The Impact of Construction and Building Materials on Energy Consumption on Saudi Residential Buildings

A thesis submitted to the University of Heriot-Watt for the degree of Doctor of Philosophy in Energy, Geoscience, Infrastructure and Society

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Abstract

As a result of increasing population and buildings construction in Saudi Arabia, the demand for electricity is growing rapidly. There should be a greater focus on buildings in the kingdom and several methods should be applied in order to reduce energy consumption and create a lower carbon economy as residential buildings account for about 70 percent of the total consumption. Saudi Arabia therefore urgently needs to develop residential buildings which use less energy and are more environmentally-friendly.

This study investigates the recent situation of Saudi residential buildings in terms of energy and building materials, using case studies. The main aim of this study is to identify suitable strategies and propose a number of recommendations that are useful in developing residential buildings in the Kingdom of Saudi Arabia.

This paper shows the importance of selecting the right, locally available, construction materials for the external wall and thermal insulation in reducing energy consumption for the cooling load, by 59% after using the most appropriate construction materials for Saudi climate. Several methods were used in this research including IES energy simulation software in order to compare the most common external walls in the kingdom in terms of energy consumption and cooling load. Then, adding and selecting the right place for 0.50 m of polyurethane thermal insulation to the selected external wall to achieve the maximum reduction of cooling load.

It uses the example of a typical Saudi house design provided by the Saudi ministry of housing in three main cities in the kingdom: Jeddah, Riyadh and Dammam. Furthermore, the paper discusses the challenges facing the kingdom of Saudi Arabia in recent years and those of the future, such as a lack of the awareness amongst the Saudi population, and a lack of building standards and regulations.

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List of Abbreviations

3D	Three- Dimensional
20-20-20	Climate and Energy Target for 2020 by EU's
A/C	Air Conditioning
ACE	Annual International Conference in Architectural and Civil Engineering
AHU	Air Handling Unit
BREEAM	Building Research Establishment Environmental Assessment Methodology
BSRIA	Building Services Research and Information Association
cm	Centimetre
cm2	Square Centimetre
CO_2	Carbon Dioxide
EAA	Electrical Affair Agency
ebpd	Equivalent Barrels Per Day
est	Estimated
EU	European Union
GBP	Great Britain Pound
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GHGs	Green House Gas
GOSI	General Organisation for Social Insurance
GW	Gigawatt
GWh	Gigawatt Hour
HCFC	Hydrochloroflurorcarbon
HVAC	Heating, Ventilation, Air Conditioning
I-code	International Code Council
IES	Integrated Environmental Solutions
IT	Information Technology
KACST	King Abdullah City for Science and Technology
KSA	Kingdom of Saudi Arabia
kW	Kilowatt
LEED	Leadership in Energy and Environmental Design

m	Meter
mm	Millimetre
MOU	Memorandum of Understanding/ agreements
MW	Megawatt
NBSLD	National Bureau of Standards Load Determination
NEEP	National Energy Efficiency Program
OAPEC	Organisation of Arab Petroleum Exporting Countries
PV	Photovoltaics
SAEEC	Saudi Arabia Energy Efficiency Centre
SASO	Saudi Arabian Standard Organisation
SBC	Saudi Building Code
SBCNC	Saudi Building Code National Committee
SCECO	Saudi Consolidated Electric Company
SEC	Saudi Electricity Company
sq km	Square Kilometre
sq mi	Square Mile
SR	Saudi Riyal
U-value	Measure of Heat Loss
UAE	United Arab Emirates
UK	United Kingdom
US	United States
USD	United States Dollar
VAV	Variable Air Volume
VRF	Variable Refrigerant Flow
WWR	Window to Wall Ratio

Published Papers

The following papers have been published as a result of this research:

Harris, D. J., Lasker, W, (2015). The Impact of Construction and Building Materials on Saudi Residential Buildings. *In 3rd Annual International Conference in Architecture and Civil Engineering.* Singapore, 13-14 April 2015. Singapore: ACE. 77-85.

Harris, D. J., Lasker, W. J., and El Bakkush, A. (2015). On-site measurements of thermal performance of a residential building in a hot-arid region. International Journal for Housing Science and its Applications, 39(3).

The following papers (as a result of this research) are in the process of submission to 9th Saudi Student Conference from 13-14 of February 2016:

Lasker W. (2015) The energy simulation analysis and results for a typical residential building in Saudi Arabia. In 9th Saudi Student Conference. The ICC, Birmingham, 13-14 Feb 2016. Birmingham: University of Birmingham.

Chapter 1

Background and Introduction Chapter

1.1Background of Saudi Arabia

1.1.1 Country Profile

Saudi Arabia occupies a territory of 2,149,690 sq. km. (829,995 sq. mi.), which equates to just over one-fifth of the size of the USA. The capital city is Riyadh, with approximately 4.7 million inhabitants. Other main cities include Jeddah (with a population of around 3.2 million), Makkah (with a population of around 1.5 million), and Dammam/Khobar/Dhahran (with approximately 1.6 million inhabitants).

The climate of Saudi Arabia may be described as arid with extreme fluctuations in temperature being exhibited in the interior. Likewise, humidity and high temperatures are also common along the coastal regions (Ashwan,Abdul Salam and Mouselhy 2012).

1.1.2 People

The total population amounted to an estimated 30,770,375 inhabitants in 2014. (Central Department of Statistics and Information, 2015). The following figure illustrates the Saudi population number and the expected growth from 2010 until 2020 (Statista 2015).

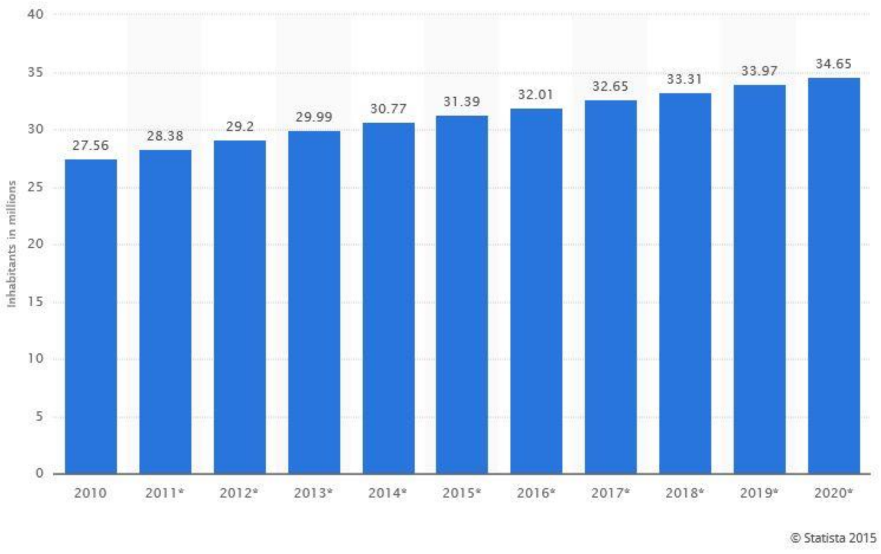

Figure 1.1: The Saudi population number and the expected growth from 2010 until 2020. (Statista 2015).

The widely used language of communication is Arabic and Islam is the common religion. The distribution of ethnic groups includes Afro-Asian that account for 10 percent of the native population and Arab that account for 90 percent of the native population. The rate of population growth based on a 2011 estimation is around 1.536 percent and the people's nationality is Saudi (Saudi Arabian). The level of literacy is about 78.8 percent (female 70.8 percent, male 84.7 percent). With regard to health, the rate of mortality amongst infants based on 2011 estimation is 16.16 deaths out of 1000 live births. The life expectancy of women is higher at 76 years compared to that of men at 72 years. The labour force based on 2011 estimation consists of 7.3 million people, 80 percent are expatriates in several sectors that include agriculture (6.7 percent), services (private and government) (71.9 percent) and industry (21.4 percent) (Ashwan, Abdul Salam and Mouselhy 2012).

1.1.3 Government

Saudi Arabia has a monarchical system of government consisting of a Ministerial Council and a Shura (Consultative Council). Unification took place on 23 September 1932. The Saudi constitution is mainly made up of Basic Law, Sharia and the Holy Quran (governed in accordance to Islamic Law). Saudi Arabia has three arms of government namely the Executive that consists of an Executive Emir (King) who acts as the head of state and government and rules using the title of "Custodian of the Two Holy Mosques"; the Legislature consists of a Shura (Consultative) Council having advisory powers and it was constituted in September 1993 and the Judiciary that consists of Appellate and First Instance Islamic Courts, Supreme Judicial Council and the Judicial Supreme Court. Administrative divisions consist of 13 provinces. Political parties are outlawed and the government does not recognise them (Youn Globe 2012).

1.1.4 History

Large swathes of the Saudi Arabian Peninsula have historically experienced limited settlement due to harsh climate, save for a thin strip on the coastal region as well as oases and large cities. Because of this, people from diverse cultures that inhabited the Peninsula did so for a period of more than 5,000 years. To contextualise this, the Dilmun culture, around the Gulf coast region, lived alongside Egyptians and Sumerians, and many global empires interacted with the peninsula states that lay on the major trade routes through trade (The Royal Embassy of Saudi Arabia in Washington 2012). Central Arabia is believed to be the cradle of Saudi state; an event that took place in 1750. In this period, a traditional clan member, Muhammad bin Saud joined Mohammad Abd Al-Wahhab and their union culminated in the formation of a political party. For a period spanning over 150 years, the political union experienced ups and downs that resulted in different rulers ruling Saudi Arabia. The modern day Saudi Arabia owes its origin to the late King Abdul Aziz Al Saud and no major changes have been made to the structure of government he established (The Royal Embassy of Saudi Arabia in Washington 2012).

1.1.5 Economy

Based on 2010 estimate, Saudi's gross domestic product (GDP) stands at 622 billion dollars, rate of annual growth is 3.7 percent whereas the Per Capita GDP stands at 24, 200 dollars. Saudi Arabia is endowed with many natural resources such as copper, silver, zinc, tungsten, phosphate, iron, coal, bauxite, uranium, gold and hydrocarbons (Saudi Arabian Monetary Agency 2010). Agricultural commodities produced in Saudi Arabia include vegetables, livestock, grains and dates. Arable land accounts for 1.76 percent in Saudi Arabia. Major industries include energy, fertiliser, cement, petrochemicals and petroleum. Based on 2010 estimates, Saudi exported petroleum products and petroleum amounting to about 238 billion dollars. On the other hand, Saudi imports amounts to 88 billion dollars mainly from products, processed food, textiles, clothing, transportation equipment and manufactured goods. Key trading partners of Saudi Arabia include the USA, the UK, Taiwan, South Korea, Singapore, Japan, India, Germany, France and China (YounGlobe 2012).

It is indisputable that, in relation to the economy of Saudi Arabia, the defining moment in the history of the country was the oil discovery. Discovery of oil in the KSA occurred in 1930 and is attributed to US geologists, even though large scale oil production commenced after World War 2. It is clear that Saudi economy has experienced rapid urbanisation and industrialisation because of oil wealth; additionally, it has propelled the country to new heights in technological advancement (Michigan State University 2012). Because of its abundant petroleum wealth, the KSA has strived to implement several plans, which are aimed at allocating income from crude oil sales for transformation of other sectors of the economy. Such an initiative seeks to divert income from oil sales to other sectors to enable them become profitable. Although the living standards amongst ordinary Saudis has improved thanks to oil wealth, the pressures from a rapid population increase have to a certain extent reduced the benefits that such initiatives could have generated. Similarly, the overreliance on petroleum income has undermined economy sectors, which might have attained rapid growth rate, if oil monopoly would not have been encouraged (Michigan State University 2012).

In addition, private businesses were encouraged through various means, for instance, the government increased grants to small and medium enterprises and businesses. Additionally, the government encouraged foreign investments through joint ventures, thus leading to huge investment in private and public companies in Saudi Arabia. Consequently, rapid growth was witnessed in the private sector, with about 70 percent of non-petrol GDP being achieved. Although the Saudi economy relied heavily on trade, there was a huge private investment in construction firms, banking, agriculture and industry (Michigan State University 2012).

1.2 Introduction and Justification for the Research

The initial aim of buildings entails fulfilling humans' safety needs: houses protect people from dangers such as wild animals and severe weather. Several shelters (houses, tents and huts) have enabled individuals to survive in diverse geographic and climatic situations. Different kinds of energy-efficient shelters have emerged globally in reaction to local climatic conditions (Husladen, Saldanha and Liedl 2006).

According to Husladen, Saldanha and Liedl (2006), buildings reflect the spirit that influenced their construction, and are an expression of the society's contemporary culture.

The extensive usage of "fossil fuels" has resulted in severe environmental conditions such as climate change and global warming, therefore, making it necessary to cut down fossil fuel consumption in future (Harris 2012).

Because numerous environmental problems (for instance, depletion of resources, environmental degradation) emanate from construction, the building sector plays a critical role in the achievement of a country's sustainable development. Buildings require raw materials and energy, and they are responsible for harmful gas emissions and waste (Alrashed and Asif 2014), thus contributing considerably to GHGs (global greenhouse gases) emission. Statistics released by the UK Government show that buildings account for 40 percent of the CO_2 (carbon dioxide) emissions and energy consumed nationally (Alrashed and Asif 2014).

Similarly, in the EU region the total energy consumed in buildings stands at 40 percent (Alrashed and Asif 2014). In view of this, the EU has come up with 20-20-20 targets that are aimed at reducing greenhouse gas emissions by 20 percent in 2020, in contrast to the levels attained in 1990. This implies an increment in the EU's renewable sources consumption by 20 percent, and would culminate in an improvement of about 20 percent in EU's energy efficiency (Alrashed and Asif 2014).

The scenario is replicated in the United States, where the USGBC (United States Green Building Council) statistics indicate that residential and commercial building industry in the US accounts for 39 percent of annual CO_2 emissions, the highest figures from any industry within the country (Alrashed and Asif 2014).

The environment suffers indirectly and directly from the impacts emanating from buildings' function and construction. According to Alrashed and Asif (2014), the environmental impact from the building sector every year encompasses 42 percent (energy use), 40 percent (atmospheric emissions), 30 percent (raw material usage), 25 percent (solid waste), 25 percent (water use) 20 percent (water effluents) 12 percent (land use) and 13 percent (other emissions). With regard to the considerable increase in new constructions coupled with the shortcomings for existing global building stock, perceiving a business in the usual context, the GHGs emission level from buildings would maintain a rising trend in future (Alrashed and Asif 2014). For achievement of desired goals of reducing GHG emissions in the building industry, it is necessary to come up with a strong and concentrated mechanism of tackling the issue and this calls for promotion of buildings that are energy efficient and sustainable. A deeper understanding on the existing scenario as well as future patterns in the industry is essential in ensuring that proper mechanisms are formulated to promote usage of smart energy buildings (Alrashed and Asif 2014).

Poor management of resources such as natural water and fossil fuels could lead to scarcity in future. A huge population is relocating from rural to urban settings, thus necessitating more construction that puts pressure on existing infrastructure and eventually increases natural resource usage, which in turn increase GHG emissions (Al Surf, Susilawati and Trigunarsyah 2014).

The issue of energy-based research has elicited significant interest, particularly with regard to the economy and energy saving. In the past 2 decades, an overwhelming understanding on the way building performance contributed considerably to severe environmental effects has existed. Buildings contribute 50 percent of carbon dioxide and 70 percent of sulphur oxide emissions (Aldossary, Rezgui and Kwan 2014).

Concerning the increased environmental pressures, the construction sector, from a global perspective consumed 25 percent of forest timber, 16 percent of freshwater and 40 percent of energy. This has compelled developed countries to come up with ways of designing environmental-friendly and sustainable buildings. Currently, the focus of architects has been on the buildings' design phase, the intention being to come up with economical buildings in terms of energy consumption (hot water supply, lighting, heating and cooling) (Aldossary, Rezgui and Kwan 2014). However, to much focus on environmental-friendly construction, with energy efficiency could compromise other architectural aspects such as operational or visual (Aldossary, Rezgui and Kwan 2014).

The magnitude of the issue is contained in the Ministry of Water and Electricity report, which suggests that electricity consumption in residential buildings in Saudi Arabia, is 52% percent. Because of the humid climatic conditions, Saudi Arabians require huge amounts of energy for air conditioners used to cool their homes (Aldossary, Rezgui and Kwan 2014).

The construction of energy-efficient buildings in Saudi Arabia is critical for preservation of resources for posterity, both internationally and locally. A risk looms for shortage of important resources such as natural water and fossil fuels in future. Electricity supply to Saudi households is a major problem, with projections that by 2050 the demand would be 120 GW; this translates to about 8 million oil barrels every day to meet the rising demand (Al Surf, Susilawati and Trigunarsyah 2014).

Saudi buildings' energy demands are high, particularly in summer because of high temperatures, even at night; the entire country requires power for warming the houses. In 2010, Saudi buildings accounted for about 65 percent of the overall electricity consumption; this translates to 47 percent above the worldwide average for the period (Alaidroos and Krarti 2015). Saudi Arabia is experiencing an increase in population (with a rate of 1.54 percent annually); this growth is responsible for the increase in the energy consumed in the kingdom, 52 percent of the overall consumption is utilised in residential buildings. Additionally, the establishment of 2.32 million housing units is expected by 2020; this will further increase the demand for electricity by residential buildings (Alaidroos and Krarti 2015). In contrast, lack of knowledge coupled with Saudis behaviour emerges as another factor that causes residential buildings to use energy excessively. Regarding oil, over more than 25 percent of produced oil is used in Saudi Arabia, with a significant quantity being utilised in the generation of electricity. Because

Saudi economy is largely dependent on revenue from exported oil, a prolonged rise in the consumption of local energy would put the country's capacity of relying on oil export incomes at stake (Alaidroos and Krarti 2015). Research indicates that when energy-efficient mechanisms are considered for Saudis upcoming buildings, a 10 percent reduction would be experienced. Moreover, decreasing the air conditioning needs could result in equal investment returns, enough for setting a 500 megawatts power facility; this would significantly mitigate environmental pollution (Alaidroos and Krarti 2015).

The SBC (Saudi Building Code) is the institution that provides required building standards, technical specifications alongside regulations of construction in Saudi Arabia in relation to "public safety". However, in the past, SBC did not consider the aspect of a building's energy-efficiency performance because the consumption of energy was not high and the peak loads were not threatening. The latest rapid increase in population and economic growth has pushed up the demand for electricity in Saudi Arabia, both from the industrial and building sectors, and lack of energy –efficiency regulations and standards has further contributed to the rise in electricity consumption in Saudi Arabia in the past decade. In view of this, it is necessary to review the SBC by formulating an energy code as well as setting minimum requirements to be followed in the construction of buildings and encouraging the development of energy-efficient performance buildings (Alaidroos and Krarti 2015).

The research presents a case study for a Saudi typical villa "residential building", which would be investigated through IES (Integrated Environmental Solution) software in three major regions of KSA they include Dammam, Jeddah and Riyadh. The simulation would indicate whether the materials used in construction have a huge effect on residential buildings in Saudi Arabia and might play a critical role of reducing the cooling burden; this makes it more environmental-friendly.

1.3 Hypothesis

The construction type and materials for the building's external envelope significantly affect the consumption of energy for emerging residential houses in KSA, and huge air-conditioning energy savings could be achieved by applying suitable thermal insulation and construction materials to the wall.

1.4 Research Questions

- What is the energy production and consumption situation in Saudi Arabia?
- Where is most energy consumed locally?
- Which type of buildings consumed the most energy?
- What are the causes for high demand/ consumption in Saudi buildings?
- What strategies offer the best possibilities for energy saving?

1.5 Aims and Objectives

1. Determine where most energy is used in Saudi residential buildings.
2. Investigate the main reasons behind increasing energy consumption in Saudi residential buildings.
3. Identify aspects of the design and construction that affect energy consumption in Saudi residential buildings and lead to substantial use of air conditioning,
4. Understand the resident behaviour in Saudi homes and investigate their awareness regarding energy saving/consumption in homes.
5. Ascertain whether there is scope for making significant changes in new or existing buildings to reduce energy consumption.
6. Investigate what methods are available for reducing energy consumption in residential buildings and minimising the impact on the environment.
7. Develop guidelines for appropriate materials and construction type for typical Saudi residential buildings, which enable them to consume minimum energy.

1.6 Research Problems and Limitations

The research might face several limitations, as follows:

1- The difficulties of getting some of the information required from a set of companies due to privacy and security considerations.

2- The difficulties of getting information from a set of experts who are working in government companies, where some may consider the information needed as being exclusively for official proposes.

3- The university's ability to provide a permanent desk or private PC/Laptop. Hot/ sharing desk is not ideal for this type of study.

4- Getting the building simulation software from the university at the required time

5- The problem of learning simulation programs to analyse the building energy and materials, where these programs require enough time and skills as these programs are very important to achieve the main target of this research.

1.7 The relationships between the Thesis Objectives and Methodologies

The following table presents how to achieve the objectives by adopting appropriate methods.

Table 1.1: The relationship between the Thesis Objectives and Methodologies.

Objective	Method
Identify the regulations governing building design, particularly related to energy use and building materials, in Saudi Arabia, and whether specific guidelines exist for the design of green buildings in Saudi Arabia.	Secondary data collection.
Investigate the main reasons behind increasing energy consumption in the Saudi residential buildings.	Primary and secondary data collection through the literature review and interviews.
Understanding the weaknesses of building materials and all issues regarding Saudi residential buildings: substantial use of air conditioning	Primary and secondary data collection through the literature review and survey.
Investigate the Saudis' behaviour and awareness regarding energy saving/ consumption in homes.	Primary and secondary data collection through the literature review and survey.
Ascertain whether there is scope for making significant changes in new or existing buildings.	Computer simulation for energy consumption of a specific model of Saudi residential building, using IES simulation software.
Investigate what methods are available for reducing energy consumption in residential buildings and minimising the impact on the environment.	Computer simulation for energy consumption of a specific model of Saudi residential building, using IES simulation software.
Investigate the effect on energy consumption of changing the outer envelope of building construction materials.	Computer simulation for energy consumption of a specific model of Saudi residential building, using IES simulation software.
Develop guidelines for typical Saudi residential buildings, which consume minimum energy and adopt appropriate materials and construction type.	Computer simulation for energy consumption of a specific model of Saudi residential building, using IES simulation software.

1.8 Work that has been conducted in the Thesis

This section explains the work, survey, meetings and interviews that have been undertaken from the beginning of the PhD study period. The work and activities will be described in order to give a brief explanation and a clear understanding of the stages of the study.

At the beginning of the study, the research area and questions were identified. Then the research background, overview of Saudi Arabia and the buildings in the Kingdom was detailed. This was followed by a comprehensive literature review of energy, building regulations, building materials and building construction. Subsequently, multiple visits were made to the Kingdom of Saudi Arabia (the first visit was from 04-06-2012 until 31-08-2012; the next visit was from 01-06-2013 until 31-08-2013). The purposes of these visits were to collect data about energy consumption, building materials, construction, building regulations, Saudi lifestyle, family size, the main regions in the country and types of Saudi residential buildings. This information was gathered from different companies and government buildings dealing with energy and residential buildings, as well as by carrying out a number of interviews with engineers, architects, experts and specialists. The next step was the selection of a typical residential building in the Kingdom of Saudi Arabia. The aim was to prepare this building to use it in a building simulation program to complete the investigations about energy consumption and identify the best methods to lower energy consumption of Saudi residential buildings and to have more environmentally-friendly buildings in the Kingdom.

The next stage started by collecting further information about factors that result in significant energy consumption in residential buildings. This information for was gathered through a survey prepared for Saudis, in order to understand the levels of comfort and conditions in homes. The survey also aimed to find out about Saudis' behaviour, knowledge, experiences and abilities to change their daily use of energy and thus, the future of the country.

After selecting a Saudi typical residential building, the next stage was to analyse the current situation of energy in Saudi residential buildings and methods to develop these buildings, using a computer simulation program called IES (Integrated Environmental Solutions). The aim of using IES was to find the possible solutions in terms of building materials and construction solutions that can be applied to these buildings in order to achieve the research aim and goals.

Finally, attending the 3rd Annual International Conference on Architecture and Civil Engineering (ACE 2015) held in Singapore on 13-14 April 2015. Attendance at this conference helped to clarify some ideas and to fit them into the context of the current research.

1.9 Thesis Layout

Chapter 1: The first part of chapter one introduced a brief background about the kingdom of Saudi Arabia size, population, government, history and economy. The second part of the chapter presented and introduced the research context and proposed the research questions, hypothesis, aims, and objectives.

Chapter 2: The second chapter of this thesis presents a range of literature covering issues such as: Saudi building standards and regulations, energy demand/ consumption, residential buildings in Saudi Arabia, building construction, building materials, and other issues relating Saudi building energy consumption and efficiency.

Chapter 3: Presents in details the research methodologies that have been used in the present work in order to achieve the research goals and objectives.

Chapter 4: Focusses on air-conditioning in Saudi Arabia. In addition it presents the working mechanism of the most common types of air conditioning under the local comfort category for residential buildings. This chapter discusses the Saudi market for AC, air conditioning types, size, and electricity tariffs.

Chapter 5: Presents one of the most important methods adopted in the thesis: A cross-sectional survey that was carried out to reflect the Saudi population, and aimed at Saudis livings in residential buildings representing different ages, educational levels, gender and income. This chapter presents a survey completed by 190 participants randomly selected from different cities in Saudi Arabia in order to understand the Saudi user's behaviour regarding air conditioning and cooling load in the Saudi residential building. The survey examined the Saudi knowledge and the abilities to move to more efficient houses in the future. It is designed to answer the thesis questions and to complete the missing data.

Chapter 6: Introduces the interview findings and results. Ten interviews were performed to governmental/ private organizations and companies from 01/06/2013 until 31/08/201. The interviews were of a semi-structured type and specific questions were prepared for each interviewee based in his organisation, working position and knowledge.

The interviews were performed with engineers, architects, experts and specialists in leading positions and having a strong background in energy, construction, building materials and Saudi buildings. The aim of this is to gather the up to date information needed regarding energy issues, Saudi buildings and the future.

Chapter 7: Presents the building energy simulation objectives and the IES software discerptions that used for calculating the cooling load. In addition, this chapter discuss the data used as an inputs for the simulation in chapter 8, which include: selected locations and cities in Saudi Arabia, weather data and a case study used for further investigations in the next chapter which include the building drawings, construction materials, AC systems and operating hours: In addition, this chapter includes the validation of the IES software.

Chapter 8: Presents the energy simulation results (first and second part) and analysis for the selected Saudi typical house in three different locations Jeddah, Riyadh and Dammam.

The first part of the results shows a comparison between the most common external walls used in the simulation in terms of thermal properties and cooling load.

The second part of this chapter discusses applying 0.50 m of polyurethane thermal insulation into three different places for the selected external wall from the first part of the result. The aim is to examine the best location to apply the insulation that could save more energy and reduce the cooling load to the minimum.

Chapter 9: Is the conclusion chapter and presents the thesis summary, findings, recommendations and further studies that could be investigated by other researchers in the future.

Chapter 2

Literature Review Chapter

2.1 Environmentally Friendly Buildings in Saudi Arabia

The government always has the power to set laws and regulations that can lead to sustainable development (Mosley 2015). Studies reveal that building and construction represents the strength of the policies for development in Saudi Arabia. This reflects on the fact that the rise and fall in the trends of the building can have either a negative or positive effect on the different sectors of development. The government has currently taken sincere concerns with regard to the green buildings. This calls for considering significant standards of building constructions and necessary approvals (Green Building in Saudi Arabia, 2010). A green building is formed through the availability of energy efficiency, resource efficiency and environmental accountability that may be reflected through the planning, design, construction and operational activities. The building council in Saudi Arabia is trying to promote and facilitate the practice of green building in the country by increasing public awareness, providing training and needed education on the issue, assisting the industry of construction alter to the specifications and needs of green building development (About SGBC, n.d.). Therefore, to achieve Green Buildings in the kingdom there are several aspects that should be taken into consideration:

1. Changes in building technology
2. Incorporating changes into regulations.
3. Enforcing regulations (About SGBC, n.d.).

However, in spite of the existence of the Saudi green building council it is not active in reality. The current Saudi government policies and regulations do not support sustainable and green buildings in the country (Mosly 2015). Taleb, in 2011, confirmed that there is a complete absence of building regulations regarding thermal performance, sustainable buildings and energy efficiency.

Mosly, (2015) states that the Saudi government should start the green building movement and should establish a new policies and regulations in the future.

2.2 Building Regulations

It has been expected that Regulation of buildings would become obligatory in Saudi Arabia in recent times. The government and the industry have been working together on this issue such that a common standard may be incorporated and applied in the process. Water and energy savings in buildings have also been considered, significantly where the Ministry of Electricity is effectively involved with the Green Building Council and other associated companies (Neuhof 2010).

Saudi Arabia has based its codes of building on I-codes (International Code Council). The International Code Council is established to make buildings sustainable, affordable, and safe. Most communities in the United State, and many others across the world choose the International Codes. Earlier in the year 2007, a memorandum of understanding had been signed by the International Code Council with the Saudi Building Code National Committee (SBCNC) to contribute to constructing secured awareness and technological know-how. This MOU included several joint projects focusing on codes of building, specifications, technical seminars, technical information services, and publications. The agreements ensured meetings among the representatives of these parties focusing on the exchange of technical expertise supporting the activities related to building codes and the promotional activities of technologies, research, publications and services (IHS 2007). Therefore, the recent actions of the kingdom of Saudi Arabia demonstrate their belief that developing regulations and standards are very important issues.

2.2.1 Use of Building Regulations in Gulf Countries

News in the year 2011 reflects on the plans of the Gulf nations which include: Saudi Arabia, Qatar Kuwait, Bahrain, Oman and the United Arab Emirates to have unified codes of building. Standardization has been considered in terms of temperature measurement, humidity and electrical quantities, thus focusing on their approval. The Gulf mass measurements have been referenced from the measurements that were maintained as standards by Dubai Central Laboratory in the UAE (Lahn, Stevens and Preston 2013). Gulf countries like Dubai are concerned with the building regulations - the Green Building Regulations and Specifications in the Emirate of Dubai- with the intention of improving the performance of the constructed buildings. Such regulations have been expected to reduce the consumption of energy, water and other resources, accompanied with the improvement of the public health as well as public safety and general wellbeing (Dubai Municipality 2010). Green building that practices the creation of structures and use of processes intending to increase the effectiveness of use of resources like energy, water, and materials, at the same time reducing the impacts of building on human health and the surroundings. Moreover, green buildings are focusing on other issues such as lifecycle of the building, with the use of enhanced design, construction, operation, maintenance, and removal. Recently Gulf countries are taking in consideration different strategic plans to adopt the green buildings concept such as Dubai city.

On the other hand, the capital city of United Arab Emirates Abu Dhabi established their own rating system, the Pearls Rating System for Estidama for buildings, villas and neighbourhoods (Elgendy 2010). Pearls referred to the previous system such as the British BREEAM rating system and the American LEED rating system. This rating system was established to understand and respect the environment and the cultural of Emirates (Elgendy 2010).

The country focuses on making use of building regulations for the sustenance of urban environment thereby enhancing the ability of the country's infrastructure facilities considering the future development of the country. These regulations have been applied to all buildings in the Emirate of Dubai (Dubai Municipality 2010).

2.2.2 Availability of Using Different Regulations

BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design) are widely recognized environmental assessment methodologies that are used worldwide in the building construction industry in the present times. BREEAM 2008 that replaced BREEAM 2006 is used for the assessment of buildings in the current times. Percentage scores and BREEAM rating are accordingly presented for the tests of the buildings. Certain mandatory ratings have also been set. Considering LEED, prerequisites have been set by the methodology before the mandatory ratings of the BREEAM as reflected through LEED 2009. There is a competition between both the methods that has led to enhanced development of building standards, and innovation (Inbuilt 2010).

BREEAM has had several revised versions since it first came into place in 1990. These revisions have been focused on the changes in the building regulations and the BREEAM methodology now intends to set the standards accordingly. “The BREEAM system is a rating tool that has specific formats for a range of buildings allowing it to be capable of meeting the different functions of key building types” (Kirkpatrick 2009).

Considering the standards maintained by LEED, the continuing use of fossil fuels has distorted the scoring of the system. The cost of the system is considered to be high. However, the rating will help to save more but over period of time. LEED is a measurement tool that still needs certain improvement in addressing the climate specific issues without which buildings may score even if they are not up to the standards (Kats et al. 2003). In fact, lots of efforts should be directed toward to develop national and regional green building standards adapted to local climatic and cultural conditions in the kingdom. Table 2.1 gives an example of three green building codes that can be adopted in Saudi Arabia and considered as a starting point for the future.

Table 2.1: Green building ranking schemes (Elgendy, 2010).

PEARLS		BREEAM		LEED	
Site selection and Natural systems	16%	Site Selection and ecology	20.5%	Site Selection	24.5%
Water	25%	Water	2.5%	Water	5.5%
Energy	25%	Energy	33%	Energy	33%
Materials	16%	Materials	13.5%	Materials	13.5%
Indoor Environmental Quality	20%	Indoor Environmental Quality	13%	Indoor Environmental Quality	14%
Innovation	2%	Innovation	6.5%	Innovation	6.5%
Integrated Design Process	7%	Facility management	12%	Regional Priority	4%

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2.3 Residential Buildings in Saudi Arabia

According to a survey done by Alaidroos and Krarti, approximately 40% of the existing residential buildings are categorised as villas (i.e., detached single family houses), with apartment blocks accounting for 35% and duplexes 12%. Thus, in Riyadh, detached family homes account for two fifths of the available residential buildings. Improving the energy performance of these building could therefore have a significant effect on reducing the overall energy consumption of the Saudi building sector (Alaidroos, and Krarti, 2015).

Saudi residential buildings are categorised in different types such as villas, traditional houses, apartments, floor in villa housing and other types of housing (table 2.2). In 2004, Saudi and non-Saudi households living in villas and traditional houses were 46.2% and households living in apartment or floors represented 47.4% of the housing stock. The vast majority of housing stock consists of small units. Residential units consisting of one or two bedrooms represent 64.3% of the total housing stock; those of three bedrooms 19.1%; and larger units (more than three bedrooms) 16.6%.

Table 2.2: Information about housing unit types in the kingdom from 1992 until 2004 (Ministry of Economy and Planning 2014).

Type of Housing Unit	1992		2004		Change 1992–2004		Average Annual Growth Rate (%)
	Number	Relative Share (%)	Number	Relative Share (%)	Number	Relative Share (%)	
Villas	454365	16.4	729780	18.3	275415	22,6	4.0
Traditional Houses	909005	32.7	1114456	27.9	205451	16,9	1.7
Apartment	847233	30.5	1505429	37.7	658196	54,2	4.9
Floor inVilla or Building	241317	8.7	386911	9.7	145594	12,0	4.0
Other Housing	325002	11.7	255207	6.4	–69795	–5,7	-2.0
Total occupied units	**2776922**	**100.0**	**3991783**	**100.0**	**1214861**	**100,0**	**3.1**

A demographic survey carried out in 2007 indicated that around one-third of Saudis reside in apartments and only around one third of these own their own flats, this is in contrast with the ownership ratio of 85% for villas and 79% for traditional houses. In Saudi Arabia, housing costs the most in Jeddah, very few are able to afford the luxury of owning a house in Jeddah. As per Jeddah Urban Observatory, around 40% of the residents own their homes in the Red Sea city and around 52% of the residents rent their living space. Figure shows that one third of Saudis live in apartments (Banque Saudi Fransi 2011). The following figures 2.1 confirm that one- third of Saudis live in apartments.

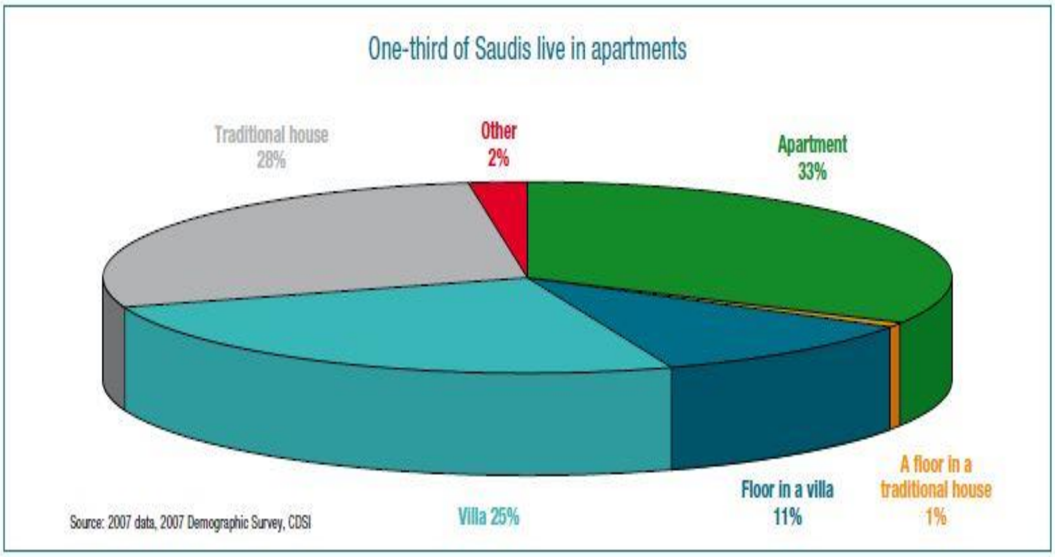


Figure 2.1: The Saudi residential categories (Banque Saudi Fransi 2011).

As per the latest (2007) official data released around 62% of Saudis own their homes. Excluding traditional houses, which exist in significant proportion, the Saudi home ownership drops to around 36%. Traditional houses those are built up of mud-houses, shacks are considered to be poorer in quality and building standards especially in comparison to other types of houses and these are not actually liveable units. These differences display the variations in house ownership in Saudi. It is believed that home ownership stands near the forty per cent mark (Saudi Gazette 2012). Owing to the fact that the rented units outnumbered the owned units, this demand led to the increase of rentals by around7% between 2010 and 2011.

2.3.1 Housing Affordability in Saudi Arabia

There are numerous factors those have led to an unprecedented growth in Saudi housing market. Some of these factors include, increase in the Kingdom's GDP, increase in population growth rate, increasing labor force, enticing options for financing. Besides these factors, increase in per capita income in Saudi has further boosted the housing market in the Kingdom.

Flip-side of such an encouraging picture of housing market is the deficiency of affordable houses, the more so there is limited ownership of villas by Saudis. Furthermore, since the land plots are high in demand in the Kingdom, their prices are abnormally high where by affording them becomes a distant dream for many Saudi citizens and developers.

It is a foregone conclusion that housing market is one of the cornerstone for development and advancement of Saudi economy. Even though, there exist numerous challenges and constraints, these cannot overshadow the potential for growth of this market. The need for quality housing, especially cost effective housing has been growing more steeply. Rapid and consistent migration of populace to the three Saudi regions namely – Makkah, Riyadh and Eastern Province has led to the increase in the pressure on the developers and financial institutions for making provision of such migrations. These regions have outgrown the other regions in Saudi (Saudi Gazette 2012). At present housing in these areas is focused around the existing population, housing development and the options available for financing. Around 66% of the residents are based in these three regions and the number of occupied properties in these regions represents around two-thirds of the Saudi Arabian population as shown in following figure 2.2 (Saudi Gazette 2012).

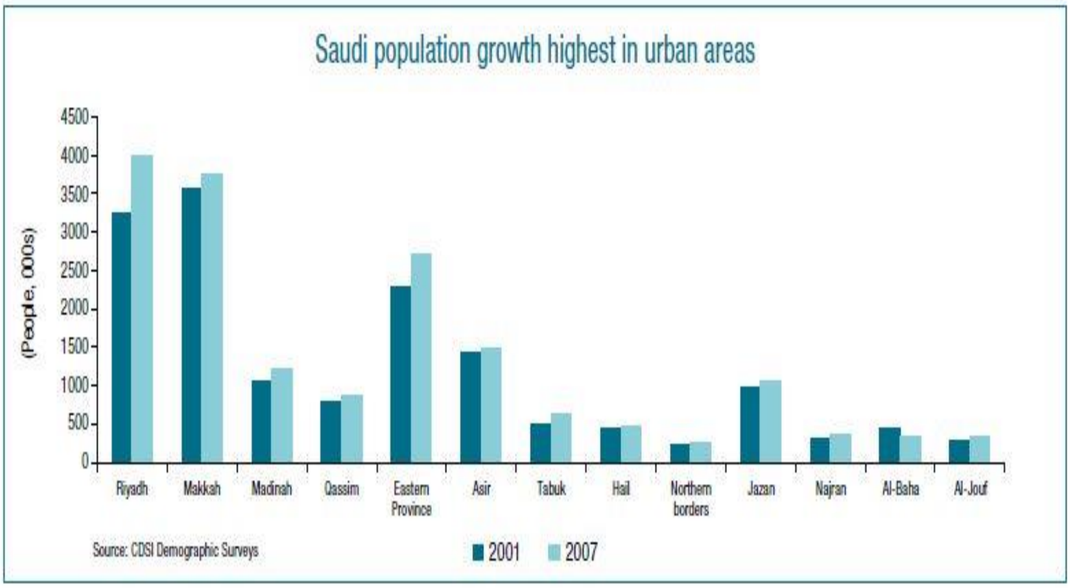


Figure2.2: Saudi population growth highest in urban areas (Saudi Gazette 2012).

2.3.2 Average Size of Saudi Household

Estimates indicate that the majority of the Saudi population is under 30 years of age (Alrashed, and Asif 2014). Another interesting observation confirmed that around 66% of the Saudi population is aged below 30 years, in other words it forms the majority of Saudi population and it also includes around 47% out of the 66% are below 20 years of age (Saudi Gazette 2012). These segments fuel the demand as they step into marrying age and this is the age when they start breaking from extended family lifestyle. Similar change in cultural norms led to the decrease in average size of household. It has been forecasted that the average household in Saudi would drop to around 5.28 persons per house by 2020 as shown in the following figure

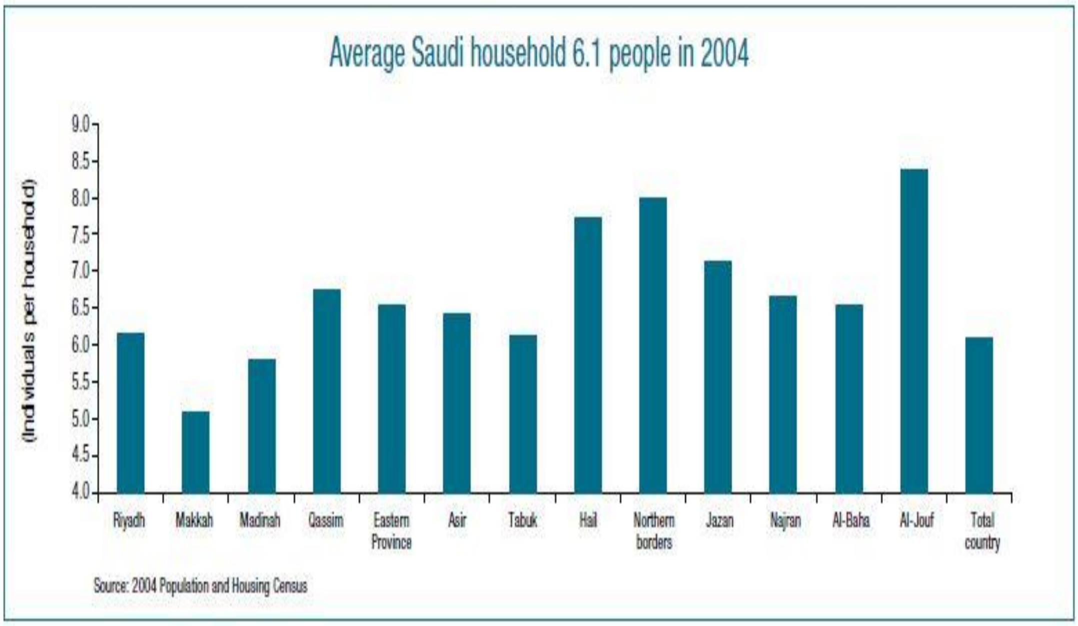


Figure 2.3: Average Saudi household 6.1 people in 2004 (Saudi Gazette, 2012).

The total number of houses is expected to increase from 4.6million units in 2010 to around 7 million units by 2020, annual demand would increase from around 195,000 units in 2011 to 264,000 units by 2020. (Saudi Gazette, 2012).

In fact, Alrashed and Asif in 2014 confirmed that if the country wants to satisfy the requirements of the continually increasing population, it must construct 2.32 million new homes by 2020.

2.3.3 Residential Cost

The living rental cost has been on the rise annually and since 2008. Profits from residential buildings in Jeddah and Riyadh range between 8-10%. This can be attributed to the notion that property developers and owners are unwilling to exit the rental markets until an imbalance involving the unit's affordability by people and the type of units that is at their disposal is created.

To depict the aspect of cheap homes in KSA, by comparing it to the United States indicates the growing gap between house prices and income. In this scenario, the "median household income" within the United States stands at 50,221 dollars, whereas the average house pricing is about 168, 000 US dollars. This implies that the ratio of affordability for housing-income is 3:4. This can be attributed to the notion that the average cost of a home is 3.4 times the country's annual average income. In contrast, Saudi Arabia's average income is about 18,851 US dollars and according to GOSI (General Organisation for Social Insurance), while the cost of a home is averagely about 144,000 US dollars. This shows that the ratio for housing affordability is 7:6 (Saudi Gazette 2012). Figure 2.4 below provides an illustration on the housing units occupied in 2012.

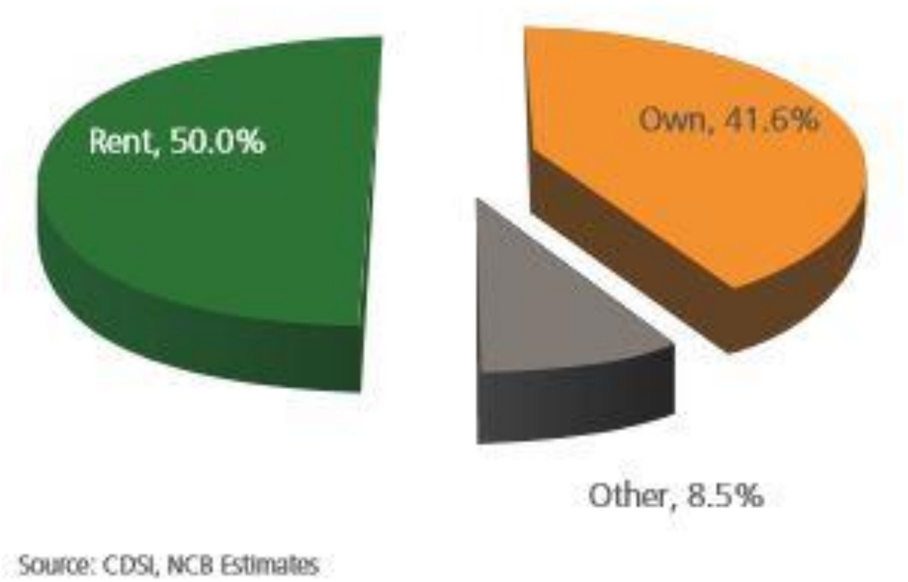


Figure 2.4: Occupied Housing Units by Type (2012) (Banque Saudi Fransi 2011).

The average pricing for an affluent apartment within the 12 districts of Dhahran, Dammam, Khobar, Jeddah and Riyadh was 485,833 Saudi Riyals (however, for the small villas, the cost was 1.06 million Saudi Riyals or 192,720 Sterling Pounds). Generally, most Saudi families have a preference for villas than apartments, but the capacity of affording such luxuriant houses is increasingly becoming complex. In Riyadh, the cost of small sized villas rose by 19 percent to 1.23 million Saudi Riyals (223,636 Sterling Pounds), whereas in Jeddah, the cost increased by 17 percent to 1.54 Saudi Riyals (280, 000 Sterling Pound). In Eastern Province, the cost of small villas was 768,000 Saudi Riyals (139, 636 Sterling Pounds). Such price increments is an indication that cultural preferences for larger homes exists, thus developers should take this into consideration. Moreover, attention should be directed to land prices because it is a factor that influences affordability (Banque Saudi Fransi 2011).

2.3.4 Residential Construction

As per a report from the Saudi Gazette in 2012, based on the assumption of high growth rates, by 2020 the residential construction sector would touch SR650 billion (Pound sterling 118 billion). The gross total expenditures will reach SR900 billion (Pound sterling 163 billion) following factoring in the allocation of SR250 billion (Pound sterling 45 billion), thus the overall deficit would be SR400 billion (Pound sterling 72 billion) to meet the SR1.3 trillion in the housing expenditure (Saudi Gazette 2012). The housing sector is also expected to witness a contribution in the investments from the public as well as private sectors. As per industry's estimates to develop 2.4 million additional housing units between 2011 and 2020 the industry needs around SR1.3 trillion (Saudi Gazette 2012) and it translates to an average annual outlay of SR 130 billion. On a macro level current investments in housing sector can be assessed by gauging the Gross Fixed Capital Formation (GFCF) expenditures in residential construction. Since the residential expenditures have reached nearly SR 43billion in 2011 the total GFCF for the period 2011 to 2020 is expected to touch SR 650billion. Even after considering recent allocation of SR 250 billion by the Government for the housing sector the figure falls short of the total investment that is SR 1.3 trillion (Saudi Gazette 2012).

In order to plug the gap of SR 400 billion that is required to meet the housing demand, additional investment from private public sectors would be essential (Saudi Gazette 2012). The concentration of housing in Riyadh, Jeddah and Eastern Province is primarily based on population, housing development and the available financing options (Saudi Gazette 2012).

In order to ease the pressure that builds up because of the increasing prices of apartments and villas, there is an urgent need for new single family homes for middle and low-income population in the areas where they are most required. Currently the Government is working on various fronts for alleviating supply constraints, last month the government dedicated SR 55 billion (USD 14.7 billion) for programmes to facilitate lower income population to buy homes (Banque Saudi Fransi,2011).

In order to finance construction of 500,000 new units the King called General Housing Authority to allocate SR 250 billion. Till 2015 the private and public developers are required to build about 275,000 units annually, in all these would be amount to around 1.65 million homes over six years and these would address the needs of population that has doubled since 1988 and it is growing at a rate of 2% annually (Banque Saudi Fransi 2011).

The government has set a target to raise ownership among citizens to 80% and this would be achieved by boosting supply of affordable housing and enabling a wider spectrum of financing options for citizens as shown in the following figure 2.6

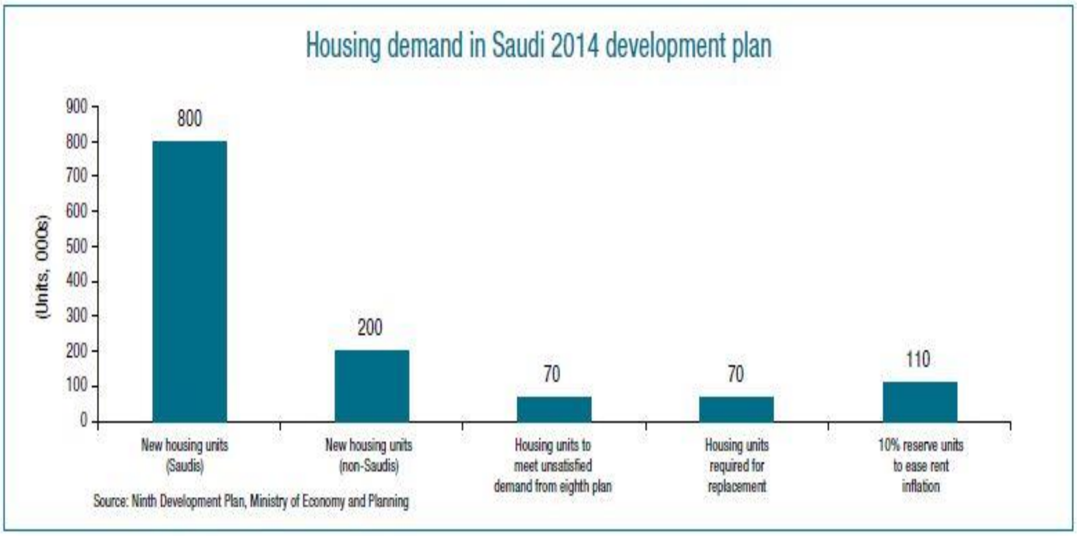


Figure 2.6: Housing Demand in Saudi 2014 Development Plan (Ministry of Economy and Planning 2014)

In the Ninth Development Plan from 2010 to 2014 (Ministry of Economy and Planning 2014) that is a far-reaching economic and social development programme, the demand estimate of the Government rests at 1.25 million, 250,000 per year. The Ninth Development Plan also estimates investments to the tune of USD 400 billion.

At the rate of 2.23% population growth through 2013, the State is expecting the Saudi households to grow by 750,000 hence spelling the need for 800,000 new homes to be built. Besides these, the Ninth Development Plan is indicative that around 200,000 housing units would also be needed to address the need of non-Saudi population, the Plan has highlighted that to ease rental inflation there is a need for 110,000 units to be built. Furthermore, there is a need for around 140,000 new units to replace the current ‘dilapidated housing units.’

As per the Government’s estimates, Makkah Province includes Red Sea port city of Jeddah with 370,000 units and then there is the Capital City of Riyadh with 325,000 units. The new demand majorly comes from Jeddah, Riyadh, Eastern Province and Madinah and it amounts to three quarters. The case of Jeddah is interesting for the fact that in the city the occupancy rates exceed 95% and the reason for such an overwhelming figure is due to damage caused by floods (Banque Saudi Fransi 2011).

