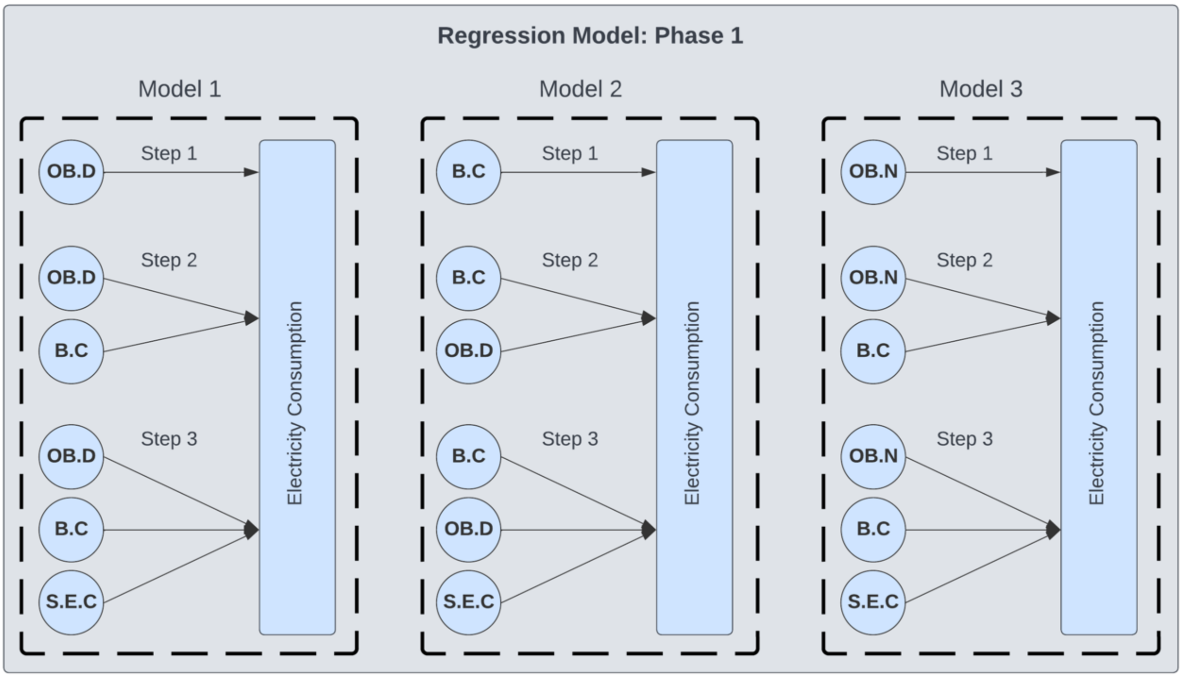


Figure 7.1 Analytical procedure for the regression models

7.3 Regression Models for Phase I

This phase was developed based on the findings of the analysis made in the previous chapter. First, only significant variables were used in the MLR analysis; second, a backward regression analysis was undertaken to remove and eliminate the insignificant variables when the variables were combined; third, the best combination of variables within the factor was selected; and last, the selected variables were subsequently entered into a standard MLR analysis. Three MLR models were proposed, as shown in Figure 7.2. In addition, the regression models' equation depicts building-level electricity consumption as a result of occupant behaviour, building attributes and household socioeconomic variables.



* OB.D refers to occupant behaviour with the duration of appliances, OB.N to occupant behaviour with the number of appliances, B.C to building characteristics, and S.E.C to household socioeconomic characteristics.

Figure 7.2 Proposed regression models for phase 1

7.3.1 Model 1

The MLR model (Model 1) was run following three steps. The first step included the occupant behaviour with respect to air conditioning, lighting and daily use of appliances; a second step was including building variables; the third step was including household socioeconomic characteristics. Table 7.1 describes the means and standard deviations for significant variables (continuous predictors). Furthermore, the number of cases for and percentages of dichotomous and transformed variables (dummy) are presented in Table 7.2.

Predictors (continuous variables)	Mean	Std. Deviation
Electricity consumption (kWh/year)	3663.09	1321.72
Number of bedrooms	3.88	1.48
Family size	5.69	2.14
Daily use of general appliances	3135.99	909.35
Daily use of food preparation appliances	2416.50	989.75
Daily use of battery charging appliances	450.21	276.05

Table 7.1 Mean and standard deviation for continuous predictors for Model 1

Predictors (categorical variables)		Number of cases	Percentage (%)
Presence in bedroom 2 (weekday)	Occupied <= 12 hrs	75	52.40
	Occupied > 12 hrs	68	47.60
Presence in main kitchen (weekend)	Occupied <= 12 hrs	98	68.5
	Occupied > 12 hrs	42	31.5
Use of natural ventilation in summer	Sometimes	49	34.2
	Rarely	33	23.1
	Never	61	42.7
Use of AC in winter	Always	11	7.7
	Usually	22	15.4
	Sometimes	49	34.3
	Rarely	22	15.4
	Never	39	27.2
Use of lighting in unoccupied spaces	No	83	58
	Sometimes	44	30.8
	Yes	16	11.2
Duration of use of lighting in family living room	Less than 2hrs	6	4.2
	Between 2 to 4hrs	13	9.1
	Between 4 to 6hrs	46	32.2
	More than 6 hrs	78	54.5
Duration of use of lighting in bathrooms	Less than 2hrs	80	55.9
	Between 2 to 4hrs	26	18.2
	Between 4 to 6hrs	14	9.8
	Always	23	16.1
Respondent's gender	Female	54	37.8
	Male	89	62.2
Tenure type	Owner-occupied	88	61.5
	Private rent	55	38.5
Household monthly income	Less than 10K SR	34	23.8
	10K to 29.999 SR	89	62.2
	30K to 49.999 SR	11	7.7
	More than 50K SR	9	6.3
Bulb types	Fluorescent	25	17.5
	LED	75	52.4
	Halogen	7	4.9
	Don't know	36	25.2

Table 7.2 Number of cases and percentages for dichotmous/dummy predictors for Model 1

As previously stated, the initial stage involved inputting the occupant behaviour variables related to air conditioning, lighting, and daily appliance usage into the MLR model. As a result, occupant behaviours variables alone explained 47.9% (R^2 =.479) of the variances in electricity consumption. The scatter plot (Figure 7.3) presents the predicted electricity consumption value by actual electricity consumption in kWh/month. In addition, a slight increase was observed in the model performance by adding building attributes variables to the model, indicating that building attributes have a small impact on electricity consumption. The second step (adding building attributes variables) is able to explain 53.8% (R^2 =.059) of the variability in electricity consumption, as shown in Figure 7.4.

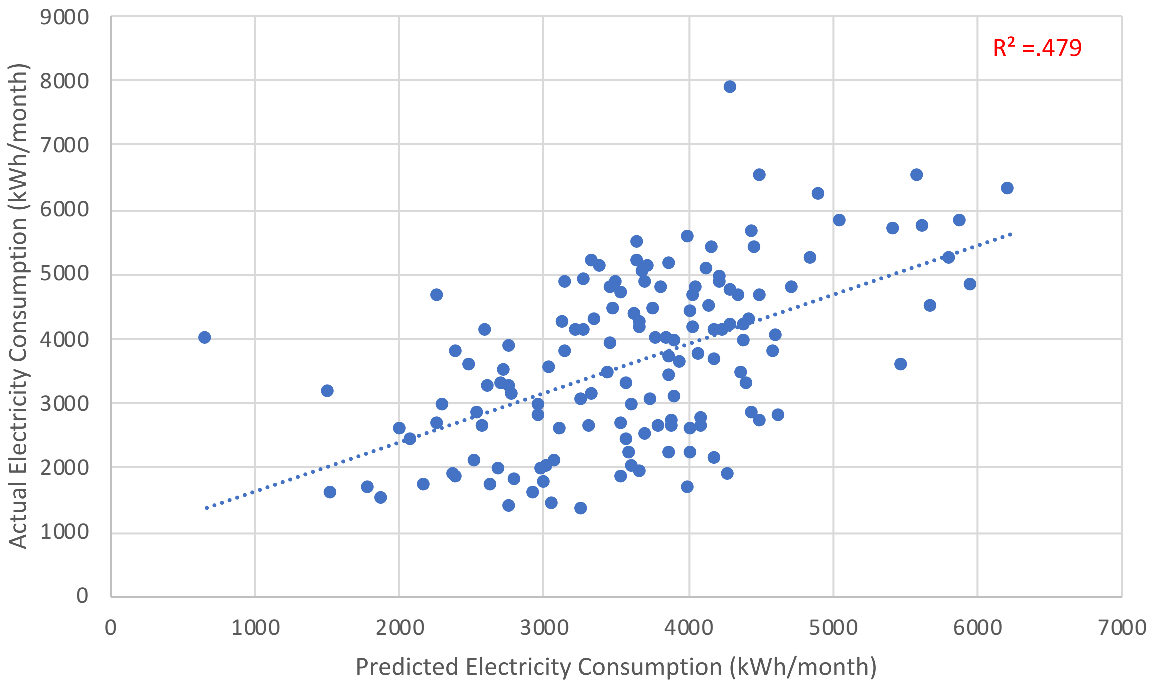


Figure 7.3 Scatter plot of actual electricity consumption (kwh/month) by predicted electricity consumption (kWh/month) for occupant behaviours in Model 1

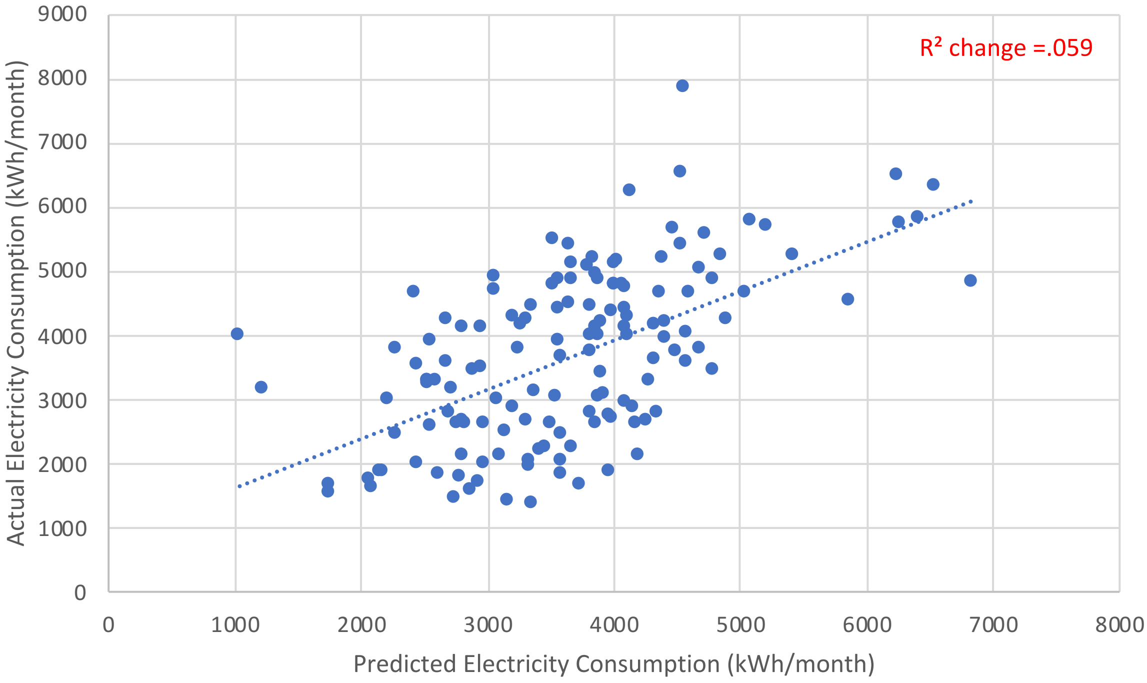


Figure 7.4 Scatter plot of actual electricity consumption (kwh/month) by predicted electricity consumption (kWh/month) for occupant behaviour and building attributes in Model 1

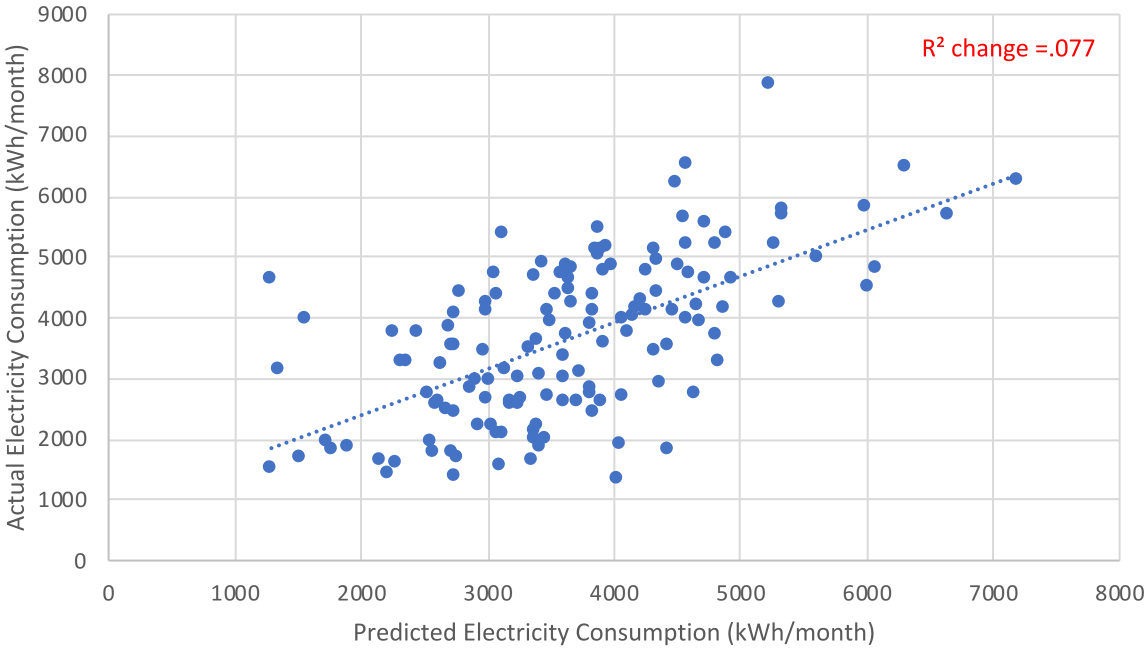


Figure 7.5 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for occupant behaviour, building attributes, and household socioeconomic characteristics in Model 1

Overall, the inclusion of occupant behaviour, building attributes and household socioeconomic characteristics in the model accounted for 61.5% of the variance in electricity consumption. This suggests that by including socioeconomic characteristics, the variance increased by 7.7%. Table 7.3 provides a summary of the model's three main steps, while Figure 7.5 depicts the overall regression line. The accuracy of the model was validated by checking the assumptions, as displayed in Table 7.4. Therefore, it can be concluded that this model is fairly accurate, as seen in Figure 7.6.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
OB.D	.692	0.479	0.398	1025.30595	0.479	5.946	19	123	0.000	
OB.D + B.C	.733	0.538	0.449	981.35945	0.059	3.816	4	119	0.006	
OB.D + B.C + S.E.C	.784	0.615	0.516	919.57513	0.077	3.755	6	113	0.002	1.756

* OB.D refer to occupant behaviour with the duration of appliances, B.C to building characteristics, and S.E.C to household socioeconomic characteristics.

Table 7.3 Summary of Model 1

Regression Assumptions	Verified	Unverified	Evidence
a) One dependent variable that is measured as a measured at the continuous variable	✓		Electricity consumption
b) Two or more independent variables that are measured either at the continuous or nominal level.	✓		
c) Independence of observations (i.e., independence of residuals), Durbin Walton's criteria values should be between 0 to 4 and close to 2.	✓		Durbin-Walton = 1.756
d) A linear relationship between the dependent variable and each of your independent variables, and the dependent variable and the independent variables collectively	✓		Assessed via partial regression plots and a plot of studentized residuals against the predicted values
e) Data needs to show homoscedasticity of residuals (equal error variances)	✓		Assessed by plot of studentized residuals vs. unstandardised predicted values
f) Data must not show multicollinearity, i.e. independent variables are not highly or perfectly correlated. Using an inspection of correlation coefficients and Tolerance/VIF values	✓		Tolerance values and VIF are within the limits
g) There should be no significant outliers via the analysis of residuals. Standard deviations are no greater than ±3.	✓		The analysis of residuals revealed no value greater than ±3
h) There should be no high leverage points. Values less than 0.2 considered as safe		✓	5% of cases were detected in the model and no entry error were found
i) No highly influential points, assessed by Cook's distance (no value above 1)	✓		The high leverage points don't lead to high influence as Cook's distance under the limit value
h) The residuals (errors) are approximately normally distributed via the standardised residuals histogram	✓		Figure 7.6

Table 7.4 The performance of Model 1 using accuracy assumptions

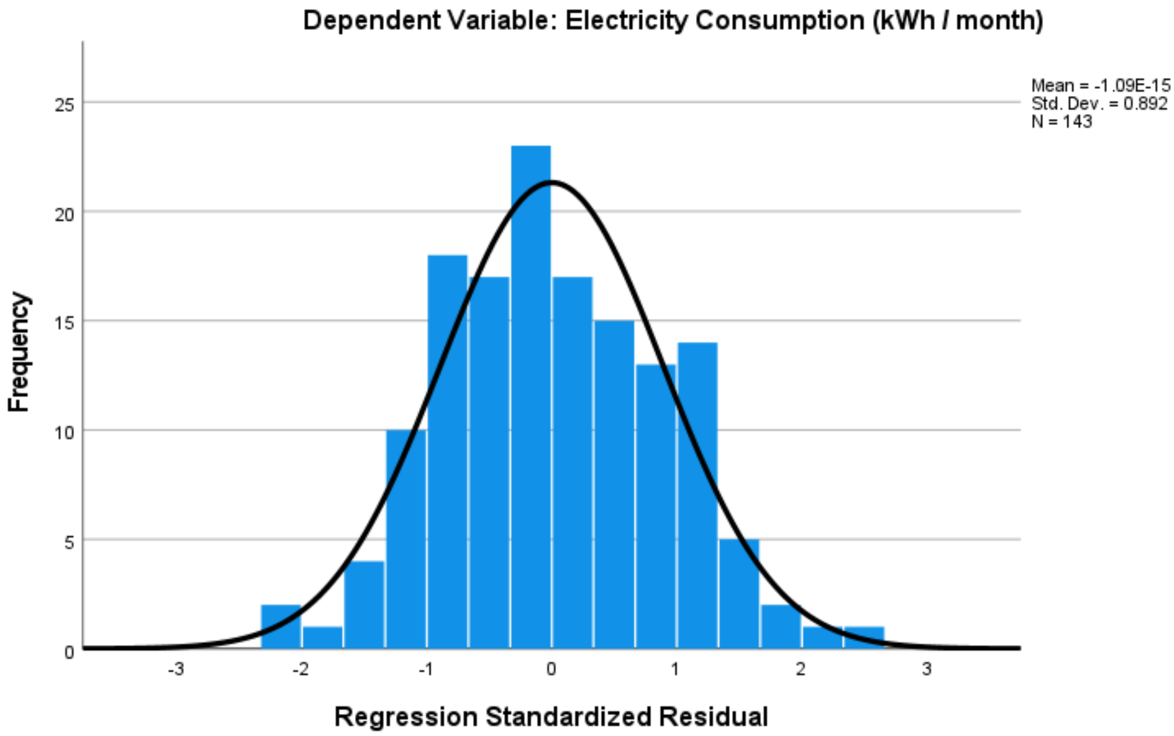


Figure 7.6 Distribution of the standardised residual for Model 1

Table 7.5 B, Standard deviation of B and Beta of the first regression model the unstandardised coefficients of B and Standard Error of B, as well as the standardised coefficient Beta for all variables included in the model. Notwithstanding that most of the predictors are not statistically significant at the .05 level, their inclusion in the regression model is valuable. An exception to number of bedrooms, tenure type, monthly income, family size, duration of use of lighting in family living rooms and use of lighting in unoccupied spaces also found to be significant predictors.

Model (R^2 =.615)		Unstandardized Coefficients		Standardized Coefficients
		B	Std. Error	Beta
(Constant)		-539.648	645.741	
1st Step: Occupant Behavioural Variables (R^2 =.479)				
Daily use of general appliances		0.124	0.099	0.085 *
Daily use of food preparation appliances		0.069	0.095	0.052
Daily use of battery charging appliances		0.292	0.364	0.061 *
Presence in bedroom 2 (weekday)		243.348	179.561	0.092
Presence in main kitchen (weekend)		265.658	204.248	0.094
Use of natural ventilation in summer	Sometimes	Reference category		
	Rarely	214.583	223.109	0.069
	Never	246.652	218.985	0.093 *
Use of AC in winter	Never	Reference category		
	Rarely	352.342	281.049	0.097
	Sometimes	608.675	219.622	0.219 *
	Usually	412.258	260.302	0.113
	Always	297.599	378.742	0.060
Use of lighting in unoccupied spaces	No	Reference category		
	Sometimes	45.805	210.410	0.016
	Yes	1024.474	306.374	0.245 **
Duration of use of lighting in family living room	Less than 2hrs	Reference category		
	Between 2 to 4hrs	1197.518	513.406	0.261 *
	Between 4 to 6hrs	1087.937	449.885	0.386 *
	More than 6hrs	1379.752	450.001	0.522 **
Duration of use of lighting in bathrooms	Less than 2hrs	Reference category		
	Between 2 to 4hrs	86.711	230.563	0.025
	Between 4 to 6hrs	-573.431	323.141	-0.129
	More than 6hrs	136.893	274.062	0.038 *
2nd Step: Adding Building Characteristics (R^2 =.059)				
Number of bedrooms		127.105	68.871	0.142 *
Bulb types	Don't know	Reference category		
	Halogen	-1054.497	456.645	-0.173
	Fluorescent	-250.290	304.776	-0.072
	LED	-310.489	246.567	-0.118
3rd Step: Adding Household Socioeconomic Characteristics (R^2 =.077)				
Family size		113.135	52.632	0.183 *
Respondent's gender		-120.863	208.143	-0.044
Tenure type		570.566	187.971	0.211 **
Household monthly income	Less than 10K SR	Reference category		
	10K to 29.999 SR	496.480	210.843	0.183 *
	30K to 49.999 SR	26.964	397.046	0.005
	More than 50K SR	1101.534	426.464	0.203 *

Note: * $p < .05$ level (2-tailed), ** $p < .01$ level (2-tailed), *** $p < .001$ (2-tailed)

Table 7.5 B, Standard deviation of B and Beta of the first regression model 1

Occupant Behavioural Variables

As can be seen in Table 7.5, duration of lighting use in family living rooms, according to the standardised coefficient Beta, is one of the most important predictors of the outcome. In addition, the B coefficient signifies to what degree each predictor impacts the outcome if the effects of the other predictors are held constant. This would imply that households who use the lights in family living rooms for more than six hours is 1379.752 kWh/month greater than households who use the lights for less than two hours.

Furthermore, households who use the lighting in unoccupied spaces or rooms explains a large part of the electricity consumption (B = 1024.474 kWh/month, $p < 0.001$). For the use of natural ventilation, such as windows during the summer season, the results reveal that households who never use the natural ventilation, e.g., windows or doors during the summer is 246.652 kWh/month greater than that those who occasionally use the natural ventilation. This has a considerable impact because of the significant variation in the outdoor temperature.

Household Socioeconomic and Building Characteristics

In this model, tenure type appears to be the most important predictor of electricity consumption in household and dwelling characteristics ($p < 0.001$), followed by family size, number of bedrooms and household monthly income ($p < 0.05$). The results confirm that an increase of one unit in the number of bedrooms is associated with an increase in electricity consumption of 127.105 kWh/month. Similarly, more energy is used in owner-occupied dwellings than in those with privately rented dwellings. This may be due to the rarity of renting in the area under investigation and the prevalence of homeownership. Given that neither building type nor floor area appeared in the regression analysis, it can be determined that neither of these factors has an impact on electricity consumption. This could be for the reason that the fact the buildings in the study area are identically constructed and it is presumed, using the same materials to construct the extended houses.

7.3.2 Model 2

A second regression model (Model 2) was developed to determine the influence of household socioeconomic characteristics, occupant behaviour and building characteristics while controlling building characteristics. This exhibited substantial differences in comparison to Model 1. Following the same technique and using the same variables in Model 1, building attributes was incorporated as a first step in Model 2, signifying that 26.1% (R^2 =.261) of the variance in electricity consumption accounted for building attributes. By including occupant behaviour, the variance in electricity consumption increased to 53.8% (R^2 =.277). Overall, by adding household socioeconomic characteristics the variance increased to 61.5% (R^2 =.077), as illustrated in Table 7.6. Figure 7.7 to Figure 7.9 illustrate the comparison between the predicted and actual electricity consumption is shown for the three steps of the model.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
B.C	.511	0.261	0.240	1152.57050	0.261	12.184	4	138	0.000	
B.C + OB.D	.733	0.538	0.449	981.35945	0.277	3.755	19	119	0.000	
B.C + OB.D + S.E.C	.784	0.615	0.516	919.57513	0.077	3.755	6	113	0.002	2.120

* OB.D refers to occupant behaviour with the duration of appliances, B.C to building characteristics and S.E.C to household socioeconomic characteristics.

Table 7.6 Summary of Model 2

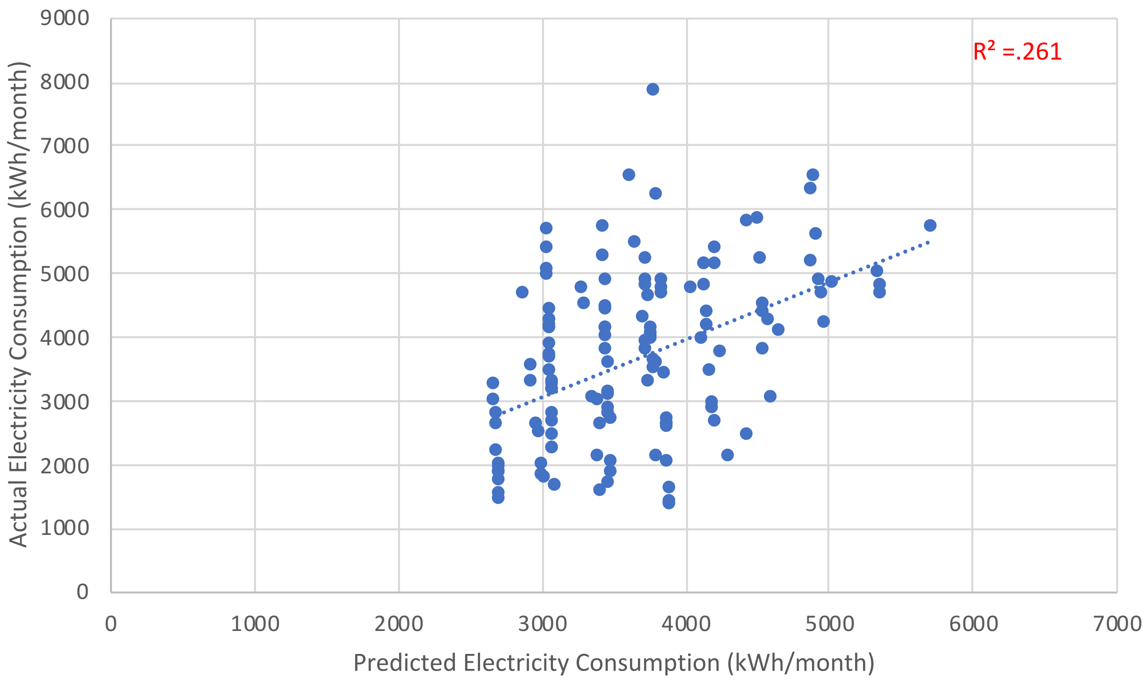


Figure 7.7 Scatter plot of actual electricity consumption (kwh/month) by predicted electricity consumption (kWh/month) for occupant behaviour and building attributes in Model 2

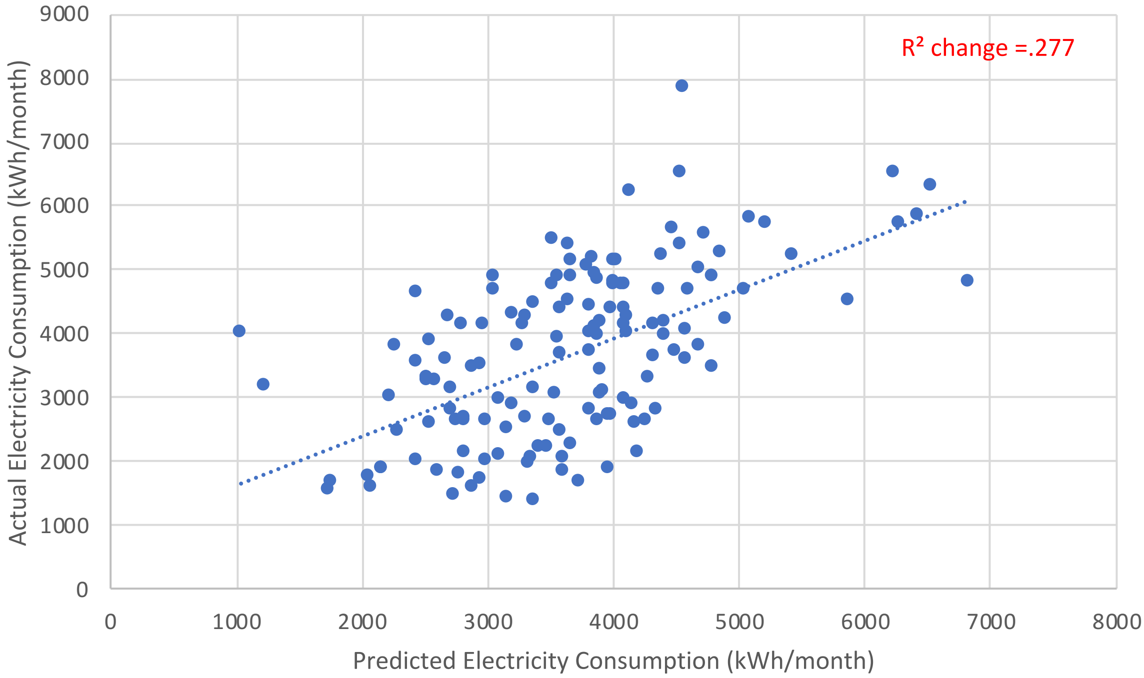


Figure 7.8 Scatter plot of actual electricity consumption (kwh/month) by predicted electricity consumption (kWh/month) for building attributes and occupant behaviour in Model 2

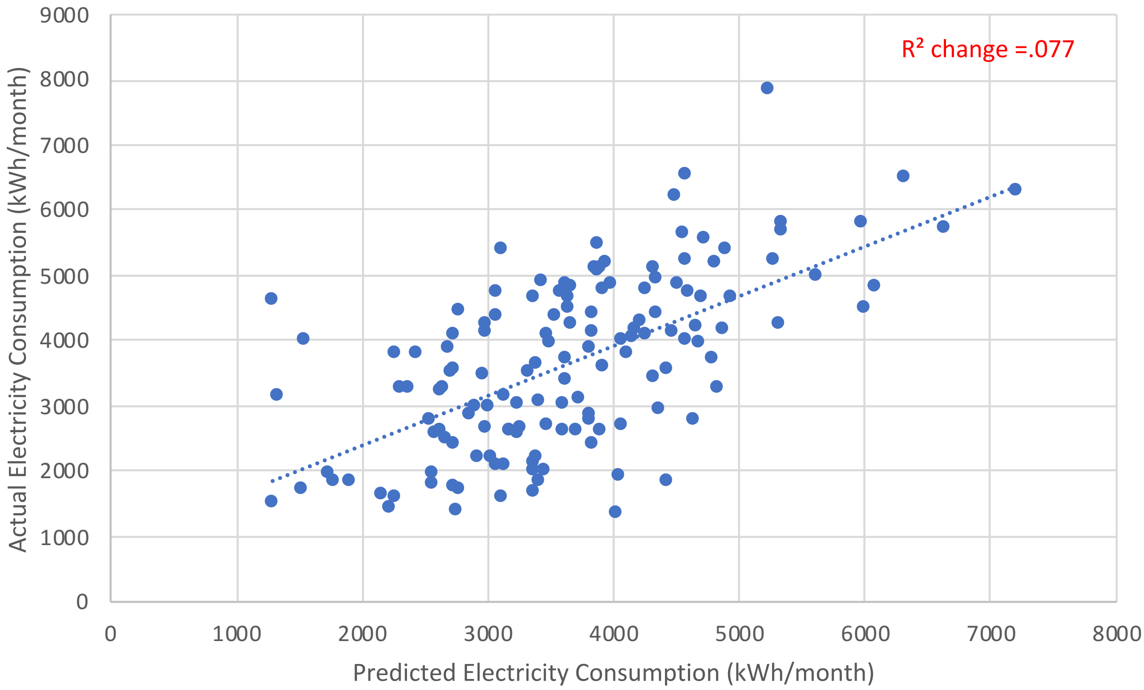


Figure 7.9 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for occupant behaviour, building attributes, and household socioeconomic characteristics in Model 2

Moreover, the model performance was diagnosed, as illustrated in Table 7.7. By comparing Model 1 and Model 2, it was observed that the influence of building attributes in Model 2 increased in comparison to Model 1. In addition, Table 7.8 further demonstrates that the impact of occupant behaviours on electricity consumption is greater than that of building attributes, even if this effect was reduced in Model 2.

Regression Assumptions	Verified	Unverified	Evidence
a) One dependent variable that is measured as a continuous variable	✓		Electricity consumption
b) Two or more independent variables that are measured either at the continuous or nominal level.	✓		
c) Independence of observations (i.e., independence of residuals). Durbin Walton's criteria values should be between 0 to 4 and close to 2.	✓		Durbin-Walton = 2.120
d) A linear relationship between the dependent variable and each of your independent variables, and the dependent variable and the independent variables collectively	✓		Assessed via partial regression plots and a plot of studentized residuals against the predicted values
e) Data needs to show homoscedasticity of residuals (equal error variances)	✓		Assessed by plot of studentized residuals vs. unstandardized predicted values
f) Data must not show multicollinearity, i.e. independent variables are not highly or perfectly correlated. Using an examination of correlation coefficients and Tolerance/VIF values	✓		Tolerance values and VIF are within the limits
g) There should be no significant outliers via the analysis of residuals are no greater than ±3 standard deviations		✓	The analysis of residuals revealed only 1 case value is greater than 3, but no entry errors. So the case were not excluded
h) There should be no high leverage points. Values less than 0.2 considered as safe		✓	5% of the cases were detected in the model, no entry error was found
i) No highly influential points assessed by Cook's distance (no value above 1)	✓		The high leverage points don't lead to high influence as Cook's distance under the limit value
h) The residuals (errors) are approximately normally distributed via the standardised residuals histogram	✓		Figure 7.10

Table 7.7 The performance of Model 2 using accuracy assumptions

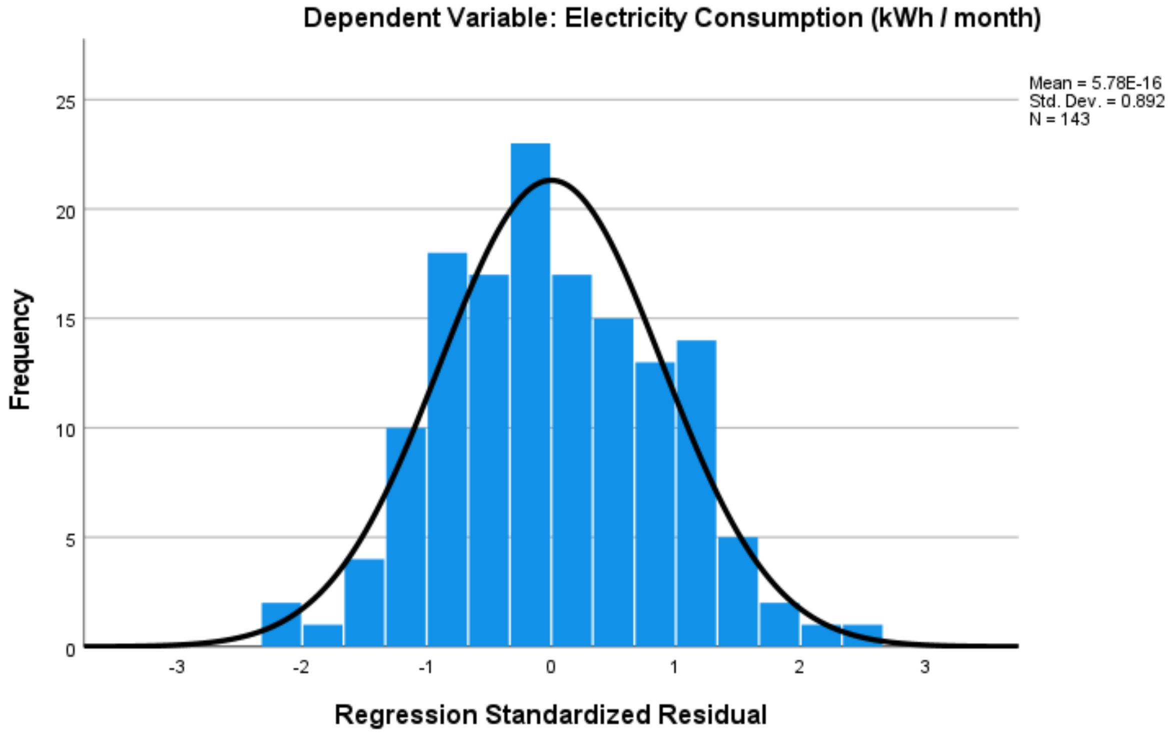


Figure 7.10 Distribution of the standardised residual for Model 2

	Model 1				Model 2			
	R	R Square	Adjusted R Square	R Square Change	R	R Square	Adjusted R Square	R Square Change
First Step	.692	0.479	0.398	0.479	.511	0.261	0.240	0.261
Second Step	.733	0.538	0.449	0.059	.733	0.538	0.449	0.277
Third Step	.784	0.615	0.516	0.077	.784	0.615	0.516	0.077

Table 7.8 Comparison between Model 1 and Model 2

7.3.3 Model 3

The third regression model was established following the analysis process explained in Figure 7.1, in order to determine the effect of occupant behaviour on air conditioning, lighting and the number of appliances. The purpose of this model is to ascertain whether the total number of appliances in use is more significant than their cumulative runtime (Model 1). Table 7.9 and Table 7.10 illustrate the statistical information pertaining to the selected variables.

Predictors (continuous variables)	Mean	Std. Deviation
Electricity consumption (kWh/year)	3663.09	1321.72
Number of bedrooms	3.88	1.48
Family size	5.69	2.14
Number of air conditioners	7.30	2.35
Number of battery charging appliances	6.41	3.70

Table 7.9 Mean and standard deviation for continuous predictors for Model 3

Predictors (categorical variables)		Number of cases	Percentage (%)
Presence in bedroom 2 (weekday)	Occupied <= 12 hrs	75	52.40
	Occupied > 12 hrs	68	47.60
Use of natural ventilation in summer	Sometimes	49	34.2
	Rarely	33	23.1
	Never	61	42.7
Use of AC in winter	Always	11	7.7
	Usually	22	15.4
	Sometimes	49	34.3
	Rarely	22	15.4
	Never	39	27.2
Use of lighting in unoccupied spaces	No	83	58
	Sometimes	44	30.8
	Yes	16	11.2
Duration of use of lighting in family living room	Less than 2hrs	6	4.2
	Between 2 to 4hrs	13	9.1
	Between 4 to 6hrs	46	32.2
	More than 6 hrs	78	54.5
Temperature control	Manual control	58	40.6
	Remote control	49	34.3
	Automatic control	36	25.2
Respondent’s gender	Female	54	37.8
	Male	89	62.2
Tenure type	Owner-occupied	88	61.5
	Private rent	55	38.5
Household monthly income	Less than 10K SR	34	23.8
	10K to 29.999 SR	89	62.2
	30K to 49.999 SR	11	7.7
	More than 50K SR	9	6.3
Bulb types	Fluorescent	25	17.5
	LED	75	52.4
	Halogen	7	4.9
	Don’t know	36	25.2

Table 7.10 Number of cases and percentages for dichotomous/dummy predictors for Model 3

Initially, occupant behaviour as regards air conditioning, lighting and number of appliances, which accounting for 45.6% of the variability in electricity use, was placed in the model. In addition, 51.9% for the second (occupant behaviour and building attributes combined) and 60.3% for third step (all factors combined). (Refer to Table 7.11 for more statistics relating to the model, Figure 7.11 for the first step regression line and Figure 7.12 for the second step regression line, and Figure 7.13 for the overall regression line).

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
OB.N	.675	0.456	0.387	1035.03406	0.456	6.597	16	126	0.000	
OB.N + B. C	.720	0.519	0.440	988.96245	0.063	4.003	4	122	0.004	
OB.N +B.C + S.E.C	.776	0.603	0.514	921.56816	0.084	4.083	6	116	0.001	1.937

* OB.N refers to occupant behaviour with the number of appliances, B.C to building characteristics and S.E.C to household socioeconomic characteristics.