The Government is anticipating to increase the number of units by one million by 2014, this would amount to a deficit of 20%. It has been estimated that in order to achieve 200,000 new units per year the pace of construction needs to be stepped up by 66%. It is worth inclusion that during the Eighth Development Plan (2005-2009) in all 120,000 new units were built per year and this figure was twice the amount of units those were added in each of the preceding five-year plans. In all these three cases in point the construction targets could not be met (Banque Saudi Fransi 2011).

In the last decade Saudi population has drifted towards urban centres. Between 2001 and 2007, in Riyadh the Saudi population increased by 23% this was the highest rate of growth in the country, as regards the non-Saudi population in Riyadh, the growth rate was 24%. At the same time in smaller towns like Al-Baha the Saudi population reduced by over 22%, in the case of Asir and Hail, the population growth was lower than 5%. This pattern is adding lot of strain on housing supply in urban centres. Increase in the influx of expatriates also adds to the increase in rentals. Another important factor is the size of families in urban areas the size of the families is smaller. As per 2004 census in Saudi the average size of the household was 6.1 and the family size in smaller cities and villages surpassed the national average. In Al-Jouf and Northerm Borders, the size of the household was 8.4 and 8 members respectively where as in Riyadh the household size was 6.2, in Makkah it was 5.1 and Madinah had 5.1 as its household size. It has been anticipated by Riyadh Development Authority that in next decade, the average family size in Riyadh would fall to 5.7. The 2010 census data is yet to be released (Banque Saudi Fransi 2011).

In the coming years, it would be extremely crucial to control the rise in property prices and this would be possible by meeting the building targets. It is expected that the private sector would chip in. As per the Ninth Plan, the private sector firms are expected to build 61% of new homes in Riyadh and 62% in Makkah. The distribution of the housing units to be built, 66000 units would be built by the Public Housing Authority and REFF would finance the creation of 109,000 housing units and 90,000 of these units would be financed. The government agencies would also be building 50,000 units for their employees. Over 26 million sq. meters of land has been dedicated to the private sector funding for housing projects on which 775,000 residential units would be constructed (Banque Saudi Fransi 2011).

2.4 Energy and Natural Resource Crisis in Developing Countries

If there is no sustainable management of non-renewable natural resources (e.g. oil, natural gas and coal) to ensure their existence for future generations, they are at risk of being consumed over the next 40 to 200 years. The availability of natural resources in a country can offer economic prosperity and a better standard of living for its populations, for example oil has generated wealth for Saudi Arabia and transformed it from a tribal desert country into one of the world's principal oil producing and exporting countries (Al Surf, Susilawati and Trigunarsyah 2014).
A common theme running through the literature on sustainability is the importance of preserving and managing natural resources for future generations (Al Surf, Susilawati and Trigunarsyah 2014).

Natural resources can be preserved by applying and adopting sustainable construction methods. Developing countries have an opportunity to implement these concepts of sustainability while projects are still under development. Saudi Arabia is one of the developing countries in Asia, and applying sustainable applications and systems to the built environment at this stage could help preserve the country's natural resources for future generations (Al Surf, Susilawati and Trigunarsyah 2014).

Environmental challenges facing the Kingdom of Saudi Arabia:

- Poorer air quality in urban areas
- High energy demand and consumption resulting from regional population growth and economic development
- Anxieties about safe drinking water supplies due to a lack of fresh water
- Industrial pollution
- Waste management

2.5 Challenges Facing the Electrical Energy Sector in Saudi Arabia

There are several difficulties facing the Saudi electrical energy sector, the most important of which fall into three categories: technical, financial, and socio-economic.

2.5.1 Technical Challenges

The technical problems entail the frequent and seasonal differences in the consumption of electricity caused by weather changes. Such differences are mainly caused by air-conditioning loads, especially in areas that experience hot weather. Additionally, the worst distribution of loads is experienced where many loads are commercial or residential because this compels utilities to perform below required levels: the generators operate on part load, thus necessitating the use costly and ineffective gas turbines for satisfaction of peak loads. The scenario worsens in summer daytime hours as the demand for the peak load occurs when highest temperatures set in, leading to efficiency and output power decline. Different alternatives such as heat storage systems, heat insulation installation and consumer incentives might be utilised in addressing the situation (Khan, Abdo and Al-Ghabban 2015).

During the summer heat, the low production capacity reserve level might pose another challenge. For instance, in 1998, the "peak load" came near the installed capacity. Furthermore, lack of qualified technicians, engineers and managers in energy-efficient fields is a problem. Additionally, lack of a central body for adopting and implementing a countrywide energy-efficient approach exists, leading to absence of building codes, legislation and standards (Khan, Abdo and Al-Ghabban 2015).

2.5.2 Financial challenges

The demands of the "supply system" can be met by expanding it; this requires considerable capital investment, especially because of the expensive nature of the electricity distribution, transmission and generation system. The overall cost required to meet the demand might reach 90 million US dollars by 2023. Unlike in the private sector, the current low tariff cannot allow investments recovery or investors to make significant profits. Another problem lies in the absence of investments in energy-efficient initiatives, by monetary institutions; the absence could be blamed on the high investment risks associated with new technologies. Additionally, Saudi Electricity Company (SEC) has been acquiring loans (amounting to 1667 million US dollars to finance the development of new power generation facilities; this becomes a huge problem, particularly when it delays supply systems that are earmarked for expansion and the rural electrification program. Another drawback that faces electricity utilities exist in the inefficient techniques of charging clients. Finally, the tariff designers disregarded the environmental expenses (Khan, Abdo and Al-Ghabban 2015).

2.5.3 Socio-economic challenges

Currently, power consumption has increasingly become wasteful thanks to the existing low energy costs. It is imperative to sensitize the utility workers, technicians and the public on the potential benefits of energy effectiveness and savings that will emanate from particular practices and technologies. Economic and social growth is contributing to the rapid rising demand; however, the present "high living standards" amongst the population present a major problem in the electricity industry to respond to the demand. Notably, the rapid annual growth in population

(3.7 percent), which is amongst the highest globally, is directly related to the increase in demand for power (Khan, Abdo and Al-Ghabban 2015).

The “government’s policy” concerning tariff regimes entails maintaining affordable costs for user services to promote economic and social welfare. However, the policy is not consistent with privatisation, particularly in rural regions that are less populated and the costs of distributing, transmitting and generating electricity are extremely high. In such regions, the costs of generating electricity may surpass by four times those for urban regions, whereas power distribution cost could surpass ten times (Khan, Abdo and Al-Ghabban 2015).

2.6 Energy Efficiency in Saudi Arabia and Worldwide

Policy makers consider energy efficiency and conservation as urgent social objectives, and previous research has demonstrated the impact of public awareness on changing bad habits to positive habits. At present, the energy efficiency situation in Saudi Arabia is problematic and largely neglected. An increasing energy demand and less efficiency in Saudi Arabia are the result of a number of factors, namely:

The problem of excessive consumption and waste in Saudi Arabia is aggravated by both energy-intensive industries and an energy-intensive lifestyle in buildings and transport, which is further encouraged by low energy prices, a high rate of population growth and economic development and a lack of public awareness. Currently, Saudi Arabia is consuming more energy than other countries (approximately 2.8 million barrels per day). With Saudi Arabia’s annual energy consumption increasing twice as fast as GDP, the energy consumption level is unsustainable. Furthermore, there is an increasing demand for its own oil and gas, which is growing at around 7% every year. In comparison to other countries with higher populations, Saudi Arabia uses more energy per capita (Khan, Abdo,and Al-Ghabban, 2015).

2.6.1 Benefits of Energy Efficiency

Energy efficiency helps to decrease both energy consumption and negative environmental impacts, thus increasing energy efficiency results in numerous national and international benefits. On a national level, economic growth is a priority for Saudi Arabia, and studies show that improved energy efficiency can enhance productivity, increasing growth and decreasing inflation. Improving energy efficiency in Saudi Arabia can also contribute to energy security goals by reducing both energy consumption and energy production. Moreover, new employment opportunities will be created through the transition to a new energy efficiency model in the country. On an international level, implementing energy efficiency measures offers many benefits, notably a reduction in carbon dioxide emissions, and a significant contribution to Climate Change Mitigation, resource management and energy prices (Khan, Abdo, and Al-Ghabban, 2015).

2.6.2 Consumer Behaviour in Saudi Arabia

Energy consumption behaviours in Saudi Arabia based on routine, "emulation" and consist of many negative habits. For example, it is normal for Saudi households to leave both inside and outside lights on when not needed, and to leave the television on when not being used and to leave electrical appliances on standby mode, with no consideration of the environmental impact. Furthermore, positive energy efficiency habits (e.g. switching off lights in unoccupied rooms, only using the dishwasher when it has a full load) are associated with elderly people and a sense of embarrassment in Saudi culture (Khan, Abdo, and Al-Ghabban, 2015).

This highlights the complex nature of behaviour among Saudis and the difficulty of changing habits as there is a lack of understanding of the concept of sustainability. The Arabic word for sustainability (Estidaama) has only recently been applied in this context in Saudi Arabia. As public education campaigns must be context- and culture-specific, a Saudi campaign would have to make the case that a new pricing system would raise living standards among the poor and create more jobs (Khan, Abdo, and Al-Ghabban, 2015).

2.6.3 Power Generation

The electricity production capacity of Saudi Arabia is 44, 485MW, which is met by natural gas (43 percent) and oil (43 percent) (Alrashed and Asif 2014). After the oil price fluctuations, natural gas has experienced a rise in terms of contributing to electricity generation (from 37 percent in 2007 to 43 percent in 2009). The demand for electricity in KSA is rising rapidly, having escalated by 6 percent annually since 1990. According to the statistics, as well as from population and economic growth, the main energy demand is expected to escalate by 50 percent in 2020, compared to 2008. Moreover, the "per capita electricity consumption" is on the rise as well because of several factors that include higher consumption by energy-intensive appliances, subsidised tariffs and urbanisation. By 2025, the sector is expected to have a double demand (Alrashed and Asif 2014). The rapid demand growth is largely because of an inefficient electricity use that is in turn linked to highly reduced tariffs. For response to the growth in electricity demand, Saudi Arabia should come up with better mechanisms that not only increase the capacity of power generation but also enhance energy efficiency within thin the residential sector. An assessment of the building sector reveals that many projects being undertaken are residential housing aimed at meeting the demand of new homes; according to the Ministry of Municipal and Rural Affairs statistics, majority of construction licenses granted in the KSA are meant for residential housing (Alrashed and Asif 2014). Saudi power generation may be understood through the figure below.

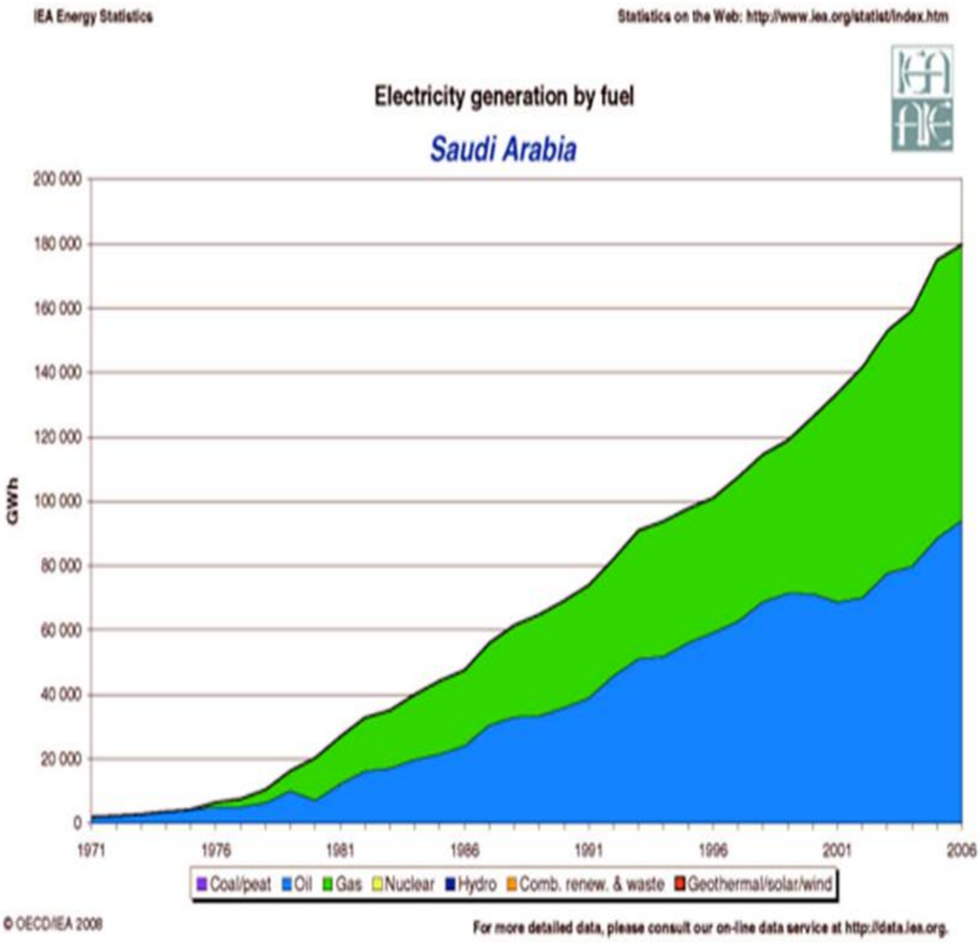


Figure 2.7: Electricity generation by fuel in Saudi Arabia (Saudi Arabia Energy Issues 2012).

The KSA has chosen crude oil, fuel oil or plants burning for production of required electricity and gas plants. In contrast, the process of developing refineries would result in the reduction of fuel oil consumption. This would in turn reduce the available supply for the power plants. For the crude oil, the study showed that the expense for burning such type of fuel was equivalent to the global market price

(Hertog and Luciani 2009). The existing generation capacity between 2005 and 2008 in the KSA is indicated in figure 2.8:

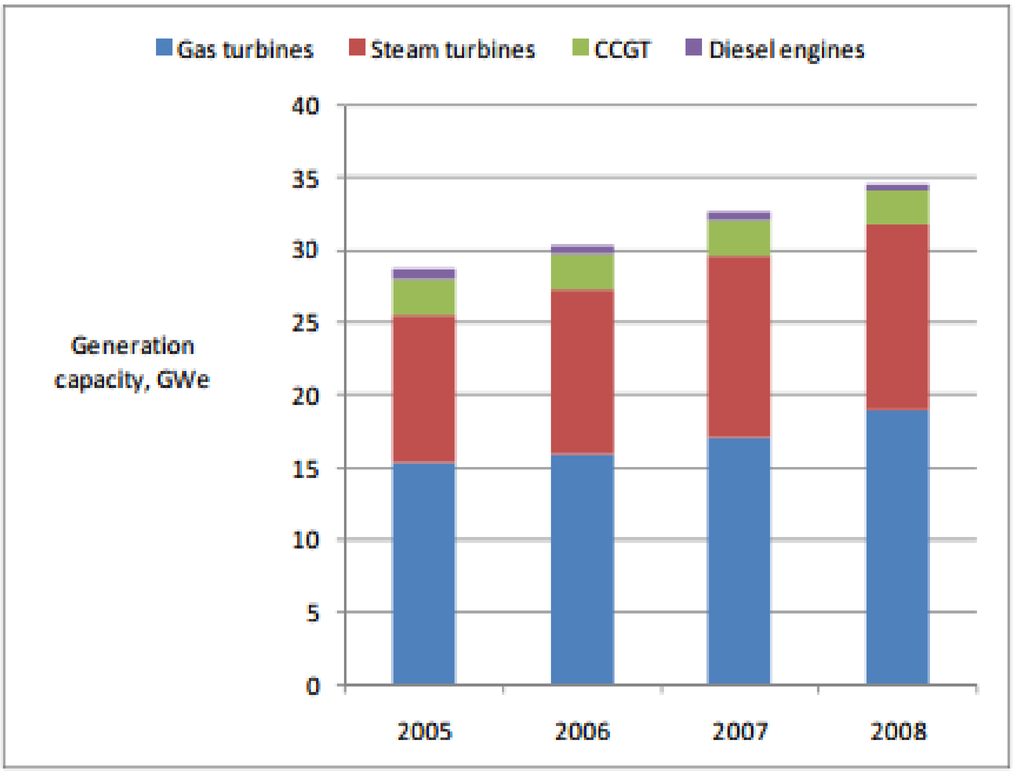


Figure 2.8: Available generation capacity in Saudi Arabia (Alyousef and Abu-ebid 2012).

2.6.4 Electrical Demand and Consumption in Saudi Houses

According to Ronald McCaffer (professor of construction management at Loughborough University), the latest electricity (energy) situation in KSA indicate that the cost energy is affordable in the Gulf region. Because of the affordable prices of energy coupled with hot weather conditions, Gulf countries depend on air-conditioned buildings (The Economist Intelligence Unit Limited 2010). The total energy consumption from 2000-2020 in the Middle East is illustrated in table 2.3.

Table 2.3: Energy consumption totals, millions tons of oil equivalent, GCC countries, 2000-2020 (The Economist Intelligence Unit Limited 2010).

Country	2000	2001	2002	2003	2004	2005 (a)	2006 (a)	2007 (a)	2008 (b)	2009 (b)	2010 (b)	2011 (c)	2012 (c)	2013 (c)	2014 (c)	2015 (c)	2016 (c)	2017 (c)	2018 (c)	2019 (c)	2020 (c)
Bahrain	8.6	8.9	9.3	9.6	9.8	10.7	11.4	12.0	12.7	13.2	13.8	14.3	14.9	15.4	16.2	16.8	17.5	18.3	19.0	19.9	20.7
Kuwait	21.6	20.9	21.0	22.8	23.9	27.5	26.9	28.1	29.8	30.5	31.7	33.0	34.3	35.6	36.9	38.4	39.9	41.4	43.0	44.6	46.4
Oman	8.6	8.7	9.1	9.0	9.6	12.3	14.1	14.5	15.3	16.1	17.1	18.1	19.2	20.3	21.5	22.8	24.2	25.7	27.2	28.8	30.6
Qatar	14.6	11.3	11.9	13.2	15.9	19.7	21.1	23.5	26.4	29.2	35.2	41.4	45.3	48.9	52.5	59.2	65.7	72.0	79.1	87.1	96.3
Saudi Arabia	114.6	121.3	127.1	133.9	144.2	153.2	160.1	169.0	179.1	187.8	198.0	208.8	220.5	233.0	246.2	260.0	274.5	289.9	306.2	323.4	341.6
UAE	42.5	43.1	46.8	47.7	50.3	52.4	55.9	60.5	66.3	67.0	70.1	73.7	77.8	82.2	87.0	91.7	96.7	102.2	107.9	113.9	120.2
GCC Total	210.4	214.3	225.3	236.1	253.8	275.8	289.6	307.6	329.6	343.9	365.8	389.3	412.0	435.4	460.5	488.9	518.5	549.5	582.4	617.7	655.7

In KSA, the overall electricity consumption was around 212,263 GWh (Gigawatt-hours) in 2010 and the demand for electric energy has been rising, with an estimated increase standing at 2015.7 GWh annually (Al-Ghamdi and Al-Feridah 2011). Indeed, each sector in KSA uses significant quantities of electricity annually; however, residential housing units are highest consumers, with 108,627 GWh (67 percent) of the overall consumption being used as illustrated by figure 2.7 (Al-Ghamdi and Al-Feridah 2011).

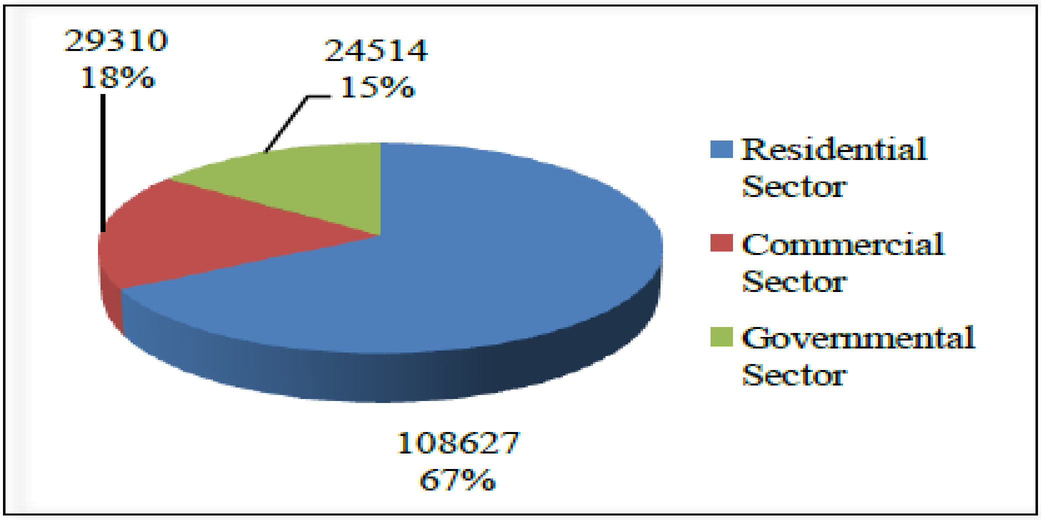


Figure 2.9: Energy consumption by different sectors in the Kingdom of Saudi Arabia in 2010 (Al-Ghamdi and Al-Feridah 2011).

The demand for electricity in residential buildings in Saudi Arabia may be grouped into several areas that include the power demand in Saudi Residential buildings can be categorised into principal areas: lighting, water heating, air conditioning, appliances and other sources, with air-conditioning accounting for the majority of consumption (figure 2.8)

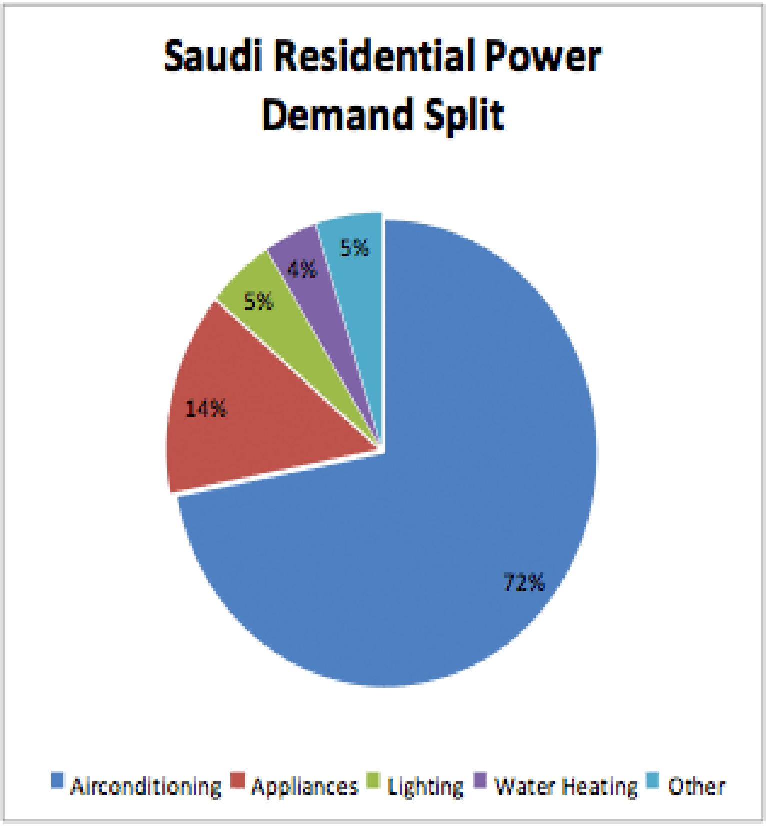


Figure 2.10: Saudi residential power demand split (Zawya 2012).

A government funded survey established that about 60 percent of the overall energy consumed during summer is utilised for air-conditioning appliances (Alrashed and Asif 2014). According to the Ministry of Water and Energy in Saudi Arabia, energy consumption within the kingdom has experienced a 35 percent rise in the last 2 decades, mainly because heavy usage of air-conditioners during the summer period. Therefore, it is important for KSA to improve electricity consumption behaviours within residential houses before proceeding to energy effective buildings.

Indeed, KSA has emerged as the highest energy consumer with an energy consumption increasing to about 3 million equivalent barrels per day (ebpd) from 2.92 ebpd, as indicated by OAPEC (Organization of Arab Petroleum Exporting Countries) report. Oil products have been found as the key component of the energy mix as consumed by the country (Saudi Gazette 2011). Therefore, electricity provision for residential building is a major problem that Saudi Arabia is still struggling to overcome, with experts warning that the demand will reach 120 GW in 2050; this implies that 8 million barrels would be required on a daily basis. The high fossil fuel demand would exert pressure on not only Saudi Arabia by the entire globe. In 2012, KSA led as the global main producer as well as exporter of petroleum liquids; in 2009, it was ranked position 13 in terms of large total globally energy, of this, petroleum-based energy accounted for 60 percent (Al Surf, Susilawati and Trigunarsyah 2014).

In the past few years, the KSA's per capita oil consumption has been the highest than other countries, with 4 million oil barrels consumed every day; this translates to an annual consumption of around 1.5 billion oil barrels, which means every household consumes 48 oil barrels annually. In contrast, the United States consumes 9 oil barrels annually, whereas the consumption for Japan is 5 oil barrels annually. Lack of conservation and preservation has characterised the consumption of KSA's premier income source; the situation is worsened by lack of alternative means of transport in Saudi Arabia. In many countries, large quantities are consumed by buildings, but in KSA, 80% of energy generated is used in housing, with air-conditioning consuming 70% of the energy. The excessive energy consumption in the KSA can be attributed to two factors: first, Saudi Arabia lacks stringent regulations that usually help constructors to adopt a particular insulation design that is consistent with conservation of energy; secondly, there are no specific laws that regulate the installation of cooling systems utilised in buildings, thus contributing to extravagant energy consumption (Al Surf, Susilawati and Trigunarsyah 2014).

2.6.5 Causes Leading to Increased Demand for Power and Electricity in Saudi Arabia

Saudi Arabia was the largest global producer and exporter of petroleum liquids in 2010. Russia was the only country, which could be compared to it in terms of crude oil production. The economy of Saudi Arabia is largely dependent on production of crude oil; 80-90% of the country's income derived from revenues associated with production and export of oil. The KSA has focused on expanding oil production because the targeted production is already attained Aljebrin 2014).

Studies show that the increasing energy demand in Saudi Arabia may be caused by several factors: the rapid population growth that stands at 3.2 percent annually (Ministry of Planning 2010), the increased power connections to many clients, the industrial development and various development projects such as rural electrification. Additionally, consumer's behaviour could be attributed to low energy costs, which encourage higher energy wastage levels, thus contributing to the rising energy demand being experienced (Obaid 2011). A total energy quantity of 114, 161 GWh was consumed by users, and at the close of 2010 this had escalated to 212, 236 GWh indicating an 8 percent (SCECO 2010). The rise in energy consumption from various sectors from 2000-2010 in KSA is illustrated in table 2.4 below.

Table 2.4: Increase of consumption of electric power from 2000 to 2010 in Saudi Arabia (Al-Ghamdi and Al-Feridah 2011).

	2000 (GWH)	2010 (GWH)	Increased (%)
Residential	56,063	108.627	93.7
Commercial	9,969	29,310	194.0
Governmental	13,896	24,514	76.4

It is clear that increasing demand for electricity in Saudi Arabia is caused mainly by households. Enhancing changes in behaviour to decrease the consumption of electricity is a difficult exercise, and on the other hand, increasing production of electricity is an easier alternative (Hertog and Luciani 2009). Another illustration for the increasing electricity consumption from various sectors that include residential, commercial, governmental, industrial and agricultural sectors in KSA from 2002-2006 is indicated in figure 2.9.

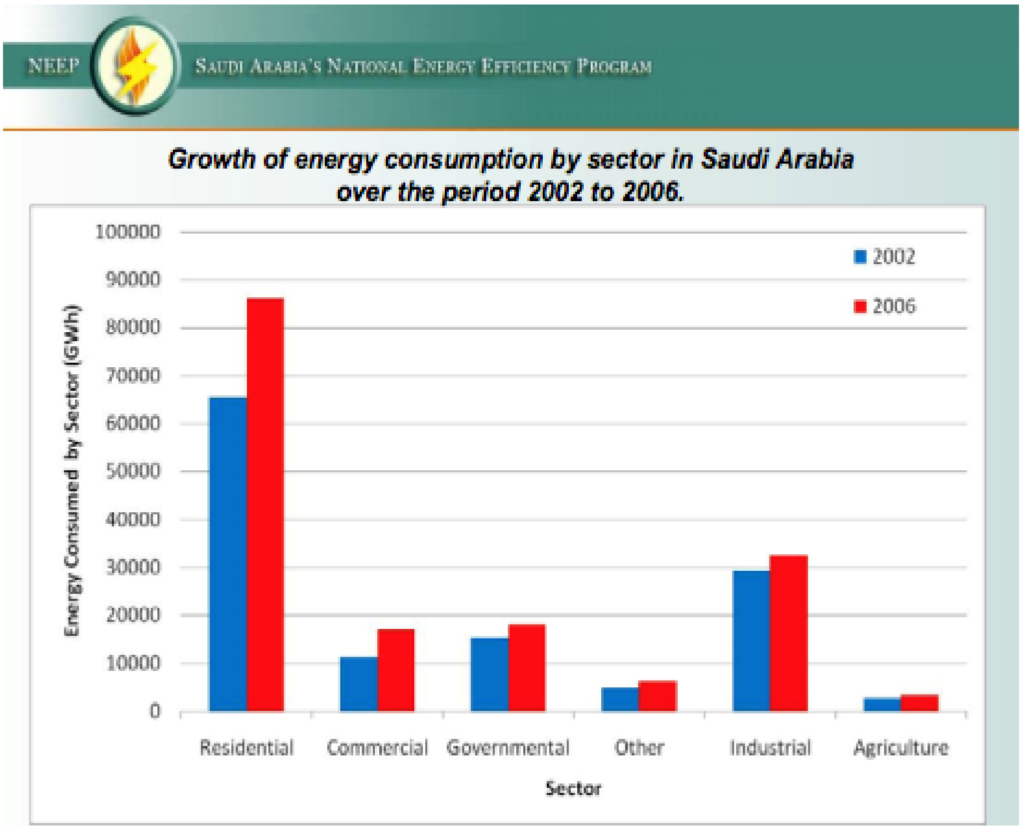


Figure 2.11: Growth of energy consumption by sector in Saudi Arabia 2002-2006 (Hertog and Luciani 2009).

In summary, it can be inferred that the major causes of increased electricity consumption in Saudi Arabia in the last 10 years are: an increase in infrastructure, building projects and industrial city projects, a rapid growth of population at 3.2 percent (Ministry of Planning 2010), lack of knowledge amongst builders coupled with lack of an energy-saving culture in buildings; and finally, the effect emanating dynamic culture regarding the energy efficiency and design (Al-Ghamdi and Al-Feridah 2011).

2.6.6 Energy Efficiency and Carbon Dioxide in Saudi Buildings

The establishment of SAEEC (Saudi Arabia Energy Efficiency Centre) is considered a major feat. The centre's responsibility will entail overseeing technology efficiency as well as conservation policies required for energy performance. The NEEP (National Energy Efficiency Program) came up with 8 objectives in 2008 aimed at reducing electricity demand and consisted energy audit services, offering assistance to the industry, effective consumption of fossil fuels such as gas and oil, efficiency standards and labels for application, construction codes alongside technical guidance and management. The consumption of energy, particularly electricity in Saudi Arabia has been rising significantly in recent years. The highest demand has been experienced in agricultural, services and residential sectors (The Saudi Energy Efficiency Center 2012).

The carbon dioxide (CO_2) and energy patterns in KSA indicate that energy consumption in the country is increasing at a faster rate compared to its Gross Domestic Product (GDP). This has in turn increased the major and overall energy demands, which differs from the existing pattern observable in various countries globally. Notably, this pattern can be attributed to the country's development dependency on energy demanding industries, alongside living standards that rely heavily on energy consumption in transport and buildings, which is further influenced low energy costs (The Saudi Energy Efficiency Center 2012). Carbon dioxide (C02) emission changes between 1990 and 2011 in various countries including the KSA are illustrated in table 2.5 (Olivier, Janssens and Peters 2012).

Table 2.5: CO_2 emissions in 2011 (million tonnes CO_2) and CO_2/capita emissions, 1990–2011 (tonne CO_2/person) (Olivier, Janssens and Peters 2012).

Country	Emissions 2011	Per capita emissions				Change 1990–2011	Change 1990–2011 in %	Change in CO_2 1990–2011 in %	Change in population 1990-2011, in %
		1990	2000	2010	2011				
Annex I*									
United States	5420	19.7	20.8	17.8	17.3	-2.4	-12%	9%	19%
EU27	3790	9.2	8.4	7.8	7.5	-1.7	-18%	-12%	6%
Germany	810	12.9	10.5	10.2	9.9	-3	-23%	-21%	4%
United Kingdom	470	10.3	9.3	8.1	7.5	-2.8	-27%	-20%	8%
Italy	410	7.5	8.1	6.9	6.7	-0.8	-11%	-4%	7%
France	360	6.9	6.9	6.1	5.7	-1.2	-17%	-9%	10%
Poland	350	8.2	7.5	8.8	9.1	0.9	11%	11%	1%
Spain	300	5.9	7.6	6.3	6.4	0.5	8%	29%	16%
Netherlands	160	10.8	10.9	10.5	9.8	-1	-9%	2%	11%
Russian Federation	1830	16.5	11.3	12.4	12.8	-3.7	-22%	-25%	-4%
Japan	1240	9.5	10.1	10	9.8	0.3	3%	7%	3%
Canada	560	16.2	17.9	16	16.2	0	0%	24%	19%
Australia	430	16.0	18.6	17.9	19.0	3	19%	57%	24%
Ukraine	320	14.9	7.2	6.7	7.1	-7.8	-52%	-58%	-14%
Non Annex I									
China	9700	2.2	2.8	6.6	7.2	5	227%	287%	15%
India	1970	0.8	1.0	1.5	1.6	0.8	100%	198%	30%
South Korea	610	5.9	9.7	12.2	12.4	6.5	110%	141%	11%
Indonesia	490	0.9	1.4	2	2.0	1.1	122%	210%	24%
Saudi Arabia	460	10.2	13.0	15.8	16.5	6.3	62%	181%	43%
Brazil	450	1.5	2.0	2.2	2.3	0.8	53%	106%	24%
Mexico	450	3.7	3.8	3.9	3.9	0.2	5%	45%	27%
Iran	410	3.7	5.2	5.4	5.5	1.8	49%	100%	27%
South Africa	360	7.3	6.9	7.1	7.2	-0.1	-1%	35%	27%
Taiwan	270	6.2	10.5	11.7	11.8	5.6	90%	119%	13%
Thailand	230	1.6	2.7	3.3	3.3	1.7	106%	155%	18%

2.6.7 Energy and Technology

The use of energy and technology can be reflected through the school building designs in the country. Passive cooling and energy conservation design strategies have been implemented in the school buildings in Riyadh which is the capital city of the country (Abanomi and Jones 2005). Building envelope designs have also been considered in several schools in the country that disconnects the outer environment from the inner environment of a building. This considerably affects the thermal performance of the building allowing energy efficiency as well as comfort for the residents of the building (Al-Rubaih 2008). Retail stores and supermarkets in the country are also modelled in a manner such that the energy consumption can be reduced, decreasing the costs of power and energy as well (Alzain, 2006, pp.19-33). Even in single family houses, measures have been initiated towards having a possible energy saving and saving of power and electricity through the appropriate use of thermal insulation in the buildings (AlGhamdi and Al-Feridah 2011).

2.7 Building Materials and Environment

Building materials should undergo processing prior to their use on a building, therefore, require producing waste and energy. Thus, the choice of materials affects the building's environmental impact. The processing differs from minimal, for instance, a traditional house constructed with local materials, to extensive, for instance, a pre-fabricated building (Roaf 2007).

All materials have an environmental impact, encompassing basic materials, for instance, 5% of the overall manmade carbon dioxide emissions emanate from cement production; 2.5% is caused by chemical reactions during the cement manufacturing process, whereas the remaining 2.5% emanates from the energy utilised in cement production (Roaf 2007).

Factors, which are influenced by the materials' quality include:

- The energy required during the production of material
- Carbon dioxide emitted in the process of material manufacture
- Impact on the surroundings emanating from the materials' extraction (for instance, oil spillage from transporting pipelines, wood harvested from forests and quarry mines among others).
- Materials' toxicity
- Transportation required in manufacturing and delivering material to the site
- Pollution level caused by the choice of material as well as design decisions, they include:

- Architectural component detailing and position
- Maintenance required alongside materials of doing it
- The role of the materials in reducing the building's environmental impact (for instance, insulation)
- Design flexibility in adapting to varying uses over time
- The material's lifespan and its recyclable potential upon demolition of the building (Roaf 2007).
-

2.7.1 Building Materials in Saudi Arabia

Saudi Arabia is endowed with different natural resources for producing high-quality materials, for instance, different kinds of glass, composite materials, ceramics, gypsum, reinforced steel, granite panels, bricks, marble, tiles, concrete and cement (Kingdom of Saudi Arabia Ministry of Economy and Planning 2010). The aforementioned building materials are mainly utilised in the construction sector in the KSA. Based on industrial census data, 533 factories existed in 2004 (refer to table 2.6).

Table 2.6: Factories and labour force by building materials segment (King Abdulaziz City for Science and Technology, Ministry of Economy and Planning 2010).

Description	Factory (No.)	Labor Force (People)	Investment Value (Million $)
Mosaic and pavement tiles	59	3350	521.13
Stones, marbles and granite	90	7202	1106.51
Cement	9	7666	14258.45
Gypsum products manufacturing	12	1058	431.74
Precast concrete panels, posts etc.	67	6860	1417.62
Fiberglass, Rockwall and glass	63	5322	1780.2
Clay, sand & cement bricks, and curbs	233	11103	3069.73
Total	**533**	**42561**	**22585.38**

The cement sector plays a critical role in the building materials' industry in Saudi Arabia. Seven firms are involved in the manufacture of Portland cement, with annual production standing at 21.5 million tonnes. Other firms are engaged in the production of crushing clinker and white cement. The annual production capacity for such materials is about 370,000 tonnes. The various cement firms serving the sector are Southern Province Cement Company, Saudi Cement Company, Eastern Province Cement Company, Yanbu Cement Company, Arabian Cement Company and Qasim Cement Company.

The main industries involved in the manufacture of building materials are National Gypsum Company, National Marble and Granite Company, Qanbar Dywidag Precast Concrete Company, Saif Noman Said and Partners and Al-Rashid A Betong Company (Shoult 2006).

2.7.2 The External Wall Materials of Saudi Residential Buildings

Almujahid and Keneesamakandi (2013) conducted experimental studies on a custom built room with various external walls, as used in Saudi Arabia. In this study, a hybrid outer wall construction was used. The research also stated that cement-based materials are used for the construction of buildings, particularly houses, in Saudi Arabia, with hollow building blocks being the most commonly used wall construction materials. These cement blocks are 20cm thick, with surface dimensions of 60 X 20 cm2.

Azouz (2013) carried out research to test and analyse the potential energy savings for a typical existing residential apartment building in Jeddah, Saudi Arabia. This research identified that the existing external wall construction in Saudi residential buildings consists of three basic layers: external cement plaster, hollow red clay brick, and interior cement plaster.

Another study by Al-Ghamdi and Al-Feridah (2011) used brick, concrete blocks and plaster for the external wall in a simulation experiment for a typical house in Dhahran, Saudi Arabia.

A recent article by Alidroos and Krati (2015), regarding residential buildings in Saudi Arabia, used a baseline energy model for a detached single family home in order to develop energy efficiency options for the design of villas in KSA. The features of the energy model for a typical villa were modelled on the findings of a study by King Abdullah City for Science and Technology (KACST), which was a study looking at a new building to be built in KACST. The information for this particular article was obtained from the following sources: a review of the building plans with local authorities; and site visits to the building under construction and interviews with the owner and contractors. The model defined the dimensions of the building materials for the wall as: 20mm plaster outside, 200 mm concrete hollow blocks and 20 mm plaster inside. Table 2.7 details some of the common wall structures used in buildings in Saudi Arabia, with their thermal characteristics (e.g. the conductance U-value, thermal resistance) (Eball 2002).

Table 2.7: Structures and thermal characteristics of walls used mostly in Saudi Arabian Residential Buildings (Eball 2002).

Wall Type	Thickness of wall components (m)	Thermal conductivity of wall components W/mK	Wall conductance U (W/m^{2}K)	Wall Resistance (m^{2}k/w)	Density kg/m^3	Specific heat J/kgK
Wall I						
External Plaster	0.02	1.20	2.25	0.44	2000	1000
Hollow bricks	0.20	0.90			1500	840
Internal Plaster	0.03	1.20			2200	1000
Wall II						
External Plaster	0.02	1.20	2.98	0.336	2000	1000
Concrete	0.20	1.75			2410	880
Internal Plaster	0.03	1.20			2000	1000
Wall III						
Stone	0.20	1.70	2.28	0.438	2250	840
Concrete	0.07	1.75			2410	880
Hollow bricks	0.20	0.90			1500	840
Plaster	0.03	1.20			2000	1000
Wall IV						
Stone	0.20	1.70	1.62	0.617	2250	840
Concrete	0.20	1.75			2410	880
Air gap	0.05	0.28				
Bricks	0.10	0.90			1500	840
Plaster	0.03	1.20			2000	1000

It is clear that the basic external wall structure has not changed in Saudi Arabia over the last decade. The literature review confirms that the outer wall of a typical Saudi house has the following main layers: plaster from the outside, hollow brick, then plaster again inside.

2.7.3 Thermal Insulation for Saudi Buildings

Insulation material increases the building’s sound and thermal insulation through decreasing of transmission heat loss as well as leading to higher surface temperatures, and minimizing ventilation heat loss during winter. This material shields from frost and condensation, whilst enhancing hygienic and comfortable indoor conditions. The effect of insulation on materials emanates from low heat (thermal) conductivity for enclosed air, with a huge effect when several smaller air pores exist, especially when they are distributed evenly (Husladen, Saldanha and Liedl 2006).

These layers of thermal insulation may be placed on the facades’ exterior or interior. Beginning from the side with rooms and moving to the exterior, the material layers that form the wall ought to be wide open to diffusion, to allow free movement of moisture. Where the floor and wall joins exist, thermal bridges should be avoided (Husladen, Saldanha and Liedl 2006).

Although insulation is not influenced by thermal insulation positioning, external insulation produces lesser thermal bridges and provides effective protection from reductions in temperature. Thermal storage masses are efficient in the building’s interior, and may enhance indoor conditions during summer. For internal insulation, where thermal storage mass is non-existent, rarely used rooms may be warmed rapidly during winter (Husladen, Saldanha, and Liedl 2006).

The specifications for home insulation may vary; the key entails choosing the appropriate insulation for a specific climate and the existing source of local energy (Roaf 2007).

Because various insulation products exist at different prices, by combining appropriate building envelope and human creativity, people are capable of living in any location with minimal fossil fuel requirements (Roaf 2007).

The loss of heat through walls may be reduced by increasing insulation, even though a limit to the required thickness for this insulation exists, depending on many factors such as the use and construction of the building, climate, fuel price and cost.

The figure below provides an illustration of several situations, including low cost of energy and high cost of energy. From the figure, it can be inferred that beyond 150 to 250 mm of insulation, the investment lacks financial significance; while for the high cost of insulation and low cost of energy, the maximum insulation thickness stands at around 30mm. The energy manager will face a challenge in the sense that despite the energy percentage and costs of insulation being identified, predicting the way energy cost would change is cumbersome. A huge change in the cost of fuel may have a significant impact on the insulation economics, as illustrated in figures below (Harris 2012).

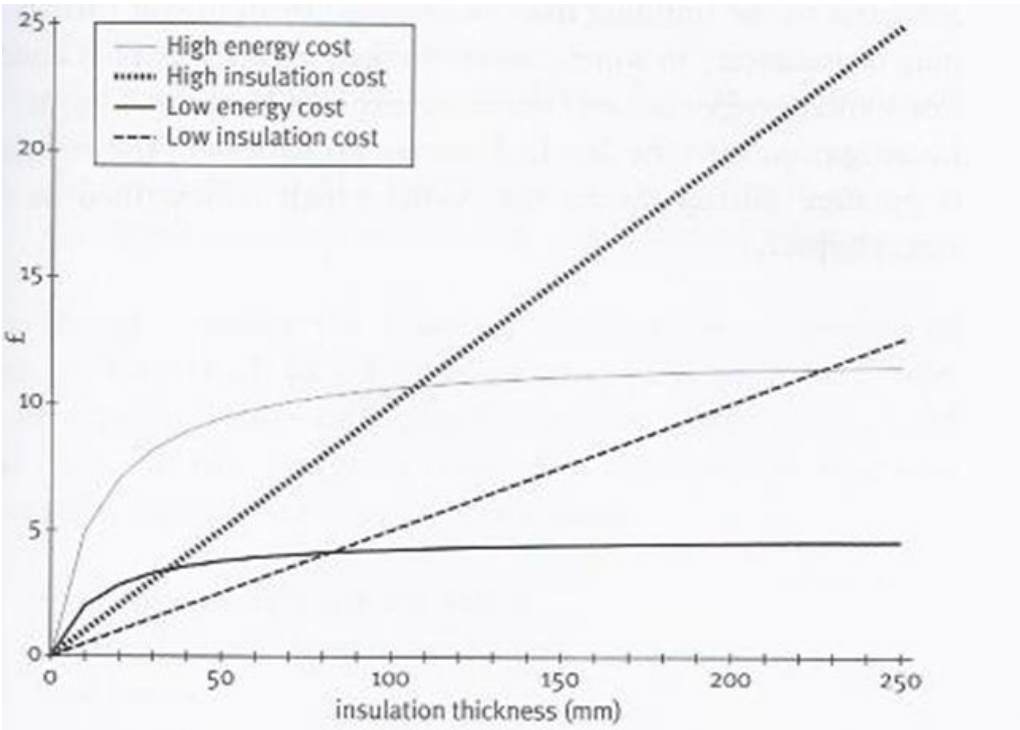


Figure 2.12: High energy/ Insulation cost and low energy/ insulation cost (Harris 2012).

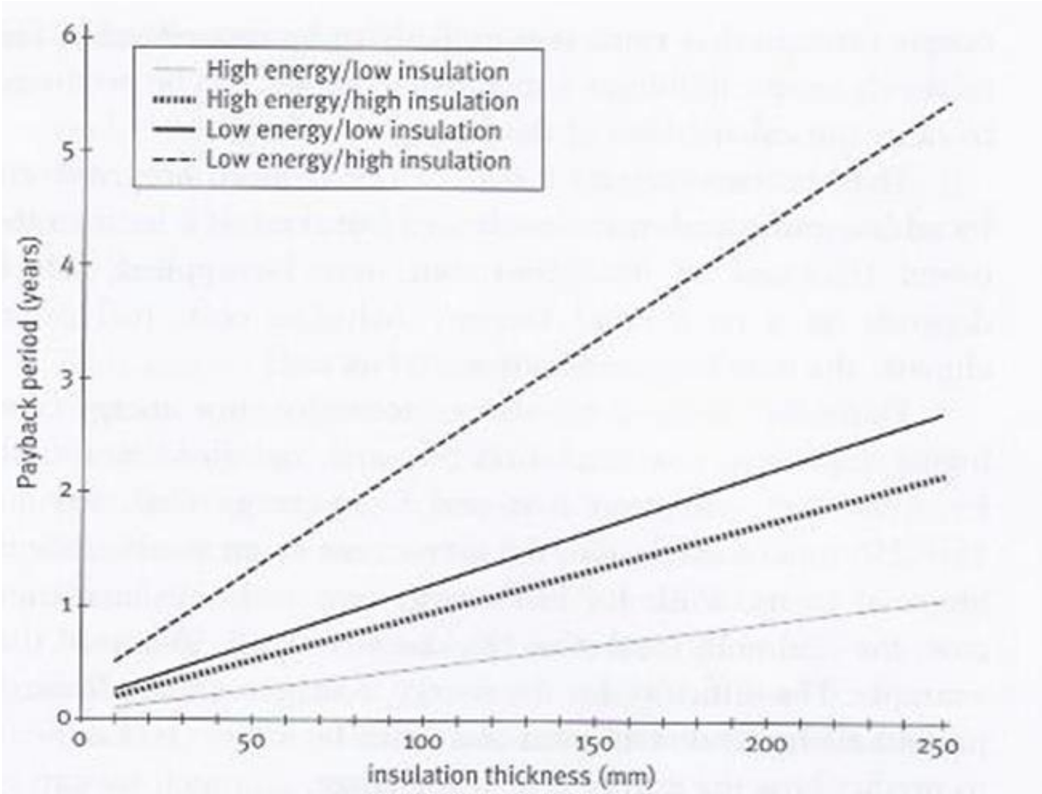


Figure 2.13: Payback periods in years for insulation (Harris 2012).

Several studies have investigated the maximum thickness as well as thermal insulation positioning for Saudi buildings. An investigation was undertaken to examine the impact of three separate roof insulation and wall thicknesses (10cm and 5, 7.5cm) in the climate of Riyadh, in line with the heating and cooling loads, with the energy simulation being undertaken by the NBSLD (National Bureau of Standards Load Determination) (Alaidroos and Krarti 2015).

The investigation revealed that the suitable "energy performance" for heat load cooling existed during thermal insulations use (5 to 10cm thick), situated within the exterior wall's outer layer. On the other hand, in air-conditioned environments, insulation that is installed within the wall's internal layer had better performance compared that located in wall's external layer (Alaidroos and Krarti 2015).

Additionally, the study examined building materials such as pre-fabricated walls, sand lime bricks, concrete blocks and clay bricks. The performance of clay bricks was the best in terms of operating costs and capital investments, and with regard to the typical residential buildings in Saudi Arabia (Alaidroos and Krarti 2015).

A typical Saudi residential building uses about 185. 4 kWh/m^2, and the increased energy consumption arises from lack of roof and wall thermal insulation, and inefficient single glazed windows. An energy reduction ranging between 21percent and 37 %, was identified after shading devices were installed, windows were upgraded to double-glazing as well as when an on-site photo-voltaic system (PV) was used (Alaidroos and Krarti 2015).

2.7.3.1 Common Thermal Insulations Materials in Saudi Arabia and Payback Periods

Insulation materials that are commonly used in the KSA, in accordance with Saudi Consolidated Electric Company (SCECO) and EAA (Electrical Affairs Agency) [1995] recommendations include:

1. Polyurethane / Polyisocynurate foam: a natural material made from oil, which provides an effective and very dense insulation, with minimum water penetration. It is usually used for insulating sidewalls.
2. Expanded and extruded polystyrene is a natural material with minimum water absorptivity and heat conductivity. Its main feature is the lightweight; thus it does not exert significant weight on the building. It is mainly utilised for wall and roof insulation.
3. Fibreglass whose thermal conductivity is low because of fibre density; the higher the density, the minimum the level of heat conductivity. It is utilised for AC ducting system insulation.
4. Mineral fibre is an organic material made using furnaces for melting natural minerals. Its thermal (heat) conductivity is low (Eball 2002).

The aforementioned forms of heat (thermal) insulation would be subjected to test to establish the one that is ideal and energy-efficient for residential buildings in Saudi Arabia.

An investigation conducted by Eball (2002) to examine Saudi's major cities of Dammam and Riyadh indicated that the periods for payback in Riyadh stood at 2.3 to 2.7 years for polystyrene whereas that for polyurethane was 2 to 2.5, depending on the kind of "wall structure". The study affirmed that residential building insulation is affordable, thus would offer the needed comfort and reduce air-conditioning use in residential buildings in Saudi Arabia.

2.8 The Impact of Shading Devices and Increasing Thermal Mass in Saudi house

Generally, the annual energy consumption in villas is not reduced significantly by shading devices, with the highest reduction attained of 6.3 percent emanating from Jeddah's 1.0m overhang. It is very clear that the reduction in energy consumption after applying the shading device is very low and it did not show a significant impact (Alaidroos and Krarti 2015). Villas with huge windows would experience considerable improvements when shading devices are used as illustrated in figure 2.14.

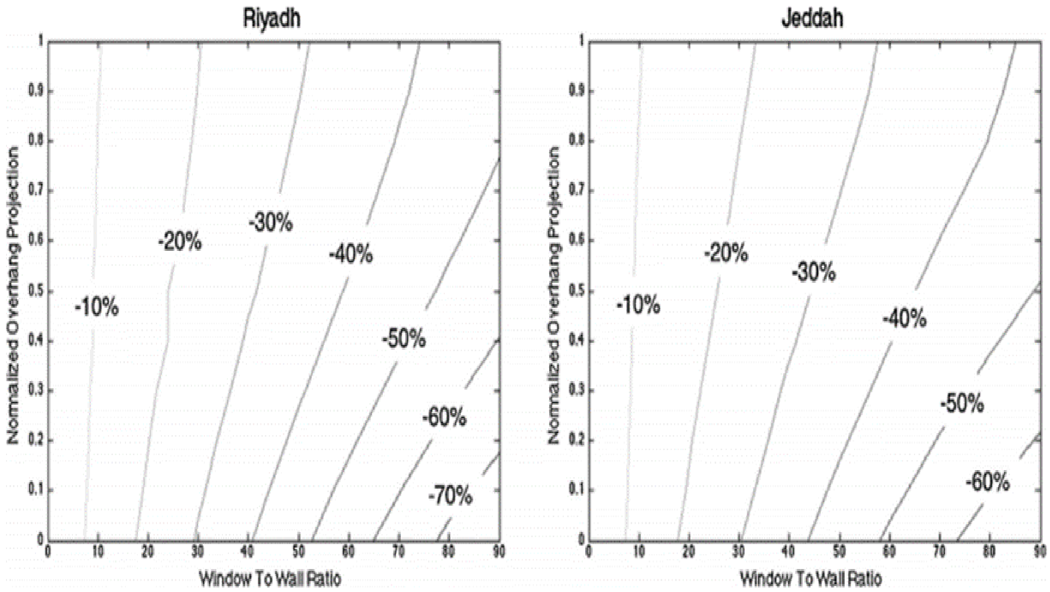


Figure 2.14: Impact of WWR and the length of overhang on energy savings for a villa located in Riyadh and Jeddah (Alaidroos and Krarti 2015).