Table 7.11 Summary of Model 3

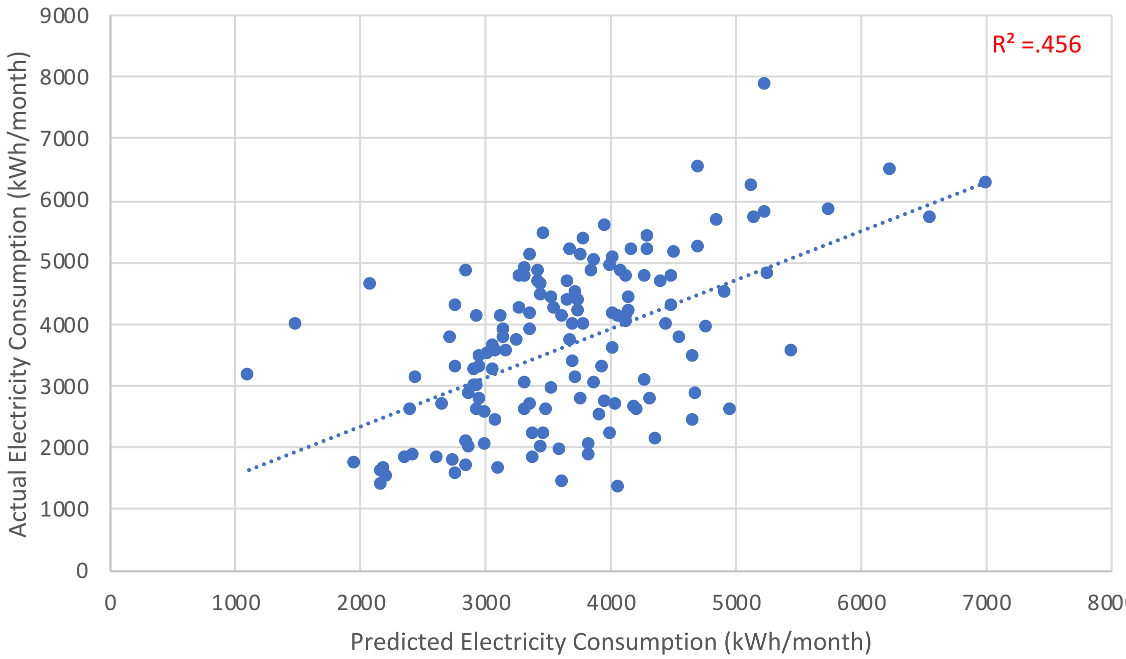


Figure 7.11 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for occupant behaviour in Model 3

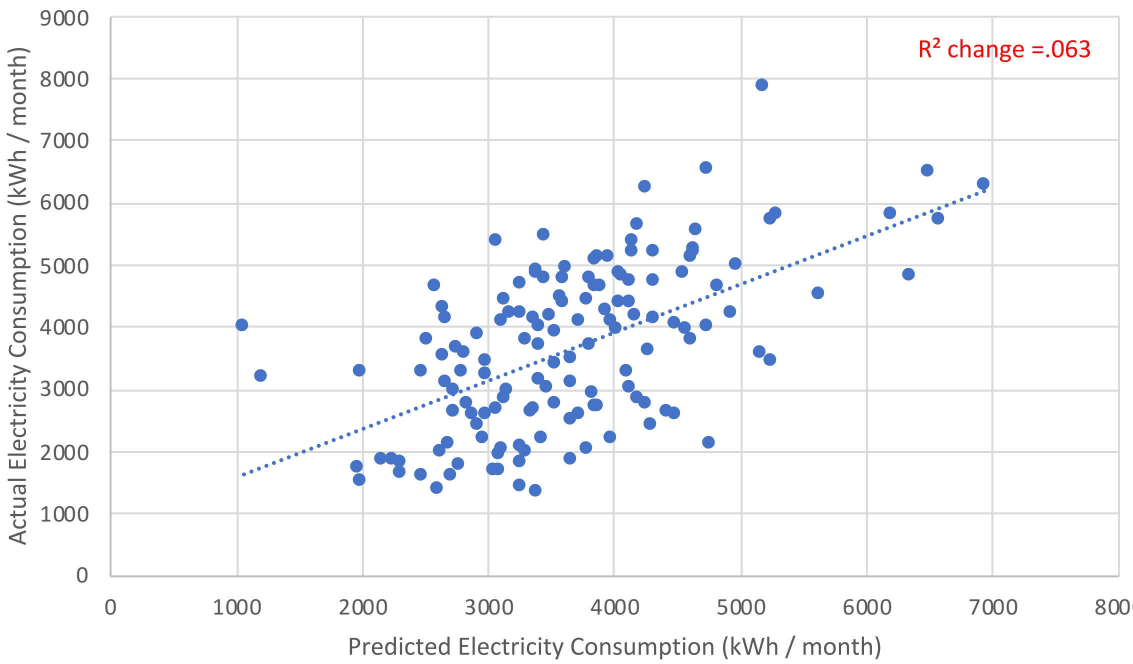


Figure 7.12 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for occupant behaviour and building attributes in Model 3

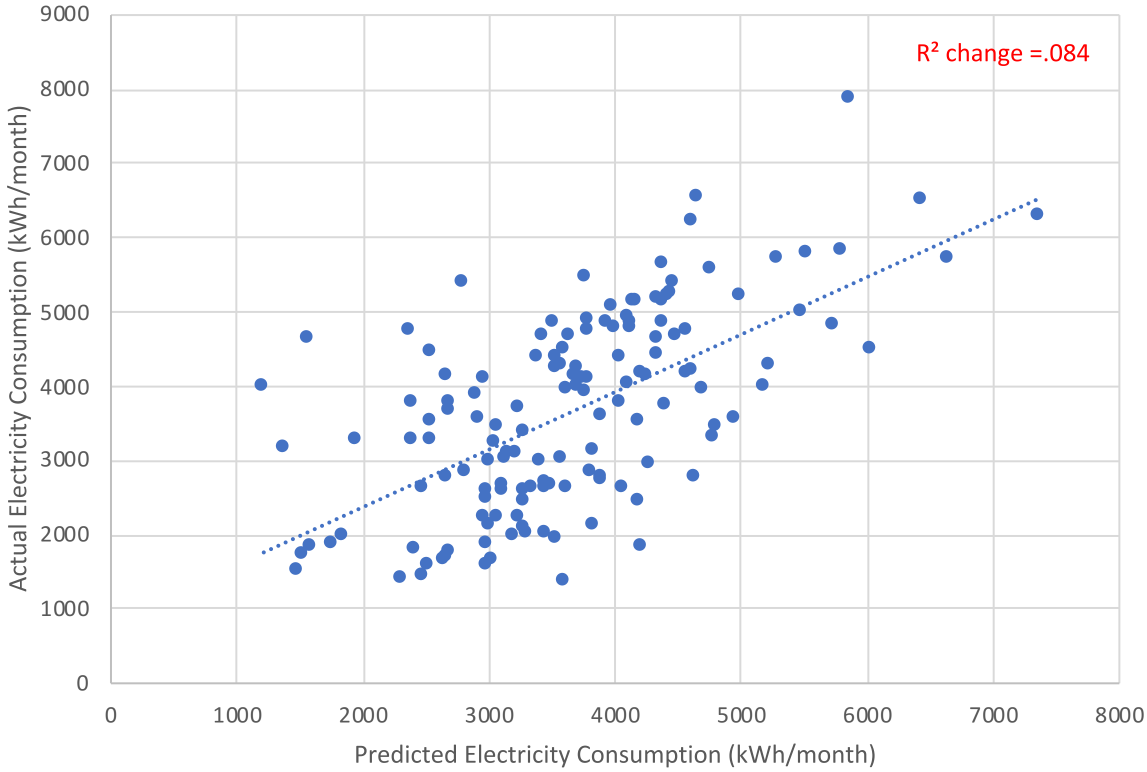


Figure 7.13 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for occupant behaviour, building attributes, and household socioeconomic characteristics in Model 3

Table 7.12 provides a list of the assumptions that need to be validated. It is possible to conclude that Model 3 is accurate to a reasonable degree. According to the findings of the analysis, there is not a significant difference between the models, as illustrated in Figure 7.15, in terms of the number of appliances (Model 3) and the duration of appliances use (Model 1).

Regression Assumptions	Verified	Unverified	Evidence
a) One dependent variable that is measured as a continuous variable	✓		Electricity consumption
b) Two or more independent variables that are measured either at the continuous or nominal level.	✓		
c) Independence of observations (i.e., independence of residuals). Durbin Walton's criteria values should be between 0 to 4 and close to 2.	✓		Durbin-Walton = 1.937
d) A linear relationship between the dependent variable and each of your independent variables, and the dependent variable and the independent variables collectively	✓		Assessed via partial regression plots and a plot of studentised residuals against the predicted values
e) Data needs to show homoscedasticity of residuals (equal error variances)	✓		Assessed by plot of unstandardised residuals vs. unstandardized predicted values
f) Data must not show multicollinearity, i.e. independent variables are not highly or perfectly correlated. Using an inspection of correlation coefficients and Tolerance/VIF values	✓		Tolerance values and VIF are within the limits
g) There should be no significant outliers via the analysis of residuals. Standard deviations are no greater than ±3	✓		The analysis of residuals revealed no value greater than ±3
h) There should be no high leverage points, considering values less than 0.2 as safe		✓	17% of cases were detected in the model, no entry errors were found
i) No highly influential points assessed by Cook's distance (no value above 1)	✓		The high leverage points don't lead to high influence as Cook's distance under the limit value
h) The residuals (errors) are approximately normally distributed via the standardised residuals histogram	✓		Figure 7.14

Table 7.12 The performance of Model 3 using accuracy assumptions

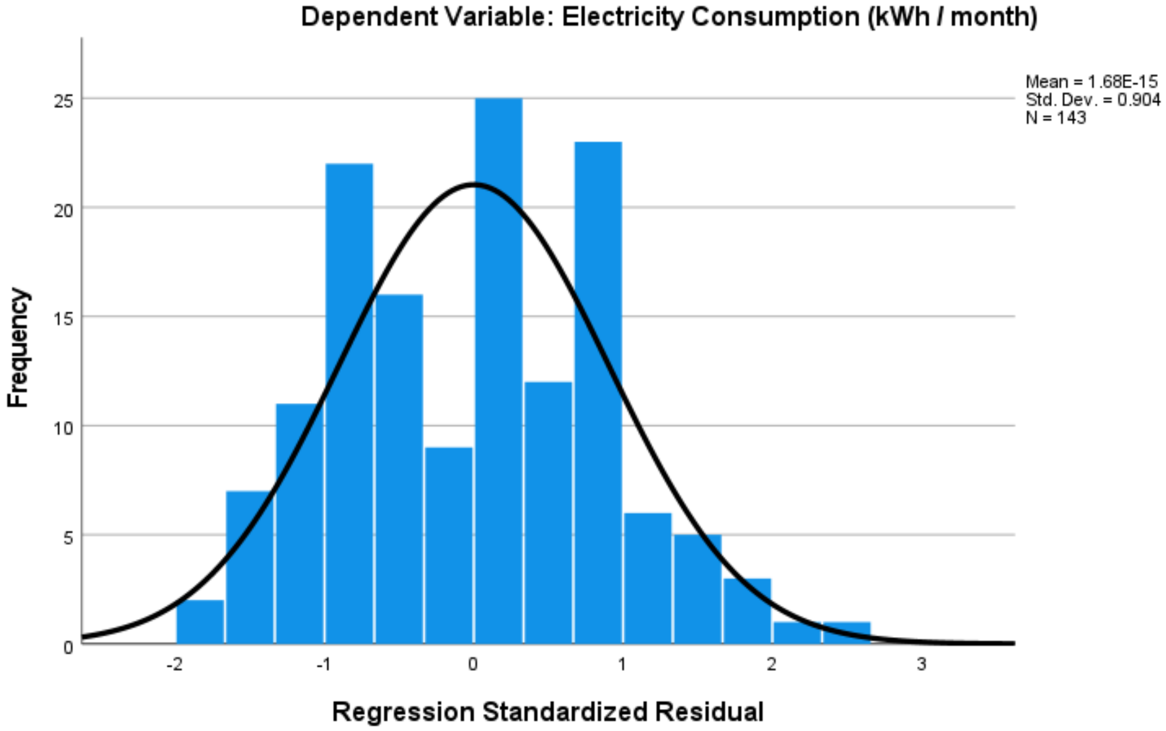


Figure 7.14 Distribution of the standardised residual for Model 3

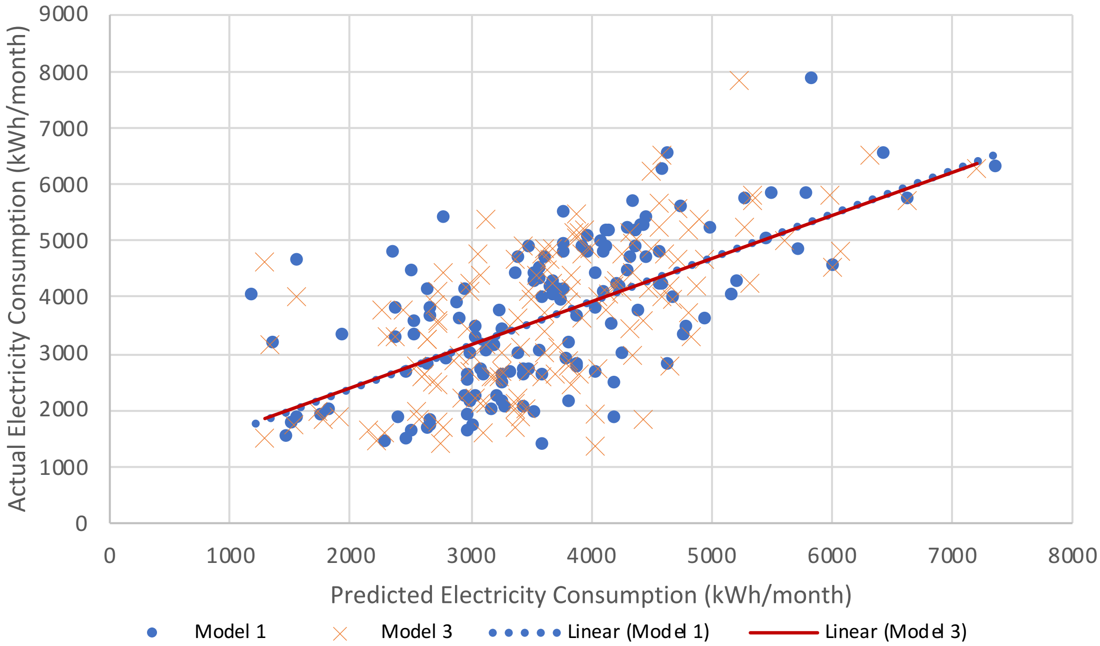
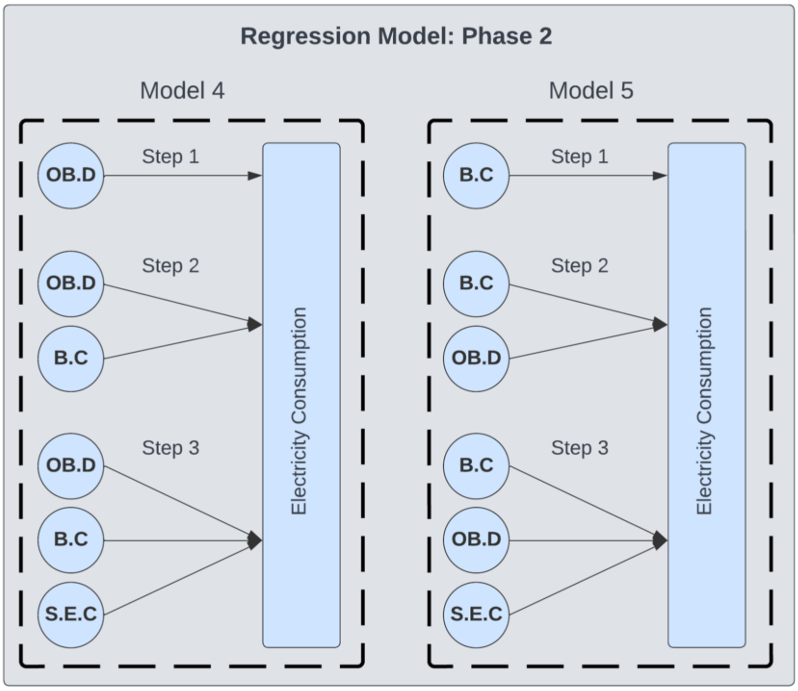


Figure 7.15 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for Model 1 and Model 3

7.4 Regression Models for Phase II

This phase is designed to examine the possibility that some factors, previously shown to have no direct impact on electricity consumption, may in fact have such impacts when combined with those of other factors. Firstly, all variables in the data set assessed in Chapter 6, regardless of their significance, were incorporated into a backward regression analysis. Secondly, the insignificant variables were eliminated. Thirdly, the best combination of variables within the factor was selected and entered into a standard MLR analysis. Two MLR models were proposed, as can be seen in Figure 7.16. Based on occupant behaviour, building attributes and household socioeconomic characteristics, the regression models' equation characterises electricity consumption at the building level.



* OB.D refers to occupant behaviour with the duration of appliances use, B.C to building characteristics and S.E.C to household socioeconomic characteristics.

Figure 7.16 Proposed regression models for phase 2

7.4.1 Model 4

Model 4 was developed by controlling occupant behaviours for air conditioning, lighting and the duration of appliances use. After the insignificant variables were removed from the entire dataset using the backward selection technique, see Figure 7.1 for the diagrammatic explanation of the process. The selected variables along with the statistics can be seen in Table 7.13 and Table 7.14. The regression model was run following three steps, as shown in Figure 7.16: the first step including occupant behaviour, the second step introducing building attributes and the third step introducing household socioeconomic characteristics.

Predictors (continuous variables)	Mean	Std. Deviation
Electricity consumption (kWh/year)	3663.09	1321.72
Number of bedrooms	3.88	1.48
Family size	5.69	2.14
Daily use of general appliances	3135.99	909.35
Daily use of battery charging appliances	450.21	276.05

Table 7.13 Mean and standard deviation for continuous predictors

Predictors (categorical variables)		Number of cases	Percentage (%)
Presence in main bedrooms (weekend)	Occupied <= 12 hrs	67	46.9
	Occupied > 12 hrs	76	53.1
Presence in bedroom 2 (weekdays)	Occupied <= 12 hrs	75	52.40
	Occupied > 12 hrs	68	47.60
Presence in main family living rooms (weekend)	Occupied <= 12 hrs	82	57.3
	Occupied > 12 hrs	61	42.7
Presence in main kitchen (weekend)	Occupied <= 12 hrs	98	68.5
	Occupied > 12 hrs	45	32.5
Use of AC in summer	Sometimes	8	5.6
	Usually	21	14.7
	Always	114	79.7
Use of natural ventilation in summer	Sometimes	49	34.2
	Rarely	33	23.1
	Never	61	42.7
Use of lighting in unoccupied spaces	No	83	58
	Sometimes	44	30.8
	Yes	16	11.2
Use of lighting in empty house	No	74	50.7
	Sometimes	24	16.8
	Yes	45	32.5
Use of AC in winter	Always	11	7.7
	Usually	22	15.4
	Sometimes	49	34.3
	Rarely	22	15.4
	Never	39	27.2
Duration of use of lighting in kitchens	Less than 2hrs	23	16.1
	Between 2 to 4hrs	63	44.1
	Between 4 to 6hrs	31	21.7
	More than 6 hrs	26	18.2
Duration of use of lighting in bathrooms	Less than 2hrs	80	55.9
	Between 2 to 4hrs	26	18.2
	Between 4 to 6hrs	14	9.8
	More than 6hrs	23	16.1
Tenure type	Owner-occupied	88	61.5
	Private rent	55	38.5
Household monthly income	Less than 10K SR	34	23.8
	10K to 29.999 SR	89	62.2
	30K to 49.999 SR	11	7.7
	More than 50K SR	9	6.3
Presence of children	No	78	55
	Yes	65	45
Respondents' gender	Female	54	37.8
	Male	89	62.2
Number of bathrooms	Three bathrooms	58	40.6
	More than 5 bathrooms	85	59.4
Bulb types	Fluorescent	25	17.5
	LED	75	52.4
	Halogen	7	4.9
	Don't know	36	25.2

Note: * $p < .05$ level (2-tailed), ** $p < .01$ level (2-tailed), *** $p < .001$ (2-tailed)

Table 7.14 Number of cases and percentages for dichotomous/dummy variables for Model 4

In this model, occupant behaviour alone explained 43.9% ($R^2 = .439$) of the variance in electricity consumption. The addition of building attributes accounted for 52.1% ($R^2 = .081$) of the variability. lastly, adding household socioeconomic characteristics cause the variation to increase by 11.7%. As a total, Model 4 was able to explain 63.8% of the variability in electricity consumption (Table 7.15). Figure 7.17 to Figure 7.19 show the regression lines for steps 1, 2 and 3, respectively.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
OB.D	.663	0.439	0.336	1076.69421	0.439	4.272	22	120	0.000	
OB.D + B.C	.722	0.521	0.408	1016.91779	0.081	3.904	5	115	0.003	
OB.D + B.C + S.E.C	.798	0.638	0.523	912.42123	0.117	4.979	7	108	0.000	2.207

* OB.D refers to occupant behaviour with the duration of appliances, B.C to building characteristics and S.E.C to household socioeconomic characteristics.

Table 7.15 Summary of Model 4

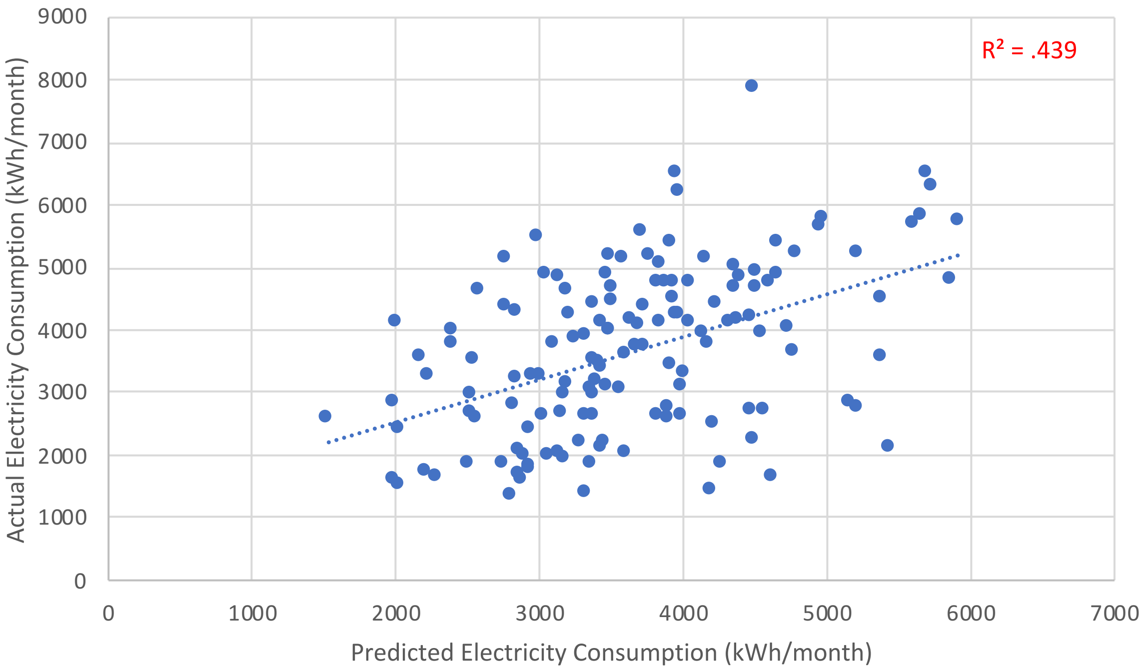


Figure 7.17 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for occupant behaviour in Model 4

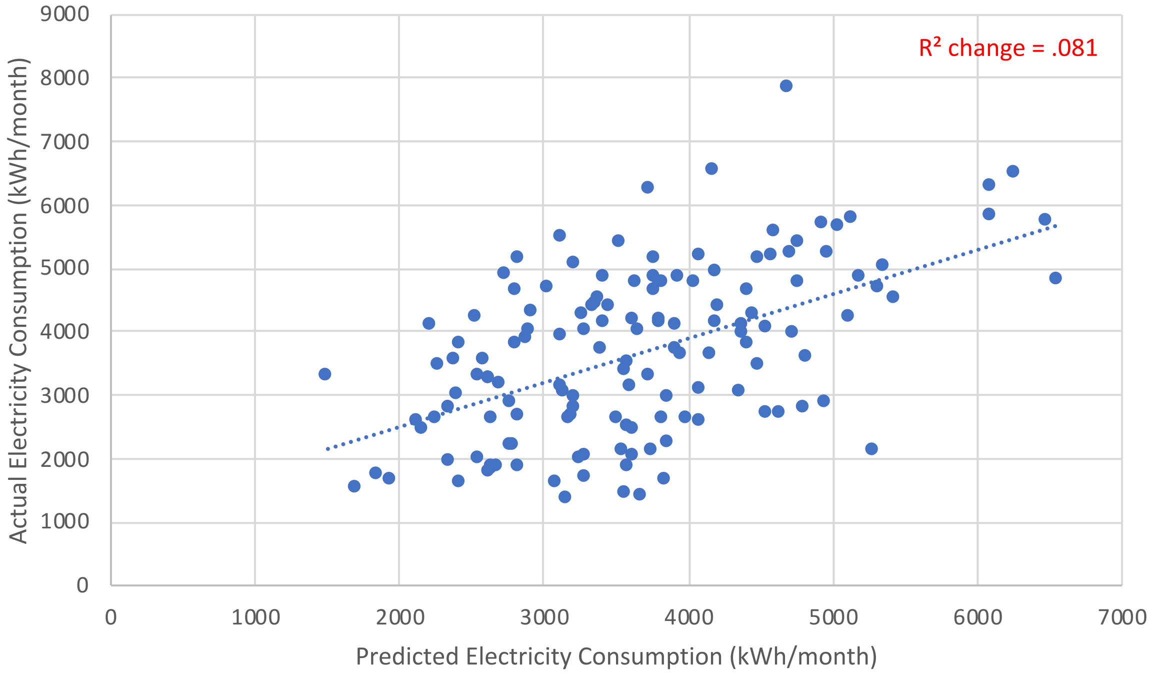


Figure 7.18 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for occupant behaviour and building attributes in Model 4

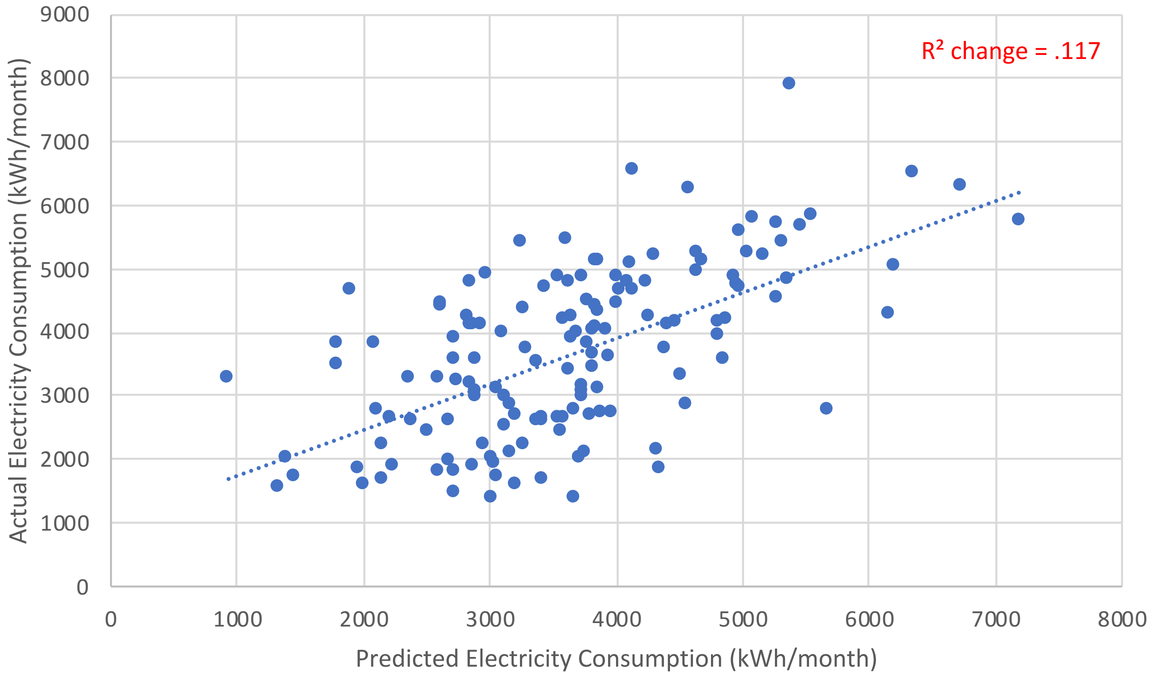


Figure 7.19 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for occupant behaviour, building attributes, and household socioeconomic characteristics in Model 4

The assumption of independence of observations has almost certainly been met as the Durbin-Watson value is between 0 and 4. Linearity was present as assessed by the partial regression plots and a plot of studentized residuals against the predicted values. There was homoscedasticity, as evaluated by visual examination of the plot of studentized residuals versus unstandardized predicted values. The model appears not to have multicollinearity problems, because tolerance values and VIF are within the limits. The analysis of residual statistics demonstrated that there are no significant problems with outliers in the model. In the model, there were no studentized deleted residuals greater than ±3 standard deviations. There are only 30 cases (21%) above the safe Leverage value 0.2. Nevertheless, they do not result in high influence as the values associated with Cook's distance all lie well below 1. The assumption of normality was met, as measured by the P-P Plot. Therefore, we can conclude that this model is fairly accurate (for regression statistics, see Table 7.16).

Model (R^2 =.638)		Unstandardised Coefficients		Standardised Coefficients
		B	Std. Error	Beta
(Constant)		273.509	590.104	
1st Step: Occupant Behaviour (R^2 = .439)				
Daily use of general appliances		0.061	0.097	0.042
Daily use of battery charging appliances		0.267	0.378	0.056
Presence in main bedrooms (weekend)		-24.907	194.445	-0.009
Presence in bedroom 2 (weekdays)		215.050	188.185	0.082
Presence in main family living rooms (weekend)		329.972	199.343	0.124
Presence in main kitchen (weekend)		112.930	228.026	0.040
Use of AC in summer	Sometimes	Reference category		
	Usually	451.436	431.932	0.121
	Always	568.403	365.197	0.174
Use of Natural Ventilation in summer	Sometimes	Reference category		
	Rarely	306.471	224.094	0.098
	Never	349.604	223.088	0.131
Use of lighting in unoccupied spaces	No	Reference category		
	Sometimes	53.405	152.281	0.013
	Yes	902.384	297.131	0.216 **
Use of lighting in empty house	No	Reference category		
	Sometimes	123.024	89.387	0.056
	Yes	262.407	193.207	0.093
Use of AC in winter	Never	Reference category		
	Rarely	139.008	289.176	0.038
	Sometimes	499.773	223.367	0.180
	Usually	240.851	274.307	0.066
	Always	-22.813	394.939	-0.005
Duration of use of lighting in kitchens	Less than 2hrs	Reference category		
	Between 2 to 4hrs	-23.438	252.329	-0.009
	Between 4 to 6hrs	-509.731	290.173	-0.159
	More than 6 hrs	-547.181	340.255	-0.160
Duration of use of lighting in bathrooms	Less than 2hrs	Reference category		
	Between 2 to 4hrs	365.710	244.740	0.107
	Between 4 to 6hrs	-229.921	333.615	-0.052
	More than 6hrs	285.249	284.181	0.080
2nd Step: Adding Building Attribution (R^2 change = .081)				
Number of bedrooms		79.369	85.253	0.089
Number of bathrooms		215.291	221.116	0.080
Bulb types	Don't know	Reference category		
	Halogen	-803.782	480.352	-0.132
	Fluorescent	-112.636	300.232	-0.032
	LED	-267.911	249.634	-0.102
3rd Step: Adding Household Socioeconomic Characteristics (R^2 change = .117)				
Family Size		175.097	57.331	0.283 **
Tenure type		616.651	200.331	0.228 **
Presence of children		-115.987	198.958	-0.044
Respondents' gender		-130.843	216.511	-0.048
Household monthly income	Less than 10K SR	Reference category		
	10K to 29.999 SR	620.751	212.703	0.228 **
	30K to 49.999 SR	50.163	402.938	0.010
	More than 50K SR	1409.510	432.326	0.260 **

Table 7.16 B, Standard deviation of B and Beta for Model 4

7.4.2 Model 5

Using the same variables as Model 4, Model 5 was built while controlling building attributes that also showed important differences. As seen in Figure 7.16, the regression model was executed in three steps: The first step covered tenant behaviour, the second included building attributes and the third enveloped household socioeconomic characteristics.

In this model, building attributes accounted for 26.1% (R^2 =.261) of the variance in electricity consumption. By including occupant behaviour, the variance in electricity consumption increased to 52.1% (R^2 =.259), and by adding household socioeconomic characteristics the variance increased to 63.2% (R^2 =.112), as seen Table 7.17. Figure 7.20, Figure 7.21, and Figure 7.22 show the results of the predicted electricity consumption and the actual electricity consumption for the model's three steps.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
B.C	.511	0.261	0.234	1156.49656	0.261	9.694	5	137	0.000	
B.C + OB.D	.722	0.521	0.408	1016.84717	0.259	2.828	22	115	0.000	
B.C + OB.D + S.E.C	.798	0.638	0.523	912.42123	0.117	4.979	7	108	0.000	2.211

* OB.D refer to occupant behaviour with the duration of appliances, B.C to building characteristics, and S.E.C to household socioeconomic characteristics.

Table 7.17 Summary of Model 5

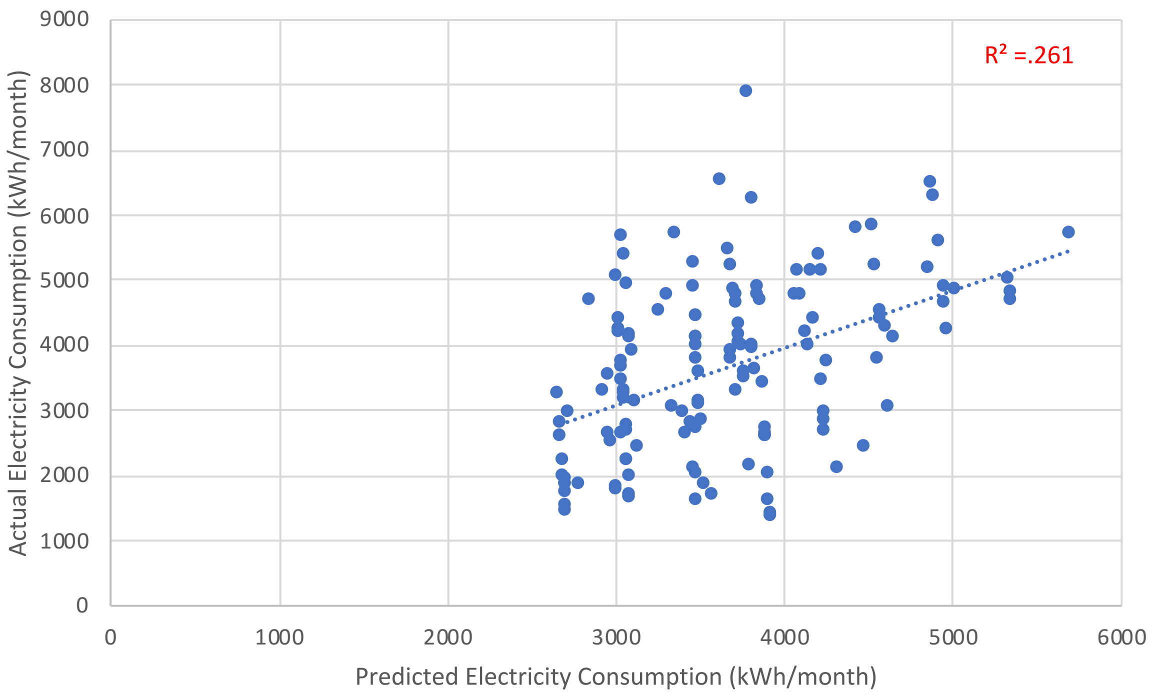


Figure 7.20 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for building attributes in Model 5

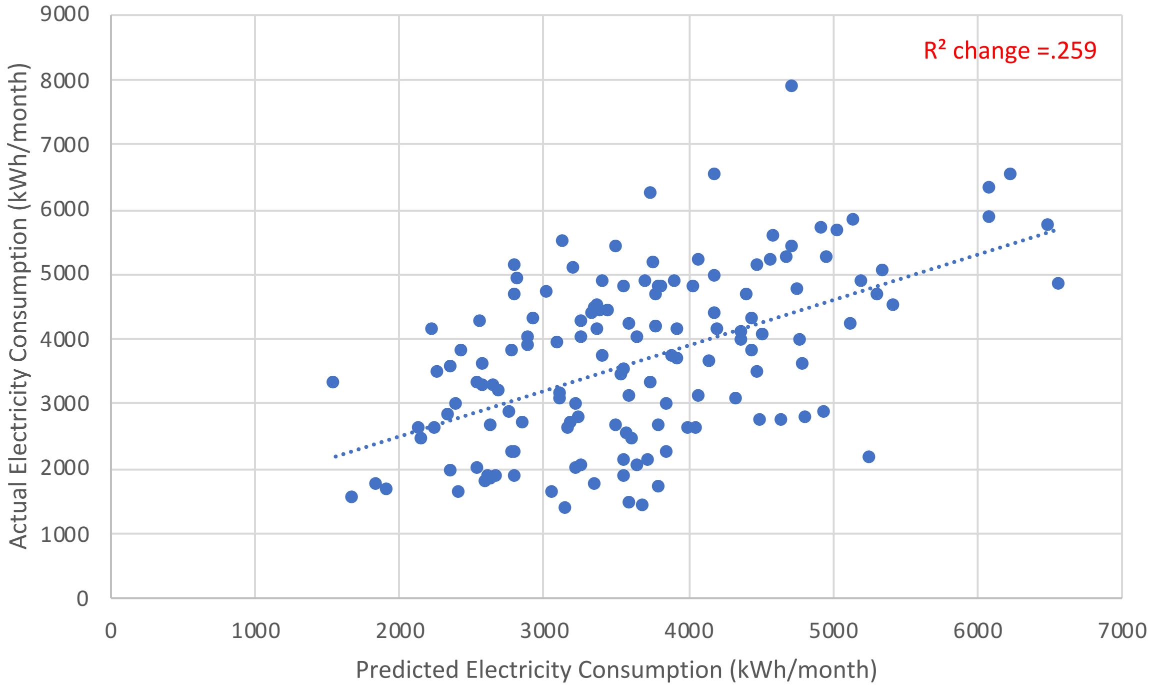


Figure 7.21 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for building attributes and occupant behaviour in Model 5

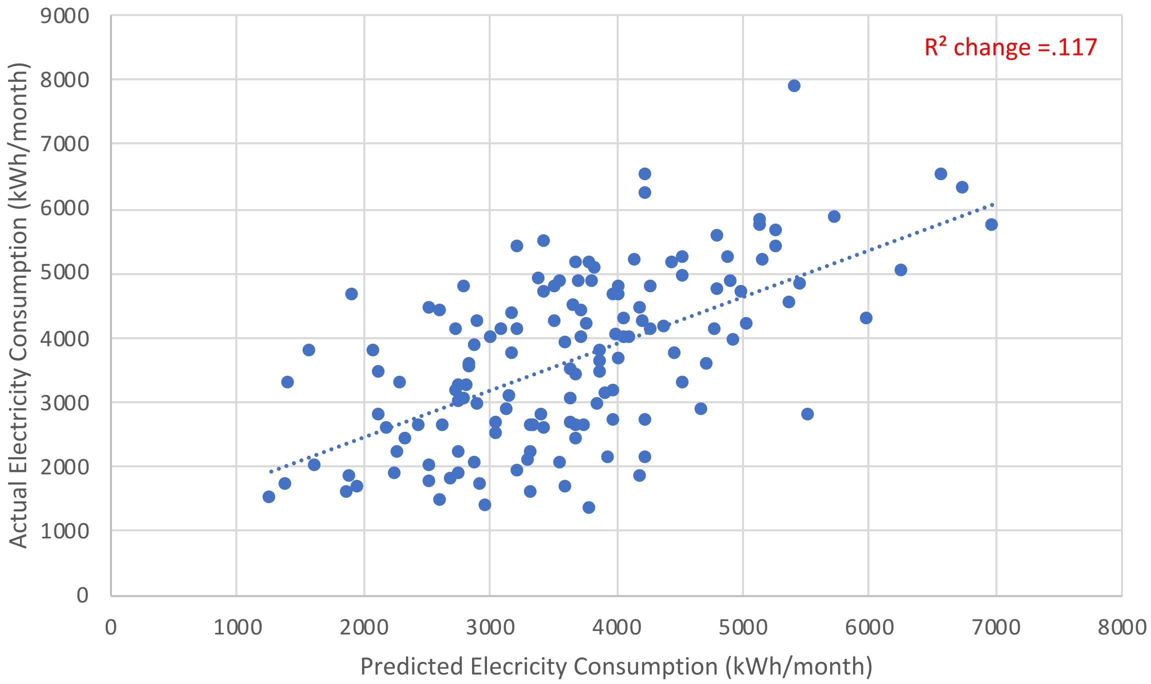


Figure 7.22 Actual electricity consumption (kWh/month) by predicted electricity consumption (kWh/month) for building attributes, occupant behaviour, and household socioeconomic characteristics in Model 5

7.5 Summary

This chapter aimed to identify the relative importance of building attributes, household socioeconomic characteristics and occupant behaviour on electricity use for air conditioning, lighting and electrical appliances in homes in Makkah, Saudi Arabia. The data collected from questionnaires and actual electricity consumption from the Saudi Electricity Company was used. Multiple linear regression analysis was applied to explain the variance in electricity consumption by occupant behaviour, household socioeconomic characteristics and building attributes. Five regression models were built and based on the above analytical results; the findings can be summarised as follow:

- Occupant behaviour is more significant than building attributes as assessed in Model 1 and Model 2. Model 1, while controlling occupant behaviour, explained 47.9% of the variability in electricity consumption and increased by 5.9% by adding building factors into the model. Conversely, Model 2, while controlling building attributes, explained 26.1% of the electricity consumption variance and increased by 27.7% by adding occupant factors to the model. Despite the increased rate of building attributes and the reduced rate of occupant behaviour in Model 2, occupant characteristics may still explain the larger rate of variation in electricity consumption in both models.
- There are no significant differences in the regression models when including the duration of appliances (Model 1) and the number of appliances (Model 3) as occupant behaviour predictors. The results show that the correlation between actual electricity consumption and predicted electricity consumption after including occupant behaviour with the use of electrical appliances in Model 1 was 0.692 (R^2 = .479). The correlation in Model 3 after including occupant behaviour with the number of electrical appliances was 0.675 (R^2 = .456).
- The regression model is more accurate by including building attributes, household socioeconomic characteristics and occupant behaviour for air conditioning, lighting and the use of electrical appliances.
- The results of Model 4 and Model 5 confirmed the findings in the first bullet points above. The results confirm that occupant behaviour in Model 4 explained 43.9% of the variance in electricity consumption and increased by 8.1% after the addition of building attributes. Conversely, by controlling building attributes in Model 5, explained 26.1% of the electricity use variance increased by 25.9% after adding occupant behaviour.
- Since the analysis in the second phase included all variables in the data set and revealed minimal variations from the first phase, it is reasonable to assume that the significant variables derived from the analysis in Chapter 6 are reliable. A reduction of 16 out 71 variables can reasonably explain the variation in electricity consumption.