It is imperative to examine how energy consumption is affected by thermal mass, particularly changing the villa's external concrete wall thickness from 5cm-40cm, to establish if thermal mass has a significant effect on overall energy consumption of the villa. The outcomes reveal that thermal mass increment in Abba produced significant impact because of the mild climatic conditions. On the other hand, thermal mass provides the minimum energy savings within the city of Jeddah that has very hot climatic conditions. The outcomes were as per the expectations because a thermal mass performs effectively in climates with huge variations between night time and day-time temperatures, permitting heat storage that may be released (Alaidroos and Krarti 2015).Therefore, because of the small reduction in energy consumption achieved, shading devices are excluded from the current research.

2.9 Material Selection and Cost Sensitivity Analysis

The energy efficiency cost mechanisms play a critical role in the creation of best designs of constructing insulation systems, through the cost analysis lifecycle. However, according to contractors as well as other sectors of the economy, a clear definition for material costs is non-existent (for instance, glazing and thermal insulation), with differences across Saudi regions (Alaidroos and Krarti 2015). The existing standard rules of selecting materials apply, that is use local and natural materials extensively (Roaf 2007).

2.10 Building Structure in Saudi Arabia

Since the government has now developed a serious interest in the development of green buildings in Saudi Arabia, the structures of the buildings are also being seriously investigated. The government has planned for certain preliminary standards for the construction of green buildings (Green Building in Saudi Arabia, 2010).

The structures are planned such that the cost of the construction and that of power and consumption of power may be reduced. Metal and glass panels can be used on the building facade instead of concrete blocks (Green Building in Saudi Arabia, 2010). When the buildings become old, the panels are able to removed, reinstalled and painted in new residential buildings, which saves a large amount of money. The buildings could contain devices to minimize the entry of harmful rays, keeping the buildings cool in the summer, warm in the winter such as using solar reflective glazing presented in figure 2.15 (IowasBestWindows, 2012) and double glazing or triple glazing presented in figure 2.16 (NEP Energy Services,2013).

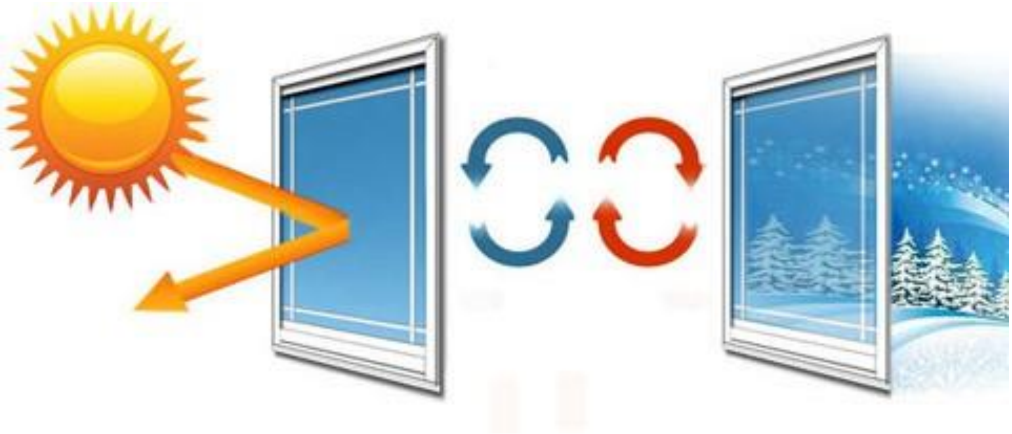


Figure 2.15: Glass energy (IowasBestWindows, 2012).

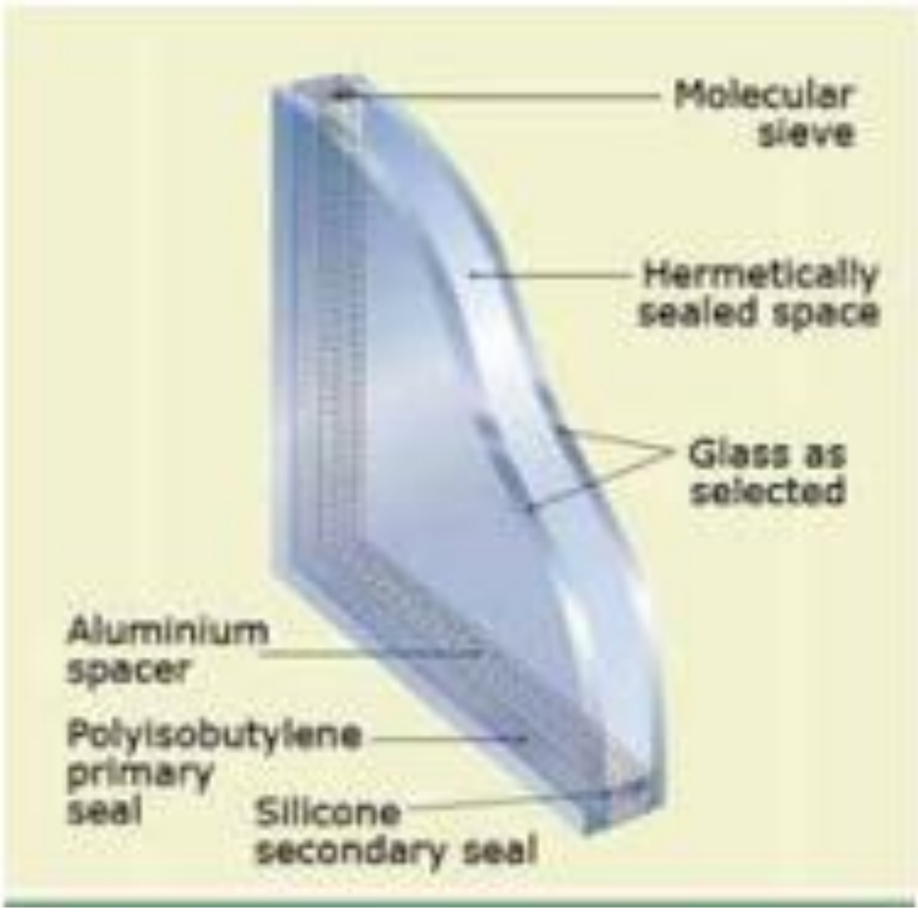


Figure 2.16: Double glazing (NEP Energy Services, 2013).

All of these have become increasingly important factors as Saudi Arabia moves forward in its development. (Green Building in Saudi Arabia, 2010).

2.11 Building Systems in Saudi Arabia

Various committees are working together towards the successful implementation of green building development in Saudi Arabia. There are also other committees that include external relations committee, government relations committee, membership committee, outreach and marketing committee, and technical and training committee that are associated with the building systems in the country (Canadian Trade Commissioner Service 2014). Saudi Arabia has been determined to show a positive and increasing interest in green building technology. Considering the design, the building and the operations of such buildings, there are several challenges that the industry is encountering with respect to the legal implications as well as development and improvements in the systems (Susilawati and Al surf 2011). However, the country has its focus on developing the building systems and has also considered intelligent integrated systems for the construction of green buildings thus trying to determine intelligent green solutions for different types of buildings (Banani 2011.).

2.12 Buildings and Water in Saudi Arabia

The recent situation of the Middle East in general is a combination of rising temperatures and expanding populations which mean that water will become increasingly scarce in the region. In fact, less wealthy countries in the Middle East are looking more seriously to reduce water demand and manage this important resource. In the Gulf countries there are concerns that the increasing salinity of water will make desalination in the future more expensive and difficult because Gulf water is already highly saline. In addition, the hot climate in the Gulf is increasing the evaporation rate (The Economist Intelligence Unit Limited 2010) Table 2.8 shows water demand in selected Gulf countries including Saudi Arabia from 2000 until 2020.

Table 2.8: Projected water demand in selected GCC countries, millions of imperial gallons, 2000-2020 (The Economist Intelligence Unit Limited, 2010).

Country	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020
Saudi Arabia	170,476	188,604	216,205	225,479	240,206	246,065	266,656	290,081	315,564	343,286	373,444
Bahrain	27,930	30,387	33,877	36,664	43,181	43,181	43,181	43,181	43,181	43,181	43,181
Qatar	32,303	34,843	34,918	36,116	48,643	56,222	65,111	75,406	84,206	94,116	104,780
Dubai	41,354	49,081	58,357	72,588	91,653	98,178	108,964	123,355	133,361	143,970	155,109

Considering the available water resources in the country, the need for green building also becomes more significant. Studies reveal that there is a huge pressure associated with the natural resources available in the country. The availability of water per person in a year has been recorded to be the lowest in the world, yet the consumption levels are very high. This reflects the need to improve environmental performance through a green buildings approach (Tassabehji 2011).

2.13 Air and Indoor Environmental Quality

The quality of air and the indoor environment generally have significant effects on the health and activities of residents or office staff of any building. Thus green buildings consider these issues seriously in their standards of building construction. With green revolution green plants can be used to make work environment healthy as well as positive. Plants have the ability to reduce the volatile organic compounds prevalent in high concentrations in the air, they can also release moisture in the air which in turn absorbs heat and noise in the environment. The productivity of the workers has been shown to enhance in the presence of green plants (Green Building Council of Australia 2010). Green cleaning products have the ability to reduce health hazards, thus allowing enhanced health of workers by improving the quality of air in the environment, and reduce the level of pollution as well. Green buildings enable these factors and if properly maintained, can protect the buildings from common pollutants like mould, mildew, dust mites and cockroaches that generally appear as a result of excess moisture. Indoor pollution is largely caused by the building materials used for the construction of the buildings. Thus implementation of green building technology in countries like Saudi Arabia can provide the country with benefits through development of pollution free buildings and hence needs to be incorporated in the systems accordingly (Green Building Council of Australia 2010).

Thus from the above literature review from the different studies and reports as obtained, it can be reflected that the importance and benefits of green revolutions and the use of green building technology in Saudi Arabia.

2.14 Techniques for Reducing Energy Consumption

The general strategy for reducing energy consumption should be to:

- Reduce loads where possible
- Use efficient plants to service the load
- Use efficient source of energy to operate the plant

Once an energy audit has identified the source of energy waste, it is important to identify techniques to reduce it (Harris 2012). These can be grouped under the following headings:

- Building fabric
- Building service plant
- Controls
- Management of the building
- Energy supply

2.14.1 Building Fabric

The majority of energy in buildings is consumed in the form of heating, cooling and lighting, and is affected by the form and construction of the building, which cannot usually be changed. However, by refurbishing a building, there may be opportunities to add a conservatory or atrium, add roof lights the or light shelves to improve daylighting, or even to change proportion of glazing on the façade. All of these factors could improve a building's energy performance, though the primary opportunity for change is through the addition of thermal insulation (Harris 2012).

Chapter 3

Research Methodology

3.1 Research Methodology

After discussing the aims and objectives of this study, the appropriate methodology is adopted to assist the researcher to achieve the research goals.

This chapter describes the methods and strategies used by implementing a variety of complementary research methods which will include quantitative data collection via the survey and qualitative research from interviews with specialists in residential buildings, observations and examination of documentary evidence. In addition, building energy consumption analysis will be carried out by using simulation software. The following figure shows the research methodologies used.

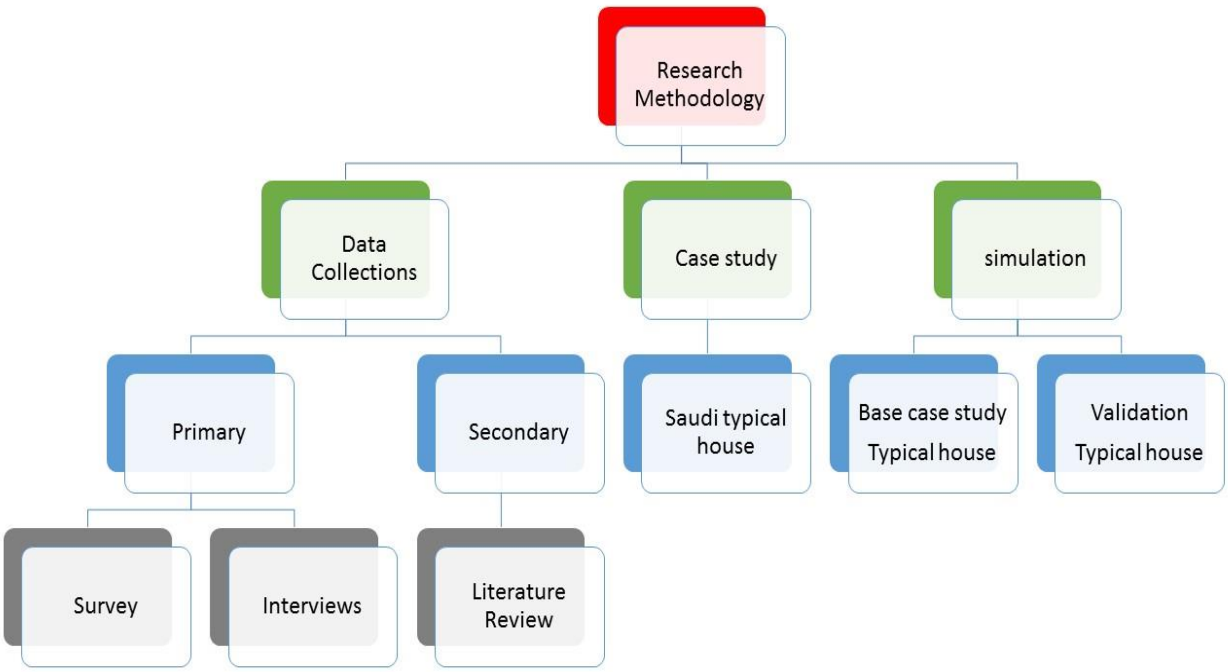


Figure 3.1: Research methodologies.

3.2 Data Collection

Data collection in this thesis is divided into two main sections: primary and secondary.

3.2.1 Primary Data Collection

Primary data collection in this research was gathered in two ways: firstly, a questionnaire prepared for interviews the field trip; secondly, a survey.

3.2.1.1 Interviews

This specific method was used to gather qualitative data in order to collect in depth and up to date information about Saudi residential buildings standards, building regulations, energy consumption, energy demand, governmental plans to face the energy challenges in the future, methods to save energy and other relevant technical data.

Interviews are one of the major methods that used in this research. It was performed during a field trip to Saudi Arabia (01/06/2013 – 31/08/2013) directly with specialists, experts, architects and engineers.

The interviews were with government, organisations, universities and company representatives who are qualified and inappropriate professional positions, having a good background regarding energy consumption/demand issues, building standards and regulations, energy efficiency and finally green buildings. Ten interviews and visits were performed in different regions and cities in the kingdom of Saudi Arabia. The interviews were of a semi-structured type; therefore, specific questions were prepared for each interview depending on the visit purposes and the interviewee knowledge and background. Ten visits were performed and the main aim of the interviews was to cover the research questions, missing data, collect newest data, and filling the research gaps (see appendix B). The details of each visit as well as the interviews finding and results detailed later in chapter 6.

The interviews and the questionnaire were divided and prepared for several visits to government and private companies. These interviews helped to obtain the newest data, thus developing the experience and achieving the research goals. The following chart 3.1 presents the interview process.

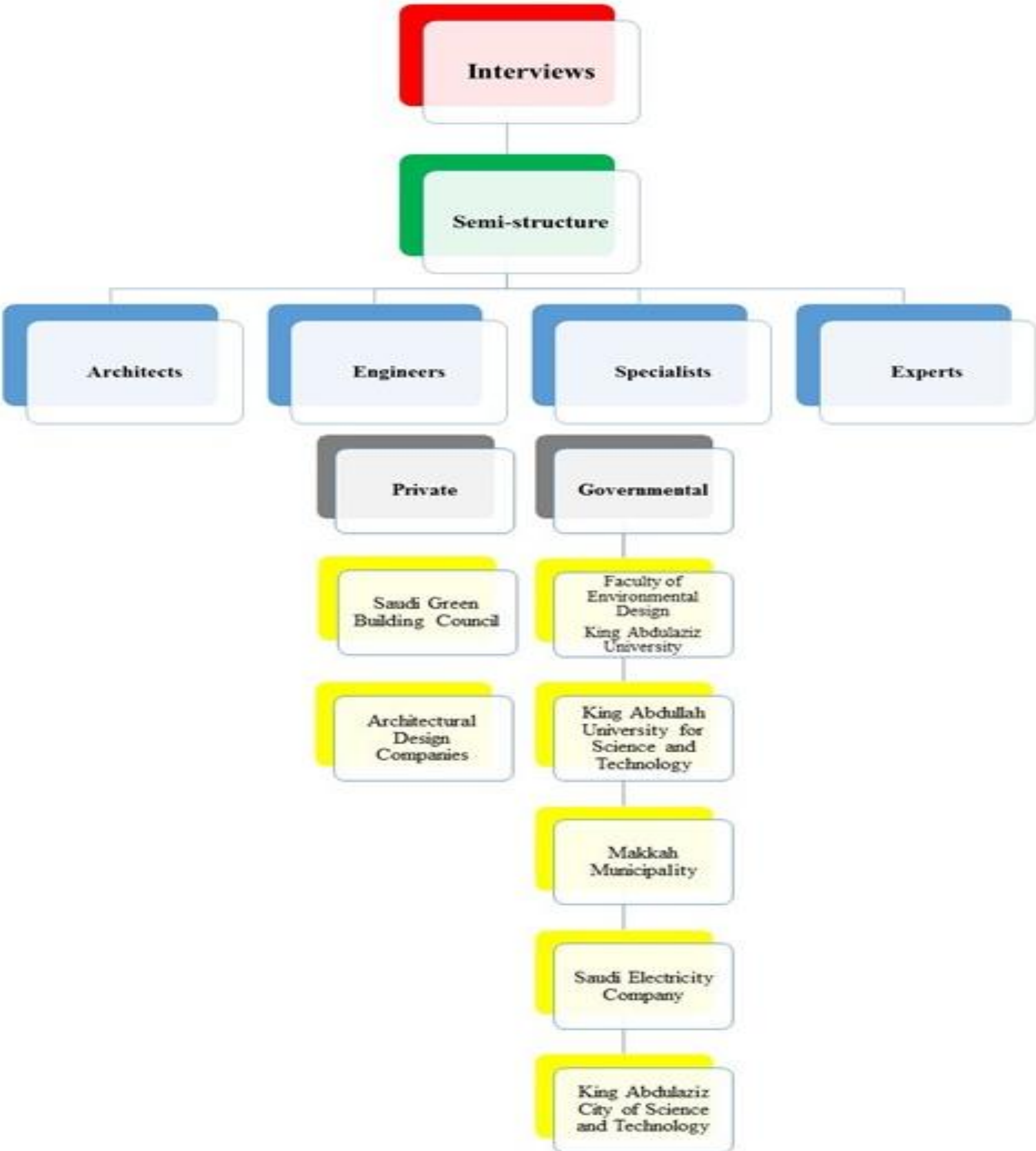


Figure 3.2: The interview process.

3.2.1.2 Survey

This specific method was used to collect quantitative data that generated numerical data regarding all energy consumption matters in Saudis homes.

A cross-section of residents in Saudi houses was used. The survey prepared to target different ages, educational levels and income. 190 participants completed the survey from the major Saudi cities. The survey included two parts, an optional part and a compulsory part, was designed by google drive and was sent via e-mail, Facebook, twitter and WhatsApp.

The survey aimed to find out the types of residential buildings in Saudi Arabia, types of air conditioning, electricity usage, thermal comfort and how Saudis deal with energy at home.

Moreover, it investigated the causes behind the high usage of air-conditioning in the Saudi residential buildings. In addition, the survey was designed to find out whether Saudis have some understanding of simple ways to lower electricity consumption in their homes. It also tested the ability of Saudis to change their behaviour and their willingness to get the best residential buildings, which are environmentally-friendly.

3.2.2 Secondary Data Collection

Secondary research refers to previous data that has been gathered using numerous studies and which is combined and evaluated in terms of objectives and aims identified at the commencement of the investigation.

Collection and validation of data from relevant sources is an easy task and offers a means in which the information could be compared. Data is obtained from different literature sources such as government publications, meetings with experts, journals and textbooks. A subsequent review would be undertaken to validate the information.

3.3 Case Study

This method was selected because it will help to understand the recent situation of residential buildings in the kingdom of Saudi Arabia regarding energy consumption and cooling load. The study will focus on different case studies, examples, and an examination of typical residential building materials and energy consumption from different zones and regions in Saudi Arabia.

The case study in this thesis is a typical Saudi residential building, in three main locations: Jeddah, Riyadh and Dammam. This case study is a new house design selected by the Saudi ministry of housing, who plan to build 500,000 units of it in all main cities in the kingdom to help the low and middle income to be home owners. The large numbers of this house planned make it essential that the building is as energy–efficient as possible. Any savings made could be replicated over half a million homes and could therefore represent significant national energy savings.

All the buildings details were used as inputs for later examination in the IES building energy simulation software. The details include the building drawings for plans, elevations and perspectives. In addition, it includes the building structure details alongside with most common external walls and thermal insulations in Saudi Arabia.

3.4 Simulation of Energy Consumption

The next phase of the research entails using a computer simulation program in understanding the energy-efficiency of Saudi residential housing through on-site assessments and energy simulation models. The analyses are intended at supporting the aims of the research and to provide clear design methods for present and upcoming eco-friendly residential buildings. The simulation entails investigation, measurement and recording of the geometric characteristics of buildings as well as energy consumption for cooling load.

IES energy simulation software was selected for this research because it is dynamic, accurate, friendly to user, and based on architectural drawings.

The energy simulation software used in the thesis is the main method in the research. It is used in two main ways. The first part focused on validation of the model by studying the results of cooling load of a typical house in Dhahran, Saudi Arabia which had been modelled using DOE energy simulation software and comparing it with the researcher's own IES results. This part is described in detail in chapter 7 under section 7.7.

The second part of the simulation examined the thermal performance of the most common external walls in Saudi Arabia in terms of energy consumption and cooling load. In addition, it investigated applying 0.50 m of polyurethane thermal insulation to the external wall in order to cut the cooling load. The following figure presents the simulation parts and purposes.

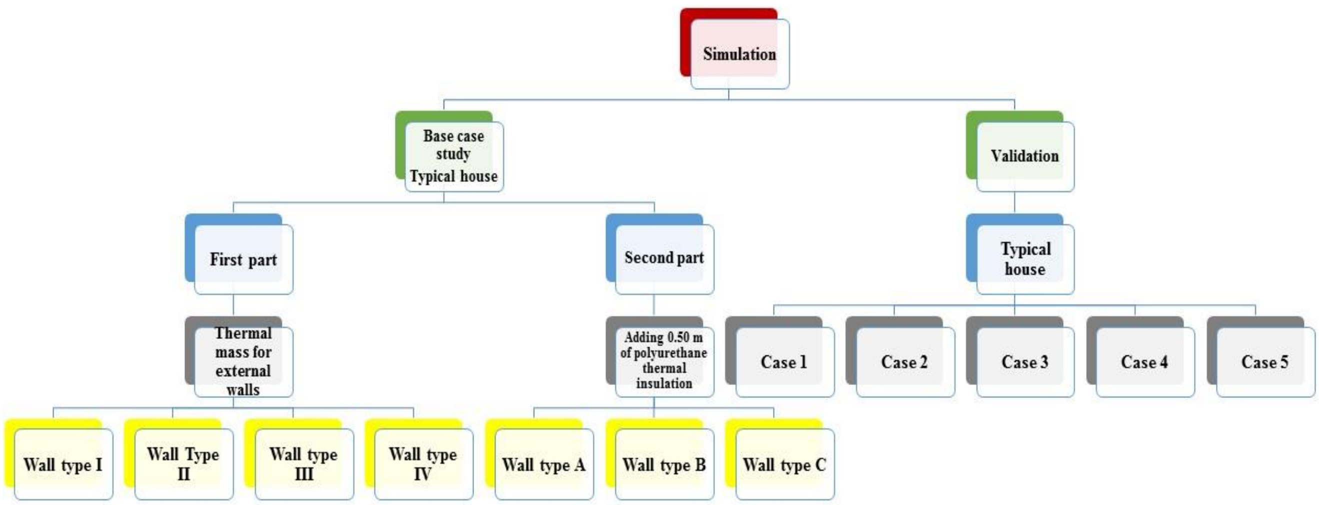


Figure 3.3: The simulation parts and purposes.

Chapter 4

Air Conditioning Chapter

4.1 Overview

Air conditioning refers to the process for altering air within a space to enable it suit the occupant's comfort. The main role of air-conditioning is to cool, even though all systems release the air whereas others provide heating or adaption to heat levels (Nicholas 2002).

A comfort level of 27^0C exists, and when the level is surpassed, which might occur because of maximum external temperatures as well as internal heat increments, thus cooling is required (Nicholas 2002). For instance, in summer, temperatures may hit 22^0C or higher, when such warm air finds its way into houses, temperatures increases because of heat gained from the sun, appliances, artificial lighting and people, by about 6^0C, thus pushing the temperatures above the required level. Office buildings could require cooling during winter, even though the external temperatures might be low because of optimum casual heat gain (Nicholas 2002).

Because of the low quantities of rainfall, low night time temperatures and high day time temperatures of the desert climate, countries such as Saudi Arabia require air-conditioning installation. The Saudi climatic regions may be divided into two major areas namely the interior and the coastal regions. Indeed, the average temperatures during summer in the middle of the day in Saudi Arabia are around 45 degrees Celsius, and heat increases immediately when the sun rises and continues until it sets. All the aforementioned factors explain why Saudi buildings require air conditioning (Weather Online 2015).

Rooms, which are vulnerable to extreme temperatures include:

- Those with potential of receiving high solar heat, for instance, rooms that face the south direction, especially those having big windows.

- Those having high-equipment densities, for instance, offices and computer rooms that rely heavily on information technology

- Those where humidity, dust and temperature (environment) sensitive function is undertaken, for instance, microprocessor manufacturing units and operating theatres.

4.2 Air Conditioning Systems

There are three major categories of air-conditioning systems:

- ➢ Local comfort cooling systems that are used for cooling the air in rooms to enable them have acceptable levels. The cooling system is installed in the room, and different types of such systems include:

- Window-sill air conditioners;
- Split systems;
- Multi split systems;
- Variable refrigerant flow-split systems

- ➢ Central air systems, where the whole cooling and heating process takes place within the central air-handling unit. Individual room temperature control may be undertaken through the systems mentioned below:

- Constant volume systems;
- VAV (variable air volume) systems;
- Double duct systems

- ➢ Centralised air systems. The central plant's location is usually within a plant room on ground floor or in some instances, on the rooftop's packaged unit (Nicholas 2002).

Partially centralised water/air systems, where air filtering is initially through a centralised-air handling unit and later utilised for cooling and heating an airstream, with adjustment in temperature made using the "equipment" within the room. The types of systems include:

- Terminal fan coil or re-heat systems.
- Induction systems.
- Displacement ventilation and cooled ceilings.

The local comfort cooling system, which would be the basis of the current research, is widely used in residential buildings in Saudi Arabia.

4.2.1 Local Comfort Cooling Systems

Comfort cooling systems operate by dispersing room air on the vapour compression cooler’s evaporator coil for cooling it. The “waste heat” in the cooling process is released externally (Nicholas 2002).

The cycle for vapour compression is utilised in various commercial room cooling equipment such as variable refrigerant flow, multi-split, split and window-sill air conditioners (Nicholas 2002).

4.2.1.1 Window-sill Air Conditioners

The simplest kind of cooling system is called window-sill air conditioners. They are mainly utilised for controlling overheating problems, caused by installation of computers in offices. The refrigeration exists in a cabinet and placed on the window-sill (Nicholas 2002).

Notably, the window should seal all existing gaps on the unit. The air conditioner’s interior is sealed from outside. A fan sucks air in the room and filters and sends it to the evaporator coil where it is cooled and returned to the room.

External air is circulated simultaneously on the condenser coil for external expulsion of waste heat. The casing stores the compressor and all controls, therefore, forming a self-contained system.

Portable air conditioners operate under similar circumstances; however, the expulsion of waste heat from a building is via the cabinet in the existing space (for instance, a window) (Nicholas 2002).

The figure 4.1 shows how the window type is working and the approximate temperatures as well as the air flow at different locations.

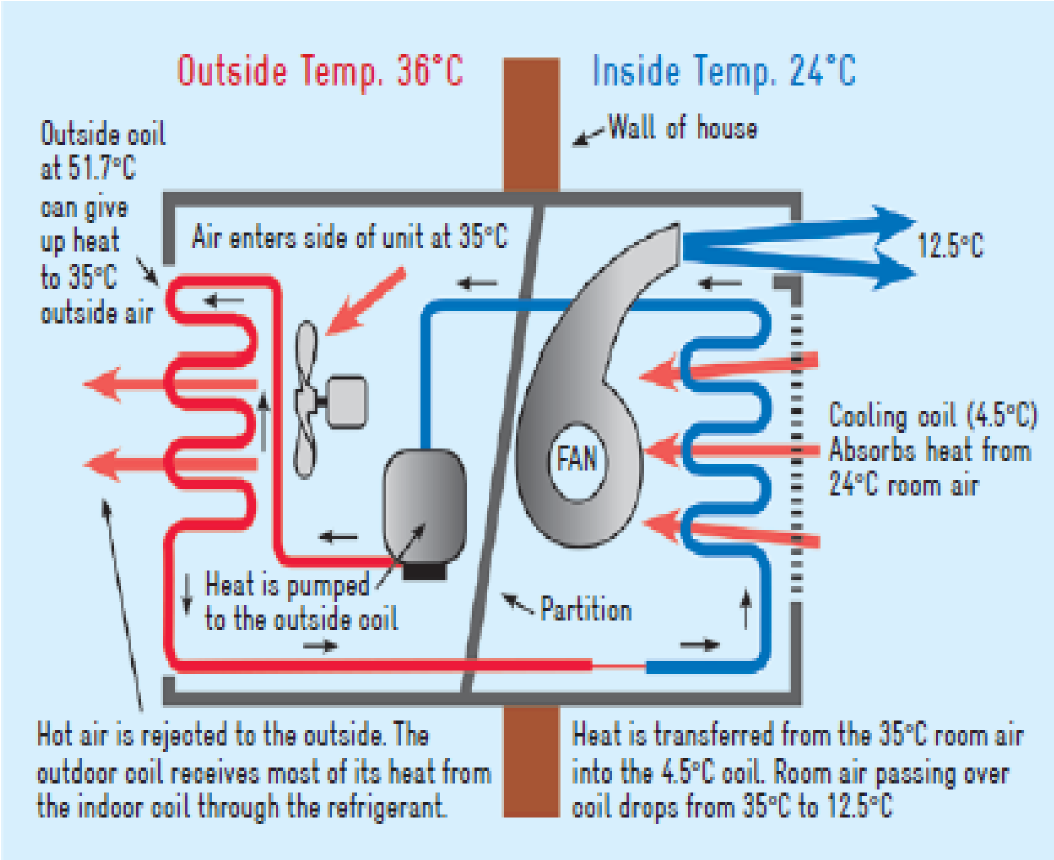


Figure 4.1: Window air conditioner system (Deutsche Gesellschaft für Internationale Zusammenarbeit 2013).

4.2.1.2 Split Air Conditioning System

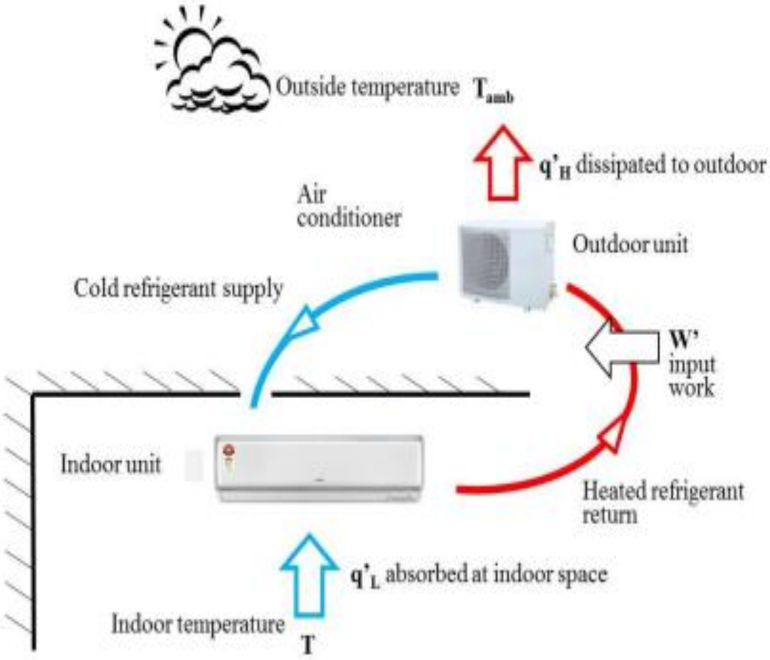


Figure 4.2: Split air conditioner (Cheng and Lee 2014).

The split cooling system has two main units, a condensing unit placed outdoors because of the noise and the heat, and an internal unit that has a blower and coil that supply the cool air. These two units internally and externally are connected with a suction line and liquid line to supply cool air (Al-Naimi 1989).

The ideal places for installing the indoor unit include a hanging ceiling, floor or wall. To ensure that hanging ceiling panels and room decor blend well with the outdoor unit, a quality finish is undertaken on it (Nicholas 2002).

A fan sucks air from the evaporator to cool it and later returns it using directional slots that are modified to drive the freezing air away from occupants in the room to overcome cold draughts. The cooled air combines with the "room temperature air" outside the area occupied and the air mixture spreads slowly in the entire room, creating a cool atmosphere (Nicholas 2002).

The air-cooled condenser is housed in the external unit, and it has a huge surface area offered by the presence of fins; it is similar to an evaporator. For expulsion of waste heat, a fan sucks air over the condenser. The indoor unit should not be placed near the outdoor unit, the distance between should be (up to 50m pipe length with a 30m vertical rise). This enhances the design's flexibility and unobtrusive positioning of the building's outdoor unit (Nicholas 2002)

4.2.1.3 Multi Split Air Conditioning

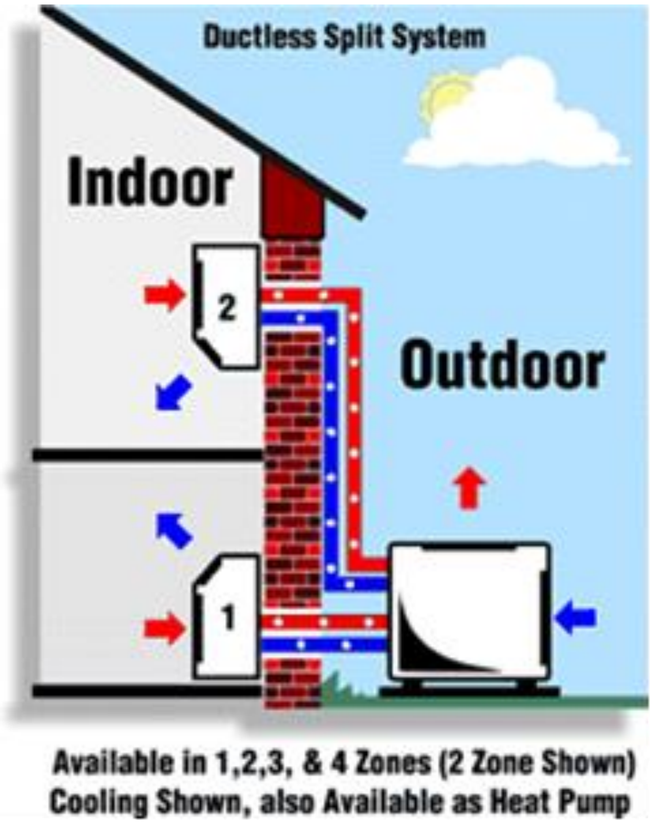


Figure 4.3: Split air conditioner system (ECR International 2015).

Multi split air-conditioning operates on the principle that is similar to that of single-split air conditioning, the only difference is that a single outdoor unit may be utilised for 4 indoor units. All indoor units have individual sets of refrigerant pipes that connect them to the outside units. The mode of operation (cooling/heating) for all "indoor units" is similar, even though individual units may be managed independently with regard to cooling or heating levels (off-full). Some indoor units have electric heaters that assist a single unit in providing heat when the multi-split group is in the cooling mode (Nicholas 2002).

4.2.1.4 Variable Refrigerant Flow (VRF) Air Conditioning

Figure 4.4: VRF air conditioner system (Phoenix Air Con Ltd 2015).

In the VRF air conditioning, 8 indoor units may be operated using one outdoor unit. The system is advantageous in the sense that all indoor units may run independently without relying on other units, both in heating and cooling mode. This is achieved through the use of collection vessels of liquid and vapour refrigerant, as well as a complex control system for redirecting the dual refrigerant phases that lead towards the indoor units as required. Notably, VRF air conditioning systems incorporate heat recovery into the operation mode; this enables the refrigerant to redistribute waste heat from the rooms on one building side to indoor units located on the other building side. The outdoor units are separated from indoor units by a distance of 100m; this includes 50m of vertical rise.

A central air handling unit is capable of supplying tempered and filtered air to all units for ventilation and heating purposes (Nicholas 2002).

4.3 Air Conditioning Market in Saudi Arabia

Although there is a financial problem in Saudi Arabia as in other countries, the construction sector is not developed thus; a potential market for air-conditioning products exists in the KSA (Garwood 2010).

Because of the rapid population growth, high per capita income and rising temperatures, Saudi Arabia offers a huge market for air-conditioning products in the Gulf region. The country is located in a desert; this implies that it experiences harsh climatic conditions in the entire year, thus making it necessary for inhabitants to seek ventilation and cooling products (The National Commercial Bank 2008).

Additionally, the demand for air-conditioning in Saudi Arabia may be attributed to the favourable government programs and lucrative real-estate sector. Based on a TechSci research (TechSci research) report, the largest share of revenue from the air-conditioners market is accounted for by the central region. The report predicts that in the 2013-2018 periods, Saudi Arabia will experience a 10 percent in incomes generated from air-conditioners market.

Despite certain variations across regions, air-conditioning equipment are considered essential and most Saudi buildings are installed with the products. In Riyadh (central region) record highest sales of about 33%, followed by Jeddah (western region) that accounts for 25%. In Dammam (eastern region) a 15% of sales were recorded, whereas the other regions accounted for 25% of the sales (Garwood 2010).

The increased sales for large and medium screw chillers is attributed to the buying power of projects that are financed by the government, especially because there has been a reduction in private projects in the economic depression period (Garwood 2010).

Building Services Research and Information Association (BSRIA), feels that the government of Saudi Arabia will be successful in sustaining huge investment in the construction sector for 2 years. However, when the crises continue and prices of oil remain intact, the government expenditure would decrease significantly. On the other hand, when the market becomes stable and oil prices recover by the close of 2011, significant growth rates would be experienced in central plant air-conditioning markets, with support from private investments in residential and commercial sectors *(Garwood 2010).*

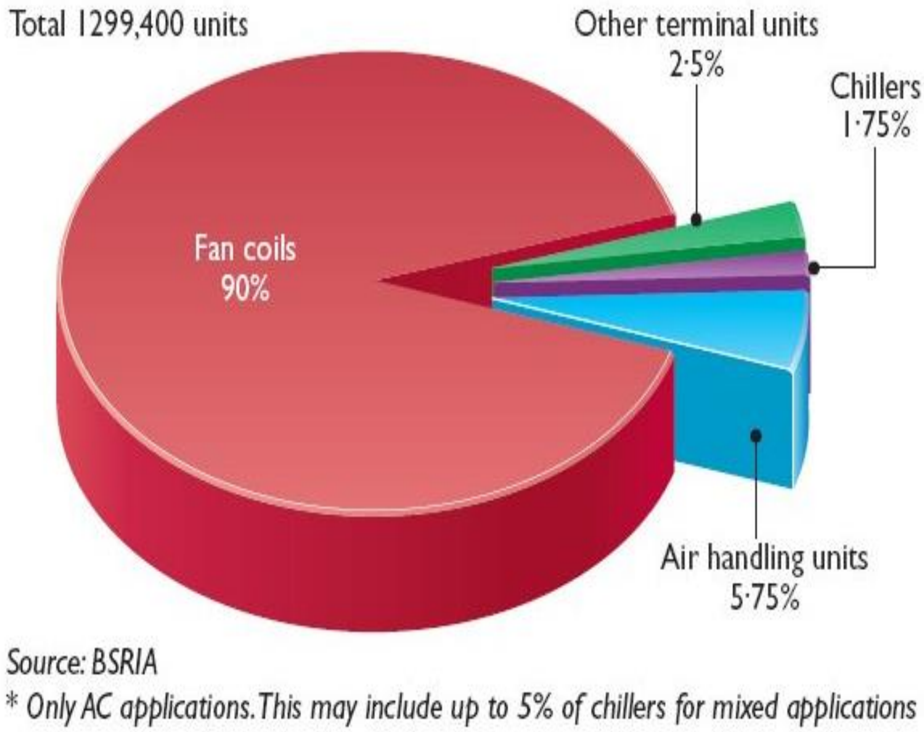


Figure 4.5: Overview of the estimated central plant air-conditioning market for 2009 (Garwood 2010).

A summary of the anticipated air-conditioning market of central plants for 2009 is illustrated by figure 3.5 basing on the type of product, even though the overall unit figure is given as an estimate. According to BSRIA, large construction projects have significantly dominated the development of air-conditioning market (Garwood 2010). For creation of shopping centres, modern hospitals, large university sites and economic cities in future, Saudi Arabia has introduced strict laws regarding air-conditioning products. Therefore, the air-conditioning market would improve significantly in the next 10 years. Large and medium units are utilised for addressing the huge volumes of air required in many new buildings (Garwood 2010).

It is believed that in 2008, the heat recovery air handling unit (AHU) models accounted for about 15% of the overall AHU market, with regard to value. Local legislation emerges as the key driver of such products, for instance, in Medina; the law stipulates that exhaust emission should go through a heat-recovery gadget (Garwood 2010).

Recently, principal contract and architects have been urged to incorporate fan-coils into new applications for further improvement of the market.

BSRIA anticipates the market of fan-coils to replicate that of chiller market growth, especially the screw chillers market. However, there is a possibility that a slight increase will be experienced in the fan-coil market compared to the chiller market because of rising cooling capacities within mid-range applications (Garwood 2010).

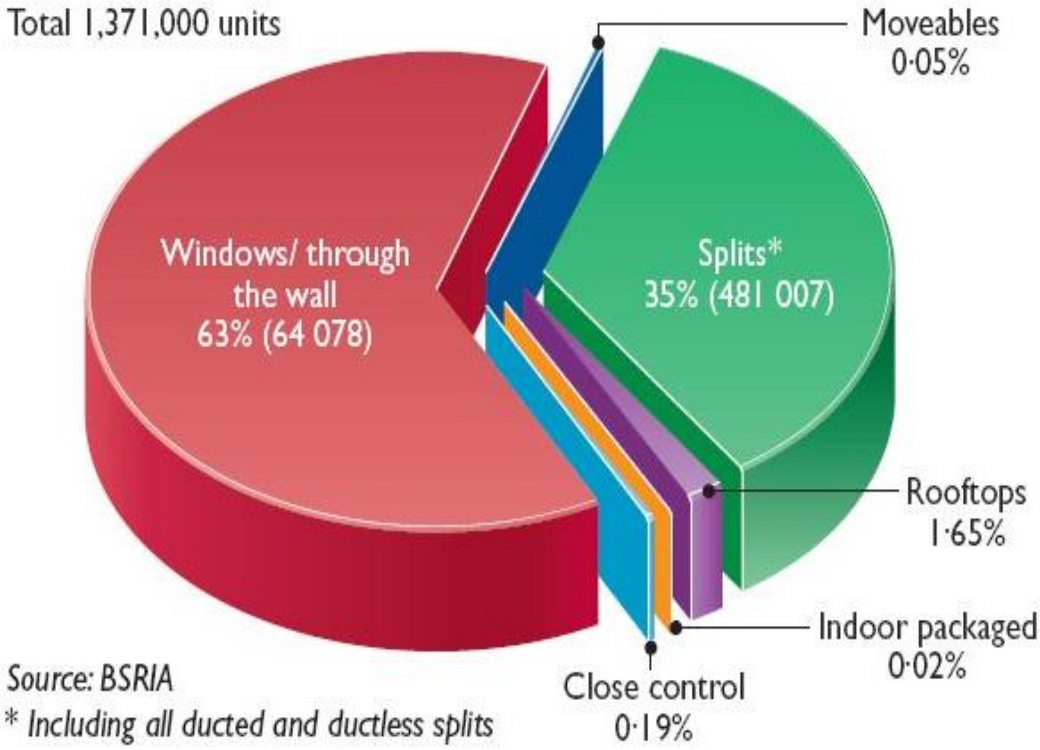


Figure 4.6: Overview of the estimated packaged air-conditioning market for 2009 (Garwood 2010).

A summary for the anticipated market of packaged air-conditioning for 2009 period basing on product type, with an estimated overall unit figure is illustrated in figure 3.6. Large and medium chillers are required in large building projects. Screws constitute a critical component for the chillers market, accounting for more than 50 percent of the value. Centrifugal chillers usually begin at 1750 kW, and all types of chillers are expected to experience maximum long-term growth. BSRIA expects that in 3 to 4 years, the share value would hit 40% (Garwood 2010). Despite the fact that reciprocating chillers are still being used, there is a decrease in their share. Scroll chillers are mainly marketed by Carrier that provides sophisticated scroll products. Because of the expensive nature of absorption chillers, they are not extensively used in the KSA; according to BSRIA estimates, their price is three times that of its equivalent alternatives.

Interestingly, in spite of the reduction in Saudi's shortage for district cooling projects, many upcoming projects plan to adopt such systems, including, King Abdullah Economic City Riyadh Girls' University and King Saud University in Riyadh, which will trigger demand for cooling within the district in future. Large 7MW centrifugal chillers are mainly utilised for serving the cooling systems in the district (Garwood 2010).

4.3.1 Packaged air-conditioning

The TechSci (2014) report indicates that an increasingly rising demand of different air conditioners (for instance, window, centralised and split) in the KSA, with the split air conditioners accounting for the huge demand.

The past few years has experienced a considerable increase in single split sales across all capacities and types of products in the KSA. However, the increase has been negated by scarcity of privately financed investments within the residential building industry that is largely dependent on the establishment of new housing (Garwood 2010).

A rapid increase is anticipated in the multi-split market, even though with slow trend. When the market hits a thousand units, the rate of growth will start replicating that of chiller market (Garwood 2010).

VRF (variable refrigerant flow) air-conditioning systems are beginning to have an impact in the Gulf region. It is anticipated that the market of such products will record a highest rate of growth for all air-conditioning equipments in the KSA. Daikin was the sole firm that was operational in the field; however, this changed in

2008, following the entry of LG with its VRF equipments and a wide room exists for other firms to come in (Garwood 2010).

Currently, the air conditioners market in Saudi Arabia is dominated by many foreign manufacturers such as Hitachi ltd, Green Electric, Samsung Electronics, Daikin and LG (TechSci 2014).

Additionally, the TechSci report in 2014 indicates that because of the latest SASO (Saudi Arabian Standard Organisation) programs, the demand for energy-efficient air conditions is likely to increase in Saudi Arabia. Those that encompass inbuilt purification functions are anticipated to acquire more shares in the market, because of the increasing air pollution fears within the country (TechSci 2014).

BSRIA expected that a moderate growth would be experienced within the close control market in future because of the end in the telecoms sector growth in the last few years coupled with significant reduction in private investments within the second part of 2008. The market consists of small units specifically meant for small telecom structures, as well as large unit meant for computer rooms (Garwood 2010).

The healthcare, residential and educational sectors would constitute the main demand sources within the air-conditioners market because of increasing government programs in the sectors. Additionally, the influx of large firms on the market is likely to trigger competition in air conditioners. According to M .Karan Chechi (TechSci's research director) "anticipated technological innovations and the incorporation of emerging energy-efficient air conditioner models would continue triggering demand in future" (TechSci 2014).

The commercial sector, particularly office blocks and hotels is characterised by the use VRF units; even though a small quantity of sales is accounted for by the residential building sector, where owners of affluent owners intent to install high-tech equipment (Garwood 2010).

4.4 Refrigerants

Although the Saudi government signed the Montreal Protocol, a target for phasing out hydro-chlorofluorocarbon (HCFC) was not available. SASO would be spearheading the process of phasing out HCFC. However, legislation is yet to be approved because local players lack the capacity of rapid switch (Garwood 2010).

With the exception of VRFs (which are R410A), all packaged equipment in Saudi market are installed with HCFC R22 refrigerant. However, chillers are fitted with R134A. Global production is shifting from R22 to R410A (Garwood 2010).

BSRIA feels that in 3-4 years, ducted splits would start changing to R410A because imports will increasingly become critical for the domestic market. When the switch takes place, the sector would switch to R410A refrigerants, overtaking R407C (Garwood 2010).

4.5 Reforming Electricity Tariffs

One main mechanism that can be applied in regulating the consumption of electricity entails ensuring that retail and wholesale prices of electricity are consistent with the overall costs. As is the case in many oil producing countries, subsidies in fossil fuels are usually utilised for poverty reduction efforts through provision of cheap energy. The government of Saudi Arabia has maintained low energy prices as way of managing inflation. However, subsidies in fossil fuels lead to many adverse effects that outweigh the positive impacts. There is a general consensus regarding the importance of reducing such subsidies, especially because of the adverse effect they have on carbon dioxide emissions. The CO^2 per capita emission in Saudi Arabia stands at 17 metric tonnes, which is similar to that of the USA (compared to China with 6, EU with 7 and the global average at 5). Moreover, subsidies in fossil fuel result in price regimes, which end up with the loss of welfare. The government loses significant amounts of revenue by subsiding local consumption (instead of exporting), compared to the increase in local consumer's surplus. Because of the price reduction for consumers, subsidies in fossil fuels promote wasteful energy use causing an increase in fuel consumption rates (Nachet and Aoun 2015).

In a real sense, non-targeted subsidies cannot provide efficient means of improving energy accessibility and benefiting impoverished people, instead, affluent homes are the main beneficiaries; this further increases social disparity. Furthermore, such subsidies are an impediment to energy sector investments, promote smuggling and extravagance, and reduce oil export revenues. This is particularly common in the KSA, where one crude oil barrel costs 5 US dollars, while when exported a barrel could cost more than 100 US dollars (average for 2011-2014) (Nachet and Aoun 2015).

Table 4.1: Oil, Gas and Diesel price in US dollar in Saudi Arabia (Nachet and Aoun 2015).

	Price paid by electricity producers	International prices
Heavy fuel oil	0.43	15.43
Natural gas	0.75	9.04
Diesel	0.67	21.67
Crude oil	0.73	19.26

4.6 Air Conditioning Types in Saudi Buildings

Due to the harsh weather conditions in Saudi Arabia there is a need for air conditioning throughout the year (Alrashed, and Asif 2014). In fact, air-conditioning is considered to be necessary in almost all buildings in the kingdom of Saudi Arabia (Garwood 2010).

There are different systems of air-conditioning in Saudi buildings. In residential buildings there are four types of air-conditioning; window type, split, central and evaporator. The majority of dwellings use mini-split system as well as the window type (Alrashed, and Asif 2014).

Central air conditioning system has also started to be fitted in recent years (Alrashed, and Asif 2014). The following figure presents the most common types of air conditioning in the residential buildings in Saudi Arabia.

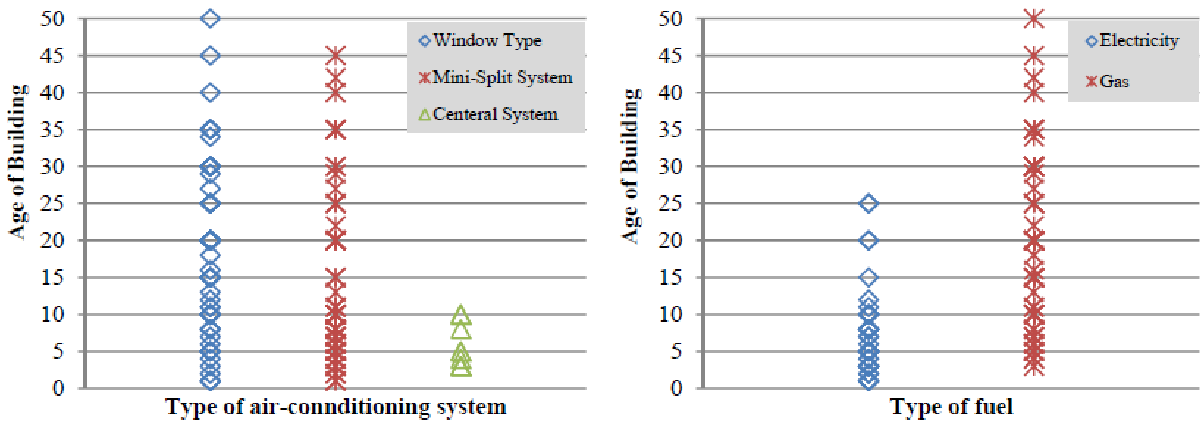


Figure 4.7: The type of air-conditioning system in dwellings and type of fuel.

In fact, a very important study done by Alrashed and Asif in 2014 shows that the mini split systems has the lowest average energy consumption in comparison with other types of air-conditioning (Alrashed, and Asif 2014).

Table4.2: Average energy consumption for residential buildings based on the type of air-conditioning system (Alrashed, and Asif 2014).