Regression model outputs vary from Model 1 to Model 2 and from Model 4 to Model 5 due to the controlling factor and its dependence on the order of inputs in relation to the mode. Upon concluding the comprehensive analysis of the research results in this and the preceding chapters, it is now essential to move into a critical phase of this study: the discussion chapter.

Throughout the discussion chapter, relevance of the results is discussed and insightful interpretations are provided that shed light on the study's broader implications. The chapter also intends to deepen our understanding of the subject matter and contribute to the existing body of knowledge by connecting the outcomes with relevant theoretical frameworks and existing literature.

Chapter Eight:

Discussion

Chapter 8: Discussion

8.1 Overview

The research findings deliver an insight into the factors that play a significant role in influencing the high level of home electricity consumption in Makkah, Saudi Arabia. This chapter begins by summarising and discussing the study's main findings, highlighting the analysis of the documentary data, which provided valuable insights into the Saudi Arabian electricity and construction industries, and the correlations between electricity usage and each factor regarding household and building characteristics, weather conditions, and occupant behaviour. Subsequently, the chapter discusses the findings of the multiple linear regression models. Additionally, the chapter contextualises the research findings within the relevant theoretical frameworks and existing literature.

8.2 Documentary Data

Based on the ECRA reports, the electricity industry in Saudi Arabia has witnessed rapid expansion, with a considerable rise in its electricity generation capacity and consumption over the years. The government's initiatives to diversify energy sources and encourage the use of renewable energy, such as solar and wind power, display a solid commitment to sustainability. Furthermore, the documents from MOMRAH, REDF, and the Holy Makkah Municipality offer detailed statistics and information on the construction industry in Saudi Arabia. The increase in the number of building permits issued over the years reflects the growth and development in the country, particularly in regions like Makkah Province. Residential and commercial buildings constitute the majority of the permits issued, indicating the demand for housing and commercial spaces.

The MRDA plays a significant role in promoting development and enhancement in the Makkah Region. The comprehensive plans for Makkah and the Holy Sites aim to create a balance between the city's spiritual, natural, and urban elements. These efforts are geared toward providing long-term benefits for permanent residents and pilgrims alike. The proposed schemes include plans to improve infrastructure, pedestrian movement, and accommodations to cater to the growing number of pilgrims over the next 30 years. To accommodate the projected population growth, the MRDA recommends the establishment of 250,000 housing units over the next ten years and 920,000 housing units over the next 30 years. The MRDA's comprehensive schemes have the potential to transform Makkah into a more efficient, enjoyable, and accessible place for everyone.

The SEEC, established in 2010 and functioning since 2018, aims to promote energy efficiency in Saudi Arabia. The centre collaborates with public and private stakeholders to develop knowledge on best practices and ensure sustainable use of national energy resources. Efforts are being made to decrease energy consumption in the building sector by implementing energy efficiency standards, such as increasing the minimum energy performance coefficient for air conditioners, reducing the energy consumption of appliances like freezers and refrigerators, and improving home and street lighting efficiency. The SEEC also conducts awareness campaigns, workshops, and lectures to educate the public about energy-saving practices and participates in national festivals and events to promote energy efficiency.

The SEC is responsible for electricity generation, transmission, and distribution in Saudi Arabia. The SEC's annual report for 2020 highlights several accomplishments, including the installation of smart meters, expansion of power-generating units, increased electricity production, reduction in diesel consumption, the establishment of transmission substations, and provision of electricity services to new customers across various sectors. The report also mentions the successful commercial operation of the Al-Fadhili plant, which produces electricity and steam through a cogeneration partnership between the SEC and Saudi Aramco.

8.3 Household and Building Characteristics

Combining the findings from the previous documents with the analysis of household and building characteristics, it is evident that the size of dwellings plays a significant role in electricity consumption. In general, the larger the dwellings' floor area, the greater the number and the use of air conditioning, lighting and electrical appliances to maintain a comfortable indoor climate, i.e., visual and thermal comfort. As a result, electricity consumption increases. A significant correlation was ascertained in this study between the house floor area and electricity consumption. This is in line with Hu *et al.* (2017); Yohanis *et al.* (2008); and Santin, Itard and Visscher, (2009). In contrast, Bedir, Hasselaar and Itard (2013) did not find an association between the house floor area and electricity use, which could be related to the fact that all houses in their study had comparable floor areas. In addition, Bedir (2017), highlighted that the number of bedrooms has a negative impact on energy consumption while the rooms used often, e.g., study or hobby rooms have an increasing impact. However, this study found a positive relationship between the number of rooms and bedrooms and electricity use. It is possible that the difference in findings can be attributed to the fact that in Saudi Arabia, bedrooms are often used for purposes other than sleeping, such as studying and recreational activities.

Since all residences in the studied neighbourhood were designed to be equally constructed and built at the same periods with the same materials, this study did not include information about the age of dwellings, insulation, or U-values. Notwithstanding that a number of the participants reported that their homes had been enlarged, it was assumed in this investigation that the type of materials used in the original construction has also been the same type of those used in the enlarged sections. Interestingly, this study established that the type of air conditioner made no difference, possibly due to the small sample size or that the duration of system use is a more significant factor.

The analysis of the independent-sample t-test confirmed that in disagreement with previous studies, for instance Lee *et al.* (2019), no significant differences were found between electricity consumption and the presence of the elderly and children. However, these results are compatible with those of Santin, Itard and Visscher (2009). One possible explanation for this discrepancy is that individuals have different preferences regarding the indoor temperature in their homes and the equipment they use. Another possible explanation includes the limited number of participants in the study.

This research interestingly found a significant relationship between electricity consumption and the presence of housemaids and drivers. This could be a result of the increased use of house spaces, appliances, lighting and air conditioning which they may not use with extra care. Unfortunately, many Saudi families today experience this situation on a regular basis. Thus, the inclusion of these parameters appeared crucial in this study. Finally, this research could not examine the impact of renewable energy, e.g., solar panels, because all of the responses from the questionnaires indicated that they had not installed solar power systems in their houses. This could be due to the modernity of the system in which there is a lack of government regulations and encouragement, in addition to the system's affordability. As Aldossary (2015) suggested that encouraging homeowners to retrofit their homes by installing solar panels can make a reduction in dwelling energy consumption.

In terms of dwelling and household socioeconomic characteristics, floor area, number of rooms and number of bedrooms, household monthly income, tenure type and presence of housemaid appeared to be the most significantly correlated parameters ($p < .001$). Dwelling type, length of residency in the current house, number of bathrooms, family size and presence of teenagers, were also determined to be parameters that correlated with electricity consumption ($p < .01$). The last group consists of respondent’s employment status, presence of driver, light bulb type and respondent’s gender ($p < 0.05$). Similar results were observed in previous studies such as (Santin, 2010; Jones and Lomas, 2015; Bedir, 2017).

8.4 Meteorological Conditions

As mentioned in Chapter 2 and Chapter 3, in relation to residential buildings in Saudi Arabia, the greatest percentage of energy is utilised by air conditioning, with a share of roughly 70%. Amongst several factors impacting air conditioning concerning energy consumption, some can be difficult to reduce because of unmanageable reasons, for example the high outdoor temperature. Nonetheless, there is the possibility that some could be reduced via methods that might be related to occupant behaviour. However, monthly averages were computed from weather data collected on an hourly basis from a weather station located in Makkah. Outdoor temperature and relative humidity were noted to be strongly correlated with electricity consumption. The findings suggest that outdoor temperature can have a significant effect on electricity consumption. This is in line with the study undertaken by Fumo and Biswas (2015).

HDD were calculated and observed to always be equal to zero regardless of the base temperature used (see Section 0), which is in line with the study completed by Indraganti and Boussaa (2017). This supports the high response rate in the surveys since 95% expressed there was no need to use heating systems in the houses. Although significant correlations were also discovered between electricity consumption and outdoor temperature, relative humidity and CDD, weather data were not included in the regression model because all the samples were located in the same area. Associated with this, additional research is evidently required that comprises more samples over a longer period and in different regions of Saudi Arabia, with the intention of acquiring significant data.

8.5 Occupant Behaviour

Regarding the occupant behaviour, this study proved that occupant behaviours significantly affect electricity consumption in residential buildings. Concerning the electrical appliances, the daily use and number of battery charging appliances, air conditioners, along with the number of general appliances had the strongest relationship with electricity consumption ($p < .001$). Followed by the daily use and number of cleaning appliances and food preparation appliances, number of extra ventilation appliances were statistically significantly correlated with electricity consumption ($p < .01$). This was followed by daily use of general appliances, number of appliances used for a hobby and daily use of extra ventilation appliances ($p < .05$). No correlation was observed between electricity consumption and the daily use of appliances used for a hobby. With this information, architects, engineers, policymakers and electricity companies can gain a better insight by identifying which home appliances have the greatest impact and then focus on attempts to minimise domestic energy consumption.

Considering presence in the household, the presence in the second bedroom during the weekdays and weekends, the presence in the main family living room and the main kitchen during the weekends are the most significant rooms in which to study the variance in electricity consumption.

Similarly, the daily use of lighting in bedrooms, family living rooms and bathrooms are significant factors that explain the variance in electricity consumption. Other essential behaviours included in this study were the use of air conditioning and lighting when the room or space is unoccupied and the use of lighting when the house is empty. Even though 62% of the responses acknowledged that they do not leave the air conditioners operating in unoccupied spaces, 58% do not use the lights in unoccupied spaces and 52% do not turn lights on when the house is empty. These factors were found to be statistically significant to study the variance in electricity consumption. There are three likely explanations for these behaviours: to feel comfortable, safety reasons or simply forgetfulness. Furthermore, the type of temperature control used for air conditioning and the length of guests' visits were ascertained to be statistically significant in examining the variance of electricity consumption. In contrast, the use of air conditioning for heating was not statistically significant. This verified findings reported in Section 0, that heating degree days equal zero at all base temperatures, indicating that no heating systems are required in Makkah's buildings.

8.6 Regression Models

Although most of the above-discussed factors significantly correlated with electricity consumption, few factors were included in the regression models because the significance level may vary when a significant variable is combined with other factors. Therefore, two phases were designed to conduct further analysis using the regression model. The first phase deals with the variables that affect electricity consumption significantly, while the second phase entails incorporating all variables in the regression model, regardless of their significance. Backward regression analysis was utilised as an initial step, then the significant variables were introduced to standard MLR analysis. This method is beneficial for determining the most significant predictors that affect electricity consumption. Five different models were proposed in this study, three models were produced in the first phase and two models in the second phase, as illustrated in Chapter 7.

According to Model 1, 47.9% (R^2 =.479) of the variability in electricity use accounted for occupant behaviour as regards air conditioning, lighting and the duration of electrical appliances were in use. As a result of adding building characteristics to the model, the variability in electricity use increased by 5.9% (R^2 = .538). Lastly, the variation increased by 7.7% (R^2 = .615), after adding household socioeconomic characteristics. Conversely, the results in Model 2 demonstrate that 26.1% (R^2 = .261 for the first step) of the variability in electricity consumption accounted for building attributes. As a second step, an increase of 27.7% (R^2 = .538) of the variance in electricity consumption is explained by including occupant behaviour in the model. Lastly, household socioeconomic characteristics accounted for an increase in the variability by 7.7% (R^2 = .615).

In contrast to the findings obtained by Santin, Itard and Visscher (2009), which found that building attributes accounted for most of the variation in energy consumption across both models (42% for first model and 25.8% for second model), the present analysis determined that occupant behaviours accounted for most of the variability in electricity consumption (47.9% for Model 1 and 27.7% for Model 2). However, the findings of this particular study are consistent with the results of those documented by Huebner *et al.*, (2016). They concluded that building attributes were largely unrelated in explaining the variance in electricity consumption, except for dwelling size, probably because heating energy consumption was not included in the analysis. However, in this study, it presumably because the residential buildings in the sample are identical, since they were built at the same time and the same type of materials were used, even for the extended houses, exhibiting relatively minor variations in building characteristics. Thus, occupant behaviour and household socioeconomic factors play a more significant role in explaining the variation in electricity consumption. Consequently, more in-depth investigation of the numerous housing type in Saudi Arabia is required.

The results of the third regression model (Model 3), 45.6% (R^2 =.456) of the variability in electricity use accounted for occupant behaviour in relation to air conditioning, lighting and the number of electrical appliances. As a result of adding building characteristics to the model, the variability in electricity use increased by 6.3% (R^2 = .519). To conclude, the variation was raised by 8.4% (R^2 = .603) after adding household socioeconomic characteristics. This shows that in comparison to Model 1, there is no significant difference between including the use of electrical appliances in Model 1 (R^2 = .615) and the number of electrical appliances in Model 3 (R^2 = .603). The results of this study are similar to the results of a study completed in the Netherlands by Bedir (2017), which included 323 houses. In Bedir's study, the total duration of appliance usage and DHES characteristics explained 58% of the variation in energy use, while the number of lamps and appliance and DHES explained 52% of the variation in energy use. The findings in this study also show that the use of electrical appliances appears more significant than the number, even with a small difference being detected. These results align with the study by McLoughlin, Duffy and Conlon (2012). They suggested that families might reduce energy usage by prioritising the use of electrical household tasks like washing clothes and dishes during peak hours.

Overall, by using the multiple linear regression model, 61.5% (Model 1) of the variance in electricity consumption can be attributed to occupant behaviour, building attributes and household socioeconomic characteristics. Similar results was found by Al Qadi, Sodagar and Elnokaly (2018) using a regression model for 14 factors collected from a survey of 322 households in Hebron, Palestine. Their model explained 60.6% of the variance in energy used for heating. Furthermore, as discussed in Models 1, 2, and 3, household socioeconomic features can account for the variation in electricity use that ranges from 7-9%. This finding is compatible with the Xu *et al.* (2020) study. They discovered that factors related to occupant characteristics significantly impact homes' electricity consumption, which can account for 10.70% of the variation in electricity consumption. Alternatively, Chen *et al.* (2013) found that socioeconomic characteristics and behaviour, with income being the most significant factor, could give reasons for the 28.8% variation in heating/cooling energy consumption.

Furthermore, it was determined in the second phase of developing the regression models that all variables, regardless of their significance, should be analysed. The rationale behind this phase is the possibility of insignificant variables having an indirect effect on electricity usage. Therefore, the novel approach consists of including both significant and insignificant variables with electricity use in a regression analysis applying the backward technique to determine the most important contributors. Subsequently, the significant variables were used in standard MLR analysis. Two models have been proposed at this stage.

The first step in Model 4 was introducing occupant behaviour, which explained 43.9 % (R^2 = .439) of the variance in electricity consumption. Then, an increase of 8.1% for the second step by including the building attributes in the model (R^2 = .521). The final step included household socioeconomic characteristics, which increase the variation in electricity use by 11.7% (R^2 = .638). Conversely, while controlling building attributes in Model 5, the results show 26.1% (R^2 = .261) of the variation in electricity use can be attributed to building characteristics. An addition of 25.9% (R^2 = .521) accounted for occupant behaviours and an increase **of** 11.7% (R^2 = .638) accounted for household socioeconomic characteristics. These results confirmed the findings in the first phase which conclude that occupant behaviour is the most significant contributor in regard to electricity consumption in Makkah, Saudi Arabia. It was also discovered that variables used in the first phase (16 out of 71 variables) are more reliable and can explain the variation in electricity consumption.

After briefly explaining the capacity of the developed models and comparing them with existing models in the literature, a discussion of the predictors will follow. The backward regression method was used to select the variables, and while some of the predictors in the models are insignificant, their inclusion appeared crucial because of the predictors' relevance in the single factor, e.g., occupant behaviours alone.

The results in Model 1 show that the duration of use of lighting in family living rooms and bathrooms, use of lighting in unoccupied rooms or spaces, the daily use of general appliances, food preparation appliances and battery charging appliances, the use of natural ventilation in summer, e.g., windows or doors, the use of air conditioning in winter, households' monthly income, tenure type, family size and the number of bedrooms are the most significant predictors. The importance of the lighting in the living rooms may be attributable to the different duration of use because it is a common area in the house and is used for various purposes like eating, watching TV, sitting with the family, etc. Moreover, residents who are not employed, particularly women, often prefer to stay up later at night.

Although the presence in each space and rooms in the sample houses were collected, as can be seen in Section 6.5.1 and Section 5.3.4, the first model demonstrates an increase in electricity use in only two rooms or spaces, such as when the second bedroom is occupied for more than 12 hours during the weekday and the main kitchen is occupied for more than 12 hours during the weekend. This implies that using regression analysis to predict electricity consumption based on occupants' presence in rooms is not particularly useful. A conclusion that could be drawn from this investigation would be that it is comparable to the research presented by Bedir (2017, P. 147), who stated that "hourly data on presence is not necessarily valuable for further research on electricity consumption, when the total duration of use of each appliance is known". This could be valid unless different data collection methods were employed, e.g., motion sensors to detect the presence of occupants accurately in each room and space in the dwellings. The justification for the comprehensive examination of the parameter presence in rooms was that it might generate more valuable data than the presence in the home for the reason that activities that produce electricity consumption can be associated with the rooms with specific functions.

The significance of the general appliances may be explained by the different durations of use and energy efficiency ratings of appliances like TVs, refrigerators and washing machines. This implies that additional research is required, specifically focusing on the energy efficiency of the various appliances. Moreover, appliances used for a hobby do not contribute to the electricity consumption in any model. This is probably because they are used for only a few hours per day since most individuals who use appliances for a hobby are children and teenagers, 14.6% and 14%, respectively. The number of occupants in a family and household monthly income affect the amount of electricity used in dwellings. These findings are consistent with those of Bedir, Hasselaar and Itard (2013); Santin (2010); and Xu *et al.* (2020) who asserted that family size is a significant predictor of electricity consumption in dwellings. This may be due to the fact that the number and use of electrical appliances increases as a family grows.

A variable that has proven significant in other research but not in this research relates to age. The presence of the elderly, children and teenagers in the family, as well as the respondent's age, were all investigated for correlations with electricity use. However, only the presence of teenagers was established to be statistically significantly correlated. The respondent's age was not included in any of the regression models, which might be due to several reasons, i.e., only adults and seniors were allowed to fill out the questionnaires, or the variable was in the categorical type and did not present the exact age. Tenure type, another variable which is also found to be significant in the literature, is also determined to be a significant contributor in the models. Additionally, number of bathrooms significantly affect electricity consumption. Nevertheless, further investigation is required for shower and bathing behaviour, which was also found to influence energy requirements for water heating in different research. In contrast to the study completed by Bedir (2017), the results in this research found a positive relationship between household income and electricity consumption and appear as a significant predictor.

In Model 3, the most significant contributors are the duration of lighting use in family living rooms, the use of air conditioning in winter, bulb type, number of bedrooms, family size, household monthly income, tenure type and temperature control. The type of temperature control used for air conditioning seemed to influence the variance in electricity consumption significantly. In general, an automatic temperature control system is designed to maintain a consistent temperature, which helps to reduce energy consumption; however, the results show that an automatic temperature control system is consuming more energy than a manual temperature control system possibly because residents using automatic temperature control systems are less likely to know the optimal temperature setting, leading to longer periods of air conditioning use. Despite the positive correlation between dwelling floor area and electricity consumption, floor area did not appear in any regression model, probably because the sample had an inaccurate representation of the variable (no significant variation in the size of the dwellings).

Finally, more research is required to determine the impact of factors, such as the number and length of showers taken per day, the residents' lifestyles concerning the electricity as well as gas consumption in homes in Makkah. The latest installation of smart metres installed by the SEC may yield more detailed information. Likewise, the duration of use of light bulbs was only taken into account in this research, yet further research is necessary on the number of light bulbs used in a dwelling.

8.7 Summary

This study investigated the factors that affect electricity consumption in residential buildings in Makkah, Saudi Arabia. The study found that the following factors have a significant impact on electricity consumption:

- The official reports from the government entities collectively indicate the efforts and achievements in enhancing the infrastructure, energy efficiency, and electricity services in Saudi Arabia, such as the significant investments in renewable energy.
- In terms of dwelling and household socioeconomic characteristics, floor area, number of rooms and number of bedrooms, household monthly income, tenure type and presence of housemaid appeared to be the most significantly correlated parameters ($p < .001$). Dwelling type, length of residency in the current house, number of bathrooms, family size and presence of teenagers, were also determined to be parameters that correlated with electricity consumption ($p < .01$). The last group consists of respondent's employment status, presence of driver, light bulb type and respondent's gender ($p < 0.05$). Similar results were observed in previous studies such as (Santin, 2010; Jones and Lomas, 2015; Bedir, 2017).
- Contrary to some previous studies, this research finds no significant difference in electricity consumption based on the presence of the elderly and children.
- The outdoor temperature, CDD, and relative humidity were also significant factors that affect electricity consumption. However, these factors were not included in the regression model because all the samples were located in the same area.
- Regardong occupant behavior, the use of electrical appliances, the presence in the household, the daily use of lighting, and the use of air conditioning and lighting when the room or space is unoccupied, and the type of temperature control used for air conditioning and the length of guests' visits were all significant factors that affect electricity consumption.
- Two phases were conducted to build regression models: the first phase considered significant variables, while the second phase included both significant and insignificant variables. The results showed that occupant behaviour, building attributes, and

household socioeconomic characteristics were significant predictors of electricity consumption. Occupant behaviour, such as air conditioning usage, lighting duration, and appliance usage, accounted for a substantial portion of the variance. Contrary to previous studies, building attributes had a lesser impact on electricity consumption. The inclusion of insignificant variables was important as they could indirectly affect electricity usage.

- The developed models explained 61.5% of the variance in electricity consumption, with occupant behaviour being the most significant factor. The study suggests the need for further investigation into different housing types and factors like appliance energy efficiency and accurate presence detection in rooms. Overall, the findings highlight the importance of occupant behaviour and socioeconomic factors in explaining electricity consumption patterns

In conclusion, this chapter summarizes the findings related to electricity consumption in residential buildings, highlighting the influence of factors such as household socioeconomic characteristics, occupant behaviour, dwelling attributes, and weather conditions. It emphasises the need for further research encompassing larger sample sizes, longer periods, and diverse regions in Saudi Arabia to gain comprehensive insights into electricity consumption patterns. The following chapter presents the Conclusion Chapter, highlighting the research contributions, limitations, and future works. It also highlights the research recommendations for various stakeholders, like government entities and dwelling occupants.

Chapter Nine:

Conclusion

Chapter 9: Conclusion

9.1 Research Summary

Despite significant developments in building design and construction technologies, there is evidence that actual energy consumption in homes differs significantly from the prediction. While many elements have been investigated regarding energy consumption, the impact of occupant behaviours and how they interact with various building systems and components remain largely unknown, notably in Saudi Arabia. Therefore, this study aimed to investigate the determinants of residential energy consumption in Makkah, Saudi Arabia and identify the impact of occupant behaviours as regards using air conditioning, lighting and electrical appliances on energy consumption. It also aimed to determine the contribution of each factor, such as building attributes, household socioeconomic characteristics, meteorological conditions and occupant behaviours, in the overall variation in electricity consumption. These goals were developed to encourage the development of more residential energy-efficient buildings in Saudi Arabia by establishing a solid foundation that considers all potential influences on residential energy consumption, including occupant behaviour.

Energy efficiency in Saudi Arabia's construction sector has seen notable improvements thanks to new practices and technologies that enhance building geometry, the quality of materials together with building and energy regulations. However, humans comprise and modify their physical surroundings to survive and perform their activities comfortably, regardless of the amount of energy they consume. As a result, their environment experiences gradual but noticeable transformation. In contrast, buildings must be designed for occupants so that energy efficiency measures are compatible with their desire for the best living environment. Accordingly, the design and operation of sustainable, energy-efficient buildings, as well as the effectiveness of their building systems, all depend on understanding human-building interactions.

To respond to this, the principal question in this research asks: What are the determinant factors of energy consumption in Makkah, Saudi Arabia? It also asks: To what extent do occupant behaviours impact residential energy consumption for the use of air conditioners, lighting and electrical appliances? This research employed quantitative and qualitative approaches to identify the factors that influence residential energy consumption in Makkah, Saudi Arabia, and to gather individual households' characteristics and behaviours and their energy consumption patterns. In this research, occupant behaviour was defined as presence patterns in a space or room and the use of air conditioning, lighting and electrical appliances.

9.2 Research Questions and Findings

1- What energy resources does Saudi Arabia possess and in what specific ways are those resources used? How does the energy consumption of Saudi Arabia fit into the bigger picture of the economy as a whole?

   a. What are the most significant environmental challenges that Saudi Arabia is presently facing?
   b. What steps are the Saudi Arabian government taking to reduce the country's overall energy consumption and boost its economy?

The review of relevant literature presented at the beginning of this thesis reveals that energy consumption (electricity and gas) has been the subject of research for many decades, yet more research and studies are being conducted due to the increasing worldwide demand for energy. The IEA, EAA, IECC and many others are all heavily focused on improving energy consumption and conservation concept.

As demonstrated in Chapter 2, the Kingdom of Saudi Arabia is a country that has an abundance of energy resources. It produces, consumes, exports and generates energy from petroleum and natural gas. Saudi Arabia, the world leader in petroleum exports and crude oil production capacity, is struggling to keep up with increasing domestic energy demand as it was ranked the tenth largest country in energy consumption globally. The residential sector, which accounts for 46% of the SEC's electricity sales, is forecast to double its energy use by 2050. The nation’s excessive energy use is highlighted in this review, which also highlights the need for new approaches to reduce energy consumption, including investigating occupant behaviours and other influential factors.

Investigating the first sub-question concerning environmental challenges in Saudi Arabia, it was ascertained that Saudi Arabia is facing several environmental challenges that need immediate action to avoid damages, one of which is air pollution in urban areas and CO_2 emissions due to the high energy demand and consumption. It is recognised that Saudi Arabia is already one of the Middle East's principal emitters, consequently such rapid growth in domestic energy demand has significant repercussions in relation to the global oil market and global emissions.

Regarding the second sub-question, Saudi Arabia’s government launched the national transformation known as “Vision 2030”, emphasising three fundamental pillars, namely culture, environment and the economy. In response to this, several executive programmes have been implemented to avoid potential economic and environmental disasters caused by the country's high energy consumption, such as the SBC, the SEEC, besides the launch of ten renewable energy projects.

2- What direct and indirect underlying causes contribute to excessive energy use in dwellings, according to the available literature?

Several factors, indeed, have been identified that could significantly impact energy consumption in residential buildings. The following factors, discussed in Chapter 2 and Chapter 3**Error! Reference source not found.**, contribute to this phenomenon:

a. Building attributes, for instance house floor area, number of rooms, number of bedrooms, building envelope and insulations, location and the age of dwelling, in addition to the type of HVAC installed.
b. Household socioeconomic characteristics like the family size, age of residents, tenure type, income, length of residency in the same house, presence of the elderly, teenagers and children, cultural characteristics of citizens and lifestyle, employment, education level, ownership of appliances and electricity tariffs.
c. Weather conditions, such as outdoor air temperature, horizontal global irradiance, wind speed, relative humidity, cooling and heating degree-days.
d. Occupant behaviours, for example the behaviour related to lighting and appliances use, HVAC system use and presence patterns.
e. Government energy subsidy and rapid population and economic growth in the context of the Saudi Arabian.

3- What is the influence of building attributes, household socioeconomic characteristics, meteorological conditions and occupant behaviours on electricity use in dwellings in Makkah, Saudi Arabia?
   a. Which factor has a significant impact on the amount of energy used in residential buildings in Makkah, Saudi Arabia?
   b. What effect do the use of air conditioners, lighting and electrical appliances have on the residential electricity consumption in Makkah, Saudi Arabia?
   c. Do households with the same socioeconomic and building attributes characteristics display a difference in electricity consumption regarding the use of air conditioning, lighting and electrical appliances?

The major key findings emerge to impact electricity consumption in the building attributes are as follow:

- Dwelling type and light bulb type significantly affect electricity consumption. The total number of rooms, bedrooms and bathrooms in the house and the dwellings' floor area appear to influence electricity consumption. Hence, large houses consume more electricity than small ones.

- No relationships were found between electricity consumption and the number of guests' living rooms, number of family living rooms, number of kitchens, number of additional rooms, e.g., office and the type of air conditioners.
- Solar panel systems were excluded from this study because none of the households in the sample mentioned have installed or use solar panels.

In terms of household socioeconomic characteristics, the length of residency in the same house, household monthly income, tenure type, respondents' employment status, respondents' gender, in conjunction with the presence of adolescents were all noted to significantly affect electricity consumption. Family size emerged as the most influential factor, which has a strong positive correlation with electricity consumption. The presence of housemaids and drivers, who live in the house, was observed to have a significant impact on electricity use. The presence of children and the elderly, respondents' education and age did not affect electricity use in residential buildings in Makkah.

Considering climate condition, outdoor temperature, relative humidity, maximum wind speed, maximum solar radiations, cooling degree-days at all temperature base that have been calculated. No correlations were determined between electricity use and monthly rainfall and the number of rainy days.

Regarding occupant behaviours, the use of lighting in bedrooms, family living rooms and bathrooms, the use of lighting in unoccupied spaces or rooms, and the use of lighting when the house is empty were found to be significantly correlated with electricity consumption. The frequency of use of air conditioning during the summer and winter and natural ventilation during the summer, the use of air conditioning in unoccupied spaces or rooms, combined with the type of temperature control system used for air conditioning significantly influence electricity use. Despite the fact that the number of guests' family rooms does not influence electricity consumption, the duration of guests' visits does. Presence of occupant in the second bedroom (weekdays) and main family living rooms and kitchens (weekend) were noticed to be significant influencing factors on electricity consumption.

With respect to the electrical appliances, the number and use of general appliances, cleaning appliances, food preparation appliances, extra ventilation appliances, and battery charging appliances and the number of air conditioners significantly correlated with electricity consumption. There were no correlations established between the use of appliances used for a hobby, the use of lighting in kitchens and electricity consumption. Similarly, no correlation was found between electricity consumption and the presence of occupant in the main bedrooms (weekdays and weekend) and the frequency of electric fans use (summer and winter).

4- How can electricity consumption in dwellings be effectively modelled in Makkah, Saudi Arabia? and how much of the variation in electricity use can be explained by this model combining building attributes, household socioeconomic characteristics, climate conditions, and occupant behaviours?
    a. What are the most significant predictors of each factor in explaining energy consumption variation in domestic buildings in Makkah, Saudi Arabia?

Five regression models were created and produced in two phases, as discussed in Chapter 7. Three models were provided in the first phase. The first model (Model 1) was built based on controlling occupant behaviours for the use of air conditioning, lighting and duration of electrical appliances use, building attributes as a second and household socioeconomic characteristics in the last step. The second model (Model 2) was developed based on controlling building attributes, occupant behaviour in the second step, whilst the last step included household socioeconomic characteristics. The third model (Model 3) was built based on controlling occupant behaviours for the use of air conditioning, lighting and the number of electrical appliances, building attributes in the second step, and household socioeconomic characteristics in the final step.

The results in Model 1 suggest that 47.9% (R^2 =.479) of the variability in electricity use accounted for occupant behaviour. An increase by 5.9% (R^2 = .538) of the variability in electricity use accounted for building characteristics. Finally, including household socioeconomic characteristics in the model increases the variation by 7.7% (R^2 = .615). Controlling building attributes in Model 2, on the other hand, explained 26.1% (R^2 = .261) of the variability in electricity consumption. As a second step, an increase of 27.7% (R^2 = .538) of the variance in electricity consumption is explained by including occupant behaviour in the model. Lastly, household socioeconomic characteristics accounted for an increase in the variability by 7.7% (R^2 = .615). As a result of these findings, it was determined that occupant behaviours accounted for most of the variability in electricity consumption (47.9% for Model 1 and 27.7% for Model 2).

The findings pertaining to the third regression model (Model 3), 45.6% (R^2 =.456) of the variability in electricity use accounted for occupant behaviour in relation to air conditioning, lighting and the number of electrical appliances. As a result of adding building characteristics to the model, the variability in electricity use increased by 6.3% (R^2 = .519). The last step incorporating household socioeconomic characteristics in the model, which as a result increased the variation by 8.4% (R^2 = .603). This indicates that in comparison to Model 1, there is no significant difference between including the use of electrical appliances in Model 1 (R^2 = .615) and the number of electrical appliances in Model 3 (R^2 = .603).

The second phase was based on incorporating all collected variables, regardless of their significance. Two multiple linear regression models were developed (discussed in Section 7.4). The first step in Model 4 introduced occupant behaviour for the use of air conditioning, lighting and the duration of electrical appliances use, which explained 43.9 % (R^2 = .439) of the variance in electricity consumption. An increase of 8.1% (R^2 = .521) for the second step (including the building attributes in the model). The final step included household socioeconomic characteristics, which increase the variation in electricity use by 11.7% (R^2 = .638). Conversely, as regards the results of Model 5, controlling building attributes revealed that 26.1% (R2 =.261) of the variation in electricity use was explained by building attributes. Occupant behaviours accounted for a further 25.9% (R2 =.521). Lastly, household socioeconomic characteristics accounted for an increase of 11.7% (R2 =.638). These results confirmed the findings in the first phase which conclude that occupant behaviour is the most significant contributor in regard to electricity consumption in Makkah, Saudi Arabia.

Finally, since the analysis in the second phase (included all variables in the data set) revealed minimal variations from the first phase (only the significant variable from Chapter 6), it is reasonable to conclude that variables used in the first phase are reliable. A reduction of 16 out 71 variables, a 23% reduction, can reasonably explain the variation in electricity consumption.

Investigating the second question, the results in Model 1 revealed that the duration of use of lighting in family living rooms and bathrooms, use of lighting in unoccupied rooms or spaces, the daily use of general appliances, food preparation appliances and battery charging appliances, the use of natural ventilation in summer, e.g., windows or doors, the use of air conditioning in winter, households' monthly income, tenure type, family size and the number of bedrooms are the most significant predictors.

9.3 Research Contributions

This study presented in the thesis was restricted due to the lack of available manpower, time and resources. Nevertheless, it has successfully achieved its goal and objectives and contributed to the body of prior knowledge, parties interested in energy consumption and residents' dwellings.

As part of this study's contribution to the body of knowledge, it provides a solid base for developing more energy-efficient residential buildings in Saudi Arabia, considering all possible influences on household energy consumption, specifically occupant behaviour. In addition, since the study of occupant behaviour has been conducted for decades in several countries, such as China, the United States, Canada and Australia, as well as many in northern and western Europe (Switzerland, Germany, the United Kingdom, Austria, Italy, the Netherlands, Norway, etc.), one of the key outcomes of this research is to pave the way in this field for future work in the Kingdom of Saudi Arabia and inspire the beginning of a series of studies explicitly prepared for Saudi culture and in the context of Saudi Arabia, taking into consideration local conditions, e.g., technical, construction and industry-related, climatic and social conditions.

This study also provides a unique contribution to the knowledge in terms of offering comprehensive data sets based on the questionnaires, actual energy consumption records and meteorological data with the purpose of investigating the effect of occupant behaviours, along with other influencing factors, on residential energy consumption in Makkah, Saudi Arabia. It has been observed that contextual and social factors, such as the home environment or daily occupant behaviours and habits, have a substantial impact on electricity consumption, along with building attributes, household socioeconomic characteristics and meteorological conditions. Moreover, this study identifies easily accessible parameters and explains the underlying variables that determine the level and variance of electricity consumption in Makkah households in Saudi Arabia. These are the original contributions of the current research to the body of knowledge.

Additionally, this research should stimulate the interested parties concerning electricity consumption, for instance, policymakers and electricity suppliers, because they revealed the determinants of electricity consumption in residential buildings in Makkah, Saudi Arabia. The results show that electrical appliances should be the primary focus of residential energy efficiency regulation and, somehow, address the inclusion of occupant behaviour into the buildings and energy code to generate the changes required. According to the study's findings, reducing the electricity use of the current dwellings in Saudi Arabia can be accomplished mainly by developing the efficiency of appliances, particularly air conditioners. As the nation prepares to manage the growing electricity demand, it is recommended that improving the efficiency of energy appliances occur as rapidly as possible and that residents are encouraged to exchange old appliances with highly efficient ones or encourage more energy-efficient behaviour.

In addition to engineers and architects, the findings are valuable to those looking to design or renovate domestic properties in Saudi Arabia to comply with energy-efficient building standards. The research broadly benefits those interested in energy consumption and energy-efficient housing by shedding light on the factors driving the region's high electricity demand. Hence, policymakers in Makkah, Saudi Arabia, can implement measures and strategies to reduce that demand. The findings obtained by this study may also be applicable to the Middle East and the GCC countries, which share similar climate conditions and a set of cultural norms.

Lastly, this research aids in supporting the attempts that are being made to persuade individuals and households to behave in a manner that is more energy efficient. Investing in research in this area is crucial so that homeowners may appreciate and comprehend the impact their daily actions have on the amount of energy they consume, which could help lower the cost and demand for electricity and in turn, diminish the environmental impact.

9.4 Research Limitations

This research attempted to investigate the impact of occupant behaviour along with other influential factors, such as building attributes, household socioeconomic characteristics and meteorological conditions, on residential electricity consumption concerning the use of air conditioners, lights and electrical appliances in Makkah, Saudi Arabia. Similar to any other research, this research has certain limitations that have impacted its design and research technique. These limitations are as follows, but in no particular order:

- The absence of local information on electricity use, meteorological data and occupant behaviour, as well as the difficulty in gaining access to the relevant data in Makkah, in contrast to the availability of such information in other countries. This is reflected in the limited availability of local specialists, studies, experiences and public awareness of residential energy use and occupant behaviour. The primary constraint was collecting electricity records and meteorological data, as well as encouraging residents to participate and be part of the study. The researcher had to go through several meetings with various authorities to gain approval in order to be allowed to collect the questionnaires in the targeted area and allow the residents to be acquainted with the ongoing research activity. In addition, it was difficult to obtain the actual electricity consumption records and meteorological data because of the confidentiality policy operated by the SEC and the Custodian of the Two Holy Mosques Institute for Hajj and Umrah Research. Nevertheless, the researcher had good access to the electricity consumption records for five years and meteorological data for two years. Therefore, the author of this work used the available data to meet the objectives of this research.
- The cultural barriers in Saudi Arabia were an obstacle during the design of the research methodologies and techniques. For instance, monitoring occupant behaviour using equipment like sensors and cameras was not considered because of the Saudi

households' cultural sensitivity and constraints. Besides, using such equipment requires enormous effort and time, according to the available literature. In addition, the face-to-face questionnaires created another obstacle as regards collecting data from females. Nevertheless, the researcher was able to adapt and address such limitations to cover the gap in dealing with females. To do so, the researcher was accompanied by a family member, his sister during the data collection in order to ensure that the questionnaires were completed correctly.