Type of air-conditioning system	Average energy consumption kWh/m²/year
Central	221.5
Mini-split	144.3
Window-type	183.3
Window-type and Mini-split	156.8

It is very clear that in order to increase the energy efficiency in the Saudi residential buildings, householders should be encouraged to use mini split air conditioning systems instead of other types (Alrashed, and Asif 2014). Al-Naimi in 1989 confirmed that the mini-split type is more efficient system in Saudi Arabia and consume less energy. In addition, it is very easy to control the split system and set the required temperature (Al-Naimi 1989).

Moreover, the split system has more advantages over the window type. The split system is not noisy as the window type during operation, because the indoor unit works very quietly and it has a noiseless fan (Al-Naimi 1989). In fact, the compressor sound of the window type air-conditioning is very high, noisy and difficult to dampen (Kansas State University 2000).
In addition, the condensing unit is set outdoors and far from the room so the system does not exhaust heat internally where the room should be cool (Al-Naimi 1989).

4.7 Selecting the Size of Air Conditioning

It is very important in any home to select the right air conditioning type, size as well as the approximate kW rang. The following figures will present examples of rooms sizes and the size of air conditioning needed (Vic Air, 2015).

Figure 4.8: Air conditioning size for room size 10-20 sq meters (Vic Air 2015).

Figure 4.9: Air conditioning size for room size 20-30 sq meters (Vic Air 2015).

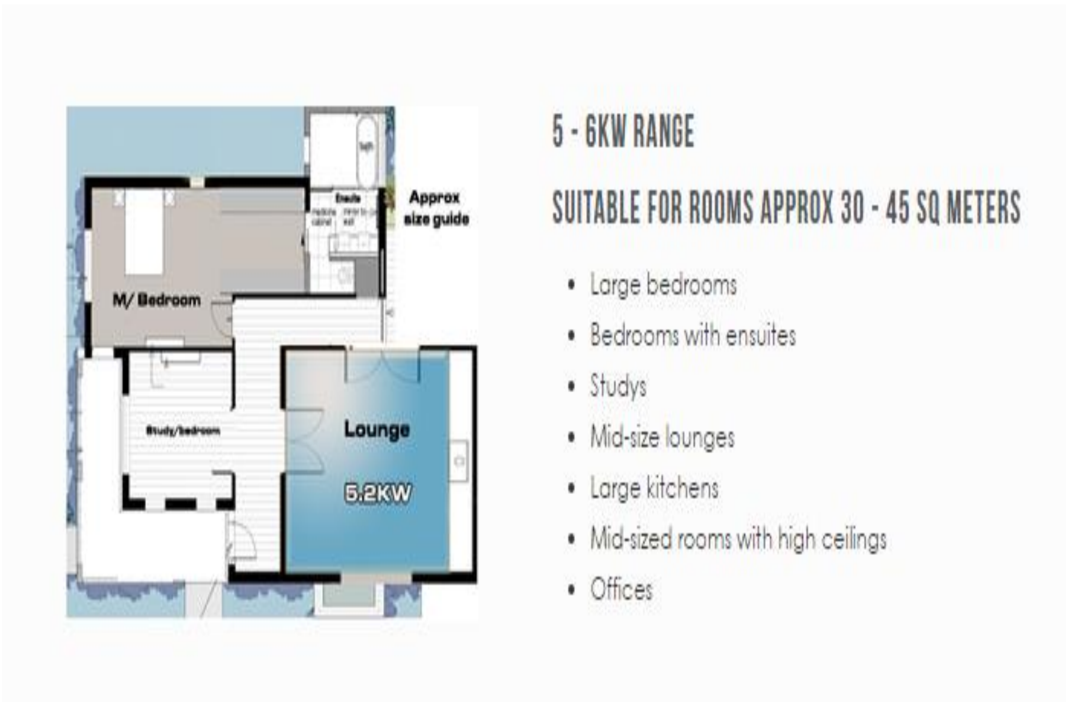


Figure 4.10: Air conditioning size for room size 30-45 sq meters (Vic Air 2015).

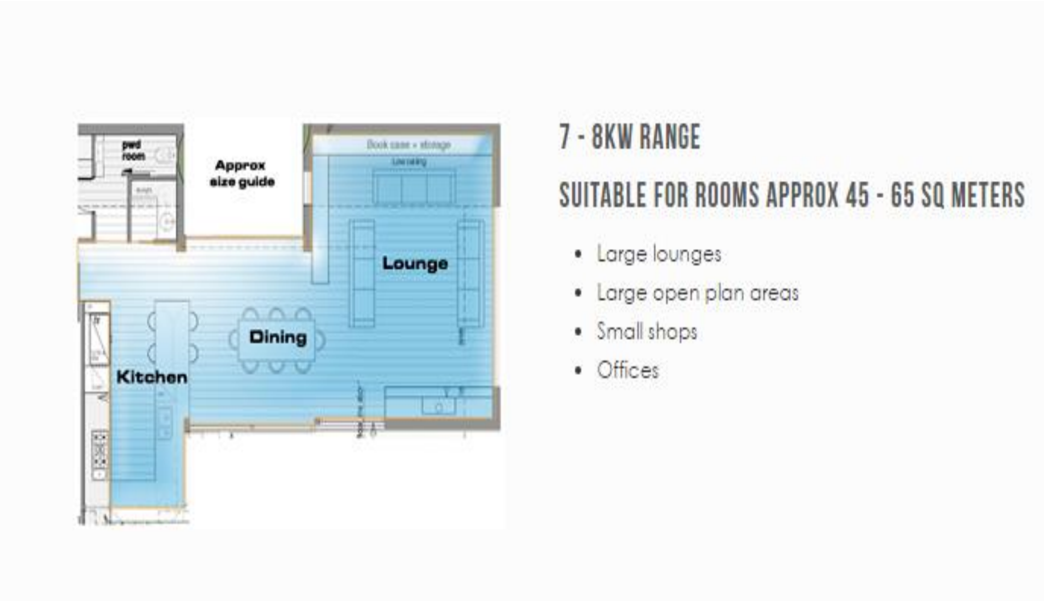


Figure 4.11: Air conditioning size for room size 45-65 sq meters (Vic Air 2015).

However, there are several factors can effect sizing of the air-conditioning size as follow:

- Insulation
- Window sizes
- Blinds and curtains
- Climate

All these factors could affect the air conditioning size as they have an impact on the cooling load. Air conditioning in Saudi Arabia is needed and required as a result of extreme temperature in the summer season as well as in specific days in other seasons (Alrashed, and Asif 2014). This chapter shows that there are several air conditioning types and sizes due to many factors such as room size. Split air conditioning type accounting for the highest demand in the kingdom of Saudi Arabia as well as the window type.

Chapter 5

The Survey Chapter

5.1 Overview

The lack of information regarding Saudis' behaviour with regard to energy, specifically their daily use of air conditioning, highlights the importance of this survey in this research. The need for the survey was further fuelled by missing data about thermal comfort in Saudi houses and the most common types of air-conditioning. Air conditioning in Saudi houses is the major consumer for energy, thus reducing this consumption and improving the system could help to save energy and maintain a sustainable environment in Saudi Arabia. Air- conditioning in Saudi houses consumes over 70 % of the total energy consumption (Al-Ghamdi and Al-Feridah, 2011). Therefore, this survey is designed to find out how Saudis use air-conditioning in their homes and to create a full picture of Saudis' behaviour.

The type of the survey is a cross- sectional survey sent randomly to all Saudi residents living in the house. The survey targeted all different ages, different genders, different educational levels, and finally, different monthly income.

A total of 190 participants completed the survey, including both males and females from different cities in the kingdom of Saudi Arabia. The survey was open to all Saudis and it is designed and published using google drive, and was sent via e-mail, facebook, twitter and whatsApp.

The survey includes the three main cities in the kingdom: Riyadh, Jeddah and Dammam, along with other cities in Saudi Arabia. The range of questions includes: gender, educational level, income level, home type and, of course, air-conditioning type. It is divided into two main sections, the first section has optional questions, whereas the second one has compulsory questions. The survey also asks participants to include their ideas and comments to save energy and improve the indoor environment quality. The participants agreed to complete the survey, and shared both their daily behaviour and their recommendations.

5.2 The Survey Results and Discussion.

The survey prepared to include two main sections, the optional section and the compulsory section. The survey will start by illustrating the optional questions followed by the compulsory questions.

5.2.1 Optional Questions

This part is not compulsory and the participants have the option to fill it or not. The first four questions in the survey were optional questions to provide some demographic information on the participants: gender, age, educational level and monthly income, as presented in the following four figures.

Male (ذكر)	**141**	75%
Female (انثى)	**47**	25%

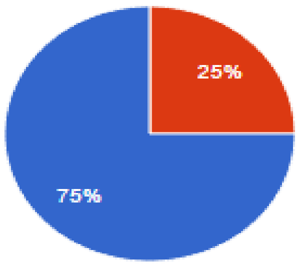


Figure 5.1: Gender of the participants.

The survey results indicate that 75% of the 190 participants were male and the rest were female.

12-17 years old	**2**	1.1%
18-24 years old	**28**	14.9%
25-34 years old	**113**	60.1%
35-44 years old	**32**	17%
45-54 years old	**7**	3.7%
55-64 years old	**4**	2.1%
65-74 years old	**2**	1.1%
75 years or older	**0**	0%

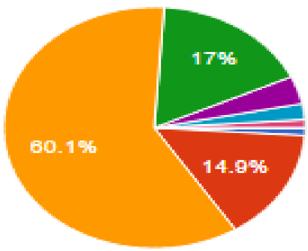


Figure 5.2: Age of the participants.

The figure 5.2 shows that 60% of the participants were 25-34 years old. Unfortunately, there were no participants aged 75 years or older. 17% of those surveyed were aged between 35 and 44. 18-24 year olds account for 14.9% of the total participants. The rest of the participants represent a small percentage.

Less than high school (اقل من الثانوية)	3	1.6%
High school (الثانوية)	25	13.2%
Bachelor degree (البكلوريوس)	77	40.7%
Postgraduate (دراسات عليا)	84	44.4%

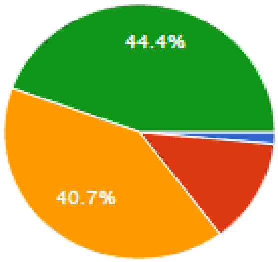


Figure 5.3: Education Level of the participants.

The educational level shows that 44.4% have a postgraduate qualification, and 40% have a bachelor degree. It is thus clear that the majority of those surveyed have a high educational qualification. The participants with high school and less only represent 14.8% of the total.

No income	24	13.2%
under 8000 SR	33	18.1%
8001- 12000 SR	44	24.2%
12001-16000 SR	42	23.1%
16001-20000 SR	22	12.1%
20000 and above	15	8.2%
Other	2	1.1%

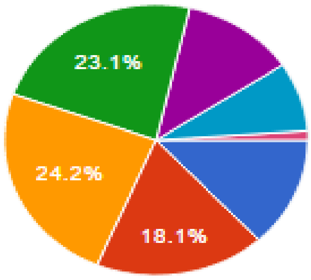


Figure 5.4: Saudi monthly income of the participants.

The final optional question was about participants' monthly income. The majority of those surveyed have an income of 8001 to 12000 Saudi Riyals (SR), accounting for 24.2%. However, it is important to note that 23.1% of participants have a monthly income of 12001-16000 SR. It is therefore evident that most of those surveyed are considered to be middle income. 13.2% of participants have no income, which could mean that they are still young, living with family or they were not working at the time of the survey.

The next section of the survey includes 21 compulsory questions; which participants were asked to answer.

5.2.2 Compulsory Questions

This part should be filled by the participants. This part includes 21 questions covering the main part of the survey to get the necessary and important details for the PhD purposes.

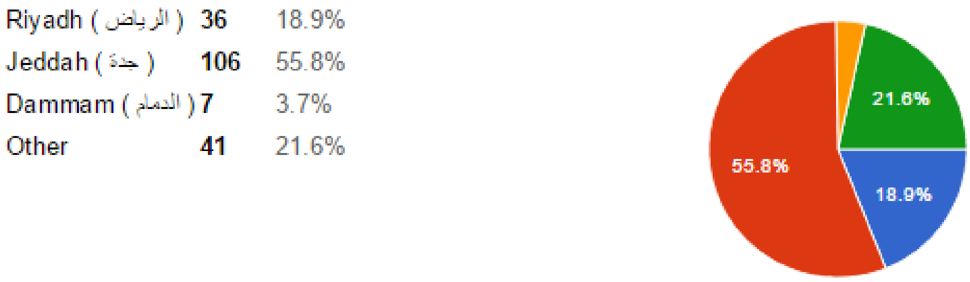


Figure 5.5: Cities of the participants.

The participants were asked to indicate the cities they live in. The main cities in both the survey and the research, as previously mentioned, are: Jeddah, Dammam and the capital city of Saudi Arabia, Riyadh. The survey included the option of "other cities" in order to accommodate Saudis that live outside of these three main cities. According to figure 5.5, most of those surveyed were from Jeddah, representing 55.8% of participants. Participants from Riyadh accounted for 18.9%, and those from Dammam 3.7%. Finally, participants from other cities in the kingdom represent 21.6%.

Flat (شقة)	**124**	65.3%
Villa (فيلا)	**44**	23.2%
Duplex villa (فيلا دوبلكس)	**13**	6.8%
Other	**9**	4.7%

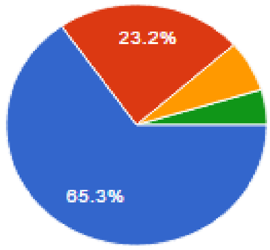


Figure 5.6: Type of house.

65.3% of Saudis confirmed that they live in flats, as illustrated in figure 5.6. Villas are the second most common type of house in the kingdom, with villas and duplex villas accounting for 30% of the total houses in the kingdom. Other homes represent only 4.7%.

Only one room (غرفة واحدة فقط)	**6**	3.2%
2-3 rooms	**37**	19.5%
4-5 rooms	**83**	43.7%
6-7 rooms	**25**	13.2%
8-9 rooms	**21**	11.1%
10-11 rooms	**13**	6.8%
Other	**5**	2.6%

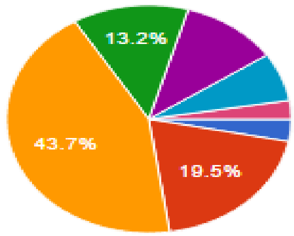


Figure 5.7: Number of rooms.

The size of the house is one of the most important questions in this survey. It is clear that medium size is the most common (see figure 5.7). Four to five rooms represent the majority of 43.7%, while the option of 2-3 rooms accounts for 19.5%. Larger houses are less common, according to the survey results, with 13.2% of participants choosing houses with 6-7 rooms, and 11.1% for houses with 8-9 rooms.

I own the house (املك المنزل)	61	32.1%
Rented house (مستأجر)	88	46.3%
Living with family (اسكن مع العائلة)	39	20.5%
Other	2	1.1%

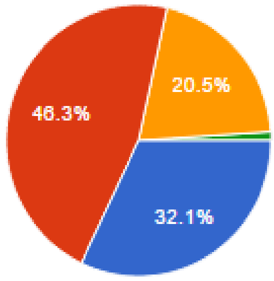


Figure 5.8: Home status.

46.3% of those surveyed confirmed that they lived in a rented house, whereas 32.1% own their homes. 20.5% of the participants in the survey mentioned that they are living with their families.

Only me	7	3.7%
1-3 persons	74	38.9%
4-6 persons	75	39.5%
6-8 persons	25	13.2%
more than 8 persons	9	4.7%

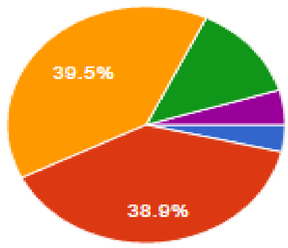


Figure 5.9: Number of persons living in the house together.

The average size of Saudi family is small and medium size, as shown in figure 5.9. Families of one to three persons represented 38.9%. Four to six persons is considered to be the most common family size in the kingdom of Saudi Arabia (39.5% of participants) according to the survey. However, figure 5.9 clearly shows that there is little difference in the responses for family sizes of 1-3 and 4-6, with only 3.7% difference

Window Air Conditioner (مكيف الشباك)	65	34.2%
Split Air Conditioner (مكيف السبليت)	43	22.6%
Central Air Conditioning System (مكيف مركزي)	9	4.7%
Window Air Conditioner and Split Air Conditioner (مكيف شباك و مكيف سبليت معا)	68	35.8%
Other	5	2.6%

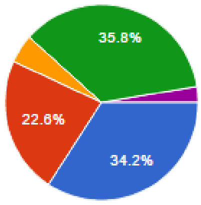


Figure 5.10: Type of air- conditioning.

This question asked about the air conditioning types used in the country. Three main types of air conditioning are mentioned in the survey to determine which type is the most popular. The results reveal that window air conditioning and split air conditioning in the same house are very common, with 35.8% of those surveyed have these two types of air conditioning together. Window air conditioning is very common as 34.2% of participants selected this option in the survey. Central air conditioning and other types are less common in the kingdom.

1-3	28	14.7%
4-6	83	43.7%
6-8	29	15.3%
8-10	16	8.4%
10-12	18	9.5%
more than 12	16	8.4%

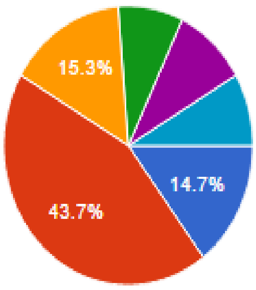


Figure 5.11: Number of Air-conditioning Units.

The results of the survey revealed that 43.7% of the people surveyed have 4-6 air conditioning units in their homes. The next largest percentage (15.3%) have 6-8 air conditioning units. Usually, each room has one air conditioning unit, which means that figure 5.11 also confirms that, according to the survey, most Saudi houses contain four to six rooms. Houses with less than four air conditioning units, or more than six, are not very common in Saudi Arabia (see figure 5.11).

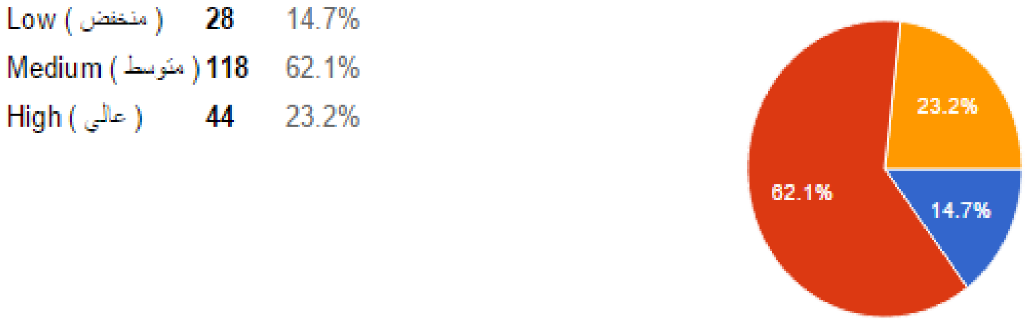


Figure 5.12: Air-conditioning settings.

It is clear that most Saudis set their air conditioning unit at medium cooling, instead of high or low, with 62.1% of those surveyed confirming this fact. 23.2% of the participants in the survey selected the high setting for cooling to be high, whereas only 14.7% chose to keep the cooling at a low setting.

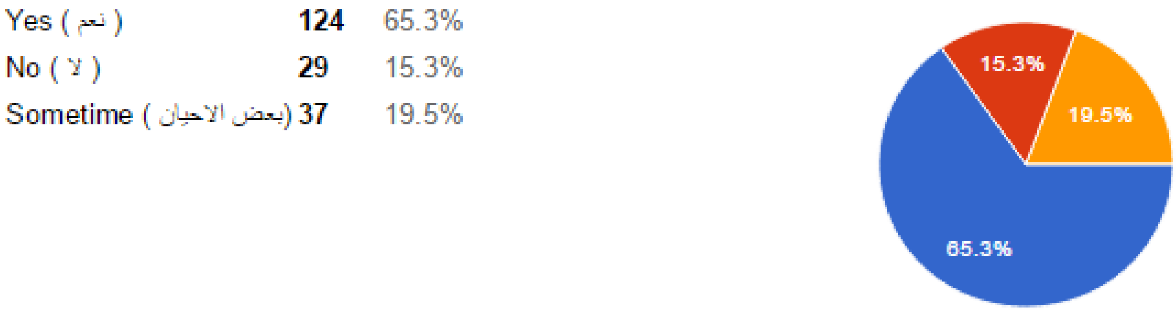


Figure 5.13: Knowing the monthly electricity bill.

Most Saudis (65.3% of the total survey participants) know their monthly electricity bill. 19.5% indicated that they sometimes know the monthly electricity bill, whereas only 15.3% of surveyed do not know.

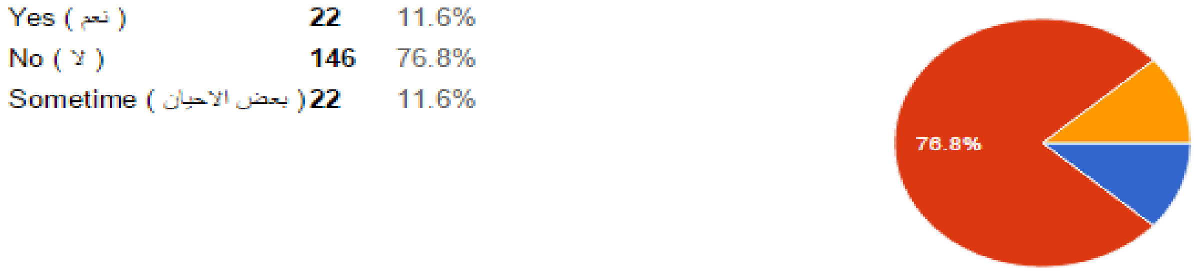


Figure 5.14: Knowing the electricity usage in KWh.

Unfortunately, figure 4.14 shows that 76.8% of Saudis do not know the monthly usage of electricity in KWh. Only 11.6% of those surveyed indicated that they know how much they electricity they consume every month. The same percentage (11.6%) of participants in the survey confirmed that they sometimes know the electricity consumption of their homes.

Figure 5.15: Number of hours usage for air-conditioning daily in summer.

This figure shows the daily use of air conditioning in Saudi houses in the summer season. 37.9% of Saudis use air conditioning from 16 to 18 hours every day in the summer. The survey also found that 34.7% of participants use air conditioning almost the whole day. The rest of the participants use AC less than 18 hours.

0-6 Hours	103	54.2%
6-12 Hours	60	31.6%
16-18 Hours	21	11.1%
18-24 Hours	6	3.2%

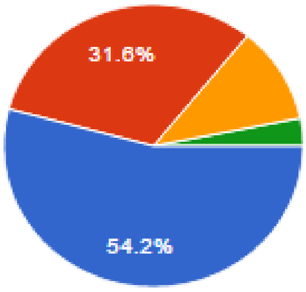


Figure 5.16: Number of hours' usage for air-conditioning daily in winter.

Winter has a different scenario because most Saudis use the AC 6 hours a day, or may even switch it off most of the day. 31.6% of the survey participants mentioned that they use the AC between 6-12 hours every day in winter. Few of those surveyed use the AC more than 16 hours a day.

Living room (غرفة المعيشة)	165	86.8%
Bed room (غرفة النوم)	145	76.3%
Guest room (غرفة استقبال الضيوف)	17	8.9%
Kitchen (المطبخ)	41	21.6%
Servant room (غرفة الخادمة)	13	6.8%
All rooms (جميع الغرف)	14	7.4%

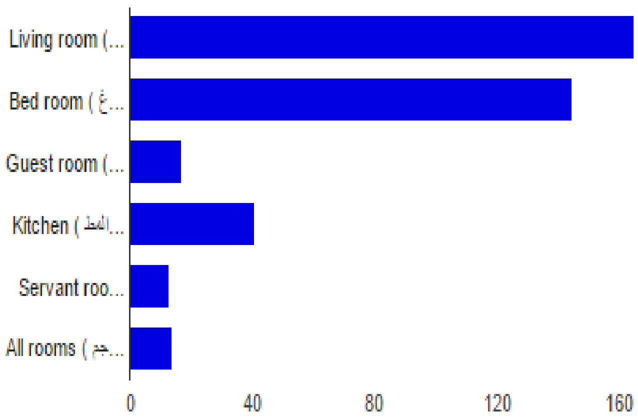


Figure 5.17: Rooms that use air-conditioning most of the time.

The survey asked about the most rooms that use air conditioning during the day. It was possible for participants to select more than one answer for this question, which will reveal where Saudis spend most of their time at home. Figure 5.17 shows that 86.8% of Saudis use the AC primarily in the living room. Bedrooms were selected as an option by 76.3% of those surveyed. The kitchen and other rooms clearly use air conditioning, but less so than the aforementioned rooms.

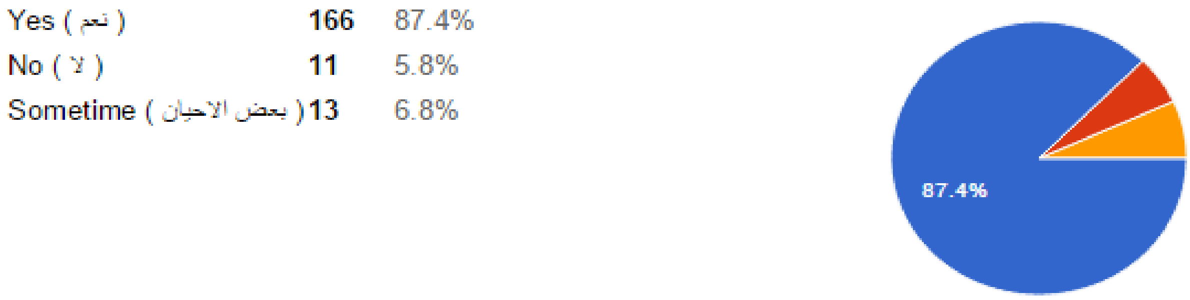


Figure 5.18: Turn air-conditioning off when not in use.

87.4% of Saudis turn the AC off when not in use, according to the figure shown above, thus this is the behaviour of the majority of Saudis. Unfortunately, it is evident that 5.8% of those surveyed keep the air conditioning working all the time even when they do not need it. 6.8% of the survey participants sometimes remember to switch the AC off when not in use.

Figure 5.19: Sometimes air-conditioning in the summer is not cooling enough.

This question was added to the survey to find out if Saudi houses really suffer from poor construction materials, which lead to overheating, increasing the indoor temperature and making air conditioning useless. As expected, 84.2% of Saudis feel that the air conditioning in the summer is not cooling enough, which means that the size of the air conditioning unit is not correct or the house construction materials are very weak in order to cope with the high temperature in summer and provide thermal comfort.

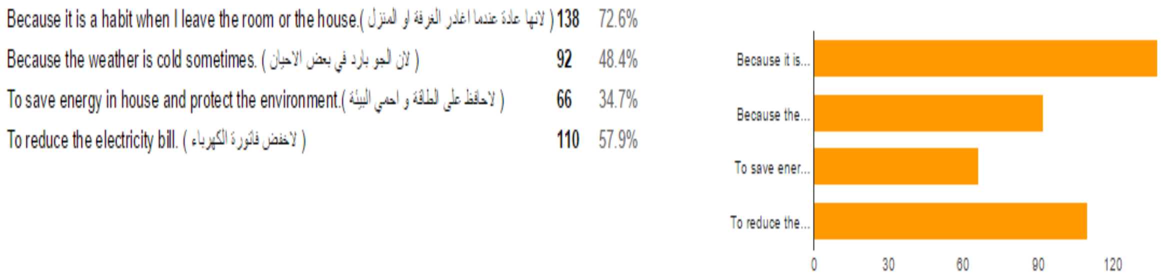


Figure 5.20: The reason for turning off air-conditioning.

This question was included in this survey in order to understand people's behaviour regarding air-conditioning in Saudi Arabia. The survey asked about the possible reasons that lead people to turn the AC off with the option to choose more than one answer. 72.6% of Saudis turn off the AC because it is a habit when they leave the house; 57.9% turn it off to reduce the electricity bill; 48.4% turn the air conditioning off when they feel the room temperature is cold. Unfortunately, only 34.7% consider the environment and turn the AC off to save and protect the environment.

Figure 5.21: Turn off the air-conditioning as the room is too cold suddenly and, after a few minutes, turn it on again.

The aim of this question is to find out the current situation of the construction materials for Saudi houses, and the air conditioning unit size if they are suffering from lack of energy management. The survey asked if participants sometimes feel that the indoor temperature is too cold and they need to turn the AC off, then a few minutes later, they need to turn it on again. The answer for this question (see figure 5.21) shows that 75.3 % of Saudis agreed with this statement, while only 24.7% did not.

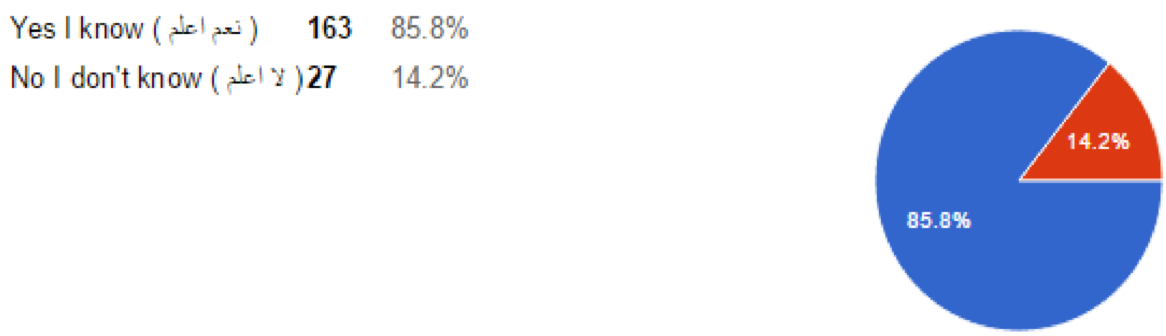


Figure 5.22: Knowing that using energy could harm our environment.

The figure above shows that 85.8% of Saudis know that using more energy and air conditioning could really harm the environment.

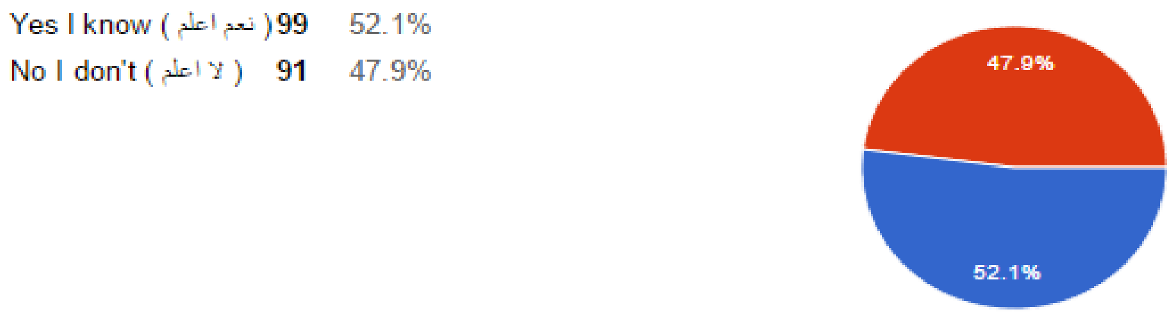


Figure 5.23: Knowing any simple methods to save energy and money regarding air-conditioning.

The aim of this question is to find out if Saudis have any experience or know of any simple methods that could help to save energy and money regarding air-conditioning. 52.1% of participants replied to this question by saying yes; while 47.1% said no.

Figure 5.24: Reduce the use of air-conditioning if the electricity bill is going to increase in the future.

In this part of the survey, participants were asked if they would reduce using air conditioning if their electricity bill will increase in the future. The result shows an almost even split, with 52% opting to reduce their use of air conditioning if the electricity bill will increase.

Figure 5.25 Pay for a more expensive house that has better energy efficiency methods that will help to reduce electricity bills in the future.

The survey asked if respondents would pay for a more expensive house that has better energy methods that will help to reduce electricity bills in the future. 59.5% replied yes, whereas 32.1% of participants in the survey were not very sure, and finally only 8.4% of Saudis said no.

In the last part of the survey, participants were asked to share their ideas, recommendations and thoughts. The first question was to determine whether the respondents knew any simple methods to save energy and money for their homes. A few participants did not leave any comments or simply said that that they don't know, whereas the majority left their ideas and comments to help to reduce energy consumption. Some useful ideas were as follows:

- Add some solar panels.
- Wall insulation and double-glazing.
- Turn devices and air conditioning off when not in use.
- Do not use devices that could increase the heat and the indoor temperature.
- Develop Saudi building standards and regulations and apply these for existing and new buildings.
- Use air-conditioning that can simply maintain a comfortable temperature and only work when the temperature increases in the room.
- Decrease the window size for homes.
- Design the indoor space as needed to serve the function.
- The Saudi government should support and provide solar panels for Saudis to reduce the dependency on oil.
- Use paints that help to reduce heat absorption and reflect the sunlight.
- Use indoor curtains.
- Buy air conditioning units that have better energy efficiency.

5.3 Survey Conclusion

The survey was prepared and designed to understand Saudis' behaviour in their homes and to identify the reasons why residential buildings consume 67% of the total energy consumption, compared to other types of buildings in Saudi Arabia.

As air conditioning consumes over 70% of energy in Saudi houses, the survey questions focused on this area. The survey started with four optional questions, followed by 23 compulsory questions. The survey results show that the majority of the participants were males, aged 25-33 years old; 44% of the participants have a postgraduate qualification, and most have a middle income.

The main cities in the research are the capital city of Saudi Arabia, Riyadh, along with Jeddah and Dammam, but the survey also covers other cities, as the aim of this survey is to understand Saudis' behaviour regarding energy consumption and cooling load in general. The figures show that almost 56% of those surveyed are from Jeddah city.

65% of Saudis live in flats and houses containing 4-5 rooms; most live in rented accommodation; and the average family size is 4 to 6 persons.

Most Saudis use two types of air conditioning in a single house: windows and the split type. They usually set the cooling load to medium. The majority of the survey participants know their bills, but do not know the usage in kWh. They use air conditioning almost 24 hours in the summer, or at least 16 hours every single day, whereas in winter the air conditioning is switched off or used for only 6 hours. It is clear that Saudis spend most of the time in the living room or bedrooms.

A positive finding from the survey is that most Saudis turn the air conditioning off when not in use. Unfortunately, over 80% feel that air conditioning in the summer does not satisfy them, which means that Saudi houses are suffering, wasting energy and providing uncomfortable indoor temperatures. However, 75% of the participants mentioned that they sometimes need to turn the air conditioning on and off multiple times in a few minutes as they feel the temperature inside the home is suddenly cold, and then gets hot again very quickly. This indicated that the construction materials for houses in Saudi Arabia could have a role to play in this and there is room for development in this regards in order to offer comfort and reduce the cooling load.

85% of the participants know that using and wasting energy could harm the environment, but they continue to use air conditioning almost 24 hours in summer, as they perhaps believe that they do not have any other option.

52% of Saudis confirmed that they could change their behaviour if electricity bills in Saudi Arabia increased, which may indicate that the government of Saudi Arabia could be a part of the solution.

At the end of the survey, many Saudis show that they have effective and simple methods to reduce energy consumption in homes, and 60% stated that they are happy to buy more expensive houses that are designed to consume less energy, provide thermal comfort and are harmless to the environment.

Chapter 6

Interview Findings and Results Chapter

6.1 Overview

The aim of this chapter is to present and analyse the findings resulting from multiple visits to Saudi Arabia. Interviews were performed with qualified interviewees holding academic qualifications in architecture or engineering specialities.

The interviews focused on different groups (specialists, experts, architects and engineers). Ten interviews were performed and the type of the interview was semi-structured. Each interview consisted of set questions designed to gather feedback and comments from such professionals. All of the interviewees either work in the governmental sector or in the private sector, dealing with housing, green buildings or energy, from various regions across Saudi Arabia. The chapter will then provide an in-depth discussion of the results, identifying possible ways to make residential buildings in Saudi Arabia more sustainable.

6.2 Interview Aims

The main aims of the interviews were: to understand the current situation of Saudi residential buildings; to identify the most common type of Saudi residential building, from specialists' and experts points of view; to determine how to improve the energy consumption of existing residential buildings; to establish whether the Saudi government has plans to protect the environment and reduce energy consumption; and finally, to understand if the Saudi government or companies follow any specific building regulations or standards, or whether the government has its own version of these regulations.

6.3 Interview Plan

The visits and interviews commenced on 01/06/2013 and continued until 31/08/2013. This consisted of visiting different cities and governmental / private companies in the Kingdom of Saudi Arabia.

The plan for the field trip and visits considered two principal sections: interviews with engineers, architects and representatives working in this field; and data collection. The aim of the latter is to gather data required in the PhD study without meetings or interviews. The final stage involved analysis and reporting. Details of the field trip plan, interview activities, activity description, interviewees' job, interviewees' qualifications, the interview objective, locations, start/end dates are provided as follows in the table 6.1:

Table 6.1: Field trip and Interviews plan.

Activity	Description	Interviewee Job Title	Interviewee High Academic Qualification	Objective	Location	Start Date	Completion Date
Multiple visits to the Faculty of Environmental Design - King Abdulaziz University	In 1997, the Faculty of Environmental Design was established in a special building, following the creation of the faculty of environmental design, with three departments: architecture, urban and regional planning, and environment architecture.	Professor of King Abdulaziz University	Doctoral Degree	Collect data about construction types, building materials, design and environmental issues for Saudi residential buildings	Jeddah, Saudi Arabia	01-06-2013	31-08-013
		Lecturer	Doctoral Degree				
Visit to Makkah Municipality	The Holy Makkah Municipality (HMM) is a Saudi government organisation, which operates over 30 business applications addressing the needs of major municipal operations and services. These include issuing licenses for construction and professionals, and managing the municipality's financial, human resources and payroll processes.	Project Manager	Bachelor Degree	Collect data about the types of Saudi residential buildings through interviews	Makkah, Saudi Arabia	07-06-2013	13-06-2013
Visit to the Saudi Electricity Company	The Saudi Electricity Company is the leading producer of electricity across the Kingdom of Saudi Arabia, providing services to various governmental, industrial, agricultural, commercial and residential sectors.	Electrical Engineer	Master Degree	Collect data about energy consumption/demand and methods to reduce and save energy through interviews	Jeddah, Saudi Arabia	14-06-2013	30-06-2103

Activity	Description	Interviewee Job Title	Interviewee High Academic Qualification	Objective	Location	Start Date	Completion Date
Visit to Jeddah Municipality Library	This is a private library located in the municipality of Jeddah, which stores books about the buildings, construction, population, procurements and all other information regarding Jeddah city.	---------------	----------------	Identify the standards and regulations for Saudi residential buildings	Jeddah, Saudi Arabia	08-07-2013	13-07-2013
Visit to King Abdulaziz City of Science and Technology (KACST)	KACST is an independent scientific organisation that reports to the Prime Minister. It is both the Saudi national science agency and the national laboratories. The science agency deals with science and technology policy making, data collection, funding of external research, and services such as the patent office.	Architectural Engineer	Bachelor Degree	Collect data related to energy strategies and plans for the future in the Kingdom of Saudi Arabia through interviews.	Riyadh, Saudi Arabia	14-07-2013	19-07-2013
		Senior Architect	Bachelor Degree				
Visit to Saudi Green Building Council (SGBC)	SGBC is a non-profit distributing organisation and linked to King Saud University for scientific committees. It was established in 2009 and is funded by an interest group of professionals and academics in the fields of engineering construction and environmental sciences.	Architect	Master Degree	Collect data about green buildings and projects in the Kingdom	Riyadh, Saudi Arabia	20-07-2013	30-07-2013

Activity	Description	Interviewee Job Title	Interviewee High Academic Qualification	Objective	Location	Start Date	Completion Date
Visit to King Abdullah University	King Abdullah University of Science and Technology (KAUST) is a new international, research univer sity with the aim of driving innovation in science and technology and support ing world-- class research in areas such as energy and the environment.	Associate Professor	Doctoral Degree	Collect data about sustainable buildings within the campus through interviews	Thuwal, Saudi Arabia	31-07-2013	10-08-2013
Visit to several Architectural Design Companies	Architectural and engineering companies that design green buildings, low energy buildings, and companies with environmental considerations.	CEO of Architectural Company	Bachelor Degree	Collect different case studies of residential projects (villas, flats) in Saudi Arabia.	Jeddah, Saudi Arabia	11-08-2013	31-08-2013
		Architect	Bachelor Degree				

6.4 Interview Changes and Limitations

A few alterations were made to the original interview plans as a result of delays with some companies in arranging appointments, and a few companies refusing to give interviews. Consequently, alternative interviews and meetings were arranged with other companies that were happy to co-operate and provide the data needed for the PhD research.

6.5 Interview Findings

6.5.1 Average Saudi Family Size

It is important for the purposes of the study to find out the average family size in Saudi residential buildings. Thus, the interview with the project manager from Makkah Municipality contained several structured questions, one of which was regarding the average size of Saudi families. The answer revealed that the average Saudi family size is five persons per household.

6.5.2 Residential Buildings in Saudi Arabia

During this research lots of questions appeared regarding housing, residential building types, residential building numbers and prices in the Kingdom of Saudi Arabia. Therefore, the project manager from Makkah Municipality was asked questions about the number of residential buildings in 2013. The representative replied that each municipality in Saudi Arabia has its own database for it is region. The interviewee provided the number of residential buildings in Makkah region, as follows:

Table 6.2: Number of residential buildings in the Makkah region.

City / Town / Village	Number of residential buildings
Jeddah	702547
Makkah	291468
Taif	177408
Qunfza	54170
Allith	23936
Rabee	18600
Algamom	18269
Klhis	11759
Alkamel	4878
Al Khurma	7949
Ranee	8005
Turba	8698
Total for Makkah region	1327667

According to the result from the interview with the Makkah municipality representative, residential buildings in the kingdom are categorised into four main types: four-storey apartment blocks, two-storey apartment blocks, duplexes and houses (villas). The project manager from Makkah municipality mentioned that all regions in the country have the same residential building categories.

In addition, the Makkah municipality representative mentioned that apartment prices usually start from 350,000 Saudi Riyals (SR) (approximately 58,333 GBP, based on 1 GBP = 6 SR). House prices start from approximately 1000,000 SR (166,666 GBP).

In contrast, rental prices vary and depend on numerous factors, such as size, location, city and region, thus making it very difficult to provide accurate details.

6.5.3 Energy in Saudi Residential Buildings

There are numerous reasons why all types of Saudi buildings, and particularly residential buildings, depend on oil. According to the interview with an electrical engineer from the Saudi electricity company, the principal reasons are that Saudi Arabia is a very oil rich country, oil is the primary energy source, and it is very cheap to use for local energy purposes.

In an interview, a representative of King Abdulaziz City for Science and Technology (KACST) working as a senior architect stated that, based on their research, it is evident that residential buildings have the highest energy consumption, accounting for over 50% of the total energy.

According to the electrical engineer from the Saudi Electricity company, and based on their statistics, 80% of the power in Saudi Arabia is consumed between June and October.

Energy technologies have the potential to improve the current Saudi situation with regard to its enormous energy demand and its dependency on oil, resulting in environmental pollution.

The KACST representative commented that energy is one of the key drivers of Saudi Arabia's development and economic growth. However, satisfying the energy demand in the Kingdom is a challenge as it is estimated that the electricity demand alone is growing in excess of 6% a year. In order to keep pace with the demand, there is a need for science to offer a variety of solutions.

The Saudi government aims to change the future by using energy technologies to produce energy by alternative means rather than oil, for example renewable energy.

The Saudi Electricity Company representative stated that the government has already signed several contracts with various companies and organisations to harness the benefits of renewable energy, particularly solar power.

It is mentioned by the KACST representative working as an architect, the Kingdom of Saudi Arabia receives 105 trillion kilowatts of sunlight per day, some of the most intense sunlight exposure on the planet. The country is therefore considered to be one of the top five places in the world for potential photovoltaic generation of electricity. Thus, Saudi Arabia's best natural resource may be sunlight rather than oil.

KACST plans to use advanced nanotechnologies to develop solar power, as there is a belief that nanotechnology devices will reduce the cost to less than 30 halals (about 0.5 UK pence) per kW of electricity.

There are also many methods that could contribute to saving energy in Saudi houses and reducing energy consumption. In the interview, the Saudi electricity company representative believed that the easiest and most efficient way to save energy in residential buildings in Saudi Arabia is by using thermal insulations in the walls and roofs, adding shade devices, and by reducing window sizes, thereby decreasing heat in houses.

The architect from KACST explained that the key to reduce energy consumption in the Kingdom by reducing the 'Peak Load'. In Saudi Arabia approximately 10% of all electricity generated and 25% of the distribution infrastructure are used for just 400 hours per year (approximately 5% of the time), and this period of time is known as peak load. The representative added that new technologies offer the possibility of providing much needed relief by better informing customers of how they can be more energy efficient during peak load times, and the immediate tangible benefits, both financial and environmental, such as lower bills and improved air quality. Even by slightly reducing the peak load, there is a potential saving of billions of dollars in infrastructure investment. This is particularly important as the interviewee said that the peak demand forecast is expected to increase by over 60% until 2021.

The KACST representative added that Saudi Arabia should also adopt the Green building concept, which reduces energy consumption through a variety of methods. Firstly, efficient building design can decrease the embodied energy in the building, using recycled and local materials, and recycling construction waste. Secondly, green building design reduces buildings' lifetime energy consumption. The need for electrical lighting during the day can be decreased by the strategic positioning of windows and skylights; reliance on air conditioning can be reduced by using a whole house fan to cool the house overnight. Furthermore, high quality insulation decreases temperature regulation costs in both summer and winter, and houses can also maximise passive heating and cooling. Heating costs can see a 20-30% reduction with south facing windows with overhangs; prevailing breezes, shading and natural plantings can keep houses cooler in summer. It is also possible to create zero energy buildings, which are structures with an onsite source of renewable energy (e.g. solar panels or wind turbines).

The architect from Saudi Green Building Council (SGBC) mentioned that it is very important to raise public awareness, provide training and education as a priority. Other priorities should include assisting the construction industry to conform to the green building requirements, encouraging building material manufacturers and suppliers to produce and supply environmentally responsible products, and promoting green labelling.

Finally, the associate professor from KAUST confirmed that Saudi cities and buildings can become more environmentally-friendly by constructing buildings with sustainable low energy consumption. The first stage is to raise awareness and understanding of the importance of green buildings.

6.5.4 The Future of Residential Building in Saudi Arabia

According to the electrical engineer from the Saudi Electricity Company, if the electricity demand remains constant, then in 20 years from now the demand will almost triple from approximately 46,000 megawatts in 2010 to 120,000 megawatts by 2032.

In light of this, the Saudi government has signed several agreements for the application of new energy technologies in buildings, which can alter the country's future by making buildings more sustainable and lowering carbon emissions.

SGBC observed that the Saudi government is working to provide sustainable and green buildings in the future. KAUST offers a very good example of some recent green buildings in Saudi Arabia as it has some sustainable buildings on campus (LEED certified, platinum certification). KAUST earned 52 of the 53 required credits.

Moreover, the KACST interviewee explained that there is a KACST Energy Technology Program which is working with scientists and organisations around the world. The 2012 Saudi Energy Efficiency Workshop, organised in partnership with the US National Renewable Energy Laboratory, is now focusing on a project looking at sustainable resources with MIT (joint Centre of Excellence for Complex Engineering Systems).

6.5.5 Green Building Regulations

Although there are no official regulations with regard to green buildings in Saudi Arabia, a variety of reference points are being used, such as: the World Green Building Council; United States Green Building Council; Green Building Council Institute; Canadian Green Building Council; Environmental Protection Agency; American Society of Heating, Refrigerating and Air Conditioning Engineers; Abu Dhabi Urban Planning Council; UAE Green Building Council and LEED, as there are many agreements between these organisations.

6.6 Interview Results

The interview results show that the population in Saudi Arabia is rapidly increasing, impacting on a similar increase in the demand for power and electricity. Moreover, as oil is a very inexpensive resource in in the country, many Saudis pay little attention to their energy usage and have no consideration of the resulting environmental damage.

These issues are also reflected in Saudi residential buildings, resulting in very high energy consumption. The interview responses clearly indicate that most Saudi regions are facing the problem of high energy loads in homes. The interview with the Saudi Electricity Company predicted that electricity demand will almost triple within a period of 20 years, reaching 120,000 megawatts by 2032, thus there is an urgent need for research and action to avoid significant increases in the energy demand, particularly as residential buildings account for over 50% of the country’s energy consumption.

The Saudi government has started to take these issues into consideration, with KAUST as a good example of the new generation of environmentally-friendly buildings with a lower energy consumption, and the campus receiving LEED certification. However, this project alone is not enough and the Saudi government must take urgent action to address the current situation of residential buildings and new builds. Saudi municipalities should have building regulations and standards for the future of the construction industry.

Most of the engineers interviewed suggested potential steps to ensure a green future and change the current situations of buildings. These steps include raising public awareness, providing training and education, assisting the construction industry to conform to green building requirements, encouraging building material manufacturers and suppliers to produce and supply environmentally responsible products, and promoting green labelling.

Chapter 7

The Description of the Building Energy Simulation Software and the Typical Saudi House Details

7.1 Overview

This chapter (6) will start by presenting the simulation objective and the simulation software selection justification, descriptions and details.

Illustrating the typical weather and climate in Saudi Arabia is also discussed and included in this chapter for the selected cities in Saudi Arabia which are Jeddah, Dammam and the capital city Riyadh. As previously mentioned, these locations were selected as they have a large population, construction and are regarded as being the main cities in Saudi Arabia.

For the validation purposes, a Saudi residential building was selected in Dhahran, Saudi Arabia. This case study was published in a scientific paper and simulated by using DOE simulation software (Ahmed 2004). Then, IES simulation software used to compare the result and to validate the model which will explain in details later on in this chapter. The validation will be described in detail in section 7.7.

Finally, it will focus on the selected typical residential building that designed by Saudi government and used as a case study in this thesis. The chapter will present the details of the Saudi house such as building floors plan, elevations and perspectives. All these data presented in this chapter will be used later on as an inputs for the IES building simulation software in the next chapter (chapter 7).

7.2 Simulation Objective

In this chapter, the aim is to analyse the recent performance and behaviour of the Saudi building, focusing on the assessment of the impact of wall content in the Saudi climate.

The energy use within the building was examined through hour by hour computer simulation of energy over an annual period. The graphs present the time frames, e.g. specific days and months. In fact, modelling is achieved by use of a weather database for specific regions in Saudi Arabia. The energy load is here defined as the amount of energy that must be removed or added to the interior of a building to maintain the desired temperature and thermal comfort.

In fact, it is very important to mention that the new residential buildings in Saudi Arabia spread all over the country in a short period of time. Unfortunately, these buildings failed to provide the acceptable comfort conditions indoors. Therefore, use of mechanical systems for cooling is a must. The main cause is extremely high ambient temperatures (Phillip 2013) and the poor thermal design of these new buildings. Saudis at present are suffering and looking for providing the required level of comfort in the Saudi house throughout the year. It is very important to note that the Saudi house requires the mechanical system for cooling to provide comfortable conditions, and in fact, a significant amount of energy consumption goes to air-conditioning to provide the acceptable level of thermal comfort (Mohammed and Budaiwi 2013). The Saudi house should take into consideration very carefully the selection of building materials (Al-Naimi 1989) to try to reduce the air conditioning requirement.

In hot and humid region such as Saudi Arabia the limit of comfort condition for minimum standards, the temperature internally should be 75°F (24.4°C) dry-bulb temperature or 79.5°F (26 .4°C) (Al-Naimi 1989).

For example, based on experiments it concluded that the required thermal comfort for Dammam is between 69°F (20.5°C) dry-bulb temperature and 80°F (26.7°C.) and humidity of 30% to 80% (Al-Naimi 1989). In addition, the Saudi building code sets two acceptable design temperatures of 20 °C and 25.5 °C for both winter and summer The Saudi building code depends on Fanger's heat balance model l, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard -55 (1992) formed the basis for this. (Indraganti 2015).

Khafaji in 1987 added that the comfort zone of tropical areas is between 23° and 30° C. The humidity should be between 30% and 70%.

The following figure presents the acceptable range of operative temperature and air speed for the comfort zone.

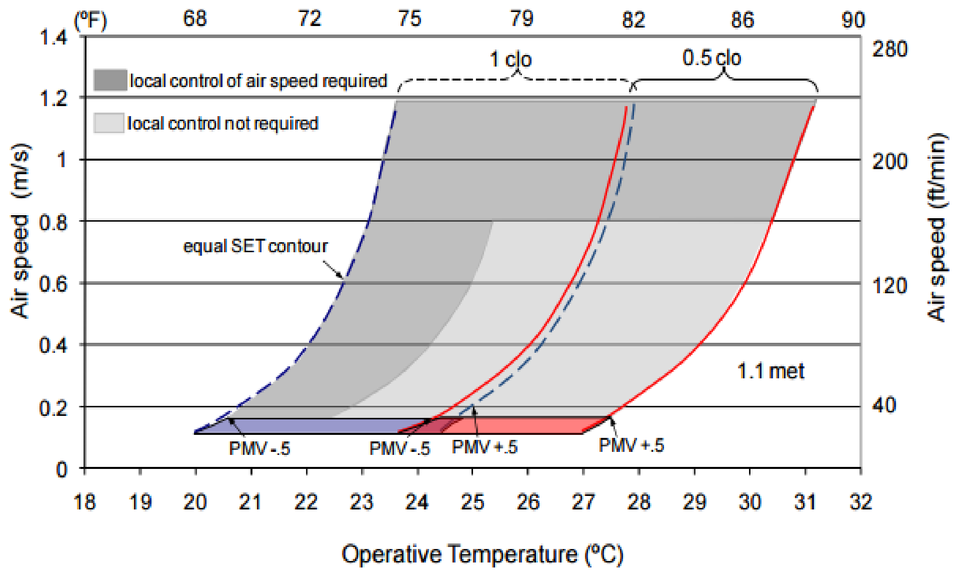


Figure 7.1: the acceptable range of operative temperature and air speed for the comfort zone.

The computer software (IES) designed to take into consideration all possible factors that could affect heat gains or losses which will be reflected in building cooling or heating loads. The IES software with the right inputs will help to find out the peak times for energy demand in the Saudi building for the selected locations and will give the user the full image of the building behaviour not only under peak conditions but also throughout a typical year. In addition, prediction of peak energy will help engineers and designers to take the best decision.

The simulations made varied both thermal mass of the external walls and to the insulation. It is not possible to separate completely these two effects as any thermal mass material also has a thermal resistance and this affects the heat flow.

To summarise, the aim is to assess the effectiveness of the external walls and the insulation in reducing cooling load. The thermal mass for the external walls will work to delay the heat transfer and the insulation will cut and reduce the overall rate of heat transfer through the wall.

7.3 Computer Simulation Studies

Computer simulation modelling is used in order to estimate and establish the energy consumption of the building. Dynamic, thermal simulation models are mathematical representations of the thermal processes occurring in a building and are commonly used for building energy analysis. This type of software can account for the transient response of various load contributors, including hourly weather data as part of their input. Thus, it is possible to estimate the energy requirements for both heating and cooling the building on an hourly, daily, or monthly basis. It is a cost- effective way to assess the impact of alternative design and building modifications on building energy consumption.

7.4 Rationale for Selection of Energy Analysis Software

There is a variety of software that can perform energy simulations, but the IES software was selected as it: offers a dynamic simulation; is friendly user; is based on architectural drawings; is accurate; and the availability of the required data. Moreover, it offers quality of output, validation and documentation.

Further to the aforementioned features, IES is a full featured, windows-based tool, which is designed to carry out a complete energy consumption analysis on an hour by hour basis. It produces charts that show the annual thermal response to the type of building construction materials used, along with numerous other factors such as: colour, orientation, shading devices, number of users, activities in the building, devices. IES provides the required output in sufficient detail for this type of research.

7.5 Integrated Environmental Solutions Software

ApacheSim (Apache Simulation) refers to a “dynamic thermal simulation program” that revolves around the first mathematical modelling principles of heat transfer procedures, which occurs around and inside buildings. Based on the categorization system of the CIBSE model, ApacheSim is a suitable dynamic model and, in different aspects, surpasses the model's requirements.

The program provides an environment, in which a comprehensive assessment of system and building designs may be undertaken, facilitating their optimisation in light of energy consumption and comfort criteria (Integrated Environmental Solutions Limited 2015).

ApacheSim may be utilised for many issues that include

• Mixed-mode systems

• HVAC systems

• Mechanical ventilation

• Natural ventilation

• Air-tightness

• Casual gains

• Solar penetration, solar gain and shading

• Glazing features

• Climate

• Building orientation and configuration

• Thermal weight (mass) and building dynamics

•Thermal insulation (placement and type)

ApacheSim offers single modelling for all building elements that include radiation, convection and conduction heat transfer procedures. Such are combined with plant, air exchanges and room heat gain models. Actual data about the weather is utilised for simulation, and covers any period ranging from 1 day -12 months. The changing thermal conditions of buildings may be monitored over time, at short intervals, for instance, 60 seconds (Integrated Environmental Solutions Limited 2015).

The outcomes produced through simulation are:

The results generated by the simulation include:

• CFD boundary conditions or comfort studies' surface temperatures

• Comprehensive performance mechanisms such as air exchanges, casual gains, plant loads, humidity and "hourly room temperatures" (dry resultant, radiant, mean and air).

• Plant sizes

• Room load statistics
• Carbon emissions
• Energy consumption
• Comfort statistics (Integrated Environmental Solutions Limited 2015).

7.5.1 Heat Conduction and Storage Fundamentals

The following partial differential equations are used to show the time-evolution of the spatial temperature distribution in a solid, without internal heat sources:

$$W = -\lambda \nabla T \quad (7.1)$$

$$\nabla . W = -\rho c \partial T / \partial t \quad (7.2)$$

Where:

T (x, y, z, t) is the temperature (ºC) in the solid at position (x,y,z) and time t

W (x, y, z, t) is the heat flux vector (W/m^2) at position (x, y, z) and time t

λ is the conductivity of the solid (W/m^2K)

ρ is the density of the solid (kg/m^3)

c is the specific heat capacity of the solid (J/kgK)

Equations 1 and 2 express the principles of conduction heat transfer and heat storage, respectively. The heat diffusion equation (in its most general form in which λ, ρ, and c may vary with position) then follows:

$$\nabla . (\lambda \nabla T) = \rho c \partial T / \partial t \quad (7.3)$$

It is important to take account of heat storage in air masses within the building. The model of this process is

$$Q = c_p \rho_a V dT_a / dt \quad (7.4)$$

Where

Q is the net heat flow into the air mass (W)

Cp is the specific heat capacity of air at constant pressure (J/kgK)

ρ a is the air density (kg/m3)

V is the air volume (m3)

Ta is the air temperature (ºC)

(Integrated Environmental Solutions Limited 2015).

7.5.2 Modelling Assumptions

ApacheSim works on the assumption that conduction within each component of the building (ceiling, roof and wall among others) is "uni-dimensional". Additionally, it assumes that the thermal-physical characteristics λ, ρ, and c for each component's stratum are even within the stratum. Such assumptions may be utilised for creating the equation below:

$$\partial^2 T / \partial x^2 = \frac{\rho c}{\lambda} \partial T / \partial t \quad (7.5)$$

The equations network is closed through application of proper boundary conditions as well as concluding that W is dynamic at the stratum boundaries.

7.5.3 Discretisation

ApacheSim utilises a finite variation method for the solution involving "heat diffusion" equation. Initially, this substitutes the element using a finite quantity of "discrete nodes" at which calculation of temperature can be undertaken. Within the "spatially-discretised" representation, equation 5 indicated below is used.

$$\frac{T_{n-1} - 2T_n + T_{n+1}}{\delta_n^{\ 2}} = -(\rho c / \lambda) \partial T / \partial t \quad (7.6)$$

Where:

Tn represents the temperature (ºC) at the node n and

δ n represents the spacing of the local node (m).

Node distribution in the strata occurs to facilitate accurate modelling of heat storage and transfer properties for the chosen time step. This choice depends upon the limits placed on the "Fourier number" as indicated below:

$$F = (\lambda / \rho C)\Delta / \delta_n^2 \qquad (7.7)$$

Where:

Δ represents the "simulation time-step" (s).

During the process each stratum could be assigned several nodes. Then, there is discretisation of the time variable. Different schemes could be applied in this phase.

Explicit techniques utilise a forward-variation scheme that uses existing and upcoming nodal temperature values in expressing the temperature time derivative ∂T / ∂t at the current time:

$$\dot{T}_n^j = (T_n^{j+1} - T_n^j)/\Delta \qquad (7.8)$$

Where

T_n^j Represents temperature (ºC) at the node n as well as time-step j,

$\dot{T}_n^j$ Represents the temperature time derivative (K/s) at the node n as well as time-step j

Pure-implicit techniques utilise a backward-difference system, in which the calculated time derivative is used one time-step within the future as indicated below:

$$\dot{T}_n^{j+1} = (T_n^{j+1} - T_n^{j}) / \Delta \tag{7.9}$$

The time derivatives within the equations are equated to ∂T / ∂t to identify a heat conduction model, which has time and space discretisation. For improvement of stability and accuracy, an implicit and explicit time stepping combination is utilised. Such scheme is exemplified by the Crank-Nicholson semi-implicit technique. The “hopscotch” technique is another one that uses implicit and explicit time-stepping for alternate construction nodes. This method is utilised by ApacheSim. The benefits associated with the technique include high accuracy level and effective computation. Myers fully describes the finite variation techniques.

7.6 Data Used and Inputs

This section will show and explain in details all data and information used in the IES simulation software as an input.

7.6.1 Simulation locations:

Notably, the KSA has 13 provinces, each having a capital city based on illustration in table 7.1 and figure 7.2 below.

Table 7.1: Saudi Arabia provinces (Information Office of the Royal Embassy of Saudi Arabia in Washington, DC 2015).

Province	Capital
Najran	Najran
Jizan	Jizan
Northern Borders	Ar'ar
Al-Jouf	Sakakah
Hail	Hail
Qassim	Buraidah
Tabuk	Tabuk
Al-Baha	Al-Baha
Asir	Abha
Eastern	Dammam
Madinah	Madinah
Makkah	Makkah
Riyadh	Riyadh

Figure 7.2: Saudi Arabia provinces map (JEP 2015).

The focus of this study will be on three Saudi cities namely Dammam, Jeddah and Riyadh. The selection of the three cities was based on several criteria. The three cities are regarded as the key cities within the country due to the location and high population, because the three Saudi regions are represented by them.

Riyadh serves as an administrative centre hosting the government ministries, diplomatic missions and embassies, and as the Saudi capital. Additionally, it hosts social, commercial, technical, cultural, agricultural, financial and educational institutions.

Riyadh city has a population of over 2 million people with the area totally inhabited exceeding 1600 km. Riyadh city hosts two universities namely Imam Mohammad bin Saud Islamic University and King Saud, alongside public libraries, stadiums and sports facilities, cultural and cultural information centres, information centres, specialised institutes and, security and military colleges.

The port city of Jeddah located along the Red Sea is second in terms of size and serves as the entry point for many pilgrims arriving by sea or air for religious functions or visit the holy mosques. The area occupied by people in Jeddah exceeds 1500km, with the population of more than 1.5 million. The city serves as an industrial and commercial centre consisting of courtyards, squares and modern features. Furthermore, it serves as a tourism centre, with an attractive corniche covering 80km on the Red Sea coast. Moreover, Jeddah is a transport centre hosting Jeddah Islamic Port and King Abdul Aziz International Airport, as well as educational centre hosting King Abdul Aziz University.

The third city, Dammam, is another critical Port city located on the Arabian Gulf in eastern Saudi Arabia. Dammam is the biggest town within Eastern Saudi Arabia, having extended to the limits of Dhahran and Al-Khobar, two other emerging towns; and its population is more than 1 million. Dammam borders globally important petroleum refining and production centres (The Saudi Network 2014).

7.6.2 Typical Weather and Climate in Saudi Arabia

The climate across most of Saudi Arabia is dry with very high temperatures, although there is some variation in temperatures across different areas of the country. Temperatures in the south are moderate, dipping down to 10 degrees Celsius (50° Fahrenheit) in summer; in winter temperatures are usually moderate, though are cold at night and can dip below freezing. There is rainfall in the Red Sea coastal areas in the months of March and April, though there is little rainfall in the rest of the country.

7.6.2.1 Riyadh Weather

Riyadh enjoys a pleasant average temperature from November until March, with the hot season lasting from April to October, and the highest rainfall in October. There are spells of rain in in January, February, March, May, June, July, August and September. The hottest month in Riyadh is July, while the coolest month is January (as shown in the graph 7.3 below).

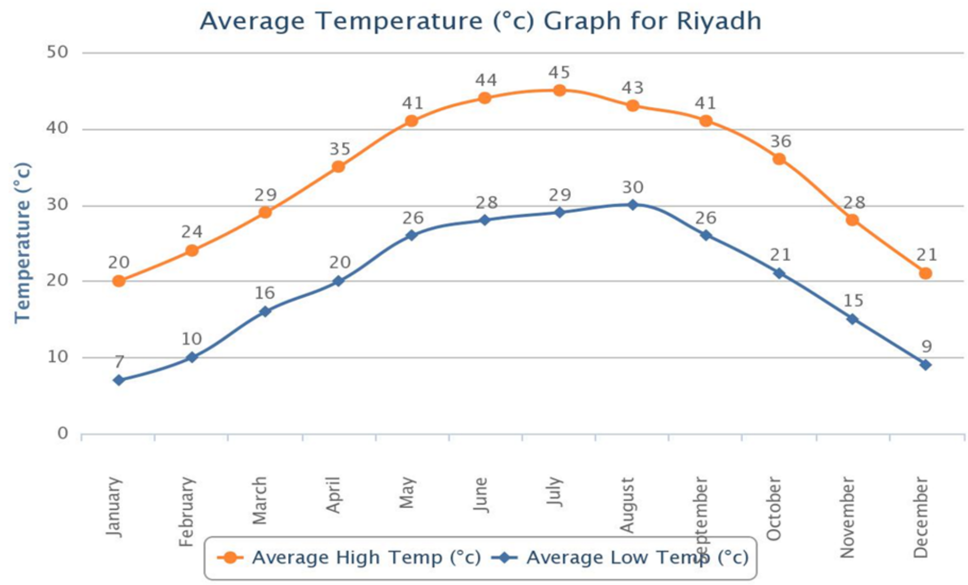


Figure 7.3: Average minimum and maximum temperature (world weather online, 2013).

7.6.2.2Jeddah Weather

The following graph 6.4 shows the average temperature for Jeddah city. It is evident that the temperature begins to rise from May until September. From October the temperature begins to falls, with January and February being the coldest months (world weather online, 2013).

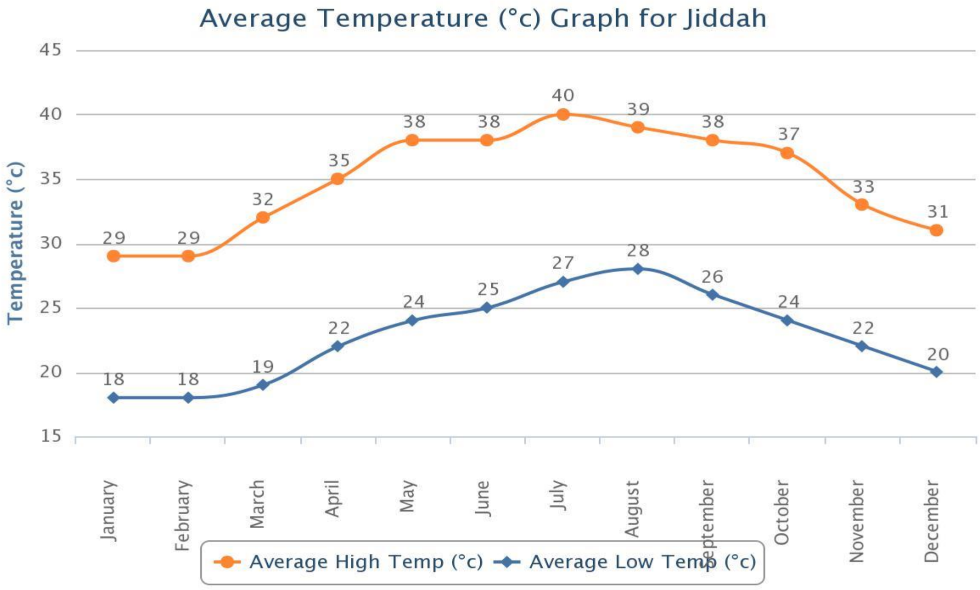


Figure 7.4: Average minimum and maximum temperature (world weather online, 2013).

7.6.2.3 Dammam Weather

The hottest season in Dammam lasts from May until the end of August, with the temperature falling from October until reaching the minimum in January (world weather online, 2013).

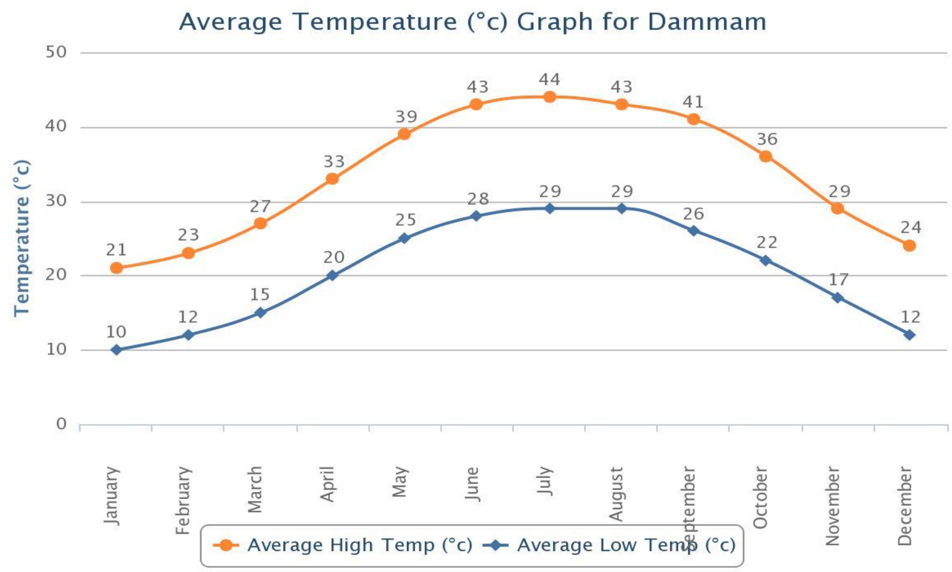


Figure 7.5: Average minimum and maximum temperature (world weather online, 2013).

7.7 Model Validation

Model validation is a key part of this research and it is important to note that the model used in this study is a typical new residential building in Saudi Arabia. Therefore, the accuracy of the data entered and the simulation results, which resulted in this step, is not known. In order to verify the accuracy and to ensure that the researcher enters all the building simulation data correctly, an existing residential building in Saudi Arabia is used for model validation, withting data such as:

- Drawing the model correctly.
- Inputting building materials in the simulation software correctly.
- Inputting the locations for the selected model correctly.
- Inputting weather data for the selected model correctly.
- Running the software and getting results correctly**.**

The aim of this validation is to provide a comparison of the results of the building energy simulation for the cooling load using the Integrated Environmental Solution software, with the existing results for the cooling load for the selected residential building in this section.

7.7.1 Location

The model house used in this research validation purposes is located in Dhahran, Saudi Arabia, approximately 10 km from the Arabian Gulf. Dhahran is situated 6 miles (10 km) west of Khobar, and together these two cities form the Dammam Area. The eastern province is the largest desert in the world, covering an area of 80km by 1200km, from the north of the Kuwaiti border to the Rub'Al Khali in the south (The Saudi Network, 2015).

Figure 7.6: The location of Dhahran

Figure 7.7: The location of Dhahran

7.7.2 Climate of Dhahran, Saudi Arabia

During the day, temperatures in Dhahran regularly exceed 40° C from April to October, with a good deal of humidity, particularly in August and September. In winter (December and January) temperatures dip to approximately 18° C during the day and 10° C at night. There is little rainfall throughout the year (The Saudi Network 2015).

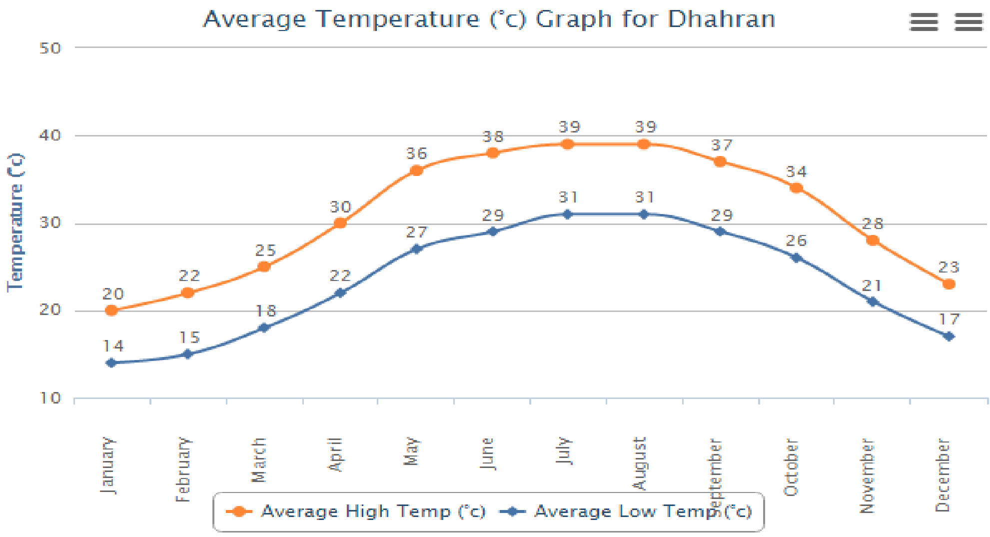


Figure 7.8: Average minimum and maximum temperatures (world weather online, 2013).

The IES building energy simulation software possesses a variety weather and climate databases for most cities and countries. The simulation of this model will use the weather database for Dhahran, with IES using an average of the weather and climate over the last 10 years.

7.7.3 Typical house details

This section discusses the building characteristics of the case study of the selected house in Dhahran, Saudi Arabia. The characteristics of the building, system, and operating conditions for this simulated typical house are detailed in the following table.

Table 7.2: Characteristics and description for the case study house (Ahmad 2004).

Characteristics	Description (for Base House)
Location	Dhahran (Lat. 26° 17′ N, Long. 50° 09′ E, Altitude 24 m)
Orientation	Front elevation facing the east
Plan shape	Rectangular
Number of stories	2
Total height	7.0 m
Floor dimensions	15.0 m × 17.5 m
Gross floor area (2 floors)	525.0 m^2
Gross wall area	455.0 m^2 (including windows)
Window area	13.29 % of Gross wall area
Window setback	50 mm
Type of glass	Single pane with indoor shading by venetian blinds (SC=0.67)
External shading devices	None
Solar absorptivities[1] (for exterior surfaces)	0.30 for external walls (white painted, semi gloss) 0.50 for built-up roof, white
External walls	20 mm plaster outside + 200 mm concrete hollow block + 20 mm plaster inside
Roof	10 mm built-up roofing + 150 mm concrete roof slab + 12.7 mm plaster inside
Floor	150 mm slab on grade
People[2]	6
Lighting[3]	3.0 kW (lower level), 2.0 kW (upper level)
Appliances[3]	2.0 kW (lower level), 1.0 kW (upper level)
Infiltration type[3]	Residential[a]

The aforementioned details in the table for the case study house will be used in the IES simulation for validation purposes.

7.7.4 House floor plans

The typical house in Dhahran, Saudi Arabia consists of two floors, with the first floor containing: the majlis (guest room), dining room, family room, kitchen and two toilets.

The second floor contains: the master bedroom with toilet, two bedrooms and a toilet. Each floor is 3.5m high, and the floor plans, elevation and 3D model perspective are as follows:

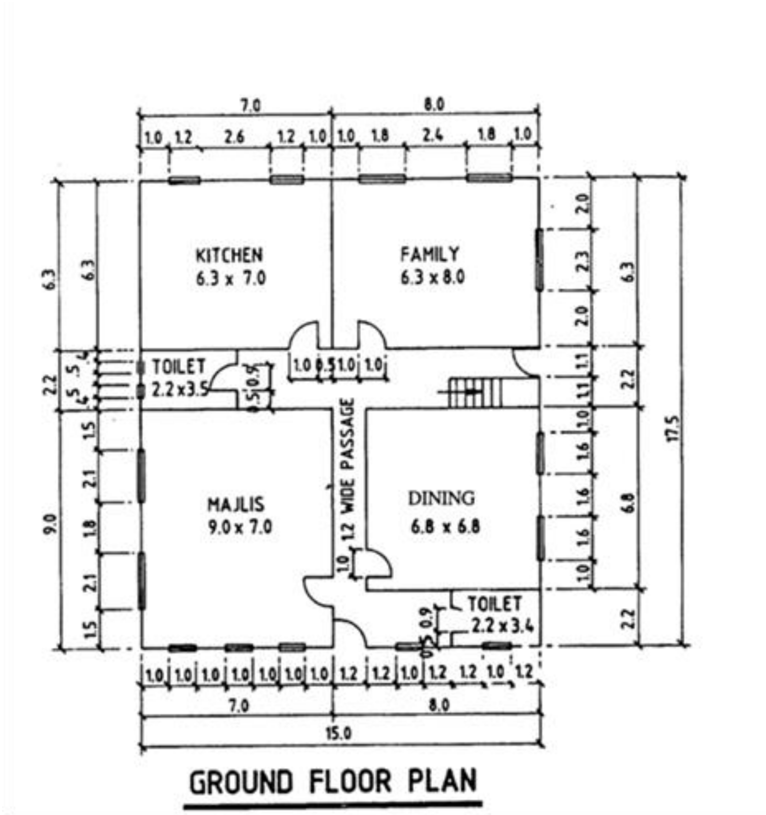


Figure 7.9: Typical house ground floor plan (Ahmad 2004).

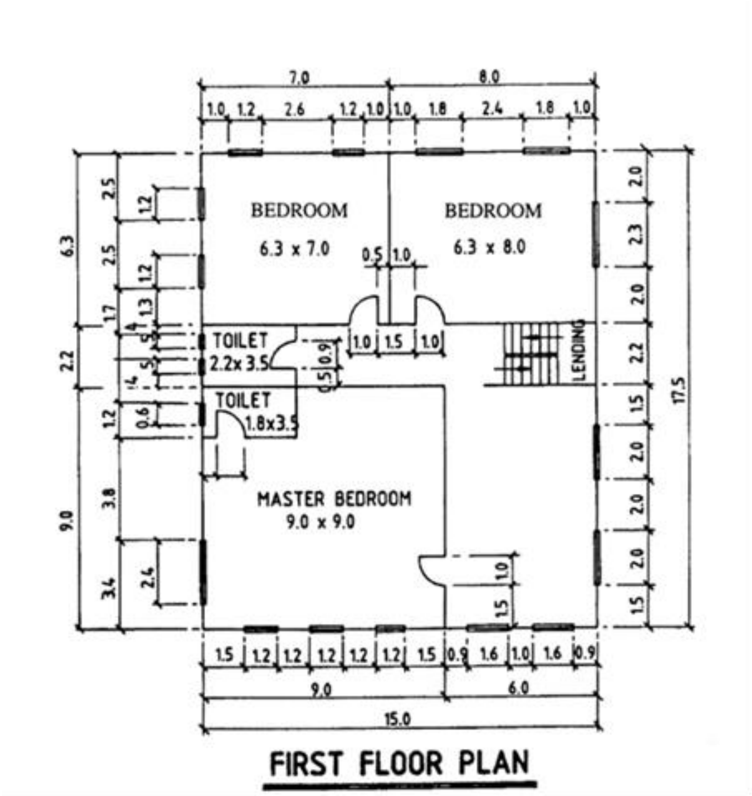


Figure 7.10: Typical house first floor plan (Ahmad 2004).

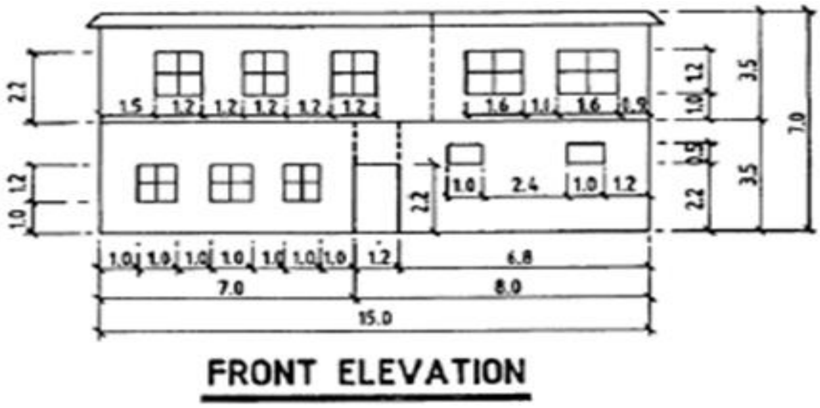


Figure 7.11: Typical house front elevation (Ahmad 2004).

The floor plans drawn using IES are based on the details and dimensions in the previous drawings. The next step in the validation process is to apply different types of building materials (see the following table and figure). Energy simulation runs were carried out for various wall and roof configurations, as shown in the table.

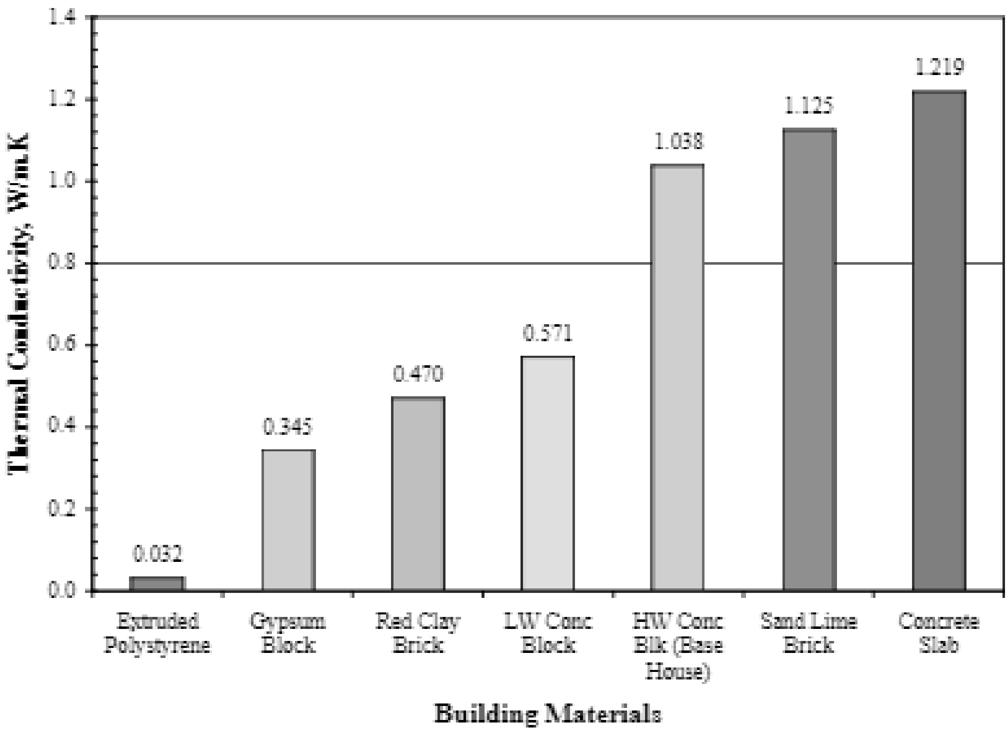


Figure 7.12: Building Materials (Ahmad 2004).

Table 7.3: Physical and thermal properties of the studied building materials (Ahmad 2004).

Table 5. Physical and Thermal Properties of the Studied Building Materials [17,18].

Type	Description	Thickness, mm	k, W/m.K	SH^1, kJ/kg.K	Density, kg/m³
1. HW Concrete Block	Hollow	200	1.038	0.84	977
2. LW Concrete Block	Hollow	200	0.571	0.84	609
3. Red Clay Brick	Hollow	200	0.470	0.84	690
4. Sand Lime	Solid	200	1.125	0.80	1864
5. Gypsum Block	Solid	200	0.345	1.09	1030
6. Extruded Polystyrene	Board	50	0.032	1.21	33.5
7. Concrete Slab	Solid	150	1.219	0.84	2122
8. Cement Plaster	Solid	20	0.797	0.84	1682
9. Built-up roofing	felt	10	0.170	1.46	1100

Table 7.4: Wall and roof configuration for different simulation cases (Ahmad 2004).

Table 6. Wall and Roof Configuration for Different Simulation Cases.

Case No.	Description
1 (**Base House**)	**Roof**: 10 mm Built-up roofing + 150 mm Normal Concrete Slab + 20 mm Cement Plaster **Wall**: 20 mm Cement Plaster + 200 mm Normal Concrete Block + 20 mm Cement Plaster
2	**Roof**: Same as for Base House (Case 1) **Wall**: 20 mm Cement Plaster + 200 mm **Lightweight Concrete Block** + 20 mm Cement Plaster
3	**Roof**: Same as for Base House (Case 1) **Wall**: 20 mm Cement Plaster + 200 mm **Red Clay Brick** + 20 mm Cement Plaster
4	**Roof**: Same as for Base House (Case 1) **Wall**: 20 mm Cement Plaster + 200 mm **Sand Lime Brick** + 20 mm Cement Plaster
5	**Roof**: Same as for Base House (Case 1) **Wall**: 20 mm Cement Plaster + 200 mm **Gypsum Block** + 20 mm Cement Plaster
6 (Insulated House)	**Roof**: 10 mm Built-up roofing + 50 mm **Extruded Polystyrene** + 150 mm Heavyweight Concrete Slab + 20 mm Cement Plaster **Wall**: 20 mm Cement Plaster + 200 mm Normal Concrete Block + 50 mm **Extruded Polystyrene** + 20 mm Cement Plaster

These details are subsequently used as inputs to validate the model and to compare the cooling load results. It must be noted that the original results were obtained using the DOE building energy simulation software, whereas the results in this research are obtained using the IES building energy simulation software.

7.7.5 Results and Analysis

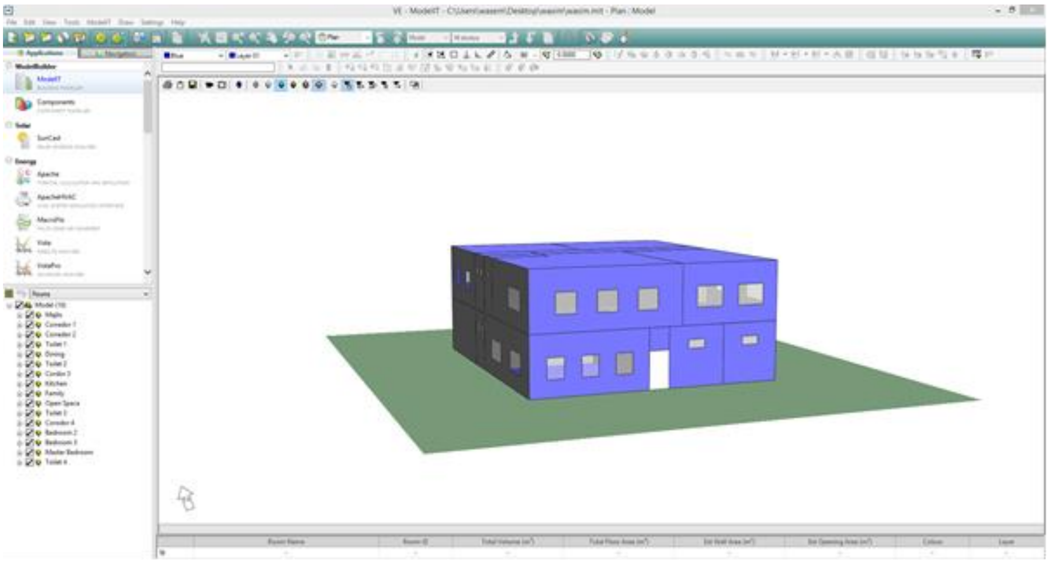


Figure 7.13: Typical house 3D perspective drew by researcher using IES.

Following the application of the various construction and building materials for walls and roofs for all case studies, the results will show the total cooling load, heating load and total energy consumption for each case. The annual energy consumption for the case study house is calculated to be 138,293 kWh, with a cooling load of 100353 kWh. The distribution of the peak cooling load is calculated by the simulation program for the case study house. It is evident that using different building materials directly impacts on energy consumption and on the air-conditioning system capacity for a simulated building, as investigated in the present study.

The following table presents the calculated annual energy consumption for a typical house, using different building material. The table presents the result for each material, with the important information here being the result for the cooling load, to compare it with the IES result.

Table 7.5: Annual electric energy consumption obtained by using the DOE 2.1E program for a typical house built using different types of building materials (Ahmad 2004).

TYPE OF HOUSE	ANNUAL ELECTRIC ENERGY CONSUMPTION (kWh)			
	Cooling	Heating	Total	% Change of Total Energy Consumption*
1. Base House – Normal Concrete Block House (Case 1)	100 353	16 827	138 293	----
2. Lightweight Concrete Block House (Case 2)	93 962	14 137	128 826	–6.9
3. Red Brick House (Case 3)	91 637	13 207	125 450	–9.3
4. Sand Lime Brick House (Case 4)	100 339	16 838	138 324	0.02
5. Gypsum Block House (Case 5)	87 930	11 672	120 013	–13.2

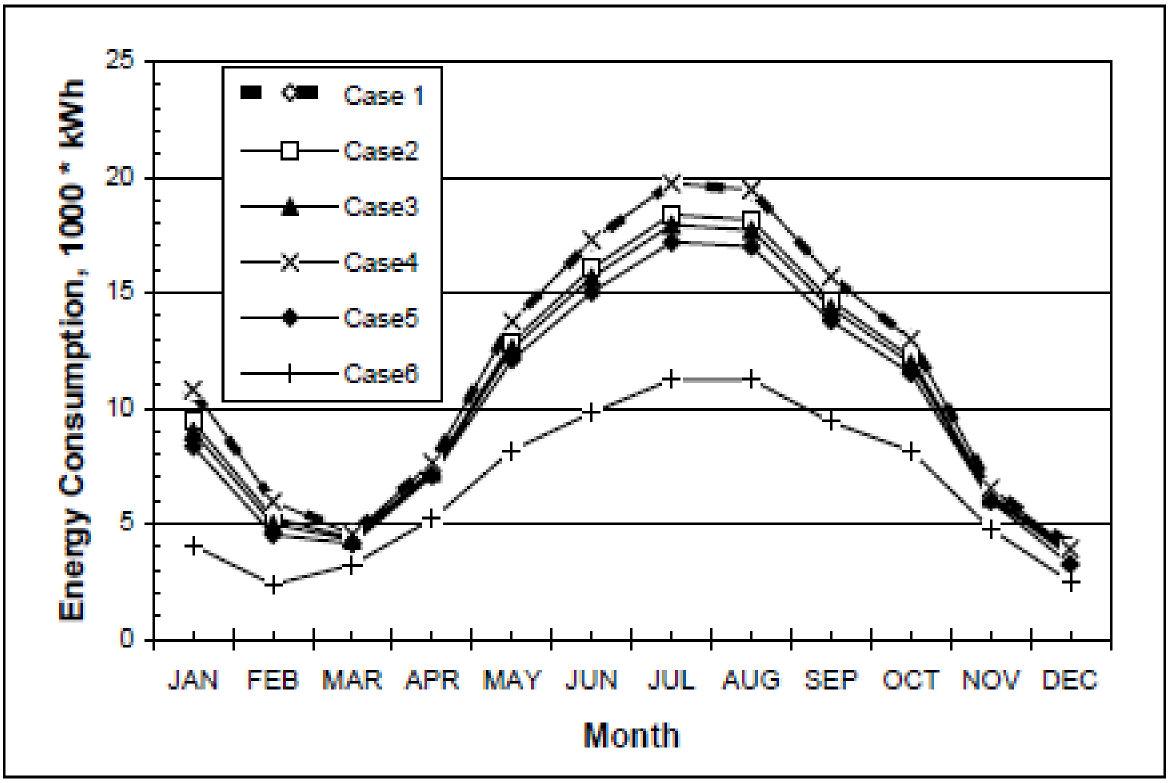


Figure 7.14: The monthly energy consumption for a house built using different types of building materials (Ahmad 2004).

The final stage of this building validation, after drawing the building in IES and studying the original results for the cooling load for this typical residential building in Dhahran, Saudi Arabia, is the comparison of the results of IES with those from DOE for the cooling load.

7.7.6 Validation Results Comparative

Five case studies were tested using IES to compare the results with those from DOE for the cooling load. The following figure presents each case study individually, with a side-by-side comparison. It is evident that there is a trend and similarity across the results of all the case studies. There is a very small difference in results, for example only 8% difference in case number five. The blue lines show the paper results for the cooling load using the DOE energy simulation software, and the red lines represent the results of the current research for the cooling load using the IES building energy simulation. It must be noted that there is potential for a slight variance in the results due to the use of different simulation software and perhaps different weather databases.

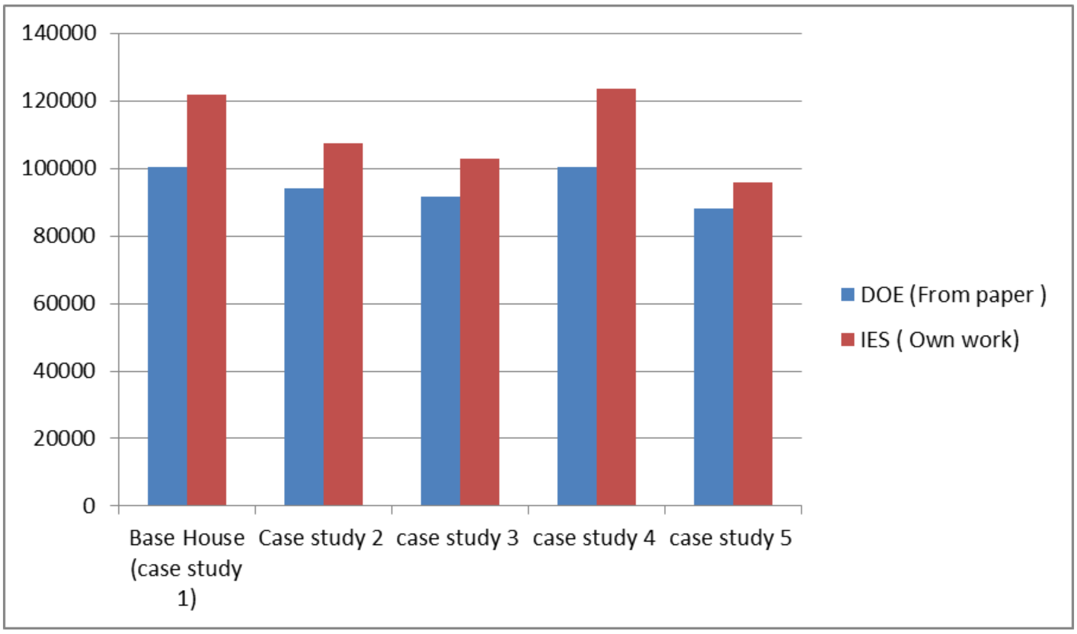


Figure 7.15: Cooling load results comparison.

The IES software has been validated as above, and will therefore be used for studies on the new house design.

7.8 Data Used in Simulation for the Selected Residential Building

7.8.1 House Details

For this study's purpose, it is imperative for a definition of residential building types in the KSA to be undertaken. Information obtained following a field trip to Makkah municipality indicates that four categories for Saudi residential buildings exist they include Villas (houses) attached houses (duplexes), two-storey apartment blocks and Four-storey apartment blocks. Of these types, villas are dominant and most sought residential buildings.

For the aims of the current study, a villa model would be utilised for studying the use of energy for the cooling load as well as techniques of improving the energy performance of residential buildings, in three specified sites in the KSA.

A typical house design in Saudi Arabia is provided on the Ministry of Housing website, with the government of Saudi Arabia planning to construct 500,000 units with the design in the kingdom. The government of Saudi Arabia has embarked on a new housing initiative for its citizens aimed at addressing the inadequate housing, which influences undermines the living conditions and it is a politically sensitive issue (Rashad 2014).

After civil unrest caused by social discontent across Arab-speaking nations in 2011, Saudi's King Abdullah unveiled a program of building 500,000 new residential buildings in the KSA, over a given duration. Funding of the project would cost Saudi government about 67 billion dollars (Rashad 2014).

However, the complexity surrounding the allocation of aid, difficulties in the acquisition of suitable land and bureaucracies have undermined rapid implementation of the program. The new project called ESKAN (housing in Arabic), which was launched recently by the Housing Ministry is aimed at overcoming such drawbacks.

The period of registering online is two months for Saudi families in need of assistance, either through sale of subsidized housing units or land or government-subsidized mortgages. The applications will be considered for three months, before a decision regarding the people who are eligible to receive aid is made.

Based on news from the local media, Shuwaish Al Duwaihi, Saudi's housing minister, all applicants to the EKSAN program and who fulfil the requirements would be given access to their new homes after 7 months (Rashad 2014).

An analyst in the real estate sector, Khaled al Rubaish, remarked that the EKSAN initiative might go a long way in solving the perennial housing problem through provision of an open, universal means for citizens in the country to acquire assistance:

"The situation would become transparent for the financiers (mortgage firms or banks), developers in the real estate sector and the private sector. All the aforementioned stakeholders would be able to identify their targets," said Khaled al Rubaish.

According to a key investment strategist in MASIC (Saudi Investment Company), John Sfakianakis, "Any move towards addressing the housing problem is not only good but welcome.... It emerged that constructing 500,000 housing units became cumbersome than it appeared, therefore there is need for increasing the pace" (Rashad 2014).

He added that EKSAN will "help in initiating a take-off for the housing market; this will address the middle class needs, where housing demand is high. When Saudis see the shortage being tackled, market imbalance in the housing sector and systemic risks would reduce."

Based on analysts' estimations, about 60% of families in Saudi Arabia (a country where 20 million people) are not home owners, which constitutes a huge ratio for such a rich country. Rent increments have escalated the problem by making it difficult for middle class individuals to afford homes; a large number of Saudis are ineligible for home loans from banking institutions (Rashad 2014).

An uncertainty looms regarding whether the Housing Ministry would be successful in adhering to the set timetable for approving applications in the EKSAN project, as well as the timelines for building new homes.

Additionally, according to Abdulwahab Abu Dahesh, an economic analyst from Saudi Arabia, difficulties are bound to occur in the verification of eligible applicants, thus delaying the homes handover (Rashad 2014).

However, the detailed requirements for the EKSAN project indicate the ministry of housing is working hard to reduce delays associated with bureaucracy by providing an open, simple system for aid allocation, and this is a progress compared to earlier programmes.

The rules state applicants should not be home owners and ought not to have been beneficiaries of aid from government-subsidized housing project; a points mechanism would be utilised for prioritising applications, considering factors such as age, monthly income and family size, and seeks to prioritise the people in need.

Applicants would be required to for the subsidized land or home, or settle their loans, by contributing a monthly instalment of 25 percent from their monthly income for 10 years (Rashad 2014).

The Ministry of Housing in Saudi Arabia chose the model because it is a reflection of the traditions and customs of Arabic community and Saudi families. Additionally, it is aimed at providing optimum housing engineering standards that include privacy, future scalability and flexibility, natural ventilation and lighting, proper room measurements, proper room distribution, implementation ease and economic design. Therefore, the current research will adopt this design (Rashad 2014).

A typical house (villa) in Saudi Arabia, based on the website details from the Housing Ministry is illustrated as follow:

Table 7.6: The ground floor plan details

NAME OF THE ROOM	SIZE
GUEST ROOM	4x6
DINING ROOM	3,8x5
KITCHEN	3x4
MEN'S TOILET	1,7x2
BEDROOM	3.8x4.6
TOILETS	2x2.8
LIVING ROOM	4x4,6

Table 7.7: The first floor plan details

NAME OF THE ROOM	SIZE
MAIN BEDROOM	4X6 WITH TOILET 1,7X2,2
FIRST BEDROOM	3,8X5
SECOND BEDROOM	3,8X4,6
SERVANT'S ROOM	1,5X2,3 WITH TOILET 1,2X1,5

Additionally, based on the Saudi Housing Ministry website, the perspectives, elevations and floor plan are indicated below.

Figure 7.16: Ground Floor Plan (Saudi Ministry OF Housing 2014).

Figure 7.17: First Floor Plan (Saudi Ministry OF Housing 2014).

Figure 7.18: Building Elevations (Saudi Ministry of Housing 2014).

Figure 7.19: Building Perspective 1 (Saudi Ministry of Housing 2014).

Figure 7.20: Building Perspective 2 (Saudi Ministry of Housing 2014).

Figure 7.21: Building Perspective 3 (Saudi Ministry of Housing 2014).

7.8.2 Construction Details

7.8.2.1 Wall structure in Saudi residential buildings

The building materials used to construct houses are stone, concrete block, brick and the required steel bars for reinforcement. Although the wall structures vary from one region to another, in Saudi Arabia they typically consist of brick, concrete and sometimes stone. Table 7.8 lists the typical wall structures for buildings in Saudi Arabia along with their thermal characteristics, including the conductance U-value, and thermal resistance. (Eball 2002).

Table 7.8: Structures and thermal characteristics of walls used mostly in Saudi Arabian Residential Buildings (Eball 2002).

Wall Type	Thickness of wall components (m)	Thermal conductivity of wall components W/mK	Wall conductance U (W/m^2K)	Wall Resistance (m^2k/w)	Density kg/m^3	Specific heat J/kgK
Wall I						
External Plaster	0.20	1.20	2.25	0.44	2000	1000
Hollow bricks	0.20	0.90			1500	840
Internal Plaster	0.03	1.20			2200	1000
Wall II						
External Plaster	0.02	1.20	2.98	0.336	2000	1000
Concrete	0.20	1.75			2410	880
Internal Plaster	0.03	1.20			2000	1000
Wall III						
Stone	0.20	1.70	2.28	0.438	2250	840
Concrete	0.07	1.75			2410	880
Hollow bricks	0.20	0.90			1500	840
Plaster	0.03	1.20			2000	1000
Wall IV						
Stone	0.20	1.70	1.62	0.617	2250	840
Concrete	0.20	1.75			2410	880
Air gap	0.05	0.28				
Bricks	0.10	0.90			1500	840
Plaster	0.03	1.20			2000	1000

These four types of walls were selected for analysis in this thesis as they represent the most commonly used building materials in Saudi residential buildings.

The main aim is to use the IES software to test these four materials and establish the best material for the selected house in terms of energy consumption. Several methods will be applied to reach the minimum energy consumption in the residential building, which will be explained in detail in the next part of this chapter.

In addition to the previous wall details, it is important to further explain the content of the construction in Saudi Arabia, such as the wall and thermal insulation in order to give the full pictures follows:

7.8.2.2 Outer Wall Building Systems

In Saudi Arabia, cement-based materials are used in building construction, particularly for houses. Walls are of a non-bearing wall type. The following are the most common wall construction methods (building systems):

- **Single Wall**
  This is usually a 20-cm thick wall, built using hollow concrete blocks. The measuring is 60x20 cm2. There is a general preconception among people, including construction contractors and even some engineers, that blocks are "good" insulators by themselves without requiring insulation materials.
  Almost two decades ago, a new type of insulated block, consisting of a 7.5cm polystyrene insulation material sandwiched between two hollow blocks, 15cm and 10cm thick respectively, was introduced in the local market. This new block is 20cm wide.

- **Composite Wall**
  This consists of thermal insulation material, such as polystyrene or rock wool, being used to insulate the wall. The insulation material is used on the interior, exterior or in the middle of the wall. (Almujahid and Keneesakandi 2013).

- **Thermal Insulations**

The literature review section entitled Common Thermal Insulators Materials in Saudi Arabia and Payback Periods, identified four main types of thermal insulations, which were discussed in detail: Polyurethane, Polystyrene, Fiberglass and Mineral fibre. As mentioned previously in the literature review section 2.7.3.1 that the payback period for polyurethane is 2-2.5 years, this particular thermal insulation will be used for the purposes of this research to determine whether it has a positive impact on the energy consumption for the cooling load, and what level of energy reduction can be achieved. Structures and thermal characteristics of polyurethane is presented in the following table 7.9:

Table 7.9: Structures and thermal characteristics of polyurethane (Eball 2002).

Thermal Insulation	Thickness of wall components (m)	Thermal conductivity of wall components W/mK	Density kg/m3	Specific heat J/kgK
Polyurethane Insulation	0.05	0.025	30	1470

7.8.3 Operating Hours

The air conditioning is designed to commence when needed, particularly when the room temperature exceeds 23 degrees centigrade. If the temperature drops below this temperature, then the air conditioning will stop and automatically switch off.

7.8.4 Cooling Systems

The chapter on air conditioning mentioned that split air conditioners are the most popular type in Saudi Arabia, and the most common according to the survey results.

In addition, the split type is very efficient compared to other air-conditioning system. Therefore, this type of cooling system was chosen for this study as mentioned in section 4.6. The size of this system is selected in accordance with the size of the rooms, with most rooms in a typical residential building measuring 19 m^2 or less. The 2.6 kW is therefore selected as it is suitable for this room size (10-20 sq metres) refer to figure 4.8.

Chapter 8

The Simulation Analysis and Results for the Saudi Typical Residential Building

8.1 Overview

The first step was to use the Integrated Environmental Solutions software (IES) to establish a model and a case study of the selected Saudi residential building which been discussed in details in the previous chapter (chapter 6). Several building materials were then applied to the model, and the weather conditions and energy consumption were studied, before considering how to develop the model. This chapter will outline the development of the model in these areas and explain the assumptions made at each stage.

The energy consumption of a Saudi residential building, discussed in the case study, was analysed using IES software, and the results calculated for a simulation of the energy use of a typical Saudi house, designed by the Saudi government. The dynamic simulation was applied to three different locations in Saudi Arabia: Riyadh, Jeddah and Dammam.

As described previously in the literature review chapter, Saudi Arabia has main four types of construction materials for the external walls and it is important to clarify that these are used as an input in the dynamic simulation to determine which combination of materials results in the lowest energy consumption, and how the material properties can be improved.

The simulation ran for a whole year for the aforementioned cities. In the IES simulation, the cooling load will start when the internal temperature reaches 23 degree centigrade. In fact, it is very important to mention that the mechanical systems for cooling is a must as mentioned previously in chapter 7 to provide the thermal comfort in the Saudi residential buildings. Unfortunately, natural ventilation does not help, the only practical choice is to use mechanical cooling (Al-Naimi 1989). Therefore, the Saudi residential buildings are a 100% dependent on air-conditioning for ventilation. Later on, the highest and lowest temperature was recorded using the IES software, though it is important to recognise that the temperature shown in the graph for the year is an overall average over a period of 10 years. The result will be explained through the graph for the total energy consumption and temperature based on the selected building material for the whole year in each location.