- This study was limited due to its narrow geographic concentration (Makkah), as it focused its investigation on only one neighbourhood in the city. The variation between dwellings in the sample, i.e., building characteristics, is a recognized limitation of this study, given that the questionnaires were collected in one neighbourhood in Makkah. The purpose of this was to direct the focus more on the effect of occupant behaviour on electricity consumption. Including other neighbourhoods and cities in the research could be beneficial to discover and compare occupant behaviours across different cultural groups on a city scale and national scale. However, doing so would have required a substantial investment of time and resources, such as the researcher's travel costs. It is essential to highlight that the current study is no different from the majority of others in that it focuses on a single nation or geographical area.
- Another limitation of this research was the assumption made for the expanded part of the houses that all buildings were following the original planning for the neighbourhood and utilising the same construction materials. This may be unachievable in practice because building materials are constantly improving. The rationale behind making such an assumption is to give a preference in relation to tracking occupant behaviours rather than gathering large amounts of information on the structure itself, such as the age of construction, insulation, U-values, etc.
- One of the acknowledged limitations of this research is the reliance on the estimation of the questionnaire respondents regarding the usage of electrical appliances and occupancy patterns. This means that there may be some degree of uncertainty or inaccuracy in the data collected, which could potentially impact the overall findings and conclusions of the study. It is important to note, however, that this is a common constraint in research of this nature and should be taken into consideration when interpreting the results. Moreover, the occupancy of a house may fluctuate during the summer season as occupants may choose to visit their summer homes or travel to colder destinations, which is also acknowledged as a limitation of the current research.

- This research was also limited due to the quarantine implemented because of the pandemic which was during the data collection stage. On the one hand, this might explain the low response rate as regards the questionnaire (27%). Another reason for the low response rate could be related to the cultural barriers and residents feeling uncomfortable with providing private information about their lifestyle and income level. It could also be associated with the length and complexity of the questionnaire.

However, it is important to note that these limitations did not invalidate the research since the current research methodologies and techniques have been designed to accommodate these considerations. This means that future work can yield more refined results by avoiding these constraints.

9.5 Future Research

In light of the research limitations, the following points describe the future research directions that could be pursued but which were not in the scope of this study.

- Future surveys could be conducted on a city scale or national scale in which all the building types and features, along with occupant behaviour are included in the study, such as insulation level in walls, floors, roofs and facades, year of construction, etc.
- More research could investigate the effect of the perceptions of thermal comfort variations on energy consumption and the efficacy of various energy-saving techniques in this context.
- It is necessary to undertake an additional study in the future to investigate the factors that determine occupant behaviour and to identify the behavioural patterns and profiles of occupants that are associated with the amount of energy consumed in the Saudi Arabian context.

9.6 Research Recommendations

The findings generated by this study can be used by government entities, electricity suppliers, architects and consumers with the aim of promoting a collaborative road map to reduce residential energy use in Saudi Arabia. Based on the findings of the study, these groups are recommended to the following:

9.6.1 Recommendations for Government Entities

- To provide financial support for studies and research pertinent to monitoring occupant behaviour throughout all building sectors in Saudi Arabia to achieve a maximum potential reduction in energy consumption throughout the country.
- To stimulate the use of the media as a way to increase the public's understanding of the importance of occupant behaviour in buildings in regard to the overall energy performance.
- To acknowledge that occupant behaviour necessitates strategic initiatives concerning this crucial issue at the nation's level in terms of reducing energy consumption and economic reinforcement.

9.6.2 Recommendations for Electricity Suppliers

- To keep updated with the most recent findings in the scientific literature on the effects of building energy efficiency and occupant behaviour by maintaining communications with experts.
- To explore the production of new technologies in the field of energy production that assist occupants to adjust their behaviour accordingly and enable their application in the building sector in Saudi Arabia.
- To collaborate with concerned parties in initiatives and policies concerning energy consumption issues and provide easy access to energy consumption public records to all those interested in studying energy consumption and occupant behaviour.

9.6.3 Recommendations for Architects and Designers

- To comprehend the role of occupant behaviour toward energy consumption and understand the significance of enabling their participation in the design, notably from the early stages, to achieve an energy-efficient building.
- To adopt the concept of designing for occupants and support using energy prediction models during the early stages of design by integrating occupant behaviour to give the architects and designers a clear picture of the potential for energy savings.

9.6.4 Recommendations For Building Users

- To inform family members of the financial advantages of lower electricity consumption as a result of making several behavioural changes by employing energy-saving techniques.

- To conserve energy by only utilising lighting and air conditioners as required and not to underestimate their use even with highly rated, energy-saving equipment.
- To respect all governmental programmes and initiatives aimed at lowering the nation's energy usage, including cutting energy subsidies and acknowledging the seriousness of energy consumption issues by urging occupants to preserve energy, starting with family members, neighbourhoods and cities

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Appendix:

Appendix

Appendix A: Leaflet Design

Appendix B: Questionnaires Design

* For the Arabic version of this page, please move to the next page
للنسخة العربية من هذه الصفحة، الرجاء الإنتقال إلى الصحفة التالية

Dear Respondent,

This questionnaire is part of academic research to obtain a PhD degree in Architecture. The study is aiming at investigating the determinants of energy consumption with particular reference to the effect of occupant behaviour for the use of air conditioning, lighting, and electrical appliances in Makkah dwellings. The research would assist in improving the current and future architectural and energy studies in Saudi Arabia. Furthermore, this research is your opportunity to support architects, decision-makers, developers and professionals involved in the residential sector to design and implement more energy-efficient houses.

The researcher attempts to collect information about the residents of King Fahad Scheme "AL-Iskan" in Makkah. This survey will positively help the researcher answering the main research question. It is 'how much does the occupant behaviour influence the energy consumption for space cooling and electricity use for lighting and appliances in Makkah domestic buildings? However, all the above depends on the cooperation and consent of the participants to take part in this questionnaire and the accuracy of their response as possible.

You have been selected randomly to take part in this survey, and it would be appreciated if you could spare some time to answer these questions (A maximum of 30 minutes). There are no right or wrong answers, and we only want to know information about the family's lifestyle along with energy consumption information. Everything you tell us will be kept strictly confidential and will be used only by the researcher and the supervisory team.

Researcher name: Hatem Abdulrahman Nojoum
PhD Researcher
Newcastle University
School of Architecture, Planning and Landscape
To contact for any queries or questions related to the questionnaire or the research:
Mobile: (+966) 503655445
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عزيزي المشارك/عزيزتي المشاركة

هذا الإستبيان هو جزء من بحث اكاديمي للحصول على درجة الدكتوراه في الهندسة المعمارية. يهدف البحث إلى دراسة التأثير الحقيقي لسلوك السكان على استهلاك الطاقة لتبريد الفراغات واستخدام الكهرباء للإضاءة والأجهزة في منازل مكة المكرمة. سيساعد البحث في تحسين الدراسات المعمارية والدراسات الخاصة بالطاقة الحالية والمستقبلية في المملكة العربية السعودية. علاوة على ذلك ، فإن هذا البحث هو فرصتك لمساعدة المهندسين المعماريين وصناع القرار والمطورين والمختصين المهتمين بالقطاع السكني على تصميم وتنفيذ منازل أكثر كفاءة في استخدام الطاقة

يحاول الباحث جمع معلومات عن سكان مخطط الملك فهد "الاسكان" بمكة المكرمة. ستساعد الردود التي تم جمعها من هذا الإستبيان بشكل إيجابي الباحث في الإجابة على سؤال البحث الرئيسي. "ما مدى تأثير سلوك السكان على استهلاك الطاقة لتبريد الفراغات واستخدام الكهرباء للإضاءة والأجهزة في المباني السكنية بمكة المكرمة؟" ومع ذلك، كل ما سبق يعتمد على تعاون المشاركين وموافقتهم على المشاركة في هذا الاستبيان ودقة ردهم قدر الإمكان

لقد تم اختيارك عشوائيًا للمشاركة في هذا الاستطلاع ، وسنكون ممتنين لو أمكنك توفير بعض الوقت للإجابة على هذه الأسئلة (بحد أقصى 30 دقيقة). لا توجد إجابات صحيحة أو خاطئة، نريد فقط معرفة معلومات حول نمط حياة الأسرة وإستهلاك الطاقة. سيتم الاحتفاظ بكل ما تخبرنا به بسرية تامة ولن يتم استخدامه إلا من قبل الباحث والفريق الإشرافي

إسم الباحث: حاتم عبدالرحمن نجوم
باحث دكتوراة
جامعة نيوكاسل البريطانية
للتواصل مع الباجث في مايخص الإستبيان أو البحث عامةً
واتس أب 503655445 (966+)
إيميل:- h.nojuom2@newcastle.ac.uk

* Do you agree to participate in completing the questionnaire?
هل توافق على المشاركة في تعبئة الاستبيان؟

- ◯ I agree
  أوافق
- ◯ I disagree
  لا أوافق

Section One:
Household Characteristics

القسم الأول:
خصائص الأسرة

* How many permanent users live in the house? including family members, servants, etc.
كم عدد المستخدمين الدائمين الذين يعيشون في المنزل؟ بما في ذلك أفراد الأسرة ، الخدم ، وما إلى ذلك

- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10

* Specify the age range, gender and level of education, employment status and the role at home for each member.
حدد الفئة العمرية، الجنس، مستوى التعليم، الحالة الوظيفية، والدور في المنزل لكل فرد

	Age Range الفئة العمرية	Gender الجنس	Level of Education مستوى التعليم	Role in House الدور في المنزل	Employment Status الحالة الوظيفية
Respondent المجيب على الاستبيان					
Person 2 الفرد الثاني					
Person 3 الفرد الثالث					
Person 4 الفرد الرابع					
Person 5 الفرد الخامس					
Person 6 الفرد السادس					
Person 7 الفرد السابع					
Person 8 الفرد الثامن					
Person 9 الفرد التاسع					
Person 10 الفرد العاشر					

* What is the total income of the whole household per month in SAR?
ما هو إجمالي دخل الأسرة الشهري بالريال السعودي؟

- Less than 10,000 SR
  أقل من 10,000 ريال سعودي
- Between 10,000-20,000 SR
  بين 10,000 - 20,000 ريال سعودي
- Between 30,000 and 40,000 SR
  بين 30,000 و40,000 ريال سعودي
- Between 50,000 and 99,999 SR
  بين 50,000 و 99,999 ريال سعودي
- Over 100,000 SR
  أكثر من 100,000 ريال سعودي

Section Two:
Household Characteristics & Presence at Home

القسم الثاني:
خصائص المبنى & التواجد في المنزل

* For how many years have you been living in this house?
منذ كم سنة وأنت تعيش في هذا المنزل؟

- Less than 5 year
  أقل من 5 سنوات
- 5-10 years
  خمسة الى عشر سنوات
- 11-20 years
  احدى عشر الى عشرين سنة
- More than 20 years
  أكثر من عشرين سنة

In what year was the building structure built? Give the best estimate
في أي عام تم بناء هيكل المبنى؟ اعطي افضل تقدير

* Which of the following best describes your housing status?
أي مما يلي يقدم أفضل وصف لحالة السكن الخاصة بك؟

- Tenant
  مستأجر
- Homeowner
  مالك المنزل
- Live with Parent
  العيش مع الوالدين
- Live with relatives/friends
  العيش مع الأقارب/الأصدقاء
- Other - please specify
  غير ذلك - فضلا حدد

* Which of the following do you believe best describes your home.
أي من الخيارات التالية تعتقد انه أفضل وصف لمنزلك

- ◯ Two-storey semi-detached house
  فيلا دوبلكس من طابقين
- ◯ One-storey semi-detached house
  فيلا دوبلكس من طابق واحد
- ◯ Flat/Apartment
  شقة
- ◯ Other - please specify
  غير ذلك - فضلا حدد

* Was the building built as it is now or it was recently extended into multiple floors?
هل تم بناء المبنى كما هو الآن أم تم تمديده مؤخرًا إلى عدة طوابق؟

- ◯ Built as it is now
  بُني كما هو الآن
- ◯ Recently extended
  تم تمديده مؤخرا

* How many bedrooms does the house have?
كم عدد غرف النوم في منزلك؟

◯ 2 ◯ 4 ◯ 6 ◯ 8
◯ 3 ◯ 5 ◯ 7

* Define the presence time during the **weekdays** (Sunday-Thursday) for each bedroom/s by determining the number of users present in the space.
حدد وقت التواجد خلال **أيام الأسبوع** (الأحد-الخميس) في كل غرفة نوم من خلال تحديد عدد المستخدمين الحاضرين في الفراغ

	Number of users between 6 am - 10 am عدد المستخدمين بين 6 صباحا الى 10 صباحا	Number of users between 10 am - 2 pm عدد المستخدمين بين 10 صباحا الى 2 ظهرًا	Number of users between 2 pm - 6 pm عدد المستخدمين بين 2 ظهرًا الى 6 مساءً	Number of users between 6 pm - 10 pm عدد المستخدمين بين 6 مساءً الى 10 مساءً	Number of users between 10 pm - 2 am عدد المستخدمين بين 10 مساءً الى 2 صباحا	Number of users between 2 am - 6 am عدد المستخدمين بين 2 صباحا الى 6 صباحا
Main bedroom غرفة النوم الرئيسية						
Bedroom 2 غرفة نوم 2						
Bedroom 3 غرفة نوم 3						
Bedroom 4 غرفة نوم 4						
Bedroom 5 غرفة نوم 5						
Bedroom 6 غرفة نوم 6						
Bedroom 7 غرفة نوم 7						
Bedroom 8 غرفة نوم 8						

* Define the presence time during the **weekend** (Friday-Saturday) for each bedroom/s by determining the number of users present in the space.
حدد وقت التواجد خلال **عطلة نهاية الأسبوع** (الجمعة-السبت) في كل غرفة نوم من خلال تحديد عدد المستخدمين الحاضرين في الفراغ

	Number of users between 6 am - 10 am عدد المستخدمين بين 6 صباحًا الى 10 صباحًا	Number of users between 10 am - 2 pm عدد المستخدمين بين 10 صباحًا الى 2 ظهرًا	Number of users between 2 pm - 6 pm عدد المستخدمين بين 2 ظهرًا الى 6 مساءً	Number of users between 6 pm - 10 pm عدد المستخدمين بين 6 مساءً الى 10 مساءً	Number of users between 10 pm - 2 am عدد المستخدمين بين 10 مساءً الى 2 صباحًا	Number of users between 2 am - 6 am عدد المستخدمين بين 2 صباحًا الى 6 صباحًا
Main bedroom غرفة النوم الرئيسية	☐	☐	☐	☐	☐	☐
Bedroom 2 غرفة نوم 2	☐	☐	☐	☐	☐	☐
Bedroom 3 غرفة نوم 3	☐	☐	☐	☐	☐	☐
Bedroom 4 غرفة نوم 4	☐	☐	☐	☐	☐	☐
Bedroom 5 غرفة نوم 5	☐	☐	☐	☐	☐	☐
Bedroom 6 غرفة نوم 6	☐	☐	☐	☐	☐	☐
Bedroom 7 غرفة نوم 7	☐	☐	☐	☐	☐	☐
Bedroom 8 غرفة نوم 8	☐	☐	☐	☐	☐	☐

* How many living rooms are constantly used in your home?
كم عدد غرف المعيشة التي تستخدم باستمرار في منزلك؟

- ◯ 1
- ◯ 2
- ◯ 3

* Define the presence time during the **weekdays** (Sunday-Thursday) for each living room/s by determining the number of users present in the space.
حدد وقت التواجد خلال **أيام الأسبوع** (الأحد-الخميس) في كل غرفة معيشة من خلال تحديد عدد المستخدمين الحاضرين في الفراغ

	Number of users between 6 am - 10 am عدد المستخدمين بين 6 صباحًا الى 10 صباحًا	Number of users between 10 am - 2 pm عدد المستخدمين بين 10 صباحًا الى 2 ظهرًا	Number of users between 2 pm - 6 pm عدد المستخدمين بين 2 ظهرًا الى 6 مساءً	Number of users between 6 pm - 10 pm عدد المستخدمين بين 6 مساءً الى 10 مساءً	Number of users between 10 pm - 2 am عدد المستخدمين بين 10 مساءً الى 2 صباحًا	Number of users between 2 am - 6 am عدد المستخدمين بين 2 صباحًا الى 6 صباحًا
Main living room غرفة المعيشة الرئيسية	☐	☐	☐	☐	☐	☐
Living room 2 غرفة معيشة 2	☐	☐	☐	☐	☐	☐
Living room 3 غرفة معيشة 3	☐	☐	☐	☐	☐	☐

* Define the presence time during the **weekend** (Friday-Saturday) for each living room/s by determining the number of users present in the space.
حدد وقت التواجد خلال **عطلة نهاية الأسبوع** (الجمعة-السبت) في كل غرفة معيشة من خلال تحديد عدد المستخدمين الحاضرين في الفراغ

	Number of users between 6 am - 10 am عدد المستخدمين بين 6 صباحا الى 10 صباحا	Number of users between 10 am - 2 pm عدد المستخدمين بين 10 صباحا الى 2 ظهرًا	Number of users between 2 pm - 6 pm عدد المستخدمين بين 2 ظهرًا الى 6 مساءً	Number of users between 6 pm - 10 pm عدد المستخدمين بين 6 مساءً الى 10 مساءً	Number of users between 10 pm - 2 am عدد المستخدمين بين 10 مساءً الى 2 صباحا	Number of users between 2 am - 6 am عدد المستخدمين بين 2 صباحا الى 6 صباحا
Main living room غرفة المعيشة الرئيسية						
Living room 2 غرفة معيشة 2						
Living room 3 غرفة معيشة 3						

* How many kitchens does the house have?
كم عدد المطابخ في منزلك؟

- ◯ 1
- ◯ 2

* Define the presence time during the **weekdays** (Sunday-Thursday) for each kitchen/s by determining the number of users present in the space.
حدد وقت التواجد خلال **أيام الأسبوع** (الأحد-الخميس) في كل مطبخ من خلال تحديد عدد المستخدمين الحاضرين في الفراغ

	Number of users between 6 am - 10 am عدد المستخدمين بين 6 صباحا الى 10 صباحا	Number of users between 10 am - 2 pm عدد المستخدمين بين 10 صباحا الى 2 ظهرًا	Number of users between 2 pm - 6 pm عدد المستخدمين بين 2 ظهرًا الى 6 مساءً	Number of users between 6 pm - 10 pm عدد المستخدمين بين 6 مساءً الى 10 مساءً	Number of users between 10 pm - 2 am عدد المستخدمين بين 10 مساءً الى 2 صباحا	Number of users between 2 am - 6 am عدد المستخدمين بين 2 صباحا الى 6 صباحا
Main kitchen المطبخ الرئيسي						
Kitchen 2 مطبخ 2						

* Define the presence time during the **weekend** (Friday-Saturday) for each kitchen/s by determining the number of users present in the space.
حدد وقت التواجد خلال **عطلة نهاية الأسبوع** (الجمعة-السبت) في كل مطبخ من خلال تحديد عدد المستخدمين الحاضرين في الفراغ

	6 am - 10 am عدد المستخدمين بين 6 صباحا الى 10 صباحا	10 am - 2 pm عدد المستخدمين بين 10 صباحا الى 2 ظهرًا	Number of users between 2 pm - 6 pm عدد المستخدمين بين 2 ظهرًا الى 6 مساءً	Number of users between 6 pm - 10 pm عدد المستخدمين بين 6 مساءً الى 10 مساءً	Number of users between 10 pm - 2 am عدد المستخدمين بين 10 مساءً الى 2 صباحا	Number of users between 2 am - 6 am عدد المستخدمين بين 2 صباحا الى 6 صباحا
Main kitchen المطبخ الرئيسي						
Kitchen 2 مطبخ 2						

* How many guest rooms does the house have?
كم عدد غرف الضيوف في منزلك؟

- 1
- 2
- 3
- 4
- 5
- 6

* Do you have separate guest rooms for male and female in the house?
هل لديك غرف ضيافة منفصلة للنساء عن الرجال في المنزل؟

- Yes
  نعم
- No
  لا

* If Yes, How many guest rooms for male in your dwelling?
إذا نعم، كم عدد غرف الضيافة المخصصة للرجال في منزلك؟

- 1
- 2
- More than 2
  أكثر من 2

* Approximately, how many times have you welcomed male guests over the past twelve months?
كم مرة تقريبًا قمت باستقبال ضيوف من الرجال خلال الاثني عشر شهرًا الماضية؟

- Less than 5 times
  أقل من 5 مرات
- Between 5 to 10 times
  بين 5 إلى 10 مرات
- Between 10 to 20 times
  بين 10 إلى 20 مرة
- More than 20 times
  أكثر من 20 مرة

* How many guest rooms for female in your dwelling?
كم عدد غرف الضيافة المخصصة للنساء في منزلك؟

- 1
- 2
- More than 2
  أكثر من 2

* Approximately, how many times have you welcomed female guests over the past twelve months?
كم مرة تقريبًا قمت باستقبال ضيوف من النساء خلال الاثني عشر شهرًا الماضية؟

- ◯ Less than 5 times
  أقل من 5 مرات
- ◯ Between 5 to 10 times
  بين 5 إلى 10 مرات
- ◯ Between 10 to 20 times
  بين 10 إلى 20 مرة
- ◯ More than 20 times
  أكثر من 20 مرة