This will be followed by the highest two months, then each month individually (see appendix A) and finally, the highest three days in the year. Similarly, the lowest temperature will be explained by following the same steps.
The IES computer analysis software was used to quantify the relative contribution of various construction components of the building envelope. The study considers all the possible factors that could save energy, though it focuses more on the outer building walls. The first part of the analysis and results will start by testing the most common external walls materials in the kingdom of Saudi Arabia: wall type I, II, III and IV. All these types of walls will be tested in details in this study in three different cities and climate zones Jeddah, Riyadh and Dammam. The main aim behind this test is to find out which of these walls has the better performance regarding cooling load and energy consumption.

The second part of the results and the analysis is to apply the polyurethane thermal insulation for the selected external wall and find out in which layer this thermal insulation in the selected external has the best impact on reducing the cooling load and of course saving energy. The first city will be tested in the IES software is Jeddah city as follow in the next part.

8.2 Results and Analysis First Part

8.2.1 Simulation Analysis for the Typical Residential Building in Jeddah City

Four types of external walls applied to the selected residential building model in Jeddah city, wall types I, II, III and IV. These are the most common external walls in the kingdom of Saudi Arabia. The investigation for the purpose of the study will start with wall type I then, the other external walls types.

8.2.1.1 Wall Type I

The first stage of the analysis is to investigate the performance of this particular external wall type in Jeddah city for the typical Saudi residential building. External wall I construction is used and applied to the typical residential building. Wall I used as an input in the IES software to identify the energy consumption for the cooling load by presenting several charts and tables. It is important to recap the construction details that have been input into the IES software for the first type of wall I. The construction details will present the properties of the external wall (i.e. density, specific heat capacity and conductivity). Another important factor that is considered in the simulation for the wall construction details is the U-value (i.e. thermal transmittance). It measures the heat transfer through the building material over a given area. In fact, reducing the u-values will help to achieve energy savings through lowering the cooling loads (refer to table 7.8).

The energy performance for air-conditioning systems was assessed in energy units. The following figure 8.1 presents the results for this case in terms of annual and average monthly cooling energy consumption. The output for cooling load consumption of the first type of wall test is as follows:

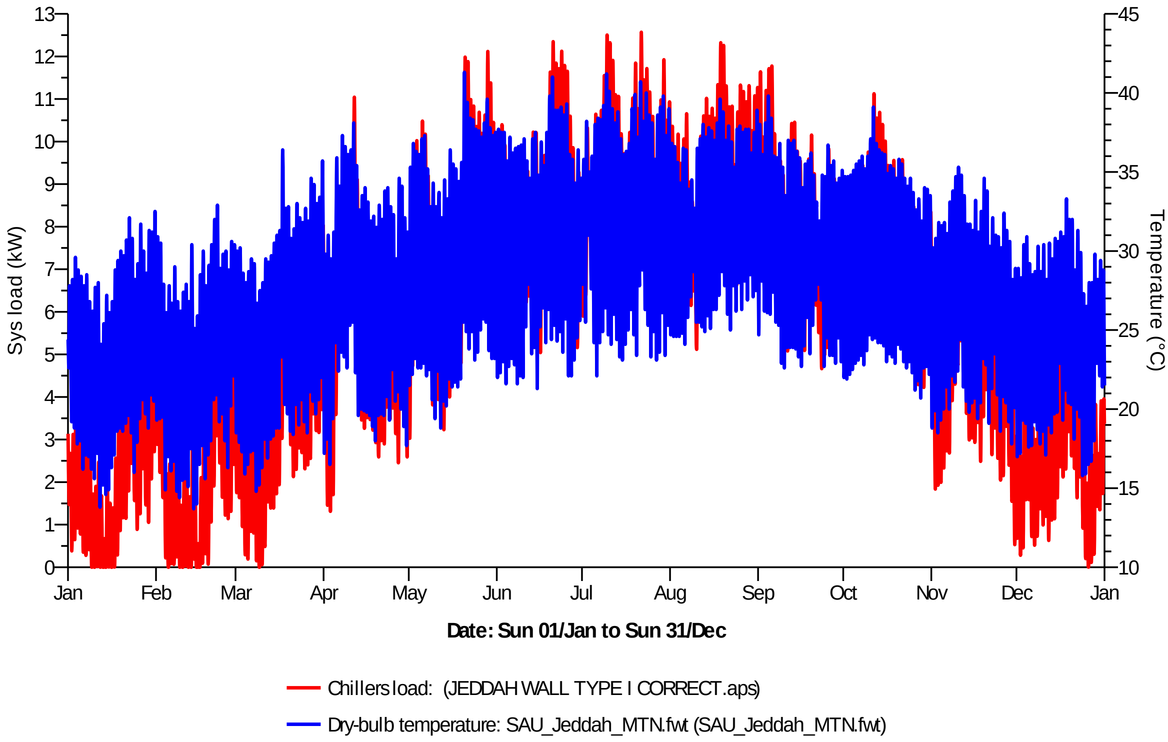


Figure 8.1: The result of the cooling load from 1st of January to 31st of December in Jeddah city for the external wall type I.

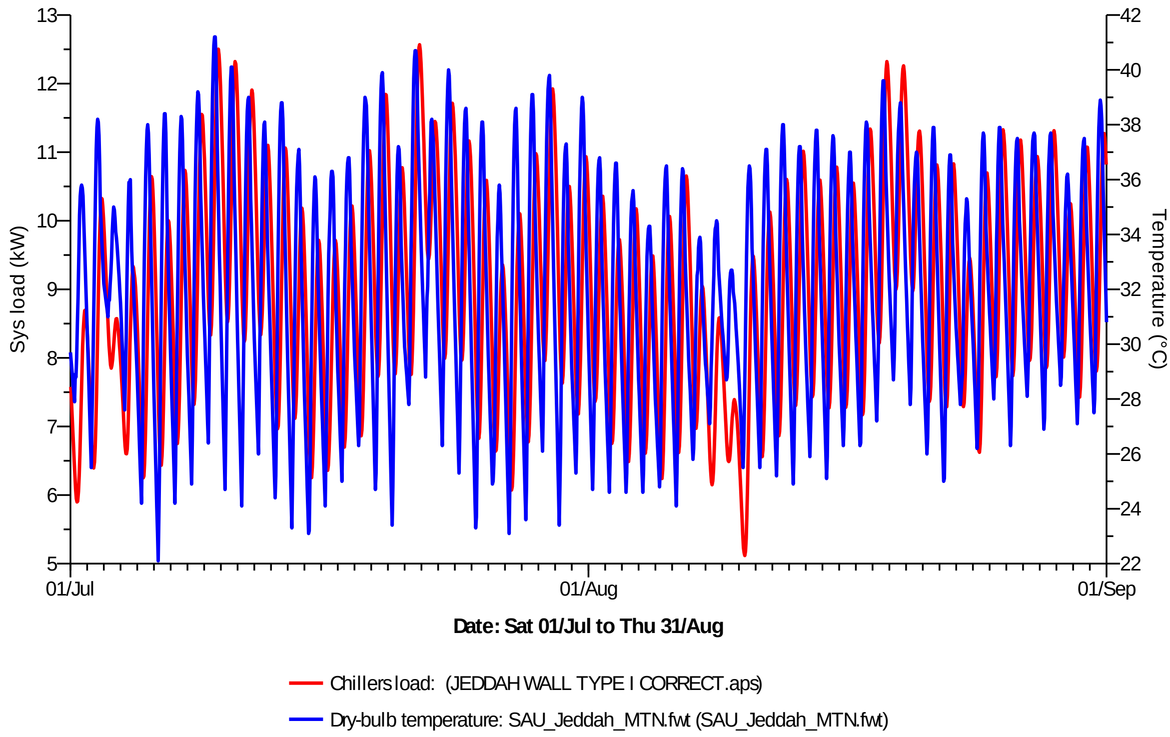


Figure 8.2: The result of the cooling load from 1st of July until 31st of August in Jeddah city for the external wall type I.

This figure 8.2 shows the results for the hottest months in Jeddah city as an average for each month, calculated over an average of 10 years. The load unit is given in Kilowatts, with the energy consumption load reaching about 13 kW as a maximum load for air-conditioning.

It is important to clarify that it was essential for the study to establish the hottest days in the year. Therefore, after identifying the hottest months in the year, each month was looked at separately (See Appendix A), day by day, to ensure that the hottest days were selected for this study. The aim is to carry out further investigation, with more results and comparisons, and finally to develop an appropriate method to achieve the most suitable construction type and development.

An energy analysis was carried out for two months during July and August. The following chart shows that the hottest days in Jeddah city, as an average, for the whole year are the 8th, 9th and 10th of July. These days will be used in the IES simulation for the other types of wall construction (Wall II, Wall III and Wall IV) to make a comparison later on and identify the most suitable wall material for the weather in Jeddah, Saudi Arabia.

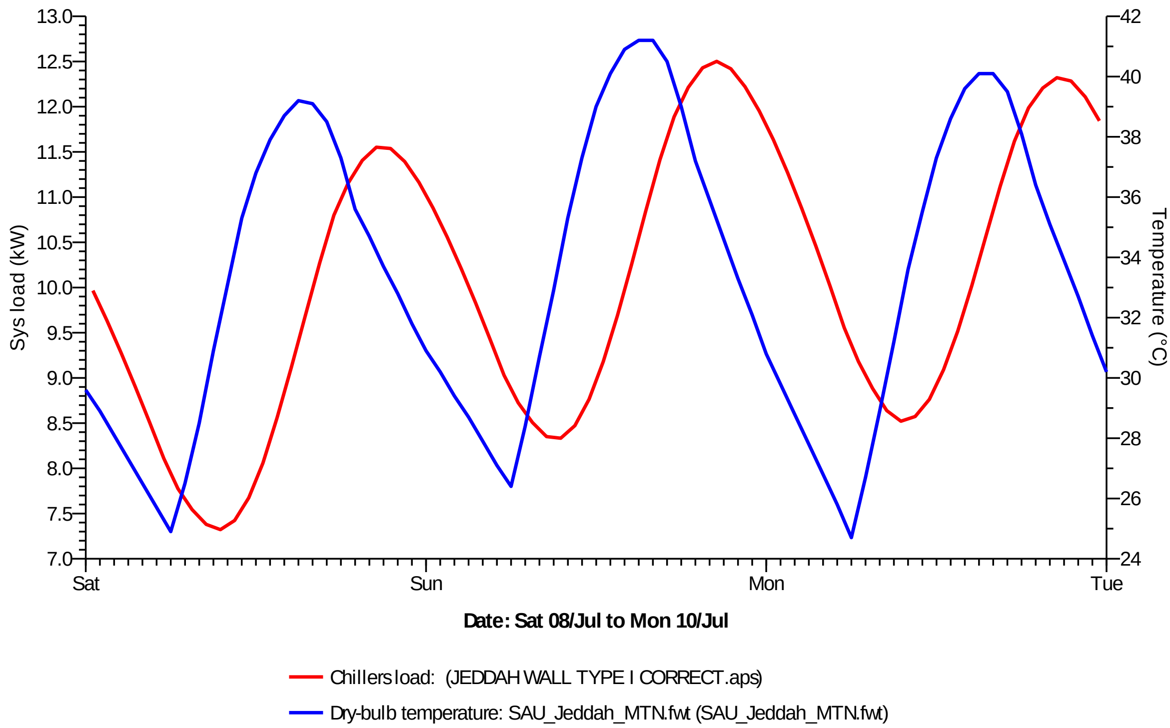


Figure 8.3: The result of the cooling load from 8th of July until 10th of July in Jeddah city for the external wall type I.

The previous chart clearly shows that there was a lag between cooling load and the outside temperature of about three hours, as a result of the thermal mass. The thermal mass of wall type I delayed the heat transfer when the outside temperature started to increase in the early morning. After approximately three hours the cooling load started to show up as shown in the red line. The cooling load started to provide the required thermal comfort for the residential building. The cooling load reached approximately 13 Kw, and the outdoor air temperature reached about 42 degrees centigrade. As expected, there was the minimum level of energy consumption for cooling during the wintertime in Saudi Arabia, which is clearly shown in the following charts. The first chart presents the months of January and February in one chart. Each month chart was looked at separately (See Appendix A). The following charts are more specific.

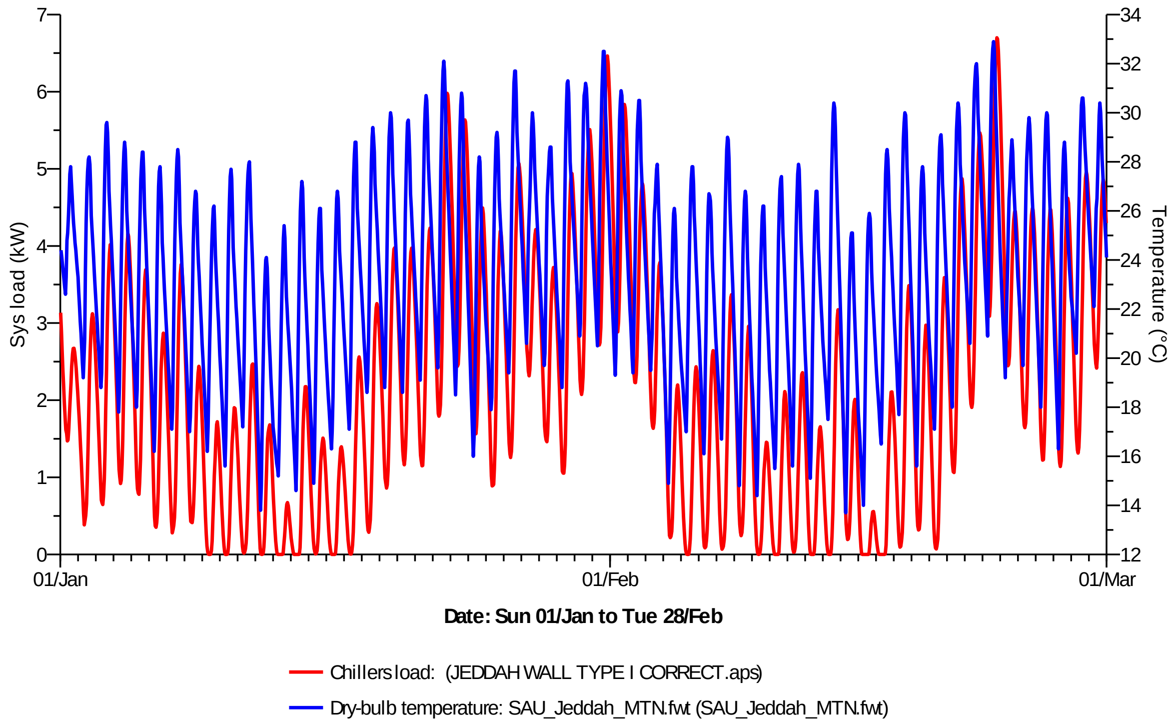


Figure 8.4: The result of the cooling load from 1st of January until 28th of February in Jeddah city for the external wall type I.

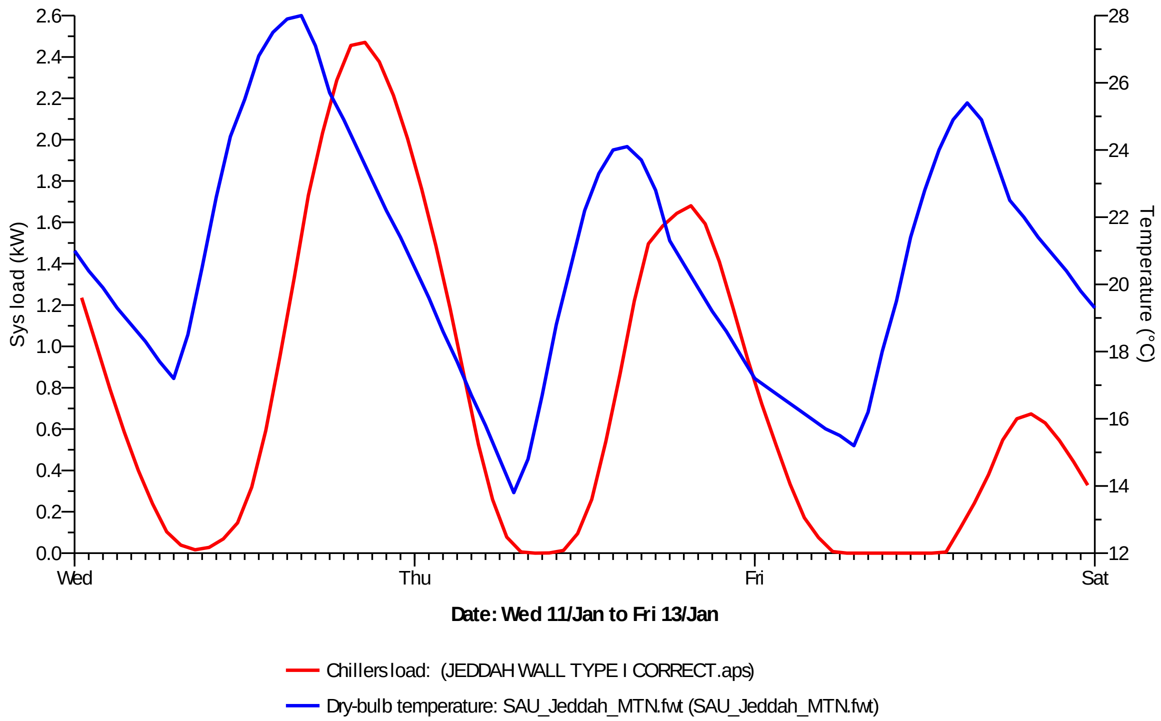


Figure 8.5: The result of the cooling load from 11th of January until 13th of January in Jeddah city for the external wall type I.

As shown by computer analysis, the coldest week in Jeddah is from the 9th of January to the 15th. It is clear that the 11th-13th of January are the coldest days, while the hottest days are the 8 th -10th of July. The chart shows that the time lag between the outside temperature and the cooling load was about four hours in the winter time. The temperature was between 12 and approximately 28 degrees centigrade, and the cooling load varied between 0.0 kW and 2.6 kW in wintertime. From the 8th-10th of July the temperature was between 24 and 42 degrees centigrade, with an increased energy consumption for the chiller, between 7 and 13 kW.

8.2.1.2 Wall Type II

The next wall tested using IES was wall II. The simulation presents the energy consumption for cooling load for the selected Saudi building in Jeddah. The construction details of wall type II (i.e. density, u-value, specific heat capacity and conductivity).is presented in chapter 7 (refer to table 7.8).

The external wall construction that was simulated reflects a typical wall used for housing in Saudi Arabia, as well as other types that were previously mentioned. The simulation results will present: the energy consumption for cooling load for wall II; the dry-bulb temperature, in the form of degrees centigrade. The simulation shows the whole average year from the 1st of January to the 31st of December. Each month chart was looked at separately (See Appendix A). July and August are regarded as being the hottest months in Jeddah. The charts will present the simulation results for cooling load for the hottest days in Jeddah city as well as the coldest days.

The next chart 8.6 represents the hottest days (8th-10th of July).

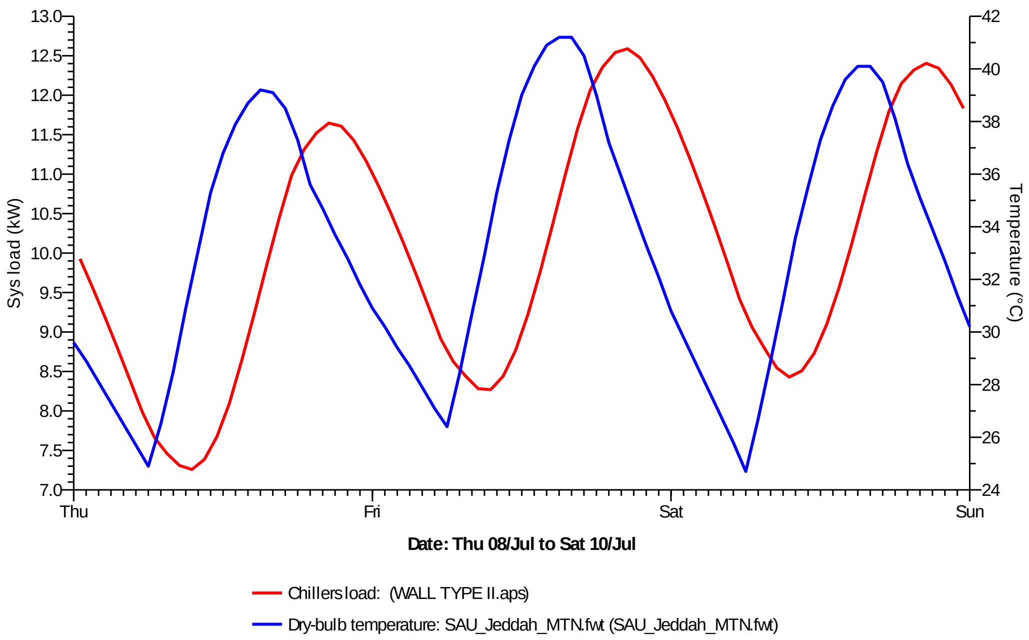


Figure 8.6: The result of the cooling load from 8th of July until 10th of July in Jeddah city for the external wall type II.

Figure 8.6 shows that the lag between the cooling load and the outside temperature is only about three hours. The thermal mass for the external wall II delayed the heat transfer for only three hours. The cooling load started to appear slightly after the outside temperature started to increase in the early morning. The cooling load peaked at approximately 13 Kwh and the dry-bulb temperature peaked at 42 degrees centigrade.

In contrast, winter will reduce the cooling load and energy consumption for cooling. During the winter, the maximum cooling load was 7kW with a maximum temperature of 34 degrees centigrade on certain days. The results show that January is the coldest month in Jeddah, with the coldest days being the 11th to 13th of January as shown in the following chart 8.7.

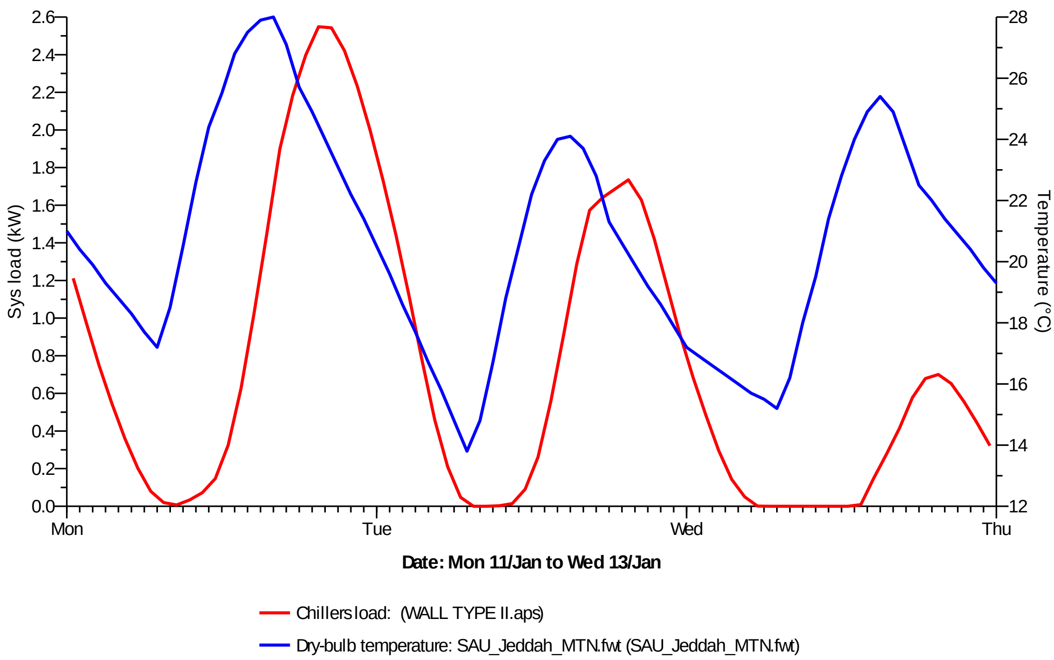


Figure 8.7: The result of the cooling load from 11th of January until 13th of February in Jeddah city for the external wall type II.

As shown above, the winter has a different scenario regarding energy consumption for cooling load. It still shows a lag between the outside temperature and cooling load of about four hours. From the 11th-13th of January the cooling load fluctuated from 0 in specific times of the day to 2.5 kW. The temperature ranged from 12 degrees centigrade to approximately 28 degrees centigrade.

8.2.1.3 Wall Type III

The third type of wall tested in the simulation was wall type III. The properties of the wall, with regard to the construction and the wall layers are explained in details in chapter 7 (refer to table 7.8).

The simulation ran for a full year (See Appendix A) in order to test the building material and monitor how it would respond to Jeddah weather conditions for the selected governmental house. The charts will present the cooling load results for the hottest and coldest days in Jeddah. It is then important to look at each month separately to identify which are the hottest months (See Appendix A).

July and August are considered to have the highest energy consumption in the form of cooling load. The next chart 8.8 represents the 8th, 9th and 10th of July, which are the hottest days in Jeddah, Saudi Arabia.

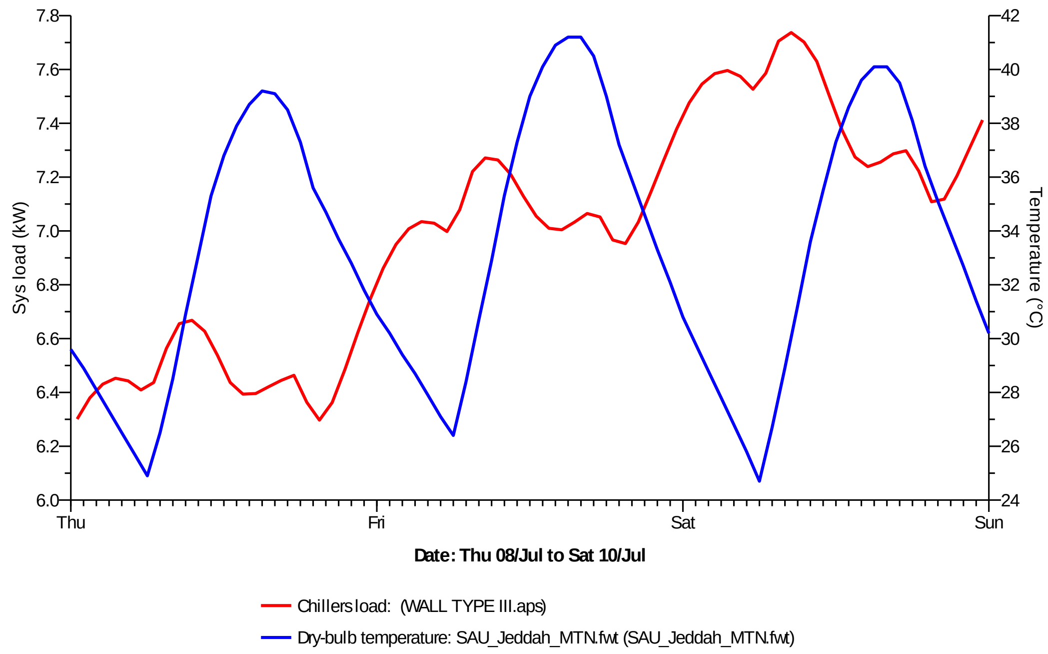


Figure 8.8: The result of the cooling load from 8th of July until 10th of July in Jeddah city for the external wall type III.

The figure 8.8 shows a lag between the cooling load and the outside temperature of about six hours after applying the external wall type III to the selected residential building. This is show the magnitude of the thermal mass for this specific wall to delay the heat transfer from outside to inside. The temperature reaches about 42 degrees centigrade and the energy consumption reached the maximum of 7.8 kW.

The coldest months in Jeddah are January and February. The charts for January and February are presented in the appendix A. The last chart in this section shows the lowest cooling load days.

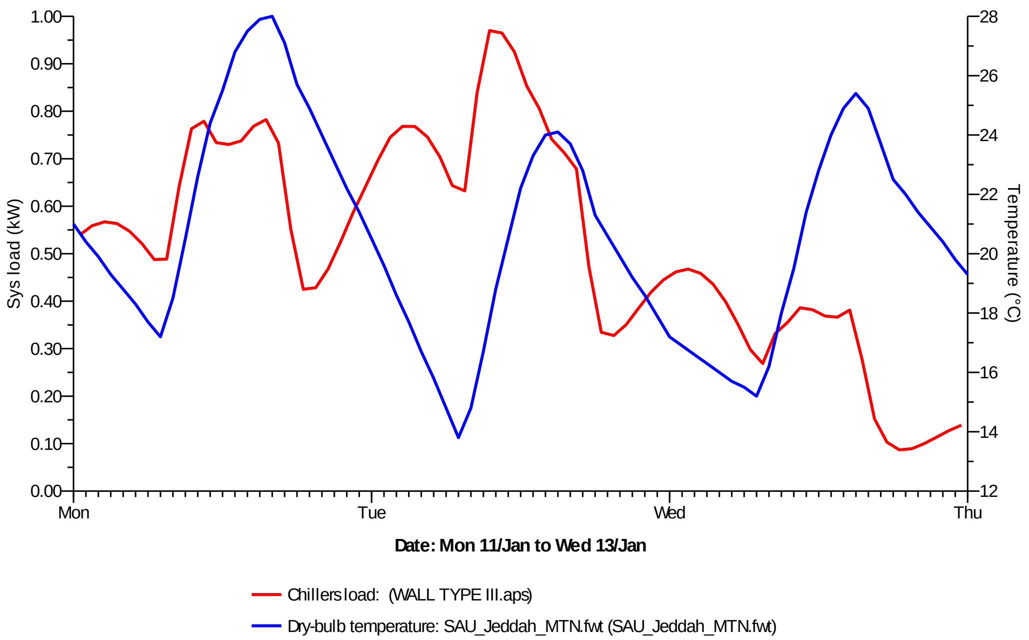


Figure 8.9: The result of the cooling load from 11th of January until 13th of January in Jeddah city for the external wall type III.

In the winter time, for these specific days, it shows that the lag between the air conditioning load and the outside temperature is about nine hours. Evidently, both the energy consumption and temperature reached the minimum over these days. The cooling load was only 1 kW, compared to a peak in the summer of almost 8kW, and the temperature fluctuated between 12 and 28 degrees centigrade. It is clear that the temperature and the energy consumption will drop to the minimum in the winter, with the opposite in the summer.

8.2.1.4 Wall Type IV

The last wall type used in the IES modelling simulation for energy consumption is wall IV. The details of the wall construction and the properties used in the computer software to test the impact of this specific external wall construction are presented on chapter 7 (refer to table 7.8).

This wall type is the fourth wall type that is commonly used in the Kingdom of Saudi Arabia. It is important, for the purposes of this thesis, to test this wall along with the others in Jeddah. The charts that present the whole year cooling load as well as each month individually are included in the appendix (See Appendix A).

The following graphs show the results of the simulation and detail the energy consumption, presenting how many kilowatts are consumed, as well as the temperature to indicate how this wall behaves in the hottest and coldest days in Jeddah city.

The first graph focus in more detail on the days that consumed the maximum of energy consumption that represent the cooling load of course

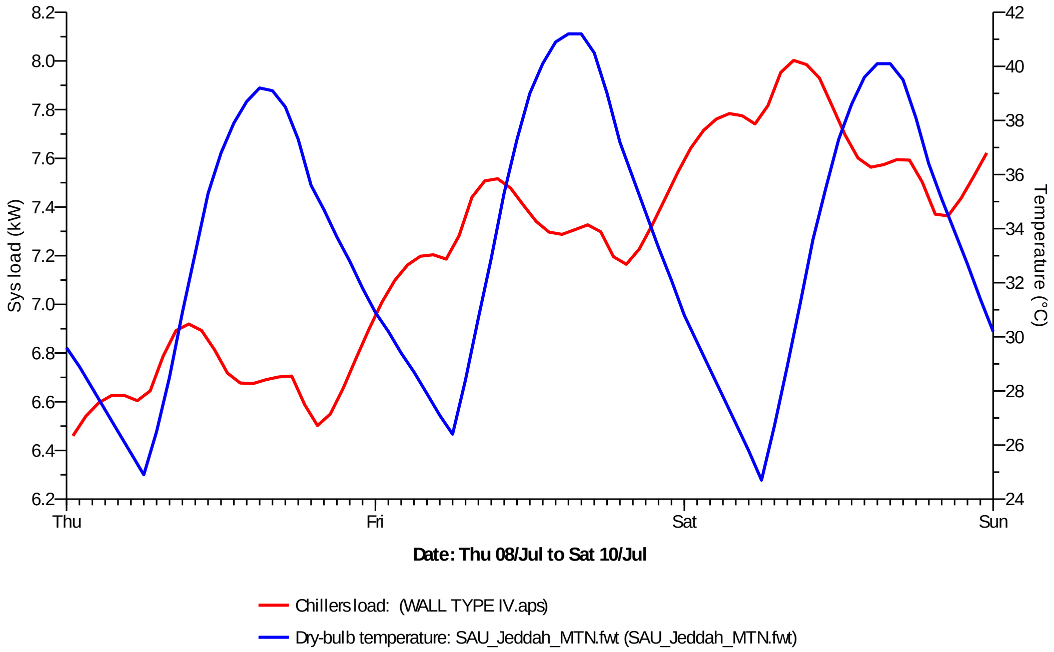


Figure 8.10: The result of cooling load from 8th of July until 10th of July in Jeddah city for the external wall type IV.

The figure 8.10 shows that the lag between the cooling load and the outside temperature for the hottest days in Jeddah is approximately six hours. The thermal mass of the external wall succeed in delaying the heat transfer for a long period of time. The chart presents the performance of this specific wall in (wall IV) in terms of cooling load.

It is very clear that the previous chart shows the worst scenario of Jeddah, with the maximum energy consumption for the cooling load over the hottest days (8th to 11th July). The chart shows that the temperature reached about 42 degrees centigrade, and the cooling load reached to above 8 kW.

The next charts will show the opposite scenario, the coldest days, thus the energy consumption and the cooling load will reach the minimum levels. Each month chart was looked at separately (See Appendix A).

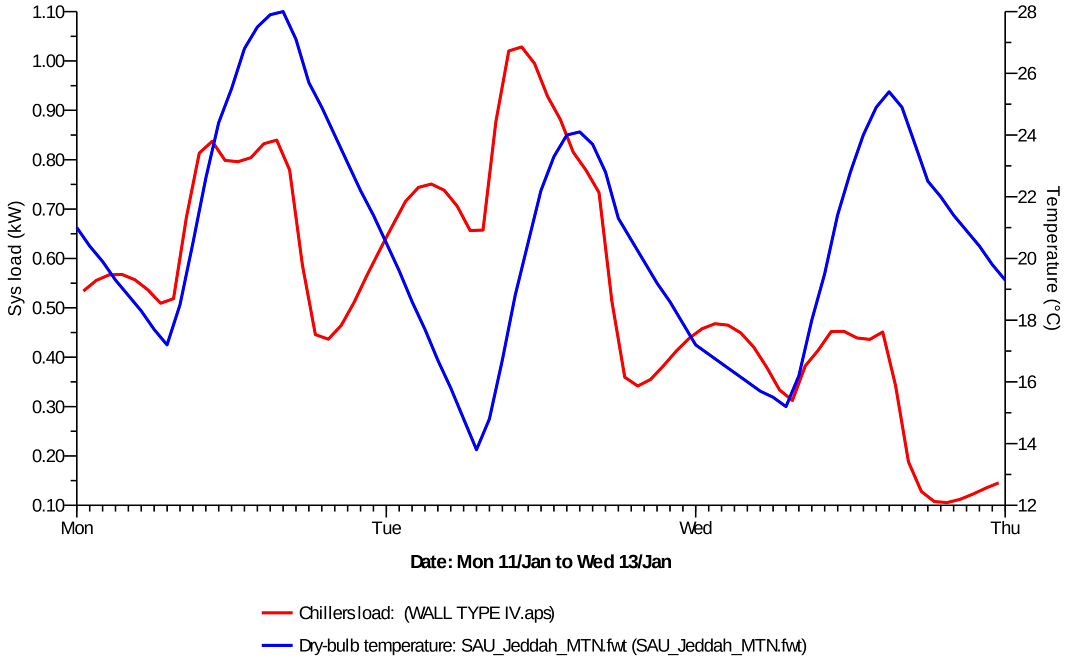


Figure 8.11: The result of cooling load from 11th of January until 13th of January in Jeddah city for the external wall type IV.

The coldest days in Jeddah city from 11-13 of January show that the energy consumption is only reached to almost 1.10 kW, with a temperature of no more than 28 degrees centigrade. The lag between the cooling load and the outside temperature is about nine hours.

8.2.1.5 The comparison between the external walls types for Jeddah city

After presenting the most common type of walls used in Saudi Arabia, and in Jeddah city specifically, it is important to discuss which type of wall has the best performance and lowest consumption and thus has the ability to improve, minimise consumption and be more environmentally-friendly. This of course will reflect the size of the thermal mass of the external walls and the heat transfer resistance.

In order to do this, there must be a comparison between these building construction materials (I, II, III and IV) of the results of the hottest and coldest days, as previously used.

The following charts will put these four types of walls together in one graph in order to make a clear contrast between them.

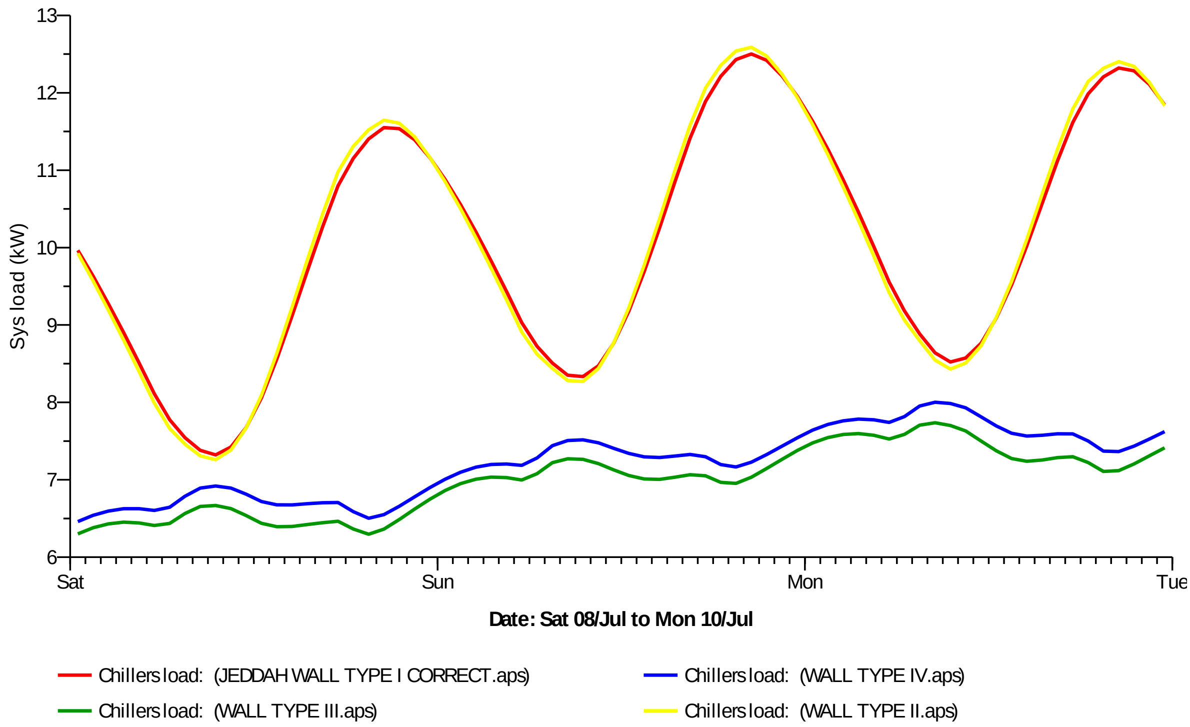


Figure 8.12: The comparative results of the cooling load from 8th of July until 10th of July for all external wall types in Jeddah.

The most common external walls in Saudi Arabia were examined in term of energy consumption and cooling load in Jeddah city. Each of these walls has a different layers, thicknesses, conductivities, densities, specific heat and U-value (refer to table 7.8).

As previously mentioned, the hottest days in Jeddah, tend to be from the 8th to the 10th of July. This chart displays the results for all external wall types tested alongside one another. These results clearly indicate that thermal resistance of the external wall I and II are very poor in terms of cooling load and they easily allow the heat to transfer from outside to inside which led to increase the cooling load from the early hours in the morning. In fact, these particular walls perform worse than the other types. In winter, wall type I and II still performs differently to the other types, which once again have a similar performance, as shown in the following figure.

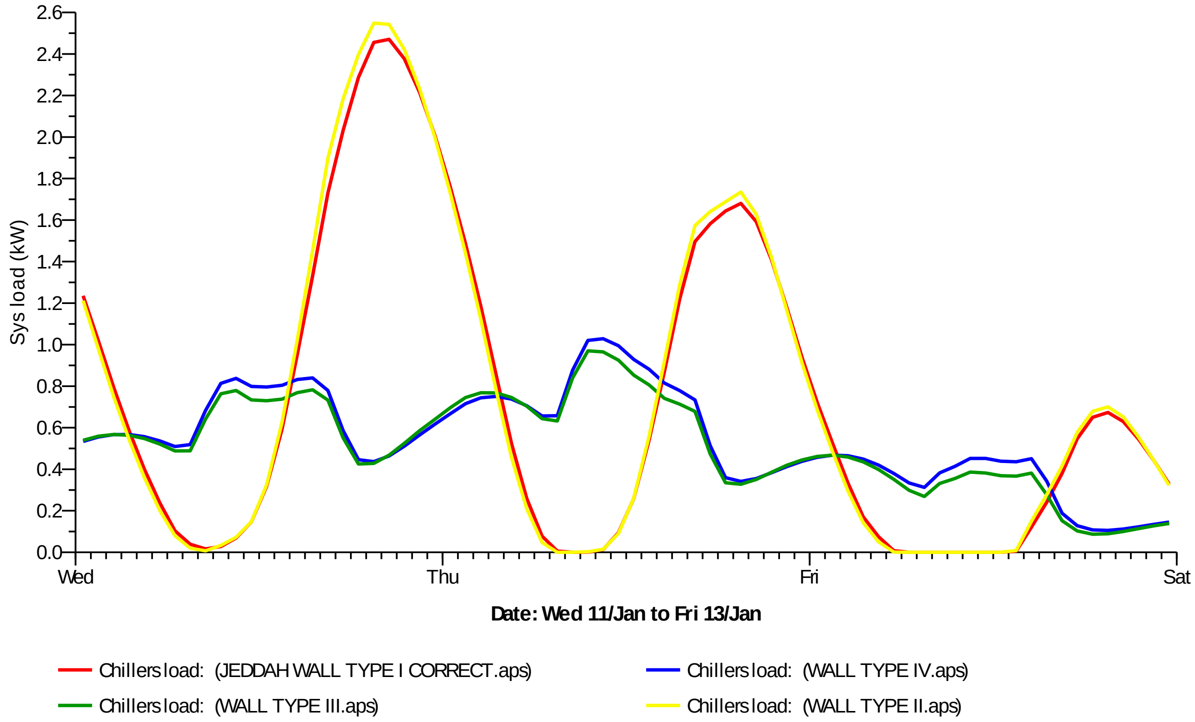


Figure 8.13: The comparative results of the cooling load from the 11th of January until the 13th of January for all external wall types in Jeddah.

As it is not possible, from the charts, to determine which external wall type performs best in terms of cooling load consumption for the modelling used in the IES, further analysis is required, with a comparison between all the wall types. This comparison is shown in the following table, with the total energy consumption with regard to the cooling load.

Table 8.1: The comparison results of the cooling load for all external wall types in Jeddah.

Date	Chillers load (MWh) Wall Type I	Chillers load (MWh) Wall Type II	Chillers load (MWh) Wall Type III	Chillers load (MWh) Wall Type IV
Jan 01-31	1.1175	1.6008	1.1017	1.1431
Feb 01-28	1.0197	1.4534	1.0124	1.0535
Mar 01-31	1.9522	2.7414	1.9249	2.0001
Apr 01-30	2.8959	4.0038	2.8682	2.9852
May 01-31	4.0488	5.6304	3.9957	4.1479
Jun 01-30	4.3275	5.9664	4.2829	4.4596
Jul 01-31	4.8519	6.7166	4.7954	4.9848
Aug 01-31	4.789	6.6058	4.7342	4.9247
Sep 01-30	4.1336	5.6788	4.0921	4.2628
Oct 01-31	3.9579	5.4913	3.9166	4.0786
Nov 01-30	2.4208	3.3254	2.407	2.5153
Dec 01-31	1.4503	2.0363	1.4345	1.4942
Summed total	**36.965**	**51.2503**	**36.5656**	**38.0496**

As these results show, external wall types I and II perform worst in terms of the total consumption for the cooling load in the typical Saudi residential building. There is only a slight difference between wall types I and II. Wall III has a better overall result. Thus, this wall type will be used for further research in the second section of the analysis.

8.2.2 Simulation Analysis for the Typical Residential Building in Riyadh City

The most common types of external wall in Saudi Arabia applied to the selected residential building model in Riyadh city, wall types I, II, III and IV. The investigation for the purpose of the study will start with wall type I then, the other external walls types to examine which wall has the best thermal performance in terms of cooling load and energy consumption.

8.2.2.1 Wall Type I

Riyadh is the capital city of Saudi Arabia, and is the second city that has been tested using the IES computer software regarding energy consumption for cooling load. The aim is to find out the behaviour of the common walls construction types in this city for the selected typical Saudi house. The steps of the simulation will follow the previous steps carried out for Jeddah city. The simulation will start by giving the image for a year as an average, then it will move to focus on specific months (see appendix A), and finally days for later comparison. Each month graph was analysed and studied in this study (See Appendix A). Once again, the first material in this section will be wall type I. The properties and the characteristics of this construction are explained in chapter 7 (refer to table 7.8). The details of the wall include the density, U-value, specific heat capacity and conductivity.

The graphs present the chiller load and temperature during the hot summer months. The study included the results for each month individually (See Appendix A).

Riyadh's climate and weather is different from Jeddah, with the temperature dropping below 5 degrees centigrade, compared to an average minimum temperature, over a 10 years' period, of 10 degrees centigrade in Jeddah. In contrast, the maximum temperature in Riyadh peaked at over 45 degrees centigrade.

The simulation result for external wall type I for the typical house shows that the cooling load started from 0 kW in winter, up to approximately 15 kW in summer. Therefore, it is evident that Riyadh has a quite different climate in both winter and summer. It will be interesting to observe whether the best wall construction type for Riyadh is different from Jeddah.

The way to find out is by testing the four types of the external walls and comparing the results.

July and August are the hottest months in Riyadh. The next chart 8.14 will discuss and focus on the hottest days in the capital city of Saudi Arabia, with temperature in Riyadh reaching 46 degrees centigrade and the cooling load reaching above 14.5 kW.

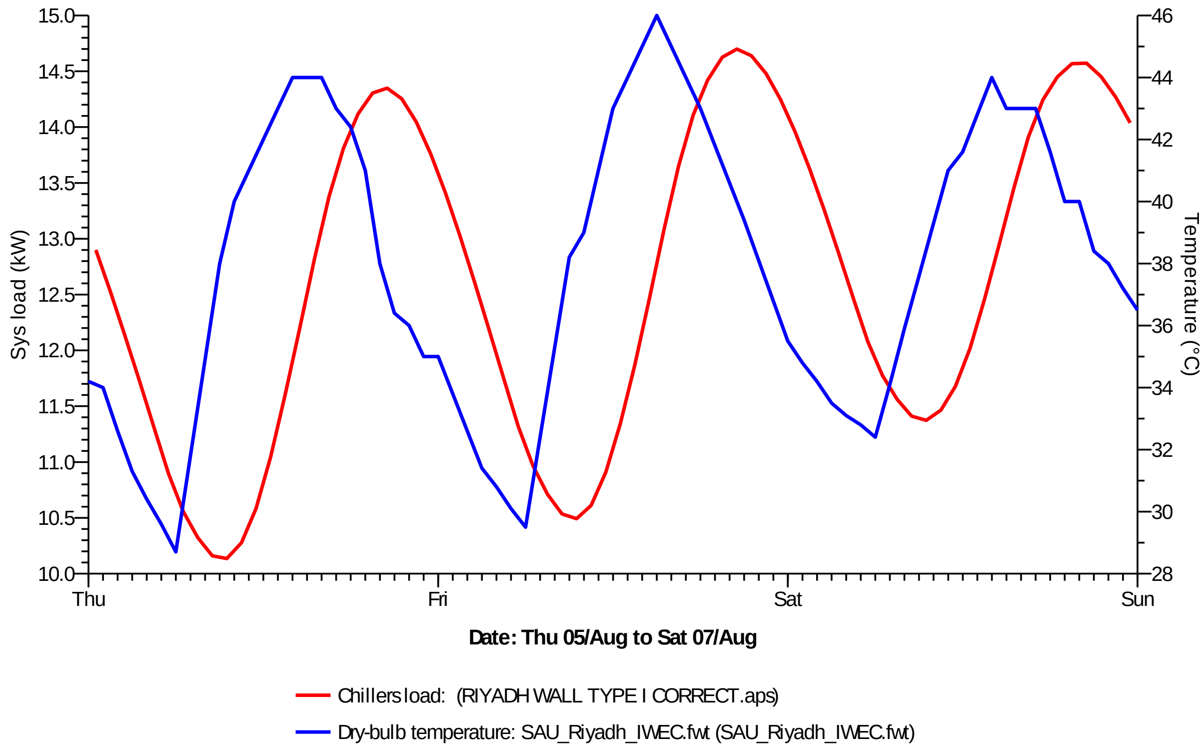


Figure 8.14: The result of cooling load from 5th of August until 7th of August in Riyadh city for the external wall type I.

From the 5th of August to the 7th of August these days considered to be the hottest days in Riyadh. On the 6th of August the temperature reached 46 degrees centigrade. The cooling load for these days was between 10 and 15 kWh. The lag between the cooling load and the outside temperature is about two hours only. This shows that any change in heat transfer needs only two hours to find its way from outside to inside. In fact, these specific days (5th - 7th August) were selected to make a clear comparison between different types of building construction materials for the summer season as they represented the hottest days in Riyadh according to the figures shown previously, as well as to see the behaviour of materials in different cities in the kingdom.

The following charts will present how the first type of construction material wall reacted in the coldest days in the winter season. It is important to mention here that the analysis includes the graph results for each month individually (See Appendix A).

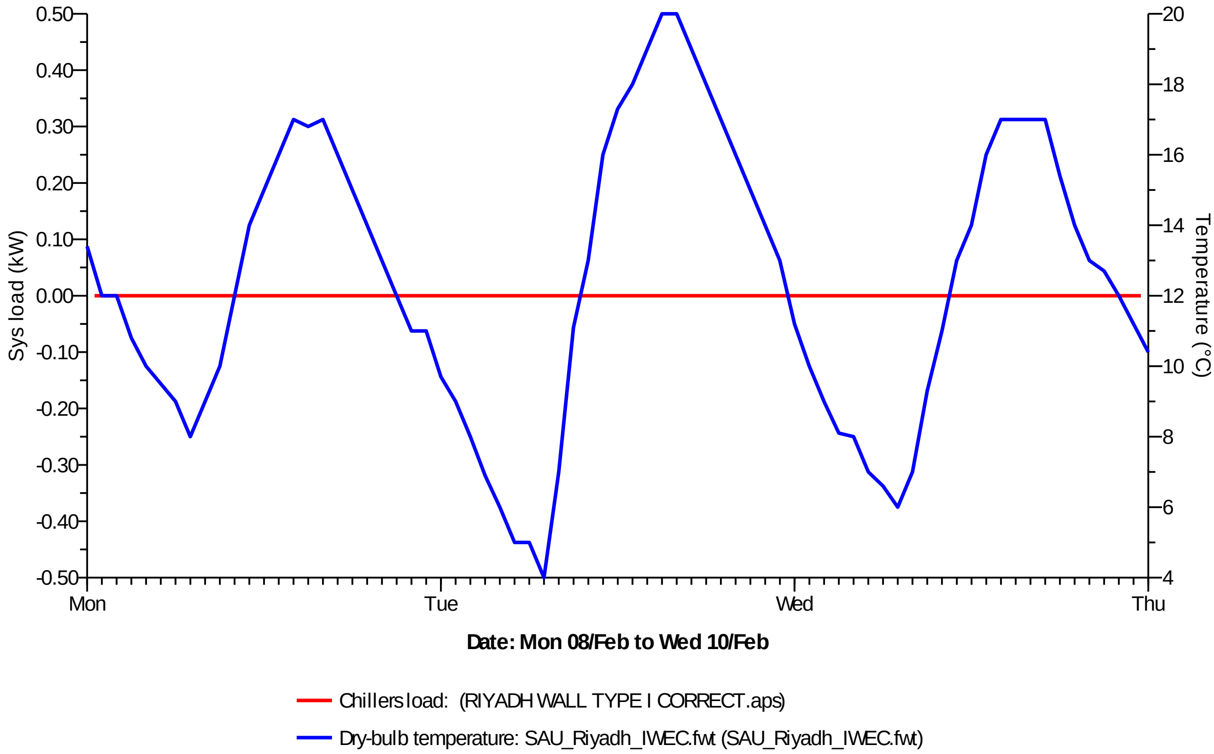


Figure 8.15: The result of cooling load from 8th of February until 10th of February in Riyadh city for the external wall type I.

January and February are the coldest months in Riyadh (the capital city of Saudi Arabia), with the temperature fluctuating between 0 and 35 degrees centigrade. Interestingly, the figure shows that the temperature did not exceed 20 degrees centigrade, and the cooling load remained constant at zero kW from the 8th to the 10th of February (the coldest days in Riyadh). This indicates that even when the weather is cold in Riyadh people don't use air conditioning, whereas people in Jeddah continue to use air conditioning in winter.

8.2.2.2 Wall Type II

The next external wall type (II) will be examined in Riyadh weather and conditions to build a better image of all types of construction walls. The details of the construction wall are shown in chapter 7 (refer to table 7.8).

Two charts will show the result of the IES building energy simulation after applying these specific construction details, location and the model of the Saudi typical house. The results start by showing the hottest days in Riyadh city, and then giving the details of the coldest days in the city of Riyadh. Moreover, the study and the analysis took into consideration the details of each month individually regarding energy consumption and cooling load (See Appendix A).

The temperature started from around 5 degrees centigrade, up to more than 45 degrees centigrade, and the air conditioning load reached above 16 kW in the summer. Each month graph was looked at and included in this study (See Appendix A). The following charts show the simulation results for the hottest days.

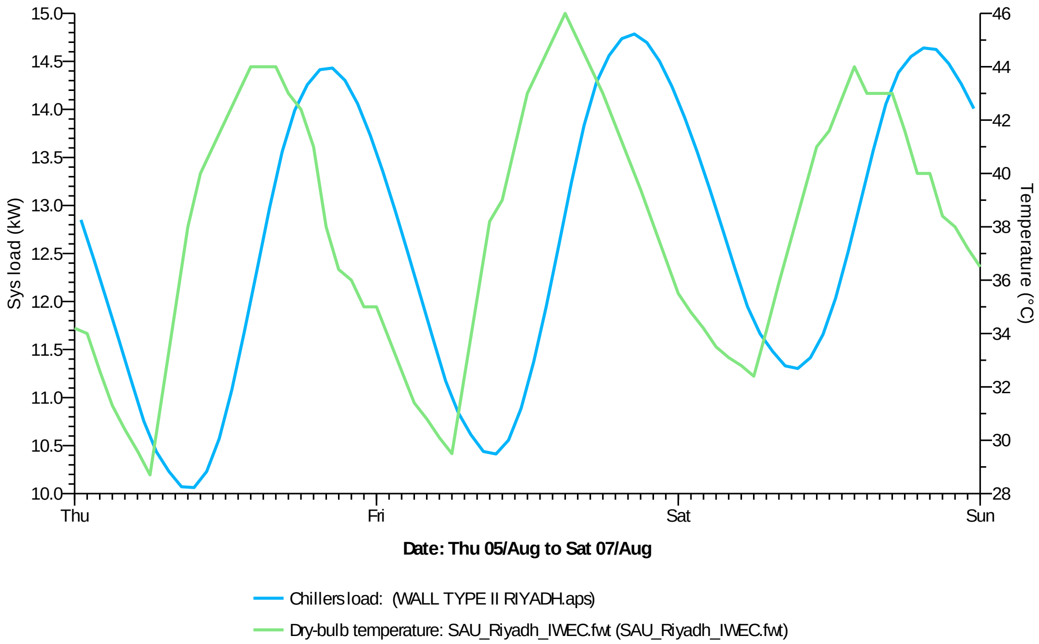


Figure 8.16: The result of cooling load from 5th of August until 7th of August in Riyadh city for the external wall type II.

The charts show that the temperature in Riyadh in the summer ranged from 25 to about 45 degrees centigrade, and the energy consumption for the cooling load reached almost 15 kW. The last chart 8.16 focuses on specific hot days in Riyadh (5th -7th of August) when it is clear that the dry-bulb temperature reached 45 degrees centigrade and the electricity load for air conditioning reached 14.5 kWh which is the peak load for cooling load in Riyadh city. The lag between the outside temperature and the cooling load is between two to three hours approximately.

The following chart presents the wall type II simulation result in the coldest days in winter season. Each month graph for the winter season for this part was looked at and included in this study (See Appendix A).

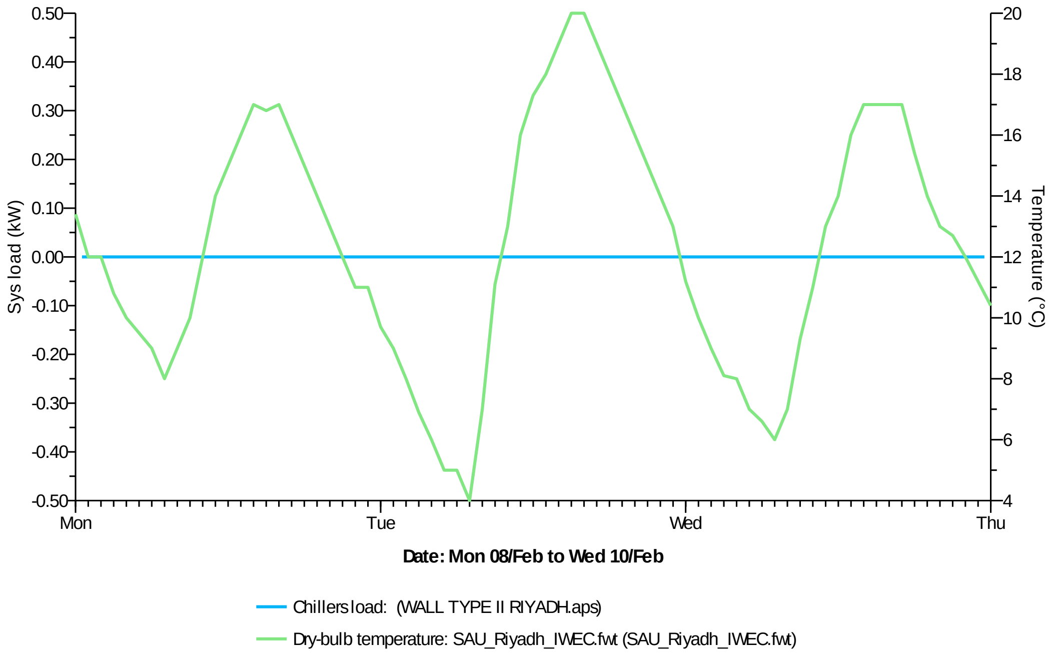


Figure 8.17: The result of cooling load from 8th of February until 10th of February in Riyadh city for the external wall type II.

From the 1st of January to the 28th of February, the temperature fluctuated from approximately 4 degrees centigrade to about 33 degrees centigrade at the end of February (see appendix A). The air conditioning started being used at the end of February, whereas in the coldest days in Riyadh from the 8th of February until 10th of February the air conditioning was not running, and the temperature ranged from 4 to 20 degrees centigrade.

8.2.2.3 Wall Type III

The third external wall type for city of Riyadh is III, and it is essential to establish which type of external wall is the most suitable for this typical house in Riyadh, having tested all the wall types using the IES dynamic simulation software. The wall construction details used in the computer software are presented in chapter 7 (refer to table 7.8).

After December the temperature reached a minimum of about 4 degrees centigrade, with a maximum in July and August of more than 45 degrees centigrade (see Appendix A). The graphs for each month individually has been explained as part of the results (See Appendix A).

The first of the following chart 8.18 gives the result of cooling load consumption for the hottest days, followed by results for the coldest days in the winter season.

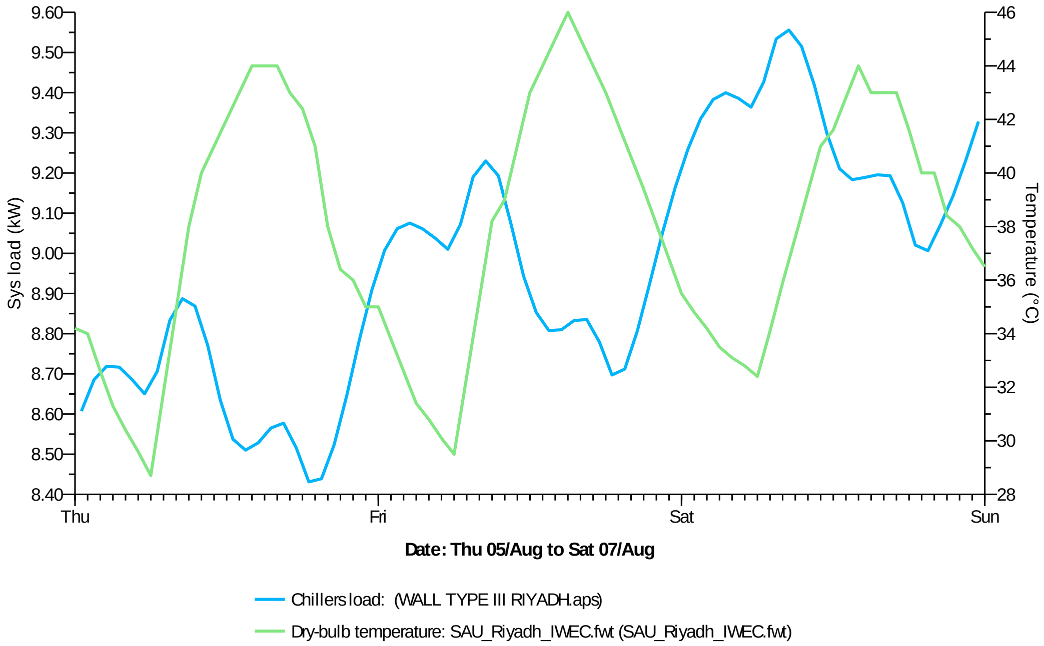


Figure 8.18: The result of cooling load from 5th of August until 7th of August in Riyadh city for the external wall type III.

It is clear according to the previous figures that the temperature reached 46 degrees centigrade in the summer, and the energy consumption for the cooling load reached about 9.6 kW for this specific wall construction type. The figure 8.18 shows the hottest days in Riyadh. As shown in the figure, the temperature fluctuated between

28 and 46 degrees centigrade over these specific days. The cooling load fluctuated between 8.40kW and 9.60kW. The lag between the cooling load and the outside temperature is about seven hours. The thermal mass for the external wall type III delayed the heat transfer for an appreciable length of time which means that this wall is very efficient regarding the energy consumption and cooling load when night time temperatures are low, as the heat is released in the evening and keeps indoor temperatures moderate. The cooling load on the other hand looks zero kW in winter and hit the peak of almost 10kW in the summer season (see Appendix A). The following charts will focus on the 8th of February until 10th of February to use it in comparison with the results for the other types of walls at the end of this section. The graphs for January and February were tested using IES and included in research results and the analysis (See Appendix A).

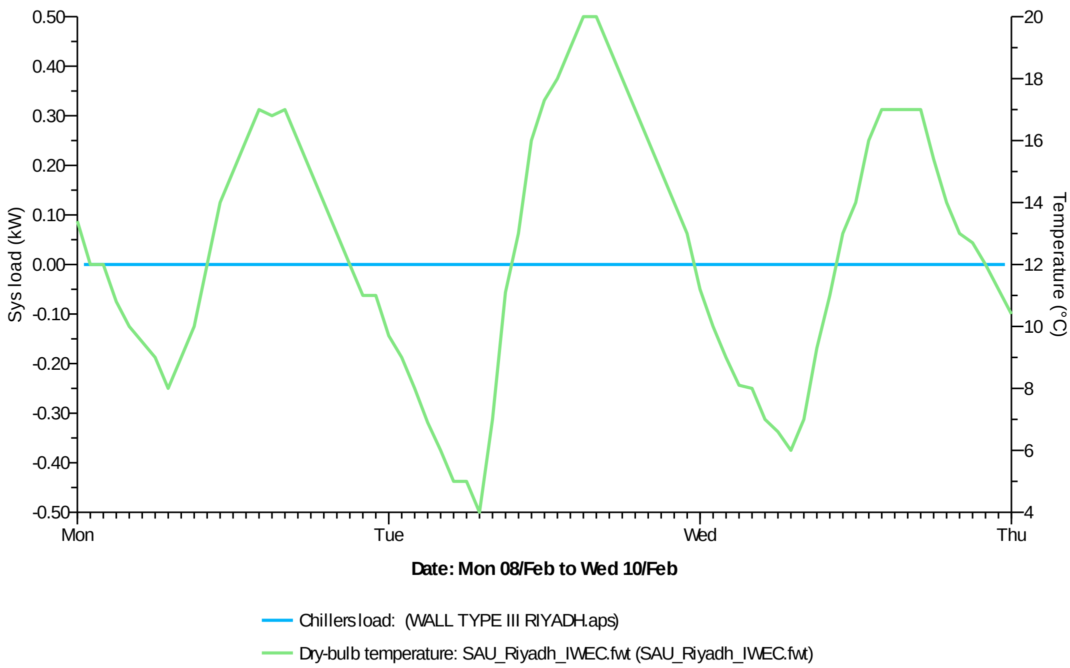


Figure 8.19: The result of cooling load from 8th of February until 10th of February in Riyadh city for the external wall type III.

The coldest months are January and February, with a low temperature in these two months until the end of February when it starts to rise (see Appendix A). The temperature in the winter is between 4 degrees and28 degree centigrade.

From the 8th of February until 10th of February the temperature reached about 20 degrees centigrade, with a cooling load of zero kWh.

8.2.2.4 Wall Type IV

The last wall type for the capital city Riyadh is wall type IV. This wall type will be examined in the IES simulation software for subsequent comparison. The table that outlines the properties of this specific wall is presented in chapter 7 (refer to table 7.8).

The charts will show the results of the simulation, starting with the results for the whole year, then summer, and finally winter (see Appendix A).

The first chart 8.20 presents the cooling load and temperature for Riyadh for the hottest days. The subsequent chart shows the reaction of the wall regarding cooling load in the coldest days in Riyadh. The graphs for the hottest months in Riyadh were discussed individually (See Appendix A).

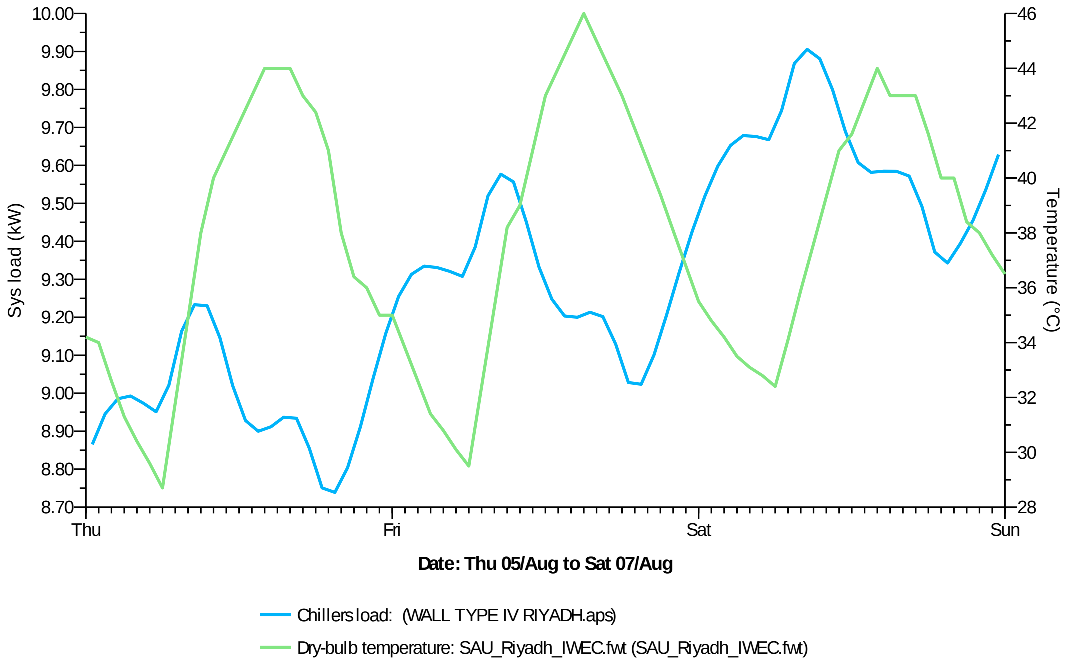


Figure 8.20: The result of cooling load from 5th of August until 7th of August in Riyadh city for the external wall type IV.

Summer is considered to be July and August. Another simulation carried out showed that the cooling load for this specific external wall construction was up to

10.5 kW and the temperature reached approximately 46 degrees centigrade. The thermal mass for the external wall type IV shows a good result as it delayed the heat transfer and created a lag between the cooling load and the outside temperature of about 7 hours.

The following charts present the cooling load results for this external wall type, used in the simulation for the Saudi typical house in Riyadh from 8th to 10th of February. The results included the graphs individually for coldest months in Riyadh (See Appendix A).

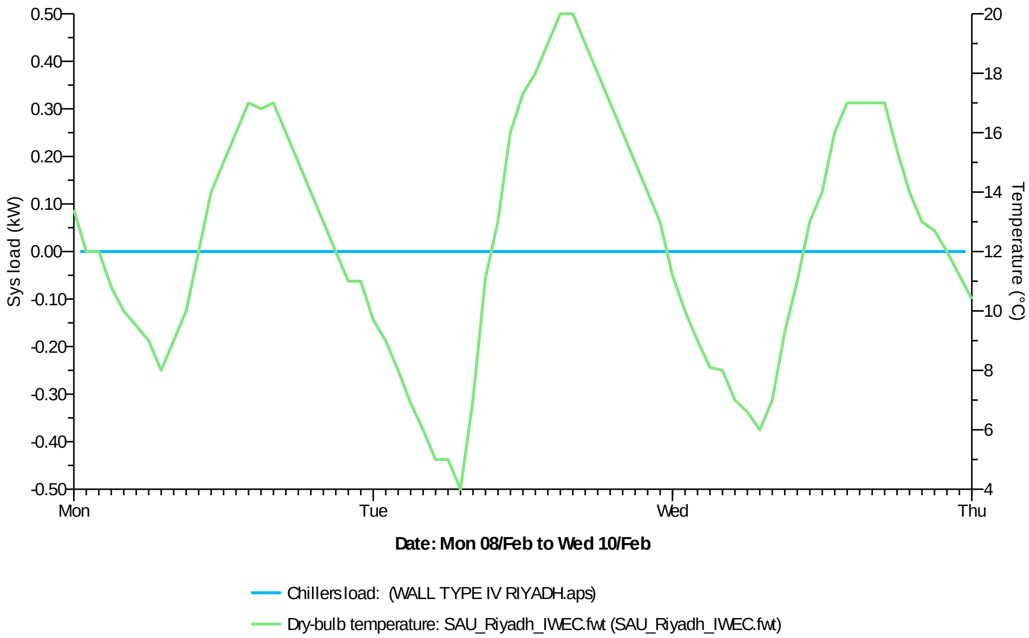


Figure 8.21: The result of cooling load from 8th of February until 10th of February in Riyadh city for the external wall type IV.

As shown previously, the cooling load during the winter is zero kW as the temperature is very low and there is no need for air conditioning. The average minimum temperature recorded, over 10 years, was around 4 degrees centigrade.

8.2.2.5 The comparative between the external walls types for Riyadh city

After presenting the most common type of external walls used in Saudi Arabia, and applying these to the simulation model for Riyadh, it is essential to establish the most suitable external wall type for the climate of Riyadh with the best energy performance and lowest consumption in terms of cooling load. The next stage is to improve the selected external wall and minimise the cooling load to the lowest possible level.

In order to do this, there must be a comparison between these building construction materials (I, II, III and IV) of the results of the hottest and coldest days, as previously used.

The following chart 8.22 shows the four types of walls in one graph in order to highlight a clear contrast between them. The first comparative chart is for the time period from the 5th until the 7th of August, comparing the cooling load performance in summer with a peak temperature during this period.

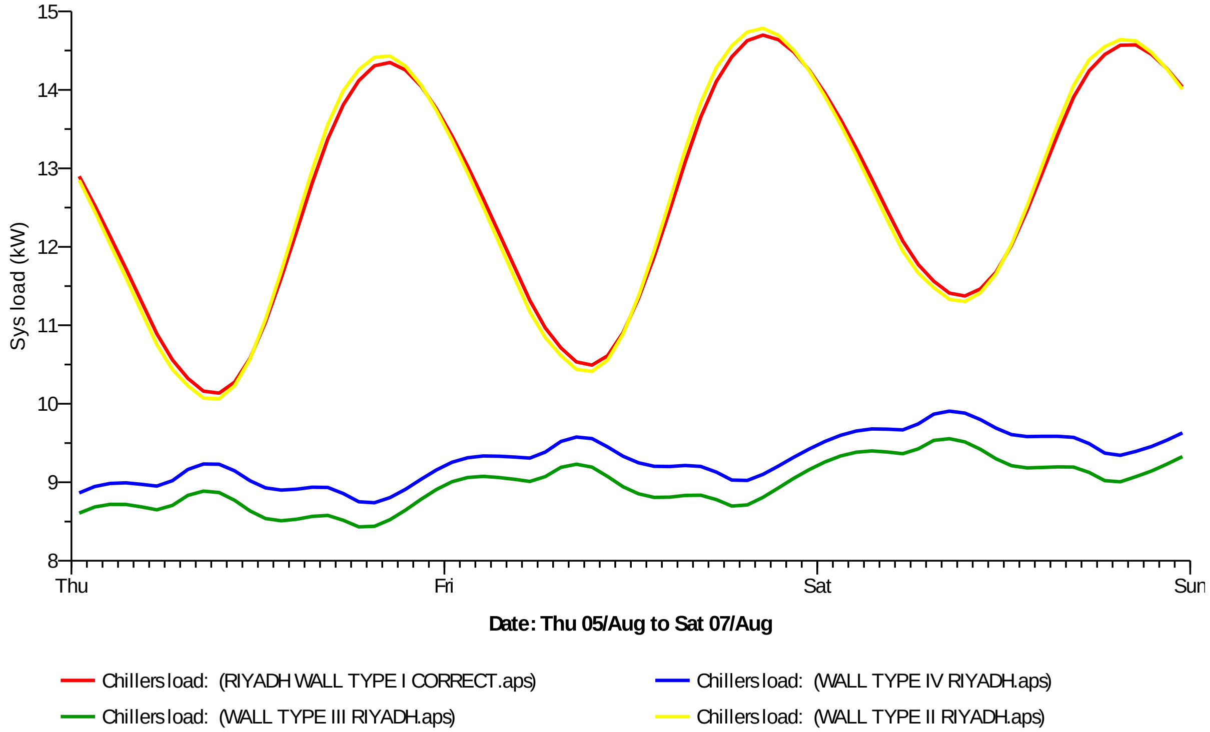


Figure 8.22: The comparative results of the cooling load from the 5th until the 7th of August for all external wall types in Riyadh.

It is evident that July and August are the hottest months in Saudi Arabia, specifically in Riyadh. This chart covers the hottest days in Riyadh (5th until 7th of August) and presents the results of all external wall types previously tested for this city in one chart, side by side. External wall types I and II performs worst. These two particular types of walls shows a poor thermal performance and allows the heat to transfer from outside to inside the residential building in few hours from the early morning. It shows that made the residential building in Riyadh city will require a significant amount of cooling. On the other hand, wall type III and IV has the lowest cooling load consumption and thus, the best performance. Wall type III shows the best thermal performance regarding heat transfer and cooling load. In winter, all external wall types have a similar performance with regard to the cooling load. For the period of 8th to the 10th of February, the cooling load remains 0 kW for all external wall types, as shown in the following figure 8.23.

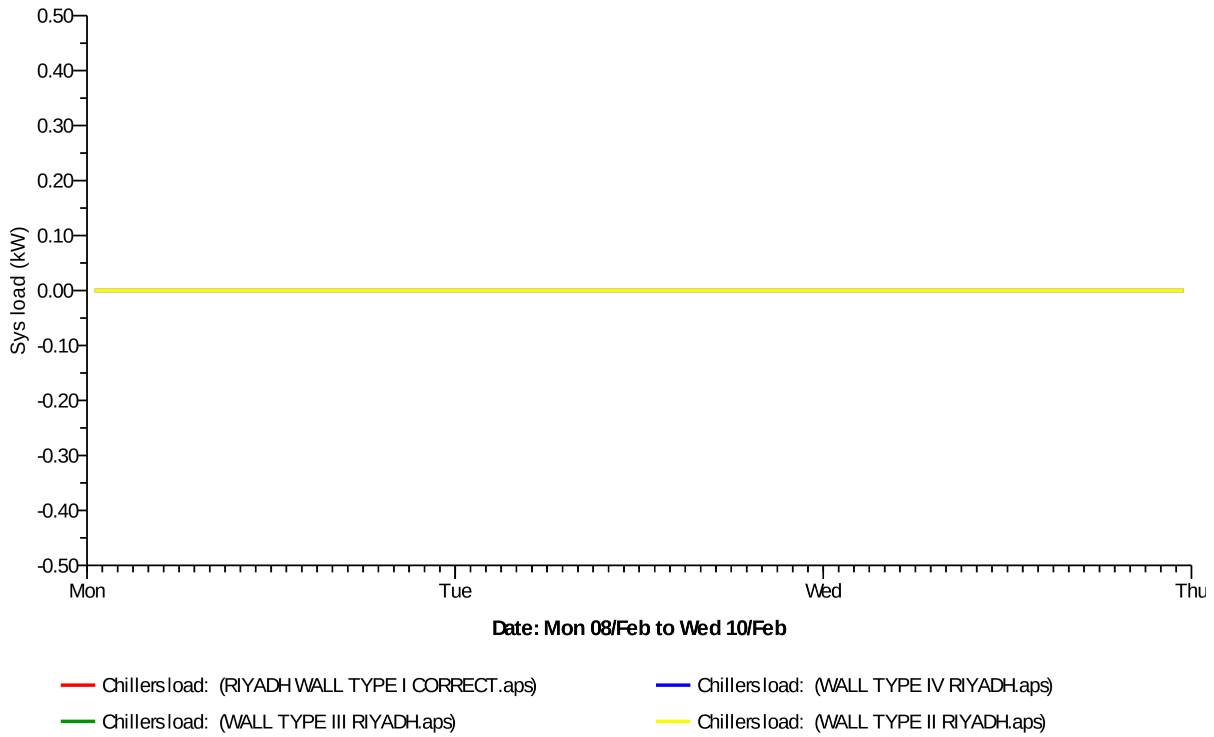


Figure 8.23: The comparative results of the cooling load from the 11th until the 13th of January for all external wall types in Riyadh.

At this stage it is important to study the total energy consumption for all external wall types used for this Saudi typical residential building to ensure that the optimum wall type is selected.

The following table compares the energy consumption for the cooling load for the four external walls.

Table 8.2: The comparative results of the cooling load for all external wall types in Riyadh.

Date	Chillers load (MWh) Wall Type I for Riyadh	Chillers load (MWh) Wall Type II for Riyadh	Chillers load (MWh) Wall Type III for Riyadh	Chillers load (MWh) Wall Type IV for Riyadh
Jan 01-31	0.0001	0.0006	0	0
Feb 01-28	0.0671	0.0734	0.022	0.0202
Mar 01-31	0.3026	0.3173	0.1476	0.1453
Apr 01-30	2.6231	2.625	1.8562	1.9214
May 01-31	6.3255	6.3244	4.5269	4.6977
Jun 01-30	7.8613	7.8583	5.6289	5.8514
Jul 01-31	8.4973	8.4941	6.0724	6.3127
Aug 01-31	8.7978	8.7934	6.3164	6.5723
Sep 01-30	6.7999	6.795	4.929	5.1347
Oct 01-31	3.9592	3.9543	2.8963	3.0248
Nov 01-30	0.8211	0.8285	0.5562	0.5852
Dec 01-31	0.0064	0.0075	0.0003	0.0003
Summed total	**46.0613**	**46.0719**	**32.9522**	**34.2659**

As shown in the previous table, the total cooling load in this typical Saudi residential building in Riyadh reveals that the external wall III has the best overall result for the thermal performance and cooling load. Thus, this wall type will be used for further research in the second section of the analysis.

8.2.3 Simulation Analysis for the Typical Residential Building in Dammam City

The most common types of external walls in Saudi Arabia applied to the selected residential building model in Dammam city, wall types I, II, III and IV. The investigation for the purpose of the study will start with wall type I then, the other external walls types.

8.2.3.1 Wall Type I

The last city tested using the IES building energy simulation software is Dammam, which is the third largest city in Saudi Arabia. The aim of the simulation is to identify the behaviour of the wall construction in a hot and humid climate, typical of this city. Four types of external walls will be applied to the selected model in order to use the most suitable one for further construction development. The simulation will run hour by hour over a full year. The IES software used a weather database to give an average for ten years.

The first wall construction used in the IES is wall type I. The table that gives the details and the layers of the construction is presented in chapter 7 (i.e. density, u-value, specific heat capacity and conductivity) (refer to table 7.8).

It is clear that the energy consumption for the cooling load reached about 11 kW. The temperature fluctuated between 5 degrees centigrade in the winter time, to almost 50 degrees centigrade in the summer time (see Appendix A).

July and August are considered to be the hottest months in the kingdom. The chiller load in the summer is between 7 kWh and 17 kWh, as the temperature reaches about 50 degrees centigrade. Each month individually were looked at and tested as a part of the analysis (See Appendix A).

The following chart will present the results of the hottest days in the country for use in comparative charts later on.

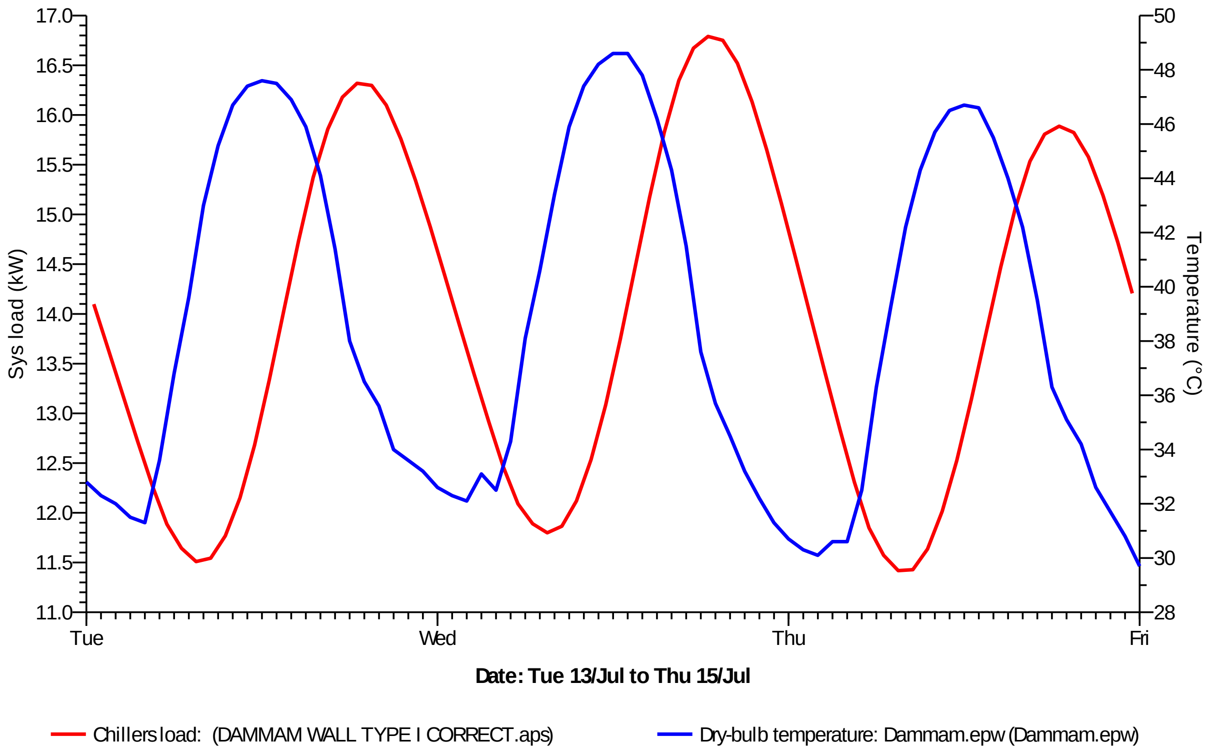


Figure 8.24: The result of cooling load from 13th of July until 15th of July in Dammam city for the external wall type I.

In hottest days of Dammam city from the 13th to the 15th of July the temperature rose to almost 50 degrees centigrade, with the cooling load reaching above16.5 kW, the maximum load over these days. The lag between the cooling load and the outside temperature is about 4 hours.

The following charts will illustrate the coldest days in the winter season. The temperature is at its minimum in Dammam city in January and February.

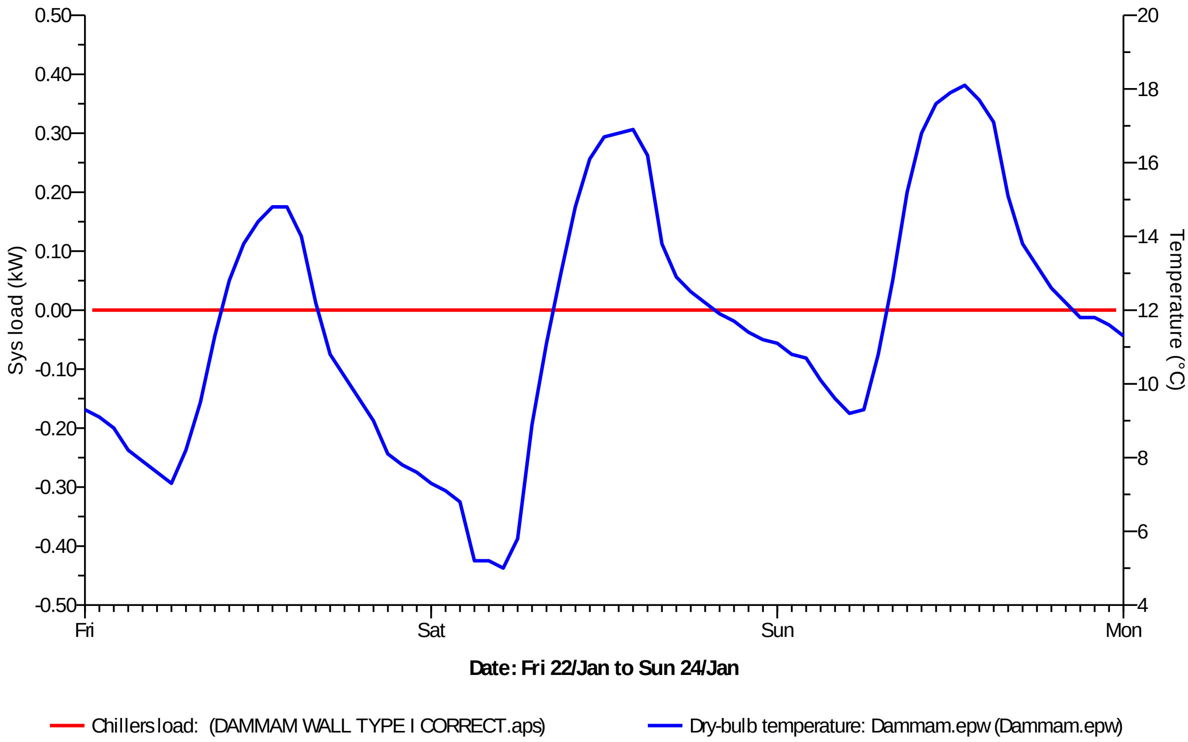


Figure 8.25: The result of cooling load from 22nd of January until 24th of January in Dammam city for the external wall type I.

The temperature is between 4 and 30 degrees centigrade in the winter season. There is no cooling load in January only in few days. In the end of February the cooling load appeared in the chart as a result of the temperature increasing. The graphs for the winter season were studied for each month individually (See Appendix A).

The last chart shows the coldest days in Dammam. The cooling load is zero because the temperature is low and, as previously mentioned, no air conditioning is required.

8.2.3.2 Wall Type II

Wall type II is the second construction wall tested in IES software for Dammam city. The details of the wall construction are mentioned on chapter 7 (refer to table 7.8).

In summer the cooling load reached 17 kW and the temperature reached about 50^0. The results start by presenting the energy consumption and the temperature for hottest days in the form of a chart. . The individual graphs for July and August were included in this study (See Appendix A).

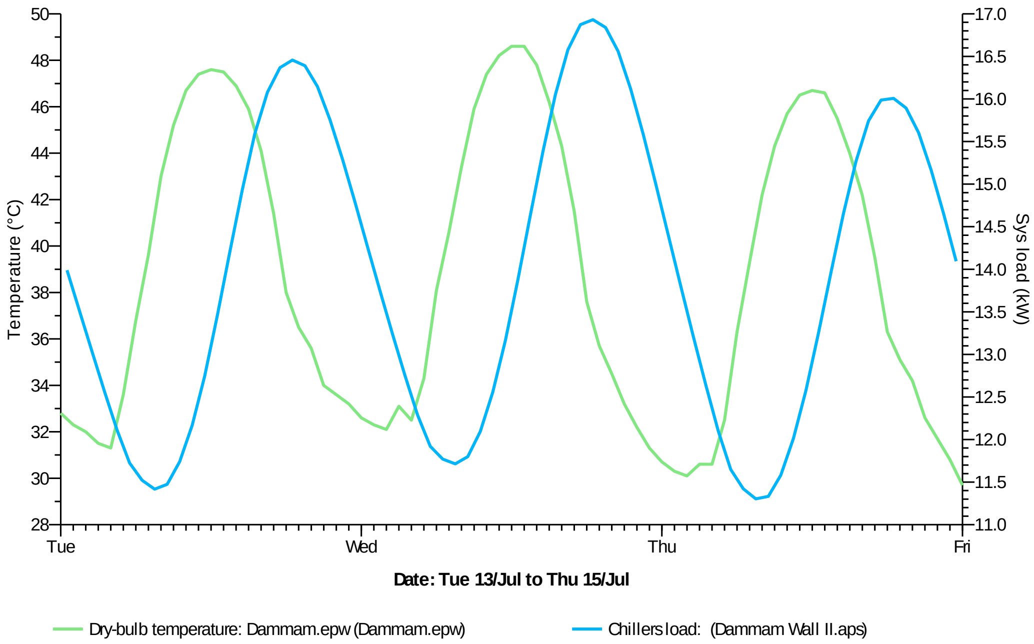


Figure 8.26: The result of cooling load from 13th of July until 15th of July in Dammam city for the external wall type II.

The chart 8.26 above shows the hottest days that temperature could be 50 degrees centigrade, or more, in Dammam and the chiller load reached over 17 kW on the 14th of July when this type of external wall applied to the model. The lag between the cooling load and the outdoor temperature is about four hours.

During the winter the temperature reached a minimum of 4 degrees centigrade, thus the cooling load is zero kW most of the time as the air-conditioning is off. There were a few days in Dammam when the temperature reached about 30 degrees centigrade in winter, meaning that air conditioning was required to cool down homes. The next charts show the reaction of the wall construction the coldest days in winter. The results in this section studied the graphs for each month individually (See Appendix A).

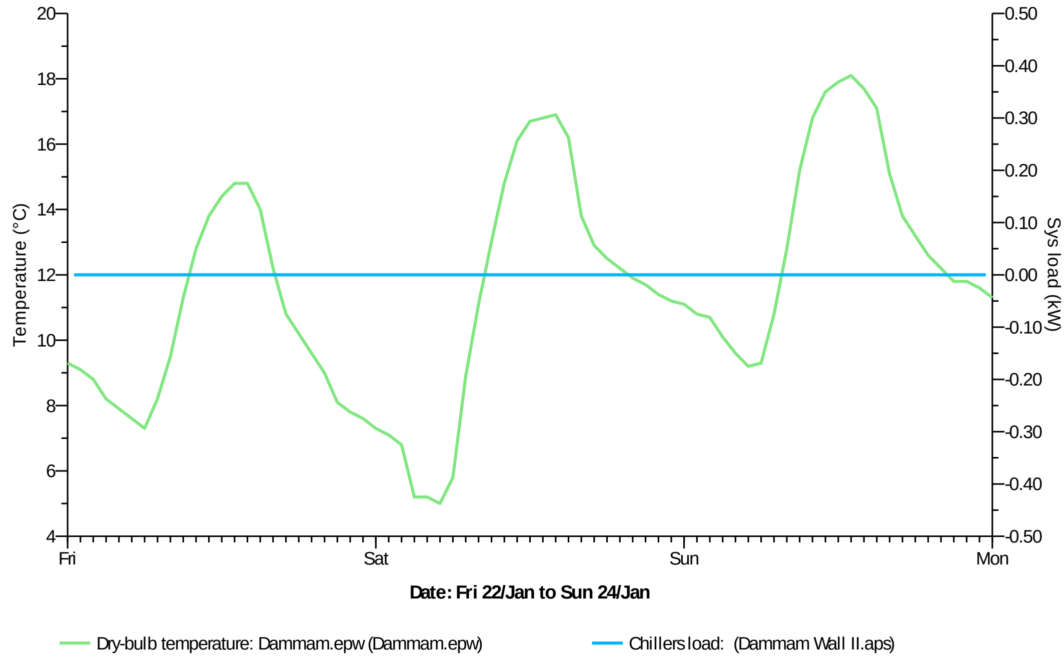


Figure 8.27: The result of cooling load from 22nd of January until 24th of January in Dammam city for the external wall type II.

The last chart 8.27 above shows the coldest days in Saudi Arabia in general, and Dammam specifically. The chart presents the simulation results from the 22nd to the 24th of January, with a maximum temperature of 20^0 and a minimum of 4^0. The load for air conditioning is 0 kW.

8.2.3.3 Wall Type III

The third construction wall tested for Dammam city is wall type III. The results will help to select the most appropriate construction that consumes the minimum energy and gives the best indoor comfort as regards the temperature.

The construction details and the properties of the external wall (i.e. density, specific heat capacity and conductivity) are explained in chapter 7 (refer to table7.8).

The temperature can reach up to 50 ^{0} in summer, and drop to only 5^{0} in winter. The cooling load, on the other hand, is between zero and 11 kW, which is the maximum load at specific times and days (see Appendix A).

In summer, as the temperature could be up to 50 degrees centigrade, the cooling load will inevitably peak. The wall construction type III in Dammam shows that chiller load is between 6.5 kilowatts and approximately 10.5 kilowatts. The air-conditioning works continuously in July, August and September. The following chart 8.28 present the simulation results for the hottest days. In addition, the results included each month individually (See Appendix A).

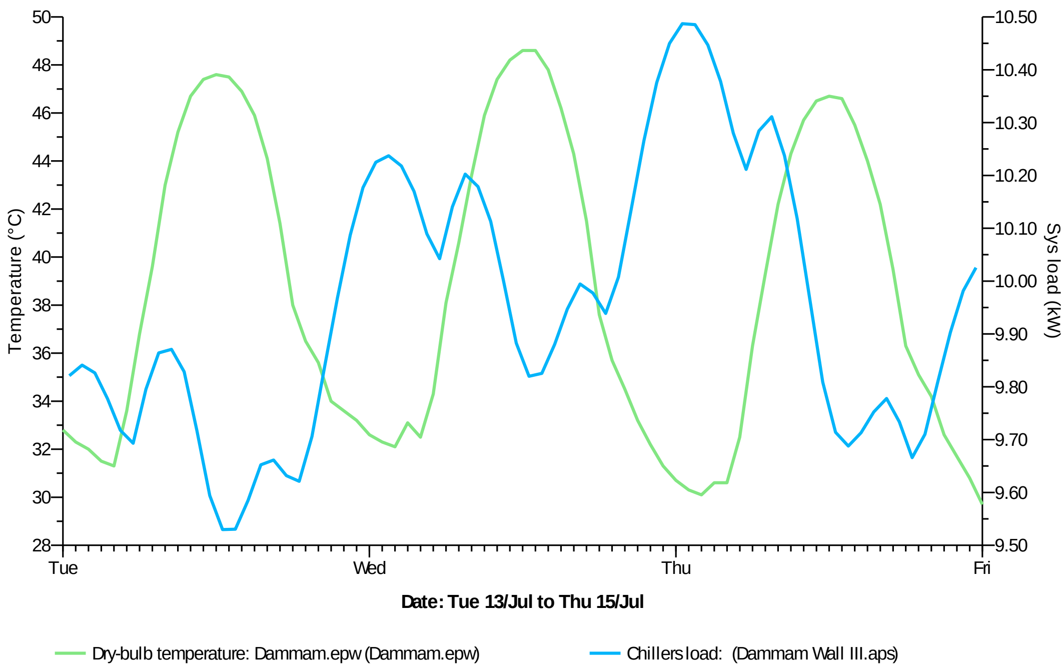


Figure 8.28: The result of cooling load from 13th of July until 15th of July in Dammam city for the external wall type III.

From the 13th to the 15th of July the building reacted according to the wall construction, thermal mass and the weather in this specific location, which were all calculated in the IES software and presented in the above chart. The lag between the cooling load and the outside temperature is between seven to eight hours. This shows clearly that the thermal mass for the external wall has a significant impact and results in delaying the heat transfer for a good amount of time.

As explained previously that the temperature goes up to 50 degrees centigrade in the morning until it drops in the night to 28 degrees centigrade. This explains why the air conditioning runs all the time, with the cooling load between 9.50 kW and almost 10.50 kW for these specific hottest days in Dammam.

The subsequent chart present the coldest days in the winter season of Dammam and the cooling load consumption over the coldest days. The individual graph for each month in the winter season were tested and presented (See Appendix A).

The temperature in winter varies between 4 and 30 degrees centigrade. The cooling load is zero kW most of the time, increasing up to 0.35 kW at specific times.

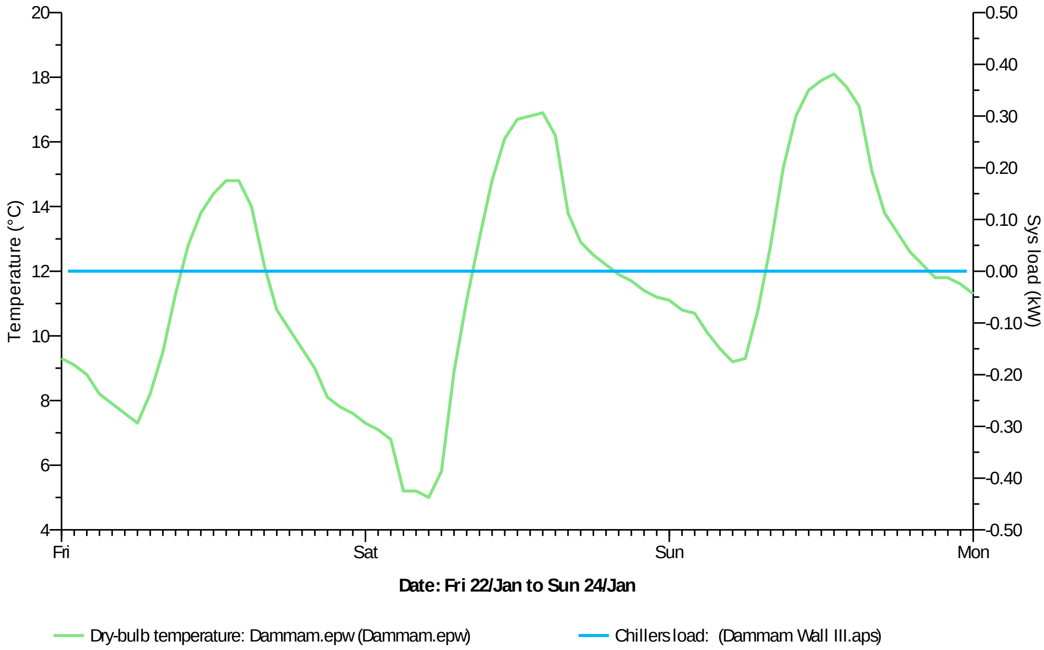


Figure 8.29: The result of cooling load from 22nd of January until 24th of January in Dammam city for the external wall type III.

The chart 8.29 above shows that the air conditioning was not turned on from the 22nd -24th of January, which indicates that during the winter there is no need for cooling most days.

8.2.3.4 Wall Type IV

The last wall type used in IES is wall IV. The wall's properties and the construction layers are explained in chapter 7 (refer to table 7.8).

It is part of this research to discover and understand the impact of this external wall on the typical Saudi house in the specified climate.

The temperature ranged from 5^0 in winter to 50^0 in summer. The cooling load is zero during the cold weather, whereas it reaches up to 11 kW in the hot season. It is clear that the cooling load begins in mid-February and decreases again after December (see Appendix).

The next chart presents and gives the result for the temperature and cooling load for air conditioning in the hottest days. The study in this section includes the graph for each month individually (See Appendix A).

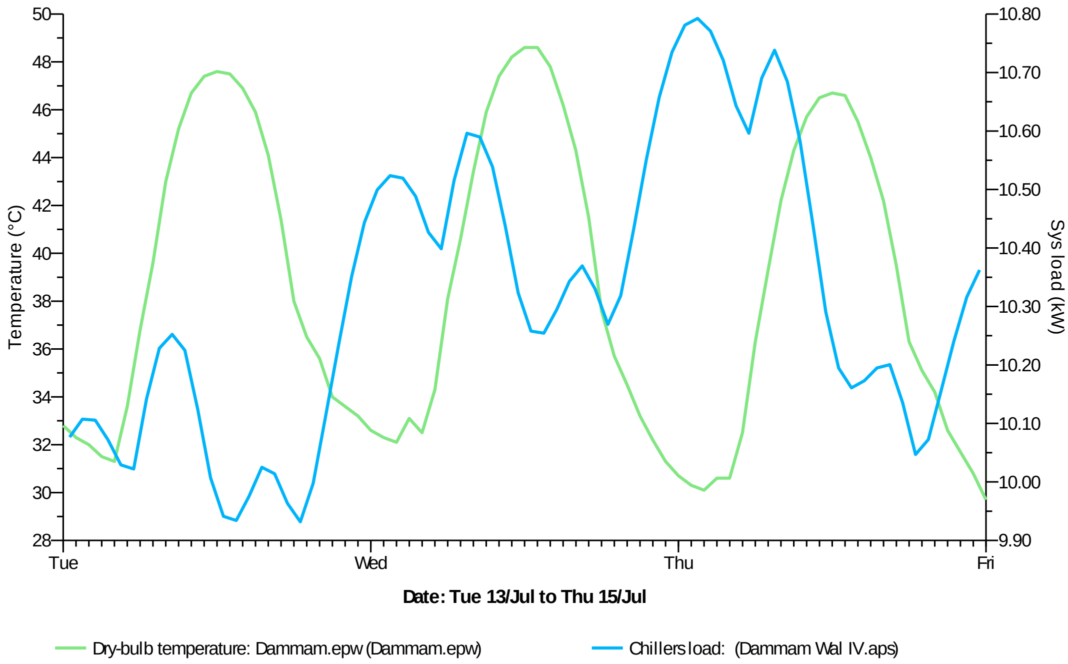


Figure 8.30: The result of cooling load from 13^{th} of July until 15^{th} of July in Dammam city for the external wall type IV.

July and August are considered to be the hottest months in Dammam. The minimum cooling load recorded was 7 kW, while the maximum was about 11 kWh (see Appendix A).

The air conditioning was, naturally, in operation day and night as a result of high temperatures. The temperature was between 24^0 and 50^0, highlighting a significant difference between day and night (see Appendix A). From the 13^{th} to the 15^{th} of July the temperature fluctuated between 28 degrees at night, up to almost 50 degrees in the middle of the day. The chiller load fluctuated between 9.90 kW and 10.80 kW. The lag between the outdoor temperature and the cooling load is seven to eight hours approximately. This external wall shows a high thermal mass and it succeeded in delaying the heat transfer for quite a long time.

The following charts present the coldest days in the winter. The charts for each month individually in the winter season were studied carefully and included in this research results (See Appendix A).

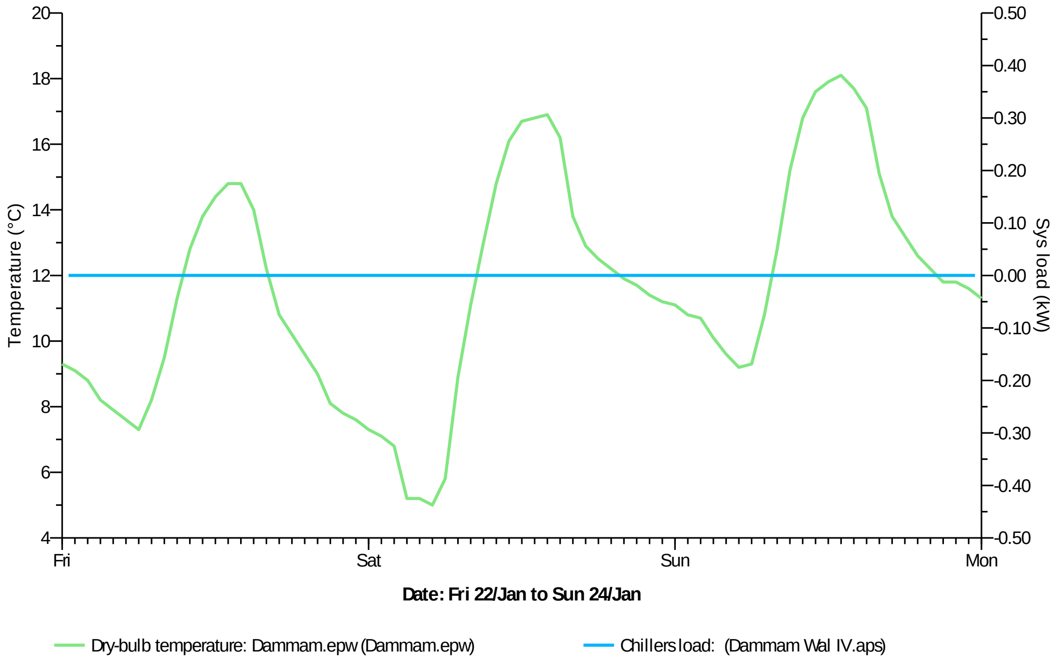


Figure 8.31: The result of cooling load from 22nd of January until 24th of January in Dammam city for the external wall type IV.

The air conditioning load is zero in January, with the load starting to appear from the 12th to the 15th of February, then again on the 25th of the same month (see Appendix A). The cooling load only reached approximately 0.50 kW as there was no need for air conditioning most of the time due to the cold weather. The temperature fluctuated, on average, between 4^{0} and 30^{0}. The last chart 8.31 shows there was no air conditioning from the 22nd to 24th of January as the temperature did not exceed 20 degrees centigrade.