* What is the usual time to welcome guests in your home?
ما هو الوقت المعتاد لإستقبال الضيوف في منزلك؟

- ☐ In the weekdays during daytime
  في أيام الأسبوع خلال النهار
- ☐ In the weekdays during the evening
  في أيام الأسبوع خلال المساء
- ☐ In the weekend during daytime
  في عطلة نهاية الأسبوع خلال النهار
- ☐ In the weekend during the evening
  في عطلة نهاية الأسبوع خلال المساء

* On a typical visit, about how many hours do guests spend in your home?
في زيارة نموذجية، حوالي كم هي عدد الساعات التي يقضيها الضيوف في منزلك؟

- ◯ Less than Two Hours
  أقل من ساعتين
- ◯ Two to Four Hours
  من ساعتين إلى أربع ساعات
- ◯ Five to Eight Hours
  من خمسة إلى ثمانية ساعات
- ◯ More than Eight Hours
  أكثر من ثمانية ساعات

* Are there any other room/s used for different purposes than the above? Such as office, gaming room, etc.
هل هناك غرف أو غرفة أخرى تستخدم لأغراض مختلفة عن ما سبق؟ على سبيل المثال مكتب، غرفة لعب، إلخ

- ◯ Yes
  نعم
- ◯ No
  لا

If Yes, How many?
إذا كانت الإجابة نعم، كم عددها

* In the last 12 months, was the house left entirely vacant for a long time (one week or more)? e.g. because of holidays.
خلال الاثني عشر شهرًا الماضية، هل تم ترك المنزل شاغراً بالكامل لفترة طويلة (أسبوع أو أكثر)؟ بسبب عطلة مثلا

- ◯ Yes
  نعم
- ◯ No
  لا

* Approximately, how many days the house has been left empty?
كم يومًا تقريبًا تم ترك المنزل فارغًا؟

Number of days
عدد الايام

* How many bathrooms does the house have?
كم عدد دورات المياه في منزلك؟

- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ More than 5
  أكثر من 5

* Is the house equipped with solar panels (PV cells for electricity production)?
هل المنزل مزود بألواح شمسية (الخلايا الكهروضوئية لإنتاج الكهرباء)؟

- ◯ Yes
- ◯ No

If Yes, How many?
إذا كانت الإجابة نعم، كم عددها؟

Section Three:
A. Electricity Consumption Information

القسم الثالث :
أ. معلومات إستهلاك الكهرباء

* Do you check your use of electricity by taking the meter reading frequently?
هل تتحقق من استخدامك للكهرباء من خلال أخذ قراءة العداد بإستمرار؟

- ◯ Yes
  نعم
- ◯ No
  لا

If Yes, Please explain why
إذا كانت الإجابة بنعم ، يرجى توضيح السبب

* Are you responsible for paying the electricity bill in the house?
هل أنت المسؤول عن دفع فاتورة الكهرباء في المنزل؟

◯ Yes
نعم

◯ No
لا

If No, who is responsible?
إذا كانت الإجابة لا، من هو المسئول؟

* If No, Do you have any idea about the value of the electricity bill?
إذا لا، هل لديك أي فكرة عن قيمة فاتورة الكهرباء؟

◯ Yes
نعم

◯ No
لا

* In the last 12 months, how much is the average value of the electricity bill in SAR?
خلال الاثني عشر شهرًا الماضية، ما هو متوسط قيمة فاتورة الكهرباء بالريال السعودي؟

◯ Less than 500 Saudi Riyal
أقل من 500 ريال سعودي

◯ From 500 to 799 Saudi Riyal
من 500 إلى 799 ريال سعودي

◯ From 800 to 1199 Saudi Riyal
من 800 إلى 1199 ريال سعودي

◯ From 1200 to 1499 Saudi Riyal
من 1200 إلى 1499 ريال سعودي

◯ More than 1500 Saudi Riyal
أكثر من 1500 ريال سعودي

* How satisfied are you with the electricity bill value?
ما مدى رضاك عن قيمة فاتورة الكهرباء؟

◯ Very satisfied
راضي جدا

◯ Satisfied
راضٍ

◯ Neither satisfied nor dissatisfied
محايد

◯ Dissatisfied
غير راضٍ

◯ Very dissatisfied
مستاء جدًّا

* How do you feel about the electricity bill value?
كيف تشعر حيال قيمة فاتورة الكهرباء؟

- ◯ I think I am paying a fair amount
  أعتقد أنني أدفع مبلغًا معقولا
- ◯ I think I should pay a lower amount
  أعتقد أنني يجب أن أدفع مبلغ أقل
- ◯ I think I should pay a higher amount
  أعتقد أنني يجب أن أدفع مبلغ أعلى

Section Three:
B. Gas Consumption Information

القسم الرابع:
ب. معلومات إستهلاك الغاز

* Do you use gas in your home?
هل تستخدم الغاز في منزلك؟

- ◯ Yes
  نعم
- ◯ No
  لا

* What are the uses of gas in your home? Multiple marks are fine.
ما هي استخدامات الغاز في منزلك؟ يمكن اختيار أكثر من إجابة

- ☐ Cooking
  الطهي
- ☐ Cooling
  التبريد
- ☐ Generate electricity
  إنتاج الكهرباء
- ☐ Other - please specify
  غير ذلك - فضلا حدد

* How does the gas get supplied into the house?
كيف يتم توصيل الغاز إلى المنزل؟

- ◯ Gas cylinders
  أسطوانات الغاز
- ◯ Gas tanks
  خزانات الغاز

* How many gas cylinders do you consume monthly?
كم اسطوانة غاز تستهلك شهريا؟

- 1 cylinder - 11 kg
  أسطوانة واحدة - 11 كغم
- 2 cylinders - 11 kg
  اسطوانتين - 11 كغم
- 3 cylinders - 11 kg
  ثلاث اسطوانات - 11 كغم
- 4 cylinders - 11 kg
  أربع اسطوانات - 11 كغم
- 5 cylinders - 11 kg
  خمس اسطوانات - 11 كغم
- Other - please specify
  غير ذلك - فضلا حدد

* Do you have any idea of your monthly gas consumption?
هل لديك أي فكرة عن استهلاك الغاز الشهري؟

- Yes
  نعم
- No
  لا

* How much gas do you consume monthly? Give your best estimate.
ماهي كمية الغاز التي تستهلكها شهريا؟ أعطي أفضل تقدير

Gas consumption - m3
إستهلاك الغاز - بالمتر المكعب

Section Four:
Heating, Ventilation & Air Conditioning Systems

القسم الرابع :
أنظمة التدفئة والتهوية ومكيفات الهواء

* Evaluate the use of the following ventilation systems if space is occupied during the **Summer** season.
قيم استخدام أنظمة التهوية التالية إذا كان الفراغ مستخدماً خلال **فصل الصيف**

	Never لا تستخدم أبدًا	Rarely نادرة الإستخدام	Sometimes بعض الأوقات	Usually عادة ما تستخدم	Always دائمة الإستخدام
Air Conditioning مكيفات الهواء	○	○	○	○	○
Natural Ventilation التهوية الطبيعية باستخدام الأبواب والشبابيك	○	○	○	○	○
Electric Fans or Evaporative Cooling مراوح كهربائية أو مكيفات صحراوية	○	○	○	○	○

* What type of air conditioners do you utilise for space cooling in the house? Check all that applies
ما نوع مكيفات الهواء المستخدمة لتبريد الفراغات في المنزل؟ حدد كل ما ينطبق

- [ ] Window Air Conditioners
  مكيفات الشباك
- [ ] Ductless, Mini-split Air Conditioners
  مكيفات الاسبليت
- [ ] Central Air Conditioning
  مكيفات مركزية
- [ ] Other - please specify
  غير ذلك - فضلا حدد

* Does each room in the house contain an air conditioner?
هل تحتوي كل غرفة في المنزل على مكيف هواء؟

- ( ) Yes
  نعم
- ( ) No
  لا

If No, which room?
إذا كانت الإجابة لا ، أي غرفة؟

* How do you control the interior temperature at home? Choose all that apply.
كيف يتم التحكم في درجة الحرارة الداخلية للمنزل؟ اختر جميع ما ينطبق

- [ ] Manually
  يدويًا
- [ ] Automatically
  أوتوماتيكيًا
- [ ] Remote Control
  بواسطة جهاز التحكم
- [ ] Other - please specify
  غير ذلك - فضلا حدد

* Do you leave the air conditions in operation if the space or room not in use? e.g. ventilating guest rooms. Why?
هل تترك مكيفات الهواء قيد التشغيل إذا كان الفراغ أو الغرفة غير مستخدمة؟ لتهوية غرف الضيوف مثلا. لماذا؟

- ( ) Yes
  نعم
- ( ) No
  لا
- ( ) Sometimes
  بعض الأوقات

Please explain why.
يرجى ذكر السبب

* Evaluate the use of the following ventilation systems if space is occupied during the **Winter** season.
قيم استخدام أنظمة التهوية التالية إذا كان الفراغ مستخدماً خلال **فصل الشتاء**

	Never لا تستخدم أبدًا	Rarely نادرة الإستخدام	Sometimes بعض الأوقات	Usually عادة ما تستخدم	Always دائمة الإستخدام
Air Conditioning مكيفات الهواء	○	○	○	○	○
Natural Ventilation التهوية الطبيعية باستخدام الأبواب والشبابيك	○	○	○	○	○
Electric Fans or Evaporative Cooling مراوح كهربائية أو مكيفات صحراوية	○	○	○	○	○

* If the temperature drops down during Winter season, will you keep using air conditioners in used spaces or rooms? Why?
إذا انخفضت درجة الحرارة خلال فصل الشتاء، فهل ستستمر في استخدام مكيفات الهواء في الفراغات أو الغرف المستخدمة؟ لماذا

- ○ Yes, Always
  نعم، دائمًا
- ○ Yes, during the day only
  نعم، خلال النهار فقط
- ○ Yes, during the evening only
  نعم، خلال المساء فقط
- ○ No, not at all
  لا، أبدًا

Please give the reason/s
يرجى تقديم الاسباب

* Do you think empowering modern technologies to control the air conditioners and temperature in the house are effective in reducing energy consumption? Such as using smartphones to turn on/off the air conditioners.
هل تعتقد أن تمكين التقنيات الحديثة للتحكم في مكيفات الهواء ودرجة الحرارة في المنزل فعالة في تخفيض استهلاك الطاقة؟ مثل استخدام الهواتف الذكية لتشغيل / إيقاف مكيفات الهواء

- ○ Yes
  نعم
- ○ No
  لا

Please explain why.
يرجى ذكر السبب

* What is the used heating system in your dwelling? Check all that applies
ما هو نظام التدفئة المستخدم في مسكنك؟ أختر جميع ما ينطبق

- [ ] Air conditions
أجهزة التكييف
- [ ] Electric heaters
الدفايات الكهربائية
- [ ] No need for heating system
لانحتاج إلى نظام تدفئة
- [ ] Other - please specify
غير ذلك - فضلا حدد

* Why do you **open** the windows in general? Check all that applies
لماذا تقوم **بفتح** النوافذ بشكل عام؟ أختر جميع ماينطبق

- [ ] To get fresh air
للحصول على الهواء النقي
- [ ] To adjust the temperature
لضبط درجة الحرارة
- [ ] To dissipate dirty air - e.g. smoke or cooking smell
لتنقية الهواء القذر - مثل رائحة الدخان أو الطهي
- [ ] Other - please specify
غير ذلك - فضلا حدد

* Why do you **close** the windows in general? Check all that applies
لماذا تقوم **بإغلاق** النوافذ بشكل عام؟ أختر جميع ماينطبق

- [ ] To block sounds from outside
لحجب الأصوات من الخارج
- [ ] To block smells from outside
لمنع الروائح من الخارج
- [ ] For safety reasons
لأسباب تتعلق بالسلامة
- [ ] To prevent the entry of dust
لمنع دخول الغبار
- [ ] To prevent the hot airflow
لمنع تدفق الهواء الساخن
- [ ] Other - please specify
غير ذلك - فضلا حدد

Section Five:
The Use of Lighting & Appliances

القسم الخامس:
استخدام الإضاءة والأجهزة المنزلية

Mark which and how much of the following appliances is present at your home, and how many hours a day **or** a week these appliances are turned on. e.g. you have two TV's, one is turned on 10 hours a day, the other 3 hours a day, totally this is 13 hours a day.

حدد عدد الأجهزة ونوعها الموجودة في منزلك وقم ابضا بتحديد إجمالي ساعات التشغيل اليومية **أو** الأسبوعية لهذه الأجهزة **حسب الإستخدام**. على سبيل المثال: لديك تلفزيونان، أحدهما يعمل على مدار ساعة في اليوم، والآخر 10 ساعات في اليوم، المجموع 13 ساعات في اليوم 3

ملاحظة

في حال عدم إستخدام الجهاز يمكنك ترك الخانات التي أمامها خالية

	Number العدد	Hours of operation a day إجمالي ساعات التشغيل اليومية	Hours of operation a week اجمالي ساعات التشغيل الأسبوعية	Place of Use مكان الإستخدام
Television sets أجهزة التلفزيون				
Broadband router جهاز الإنترنت				
Desktop Computer جهاز الكمبيوتر المكتبي				
Refrigerator with Freezer ثلاجة مزودة بمجمد				
Freezer مجمد				
Washing Machine غسالة ملابس				
Video game consoles ألعاب الفيديو				
Dishwasher غسالة الصحون				
Iron مكواة				

	Number العدد	Hours of operation a day إجمالي ساعات التشغيل اليومية	Hours of operation a week إجمالي ساعات التشغيل الأسبوعية	Place of Use مكان الإستخدام
Stereo and/or radio جهاز التسجيل الصوتي أو الراديو				
Tumble Dryer مجففة ملابس				
Home cinema set المسرح المنزلي				
DVD player مشغل الاسطوانات				
Video recorder آلة تسجيل الفيديو				
Wireless home phone هاتف المنزل اللاسلكي				
Coffee maker آلة تحضير القهوة				
Electric kettle غلاية كهربائية				
Toaster محمصة الخبز الكهربائية				
Electric grill or oven شواية كهربائية				
Microwave ميكروويف				
Electric cooker or oven فرن كهربائي				
Cooker hood جهاز شفط الهواء في المطبخ				
Hair drier مجفف الشعر				
Hair straightener مكواة الشعر				

	Number العدد	Hours of operation a day إجمالي ساعات التشغيل اليومية	Hours of operation a week إجمالي ساعات التشغيل الأسبوعية	Place of Use مكان الإستخدام
Vacuum مكنسة كهربائية				
Shaver آلة الحلاقة				
Extractor fan مروحة كهربائية				
Water heater سخان الماء				
Water-cooler مبرد مياه				
Juice blender خلاط العصير				
Dough mixer خلاط العجين				

* How many appliances with chargers or batteries do you charge regularly at home? Consider mobile phones, cameras, laptops, loose batteries, and so on.
كم عدد الأجهزة المزودة بشواحن أو بطاريات والتي يتطلب شحنها بانتظام في المنزل؟ على سبيل المثال الهواتف المحمولة والكاميرات وأجهزة الكمبيوتر المحمولة والبطاريات السائبة وما إلى ذلك

	Number العدد	Charging hours a day إجمالي ساعات الشحن في اليوم
Appliances with chargers or batteries الأجهزة المزودة بشواحن أو بطاريات		

* Which type of light bulbs do you use at home? Check all that applies.
ما نوع المصابيح الكهربائية التي تستخدمها في المنزل؟ أختر جميع ماينطبق

- [ ] LED Light
ال اي دي موفرة للطاقة
- [ ] Halogen
هالوجين
- [ ] Fluorescent
فلورسنت
- [ ] I have no idea
ليس لدي أي فكرة

* Do you leave the lights in operation while you are not in space? Why?
هل تترك الأضواء تعمل أثناء عدم تواجدك في الفراغ؟ لماذا ا؟

- Yes
  نعم
- No
  لا
- Sometimes
  بعض الأوقات

Please explain why.
يرجى ذكر السبب

* Do you deliberately leave lights turned on in the case of absence from home? Why?
هل تتعمد ترك الأنوار قيد التشغيل في حالة الغياب عن المنزل؟ لماذا؟

- Yes
  نعم
- No
  لا
- Sometimes
  بعض الأوقات

Please explain why.
يرجى ذكر السبب

* Will you be interested in installing motion sensors to control the light in your house?
هل ستكون مهتمًا بتثبيت أجهزة استشعار الحركة للتحكم في الإضاءة بمنزلك؟

- Yes
  نعم
- No
  لا

Please explain why.
يرجى ذكر السبب

* How many hours a day do the lamps remain in use in bedrooms?
بمعدل كم ساعة في اليوم تظل المصابيح قيد الاستخدام في غرف النوم؟

- Less than 2 hours
  أقل من ساعتين
- Between 2 to 4 hours
  من 2 إلى 4 ساعات
- Between 4 - 6 hours
  من 4 إلى 6 ساعات
- More than 6 hours
  أكثر من 6 ساعات

* How many hours a day do the lamps remain in use in living rooms?
بمعدل كم ساعة في اليوم تظل المصابيح قيد الاستخدام في غرف المعيشة؟

- Less than 2 hours
  أقل من ساعتين
- Between 2 to 4 hours
  من 2 إلى 4 ساعات
- Between 4 - 6 hours
  من 4 إلى 6 ساعات
- More than 6 hours
  أكثر من 6 ساعات

* How many hours a day do the lamps remain in use in kitchens?
بمعدل كم ساعة في اليوم تظل المصابيح قيد الاستخدام في المطابخ؟

- Less than 2 hours
  أقل من ساعتين
- Between 2 to 4 hours
  من 2 إلى 4 ساعات
- Between 4 - 6 hours
  من 4 إلى 6 ساعات
- More than 6 hours
  أكثر من 6 ساعات

* How many hours a day do the lamps remain in use in bathrooms?
بمعدل كم ساعة في اليوم تظل المصابيح قيد الاستخدام في دورات المياه؟

- Less than 2 hours
  أقل من ساعتين
- Between 2 to 4 hours
  من 2 إلى 4 ساعات
- Between 4 - 6 hours
  من 4 إلى 6 ساعات
- Always in use
  دائمة الاستخدام

Section Six:
Additional Information

القسم السادس:
معلومات إضافية

* How do you evaluate the following questions? 1 is the lowest - 5 is the highest
كيف تقيم الأسئلة التالية؟ 1 الأقل - 5 الأعلى

	مستاء جدًا 1	غير راضي 2	محايد 3	راضي 4	راضي تمامًا 5
How satisfied are you with the indoor climate (temperature distribution, humidity)? ما مدى رضاك عن المناخ الداخلي (توزيع درجة الحرارة ، الرطوبة)؟	○	○	○	○	○
How satisfied are you with indoor air quality? ما مدى رضاك عن جودة الهواء الداخلي؟	○	○	○	○	○
How satisfied are you with the level of thermal insulation in your house? ما مدى رضاك عن مستوى العزل الحراري في منزلك؟	○	○	○	○	○
How comfortable do you feel in your house? ما مدى شعورك بالراحة في منزلك؟	○	○	○	○	○

* In recent years, has your behaviour changed towards consuming energy? Why?
في السنوات الأخيرة ، هل تغير سلوكك نحو استهلاك الطاقة؟ لماذا ا؟

○ Yes
نعم

○ No
لا

Please explain why.
يرجى توضيح السبب

* What do you think about the general rate of energy consumption in your house?
ما رأيك في المعدل العام لاستهلاك الطاقة في منزلك؟

- Above average
  فوق المتوسط
- Average
  متوسط
- Below average
  أقل من المتوسط

* Do you have any concerns about energy consumption at your home? Why?
هل لديك أي مخاوف بشأن استهلاك الطاقة في منزلك؟ ولماذا؟

- Yes
  نعم
- No
  لا

Please explain why.
يرجى ذكر السبب

* Do you wish to be contacted for more involvement in the research to clarify and understand the impact of the occupants' behaviour on energy consumption in domestic buildings?
هل ترغب في أن يتم الاتصال بك لمزيد من المشاركة في البحث لتوضيح وفهم تأثير سلوك السكان على استهلاك الطاقة في المباني السكنية؟

- Yes
  نعم
- No
  لا

* Please provide the information below for future communication.
يرجى تقديم المعلومات أدناه للتواصل مستقبلا.

Name
الاسم

Email Address
البريد الإلكتروني

Mobile Number
رقم الجوال

In the end, I would like to thank you for your time and effort in participating in this questionnaire which will contribute to revealing the real effect of occupant behaviour on energy consumption in Saudi residential buildings, especially in Makkah.

في النهاية ، أود أن أشكرك على وقتك وجهدك في المشاركة في هذا الاستبيان والذي سيساهم في الكشف عن التأثير الحقيقي لسلوك السكان على استهلاك الطاقة في المباني السكنية السعودية ، وخاصة في مكة المكرمة