8.2.3.5 The comparative between the external walls types for Dammam city

The most common types of the external wall were used and tested by the IES building energy simulation software after applied these external walls on the selected house model. The important stage at the moment to compare the results of the simulation to find out which wall is more suitable to the city climate and has better energy performance regarding cooling load and thermal mass. The comparison will start by comparing the external wall type I, II, III and IV in hottest days as well as coldest days that previously selected for this purpose. The following charts will put these four types of walls together in one graph in order to make a clear contrast between them.

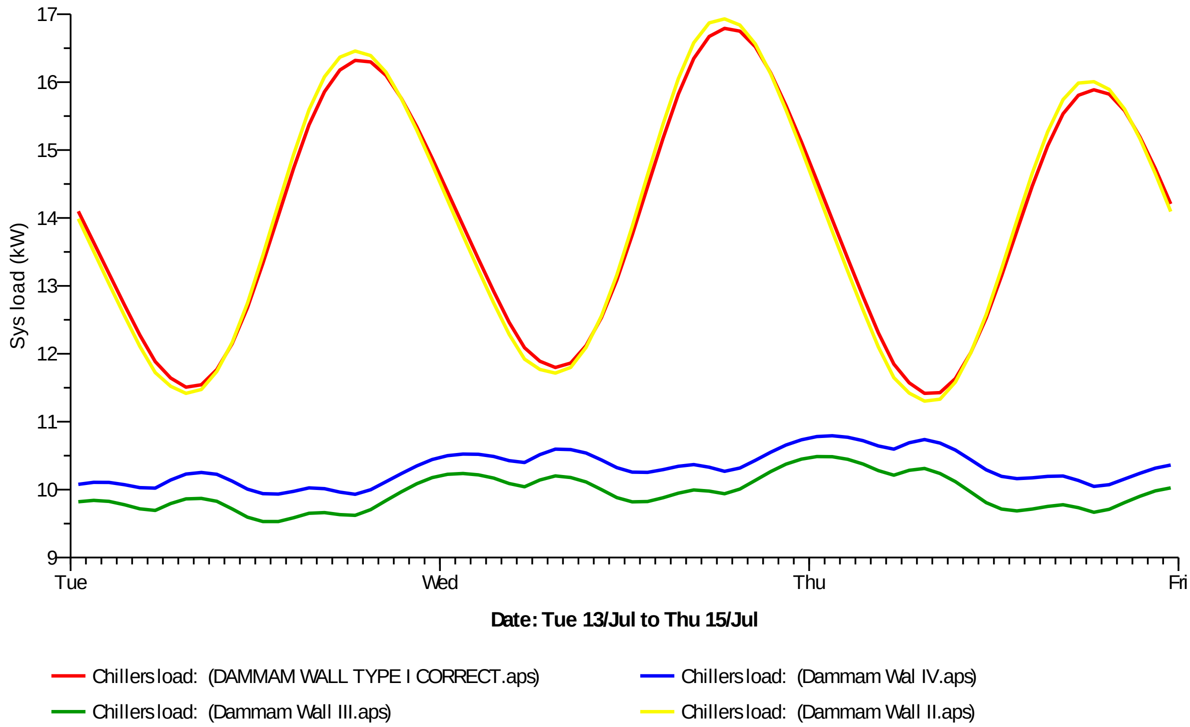


Figure 8.32: The comparative results of the cooling load from the 13th until the 15th of July for all external wall types in Dammam.

At the beginning of this chapter, the simulation results showed the cooling load consumption for both summer and winter. Specific days were then chosen for a comparison to identify which wall has the most positive impact on energy and cooling load, reducing the consumption as much as possible. The first chart showed the simulation results for the 13-15 of July for the cooling load for all external wall types used for the typical house in Dammam. In general external wall types I and II performs worst. These two walls shows a poor thermal performance that allow the heat to transfer from outside to inside the residential building in few hours from the early morning and result in increasing the cooling load. There is no doubt that external wall type III had most effectively reduced the cooling load on very hot days, compared to the other wall types. In fact, wall type III has a good impact on the energy consumption.

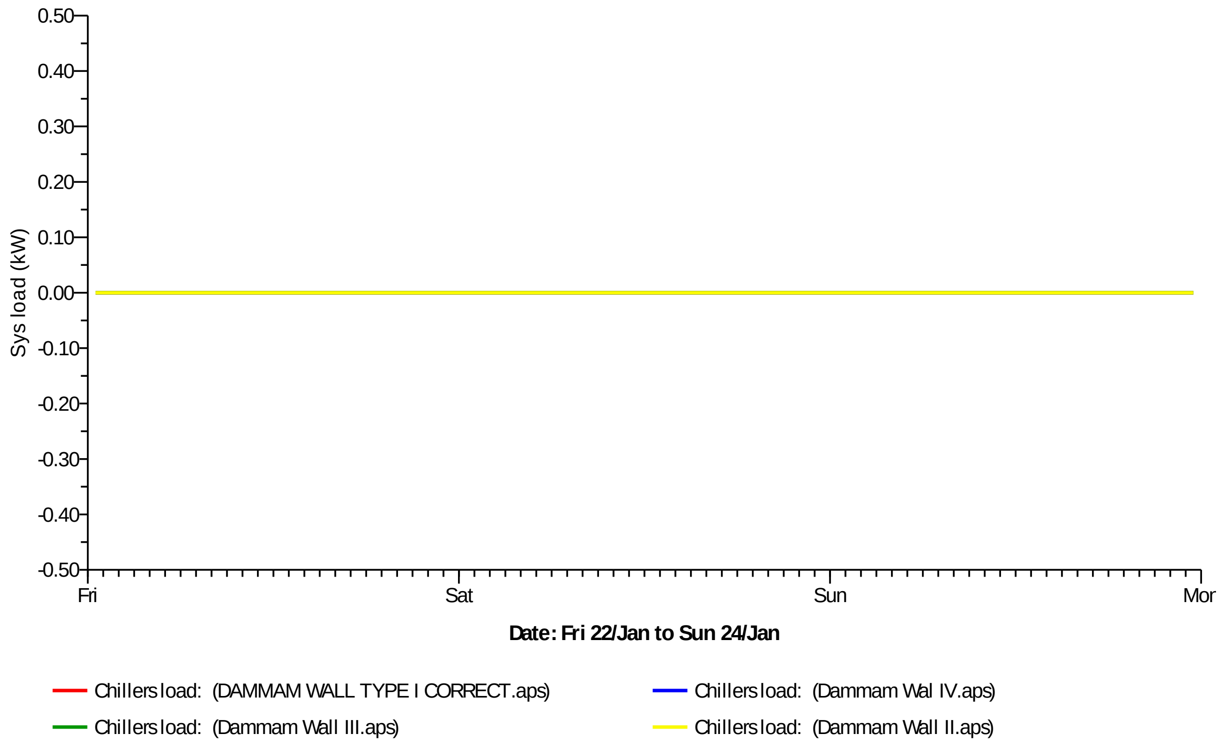


Figure 8.33: The comparative results of the cooling load from 22nd of January until 24th of January for all types of the external walls in Dammam.

In the winter time the performance of the external walls for this specific model and location looks very similar as the cooling load is remain constant of zero kW for the days from 22nd of January until 24th of January. To make sure that wall type III is the most suitable for the model and the location it is better to compare the overall cooling load consumption for these external walls as shown in the table below.

Table 8.3: The comparative results of the cooling load for all types of the external walls in Dammam.

Date	Chillers load (MWh)Wall Type I for Dammam	Chillers load (MWh) Wall Type II for Dammam	Chillers load (MWh) Wall Type III for Dammam	Chillers load (MWh) Wall Type IV for Dammam
Jan 01-31	0.0034	0.0044	0	0
Feb 01-28	0.0388	0.046	0.0061	0.005
Mar 01-31	1.1424	1.1614	0.7373	0.7539
Apr 01-30	3.6259	3.6326	2.5442	2.6321
May 01-31	7.0202	7.0204	5.0022	5.1989
Jun 01-30	8.4493	8.4484	6.0204	6.2593
Jul 01-31	9.41	9.4076	6.7389	7.0114
Aug 01-31	8.642	8.6403	6.1777	6.4281
Sep 01-30	7.4002	7.397	5.318	5.5393
Oct 01-31	5.3425	5.3398	3.8469	4.0102
Nov 01-30	1.6272	1.6279	1.1948	1.2501
Dec 01-31	0.0557	0.0607	0.0183	0.0178
Summed total	**52.7577**	**52.7866**	**37.6047**	**39.1062**

The results in the table above for the total cooling load in this typical Saudi residential building in Dammam confirm that external wall III performs best in terms of reducing the overall cooling load. Thus, this wall type will be used for further research in the second section of the analysis.

8.3 Results and Analysis Second Part

After the first part of the analysis in this chapter showed that wall type III has the best thermal performance and is the best at saving more energy in Saudi Residential Buildings, three different regions and cities, Jeddah, Riyadh and Dammam, were studied in the same way. The next step of the research is to find out how adding a thermal insulation to the external wall type III can make a difference. The aim is to test the selected insulation in Saudi residential buildings with a specific thickness and different locations. The most common wall insulation types are mentioned previously in the literature review.

From the literature review, the polyurethane thermal insulation shows a short payback period time. Therefore, a medium size of 50 mm of Polyurethane was selected for examination in three different places in the external wall to determine whether the location of insulation in the external wall could also help to save more energy.

- **Wall A**

  The first place of 50mm Polyurethane insulation with wall III will be named as A and presented in the following table 8.4 and the figure 8.34 below.

Table 8.4: Structures and thermal characteristics of wall type A.

Wall Type	Thickness of wall components (m)	Thermal conductivity of wall components W/mK	Wall conductance U (W/m2K)	Wall Resistance (m^2k/w)	Density kg/m^3	Specific heat J/kgK
Wall A						
Stone	0.20	1.70	2.28	0.438	2250	840
Concrete	0.07	1.75			2410	880
Polyurethane Insulation	0.05	0.025			30	1470
Hollow bricks	0.20	0.90			1500	840
Plaster	0.03	1.20			2000	1000

Outside

External Wall A

Stone 0.20 m

Concrete 0.07 m

Polyurethane Insulation 0.05 m

Clay Hollow bricks 0.20

Plaster 0.03

Inside

Figure 8.34: External Wall A layers.

- **Wall B**

The second place of 50mm Polyurethane insulation with wall III will be named as B and presented in the following table 8.5 and the figure 8.35 below.

Table 8.5: Structures and thermal characteristics of wall type B.

Wall Type	Thickness of wall components (m)	Thermal conductivity of wall components W/mK	Wall conductance U (W/m²K)	Wall Resistance (m2k/w)	Density kg/m³	Specific heat J/kgK
Wall B						
Stone	0.20	1.70	2.28	0.438	2250	840
Concrete	0.07	1.75			2410	880
Hollow bricks	0.20	0.90			1500	840
Polyurethane Insulation	0.05	0.025			30	1470
Plaster	0.03	1.20			2000	1000

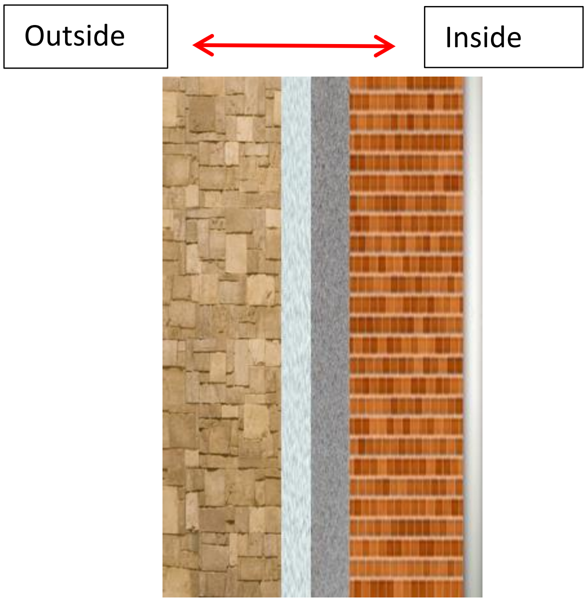
Figure 8.35: External Wall B layers.

- **Wall C**

The third place of 50mm Polyurethane insulation with wall III will be named as C and presented in the following table 8.6 and the figure 8.36 below.

Table 8.6: Structures and thermal characteristics of wall type C.

Wall Type	Thickness of wall components (m)	Thermal conductivity of wall components W/mK	Wall conductance U (W/m²K)	Wall Resistance (m2k/w)	Density kg/m³	Specific heat J/kgK
Wall C						
Stone	0.20	1.70	2.28	0.438	2250	840
Polyurethane	0.05	0.025			30	1470
Concrete	0.07	1.75			2410	880
Hollow bricks	0.20	0.90			1500	840
Plaster	0.03	1.20			2000	1000



External Wall C

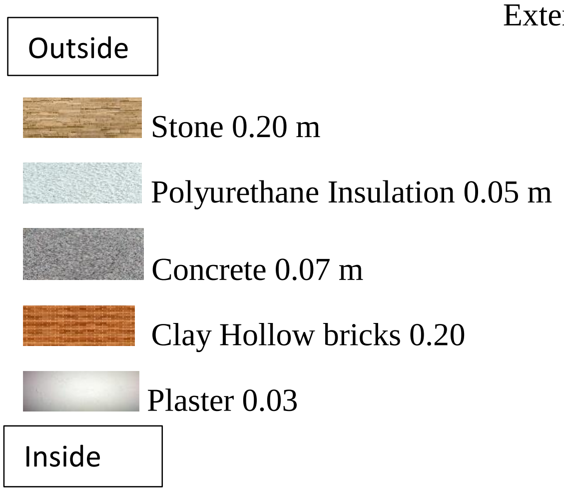


Figure 8.36: External Wall C layers.

The thermal insulation will be applied for the Saudi typical house again in three locations Jeddah, Riyadh and Dammam. The results later on in this chapter will discuss how adding the 0.50m of polyurethane thermal insulation to the external wall type III can reduce energy consumption, what is the reduction percentage and best location for thermal insulation.

8.3.1 Simulation Analysis for the Typical Residential Building in Jeddah City-Second Part

50mm Polyurethane insulation was applied to the external wall of the Saudi typical building in order to determine the difference in performance. The criterion chosen was cooling load, as this is the major consumer of energy.

The results of course will present the energy consumption for air-conditioning for the whole year, as well as on specific days that presented the hottest days in Jeddah.

The first location for the polyurethane insulation is applied to the model in order to find out how the building behaves when the temperature hits the peak in the summer. The first chart (Figure 8.37) presents a comparison between the selected wall type III without any insulation, and the same wall type but this time with 50mm polyurethane insulation.

The figure shows the energy consumption for air-conditioning from 8-10 July for two types of walls as mentioned previously.

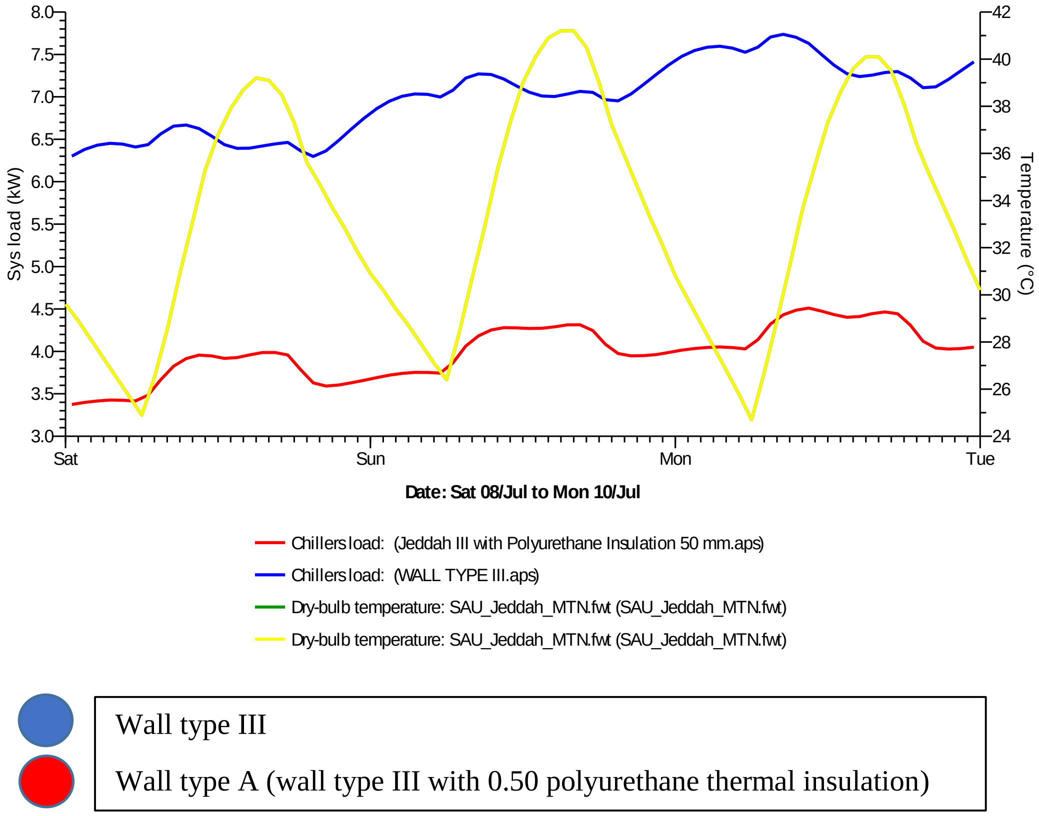


Figure 8.37: The cooling load results comparison between wall type III and the same wall type with polyurethane insulation, from the 8th until 10th of July.

It is very clear that there is a huge difference between two types of walls. The blue line represents wall III with no insulation, which consumed between 7 kW – 7.5 kW cooling load, whereas the same wall type (Shown in red) with insulation (wall type A) has a cooling load between 3 and slightly above 4 kW. In fact, the time lag between the cooling load and the outside temperature for both walls is similar but not identical. In addition, the thermal mass for both walls is similar but the only difference is adding the 0.50 m of polyurethane thermal insulation to the wall type III (wall type A). Adding thermal insulation to the external wall type III improved the efficiency of the wall and reduced the cooling load for about 40%. The combination of a good thermal mass for the external wall and thermal insulation succeeded in reducing the energy consumption and cooling load for the Saudi residential building in Jeddah city in the hottest days.

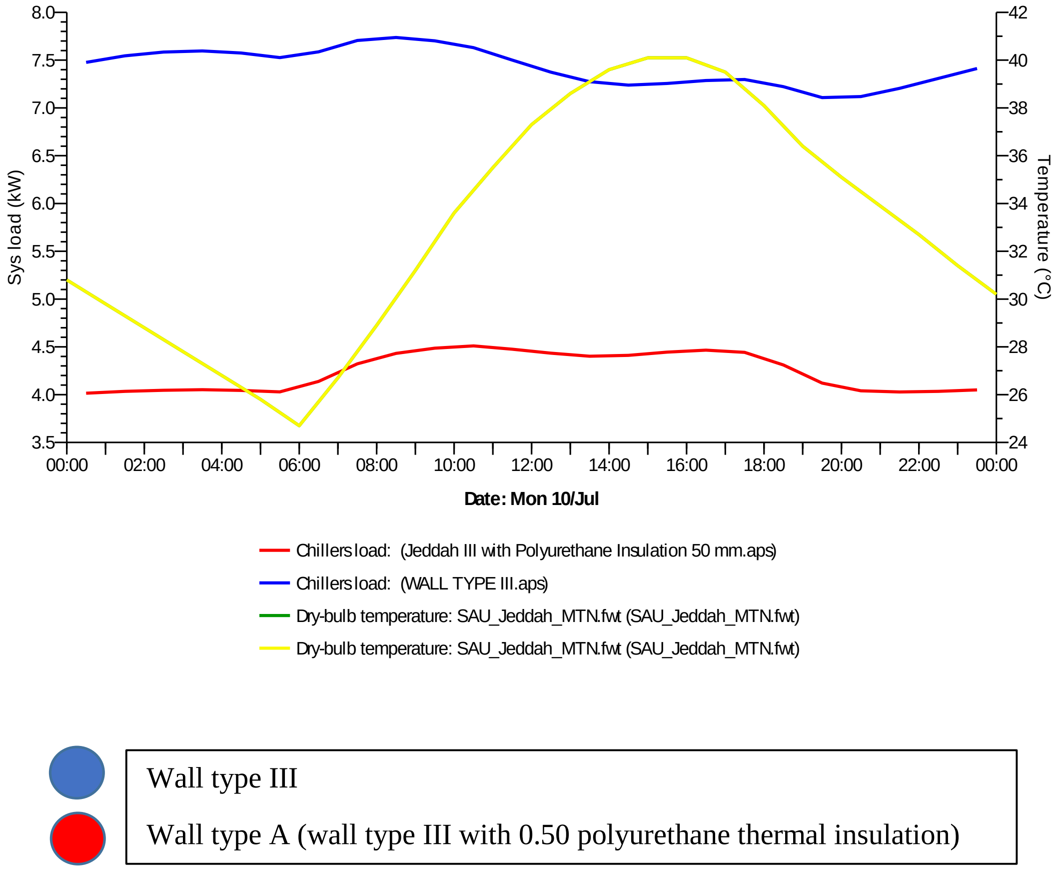


Figure 8.38: The cooling load results comparison between wall type III and wall type A on the 10^{th} of July.

On the hottest day in Jeddah, 10th of July the cooling load for the original wall (wall type III without insulation) was approximately 7.5 kW, but with the new wall with insulation (wall type A) the load was reduced to only 4-4.5 kW. This explains again that the thermal mass of the external wall type III is good but adding the thermal insulation will make it better. This combination reduced the energy consumption for the cooling load by more than 40%.

Table following table 8.7 presents in detail how thermal insulation on 10th of July helped to reduce the cooling load on a very hot day by up to 47% at some hours and overall by 43%.

Table 8.7: The cooling load results comparative between wall type III and wall type A on 10th of July.

Date	Time	Chillers load (kW)	Chillers load (kW)	Dry-bulb temperature (°C)	kW Reduction (Percentage %)
10 July	24:00:00	Jeddah III with Polyurethane Insulation 50 mm (wall type A)	WALL TYPE III		
	00:30	4.0146	7.4766	30.8	46%
	01:30	4.0339	7.5457	29.8	47%
	02:30	4.0454	7.5845	28.8	47%
	03:30	4.0515	7.5963	27.8	47%
	04:30	4.0442	7.5745	26.8	47%
	05:30	4.0287	7.5263	25.8	46%
	06:30	4.1379	7.5861	24.7	45%
	07:30	4.3218	7.7054	26.7	44%
	08:30	4.4314	7.737	28.9	43%
	09:30	4.4858	7.702	31.2	42%
	10:30	4.5098	7.6301	33.6	41%
	11:30	4.4754	7.5006	35.5	40%
	12:30	4.4341	7.374	37.3	40%
	13:30	4.4024	7.2747	38.6	39%
	14:30	4.4104	7.2389	39.6	39%
	15:30	4.4443	7.2557	40.1	39%
	16:30	4.4654	7.2863	40.1	39%
	17:30	4.4427	7.2981	39.5	39%
	18:30	4.3104	7.2227	38.1	40%
	19:30	4.1201	7.1083	36.4	42%
	20:30	4.0396	7.1183	35.1	43%
	21:30	4.0279	7.205	33.9	44%
	22:30	4.0342	7.3089	32.7	45%
	23:30	4.0496	7.412	31.4	45%
Summed total		101.7615	178.268		43%

As shown above in the table and chart, (wall type A) can play a significant part in saving energy for a hot day in Jeddah city.

The next important investigation is to see whether changing the location of the insulation in the external wall could also save more energy.

Figure 8.39 shows a comparison between three external walls A, B and C both with thermal insulation but this time in different positions within the wall.

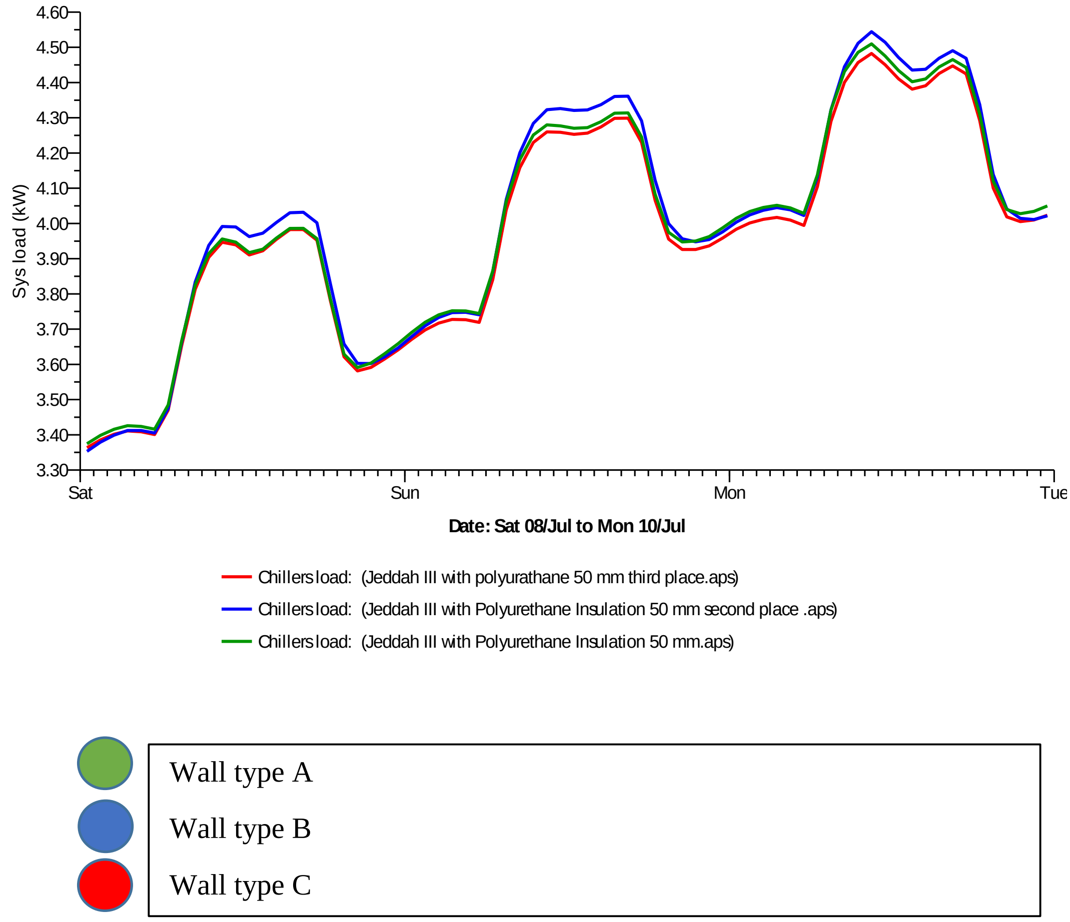


Figure 8.39: The cooling load results comparison between wall types A, B and C, from the 8th until 10th of July.

The figure 8.39 presents the energy consumption for cooling load for three types of external wall from 8-10 of July. All walls include Polyurethane Insulation 50mm but in different places in the external wall type III. The performance of the walls is very similar with only a slight difference. All walls consumed between 3.30 kW up to 4.6 kW. For wall B the thermal insulation is close to the inside of the building (stone, concrete, hollow bricks, thermal insulation and plaster). The performance of wall types A and C in terms of cooling load are slightly better. This is proven that moving the place of the insulation to the outside of the external wall is more efficient for Jeddah city. It is very important to mention that wall A, B and C all has the same layers, materials and u-values. The only different between these walls is the place of the thermal insulation.

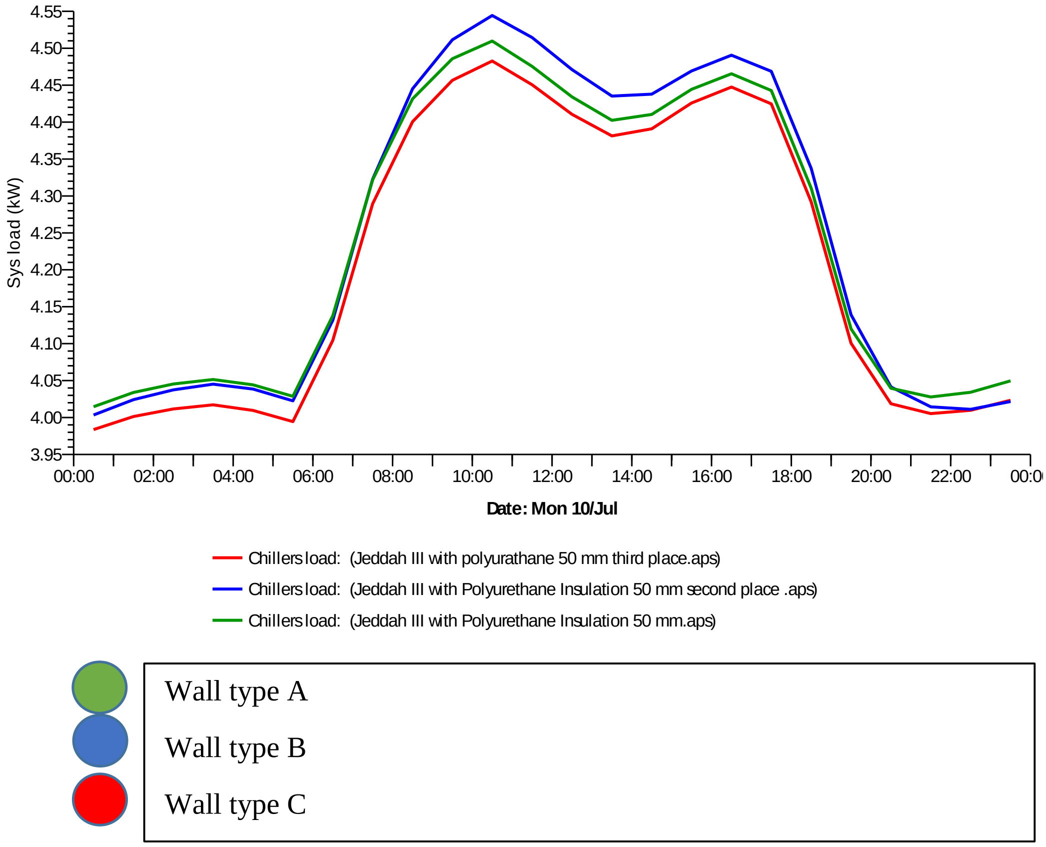


Figure 8.40: The cooling load results comparative between wall type A, B and C on 10th of July.

On the 10th of July it seems that when temperature goes from 10am to 5 pm the Polyurethane Insulation 50mm in the third place (wall type C) in red colour has an advantage over the same wall in other places (wall A and B). The Polyurethane Insulation 50mm in the third place (wall type C) reached the maximum cooling load of 4.50 kW whereas Polyurethane Insulation 50mm in other places reached to about 4.55 kW. Again, this is shows that wall type C where the insulation is close to the outside has a better impact on energy consumption regarding the cooling load in the hottest day in Jeddah city.

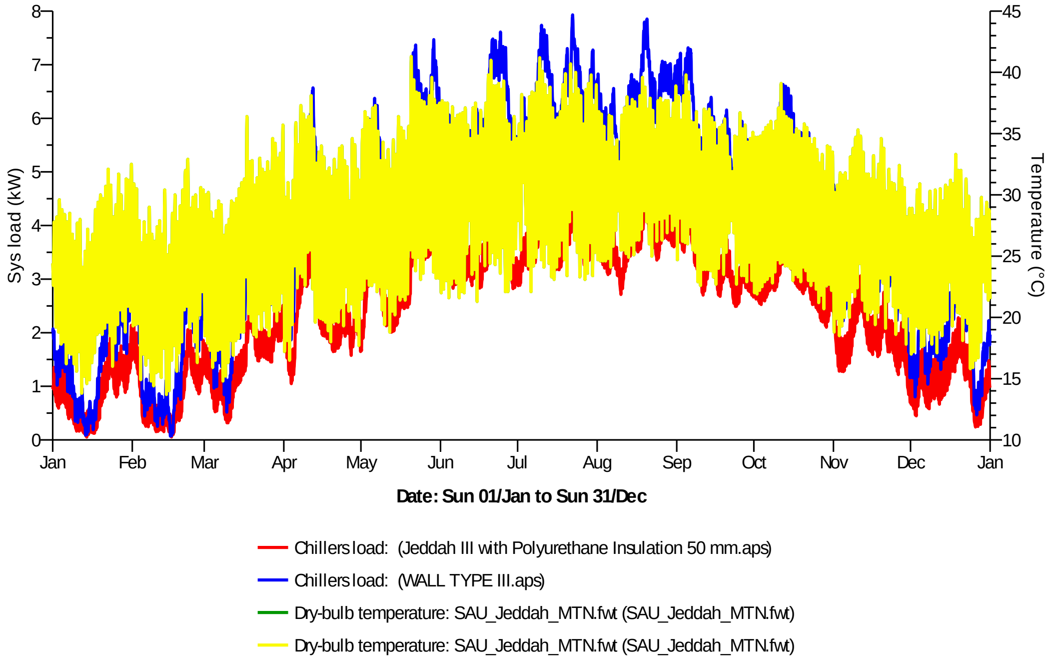
The next table 8.8 will show the hourly changes of cooling load consumption on 10th of July for all types of external walls.

Table 8.8: The cooling load results comparative between wall type A, B and C on 10th of July.

Date	Time	Chillers load (kW)	Chillers load (kW)	Chillers load (kW)
		Wall Type C	Wall Type B	Wall Type A
10 July	00:30	3.9837	4.0034	4.0146
	01:30	4.0013	4.0242	4.0339
	02:30	4.0117	4.0375	4.0454
	03:30	4.0171	4.0451	4.0515
	04:30	4.0097	4.0385	4.0442
	05:30	3.9945	4.0226	4.0287
	06:30	4.1044	4.1318	4.1379
	07:30	4.2894	4.3227	4.3218
	08:30	4.4005	4.4452	4.4314
	09:30	4.4566	4.5115	4.4858
	10:30	4.4827	4.5443	4.5098
	11:30	4.4505	4.5144	4.4754
	12:30	4.4105	4.4711	4.4341
	13:30	4.3814	4.4353	4.4024
	14:30	4.3908	4.4379	4.4104
	15:30	4.4258	4.4692	4.4443
	16:30	4.4474	4.4905	4.4654
	17:30	4.4246	4.4688	4.4427
	18:30	4.2919	4.3372	4.3104
	19:30	4.1005	4.1391	4.1201
	20:30	4.0186	4.0414	4.0396
	21:30	4.0053	4.0144	4.0279
	22:30	4.0098	4.0111	4.0342
	23:30	4.0233	4.0216	4.0496
Total		**101.132**	**101.9788**	**101.7615**

As shown above in the table, the location of the insulation is not causing a significant reduction in cooling load in the 10th of July. However, the performance of the wall type C where the Polyurethane Insulation 50mm close to the outside of the residential building has a better overall performance.

It is very important to see what difference in total energy reduction for the whole year between an external wall without thermal insulation and a wall having the selected thermal insulation of 50mm Polyurethane. Figure 8.41 shows a comparison between these two types of walls for the whole year.



Wall type III

Wall type A (wall type III with 0.50 polyurethane thermal insulation)

Figure 8.41: The cooling load results comparative between wall type III and A from 1st of January until 31st of December.

Figure 8.41 shows that minimum temperature is 10 degrees centigrade and the maximum is 45 for Jeddah city. The cooling load on the other hand fluctuated between 0 and 8 kW. According to figure 8.41 above, it is very clear that wall with Polyurethane Insulation 50mm has a better performance specially in summer time when temperature above 40 degrees centigrade. The external wall with Polyurethane Insulation 50mm (wall type A) reached a maximum load of only 4.5 kW in summer as shown in the figure below whereas the load for the same type of wall without insulation was almost double at 8kW as shown in the figure above.

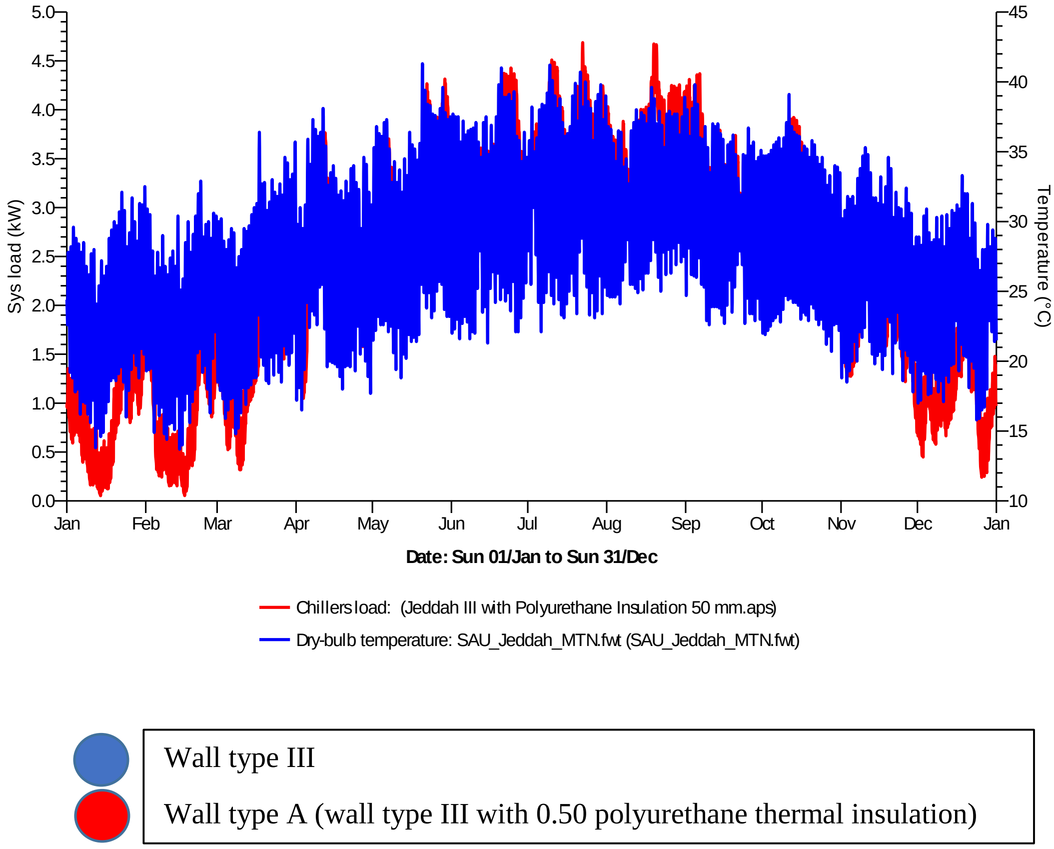


Figure 8.42: The cooling load results of wall type A from 1st of January until 31st of December.

Table 8.9 present the whole year cooling load for two types of wall (wall type III and A). The table presents month by month energy consumption for cooling load between external wall type III and A, giving the total in MWh. Finally, it shows the total energy reduction achieved.

Table 8.9: The cooling load results comparative between wall type III and A from 1st of January until 31st of December.

Date	Chillers load (MWh)	Chillers load (MWh)	MWh Reduction (Percentage %)
	Jeddah III with Polyurethane Insulation 50 mm (wall type A)	WALL TYPE III	
Jan 01-31	0.6179	1.1017	44%
Feb 01-28	0.5737	1.0124	43%
Mar 01-31	1.0976	1.9249	43%
Apr 01-30	1.6487	2.8682	43%
May 01-31	2.3011	3.9957	42%
Jun 01-30	2.479	4.2829	42%
Jul 01-31	2.7738	4.7954	42%
Aug 01-31	2.7447	4.7342	42%
Sep 01-30	2.3644	4.0921	42%
Oct 01-31	2.2173	3.9166	43%
Nov 01-30	1.368	2.407	43%
Dec 01-31	0.8071	1.4345	44%
Summed total	20.9934	36.5656	43%

Without doubt the Polyurethane Insulation minimized energy consumption for the typical Saudi house by 43% according to the table above. During the summer time the building consumed 4.7954 MWh in July for example but the same building with Insulation for external wall consumed only 2.7783 MWh, meaning that the total energy reduction for cooling load is 42%. Even in winter time there is still an advantages of the thermal insulation when air-conditioning is needed. This table confirmed that adding the thermal insulation to the best type of external wall (wall type III) increased the efficiency and achieved a further reduction in cooling load.

Figure 8.43 presents' three types of walls, all with Polyurethane Insulation but this time in different locations in the external wall (wall type A, B and C), to determine whether there is a significant difference in wall performance.

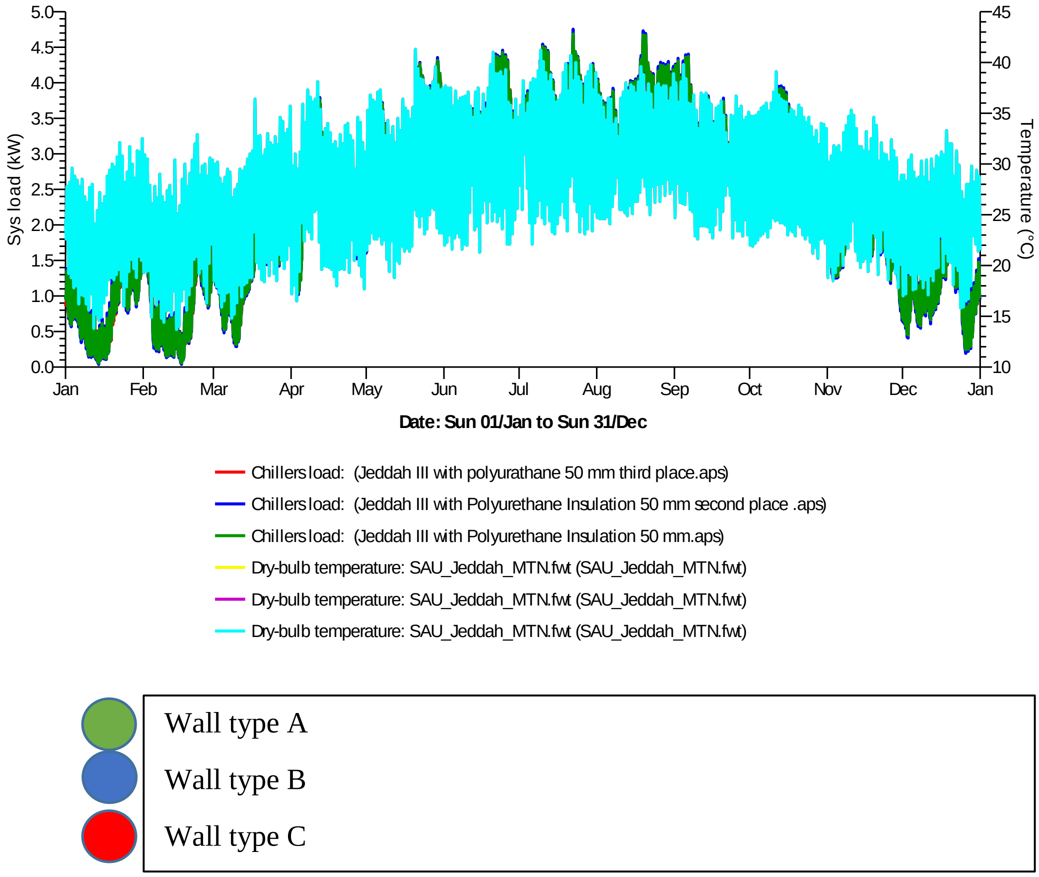


Figure 8.43: The cooling load results comparative between wall type A, B and C from 1st of January until 31st of December.

It shows that dry bulb temperature is between 10 degrees centigrade in winter and up to 45 degrees centigrade in summer. Chiller load is between 0 kW in winter to approximately 5 kW in summer. All walls performed similarly, and the next table (Table 8.10) shows a more detailed picture.

Table 8.10: The cooling load results comparative between wall type A, B and C from 1st of January until 31st of December.

Chillers load (MWh) Date	Chillers load (MWh)	Chillers load (MWh)	Chillers load (MWh)
Date	Wall Type C	Wall Type B	Wall Type A
Jan 01-31	0.6121	0.6221	0.6179
Feb 01-28	0.5732	0.5747	0.5737
Mar 01-31	1.0954	1.0983	1.0976
Apr 01-30	1.6487	1.6474	1.6487
May 01-31	2.2972	2.3021	2.3011
Jun 01-30	2.4809	2.4779	2.479
Jul 01-31	2.7728	2.774	2.7738
Aug 01-31	2.7445	2.7444	2.7447
Sep 01-30	2.3662	2.3627	2.3644
Oct 01-31	2.2183	2.2165	2.2173
Nov 01-30	1.3715	1.3649	1.368
Dec 01-31	0.8087	0.8078	0.8071
Summed total	**20.9895**	**20.9927**	**20.9934**

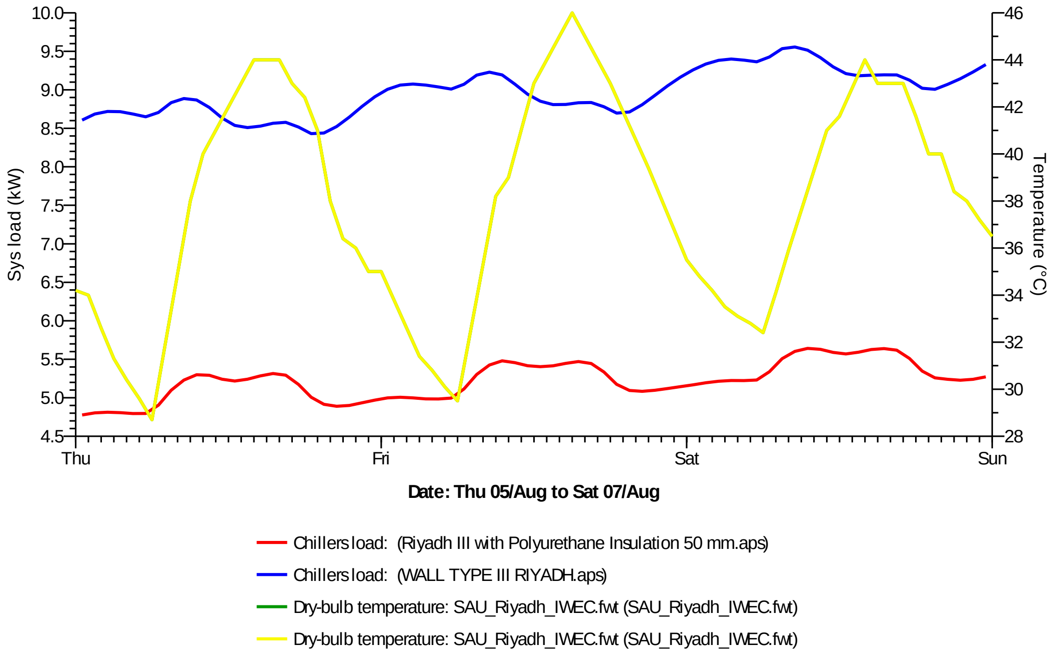
Once again, the results show a slight difference in the total cooling load across all wall types. However, wall type C has a slight energy saving advantage over all other types, though the total reduction is negligible. In fact, this clearly shows that the place for the thermal insulation in wall type C has a better impact on the cooling load. The best place for the thermal insulation in the outer layers of the external wall.

8.3.2 Simulation Analysis for the Typical Residential Building in Riyadh City-Second Part

The next city will be tested for polyurethane thermal insulation is Riyadh city. It is very important to understand and know how the typical Saudi house will perform in the different climate zones of the country. The results will present the energy consumption for air-conditioning for the whole year as well as for specific time and days.

The external wall selected is wall type III with 50mm polyurethane thermal insulation applied into three different locations in the wall as mentioned previously at the beginning of this chapter.

The first chart 8.44 present example of the hottest days in the country in general and in Riyadh specifically. The chart makes a comparison between two walls, (wall type A) which is wall III with the insulation and the other one without. It shows how thermal insulation for external walls can make difference to the cooling load on a very hot day.



Wall type III

Wall type A (wall type III with 0.50 polyurethane thermal insulation)

Figure 8.44: The cooling load results comparative between wall type III and wall type A from 5th of August until 7th of August.

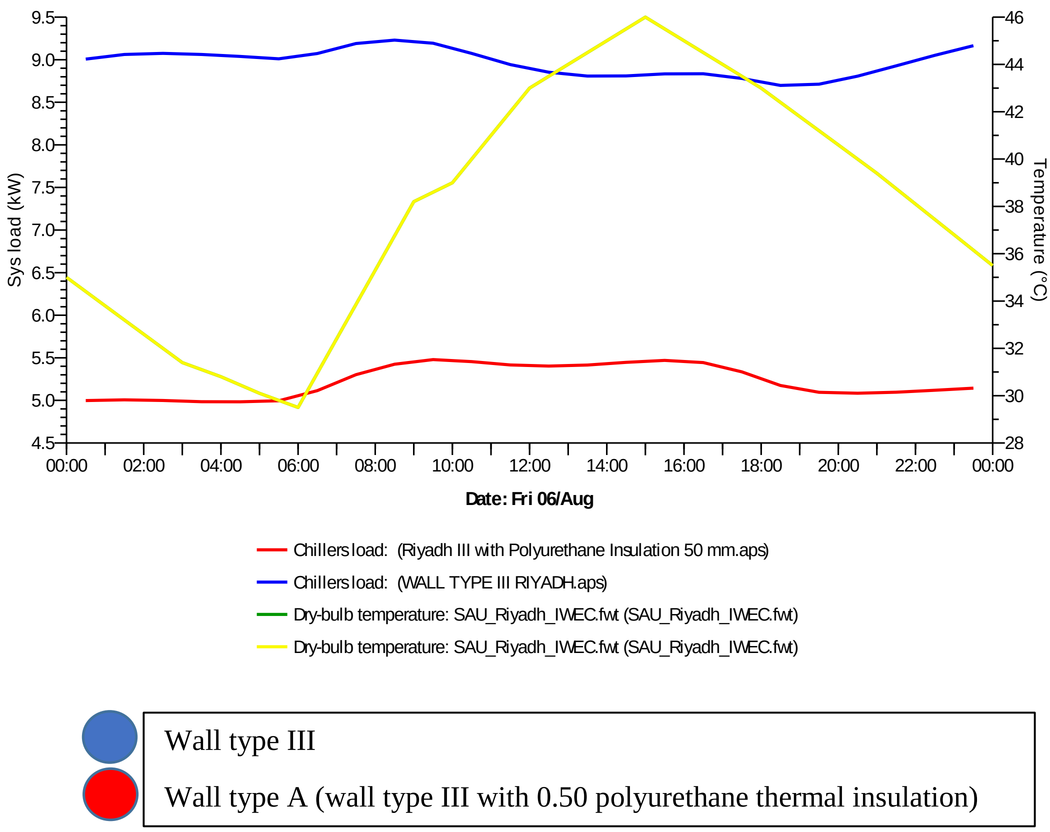


Figure 8.45: The cooling load results comparative between wall type III and wall type A on 6th of August.

From 5-7 of August the wall with no insulation shows that cooling load fluctuated between above 8 kW to almost 9.5 kW but the same type of wall with 50mm Polyurethane Insulation performed better. Wall III with the insulation consumed less than 5.5kW in the hottest day in Riyadh.

6th of August chart shows clearly how thermal insulation could help to reduce energy consumption for cooling load by more than 40% on a very hot day. The time lag between the cooling load and the outside temperature for both walls are similar but not identical. Both walls have the same layers and construction materials the only difference that wall type A has a thermal insulation. Adding 0.50m of polyurethane insulation to the external wall (wall type III), that has a good thermal mass, increased the efficiency of the wall and reduced the cooling load significantly. The combination of the thermal mass and the insulation has a positive impact on reduction the cooling load as shown in the result.

Table 8.11: The cooling load results comparative between wall type A and wall type III for the 6th of August.

Date	Time	Chillers load (kW)	Chillers load (kW)	Dry-bulb temperature (°C)	Total cooling load reduction percentage %
	24:00:00	Riyadh III with Polyurethane Insulation 50 mm (Wall Type A)	wall type III Riyadh		
	00:30	4.9984	9.0073	35	45%
	01:30	5.007	9.0613	33.8	45%
	02:30	4.9987	9.0752	32.6	45%
	03:30	4.9853	9.0611	31.4	45%
	04:30	4.9834	9.0379	30.8	45%
	05:30	4.9956	9.0101	30.1	45%
	06:30	5.114	9.0722	29.5	44%
	07:30	5.3023	9.1902	32.4	42%
	08:30	5.4246	9.2301	35.3	40%
	09:30	5.4794	9.1933	38.2	40%
06 August	10:30	5.4553	9.0734	39	40%
	11:30	5.416	8.943	41	39%
	12:30	5.4033	8.8527	43	39%
	13:30	5.4147	8.8077	44	39%
	14:30	5.4462	8.8098	45	38%
	15:30	5.4698	8.8329	46	38%
	16:30	5.4445	8.8352	45	38%
	17:30	5.3348	8.7797	44	39%
	18:30	5.1751	8.6973	43	40%
	19:30	5.0947	8.7119	41.8	42%
	20:30	5.0841	8.807	40.6	42%
	21:30	5.0966	8.9277	39.4	43%
	22:30	5.1192	9.0519	38.1	43%
	23:30	5.1433	9.1642	36.8	44%
Total		**125.3863**	**215.2331**		**42%**

The total energy reduction for 6th of July is 42%. 215.23 kW reduced to 125.39 kW, meaning that adding the Polyurethane insulation played a significant role in energy saving. In the middle of the day the reduction percentage was 39% and during specific hours reached 45%.

The next part is to compare three types of external walls (wall type A, B and C). All with Polyurethane insulation but in different places within the wall type III. It is important to mention that all walls have the same thermal mass and u-values. The following chart again presents 5-7 of August and later on 6th of August for more detailed comparison.

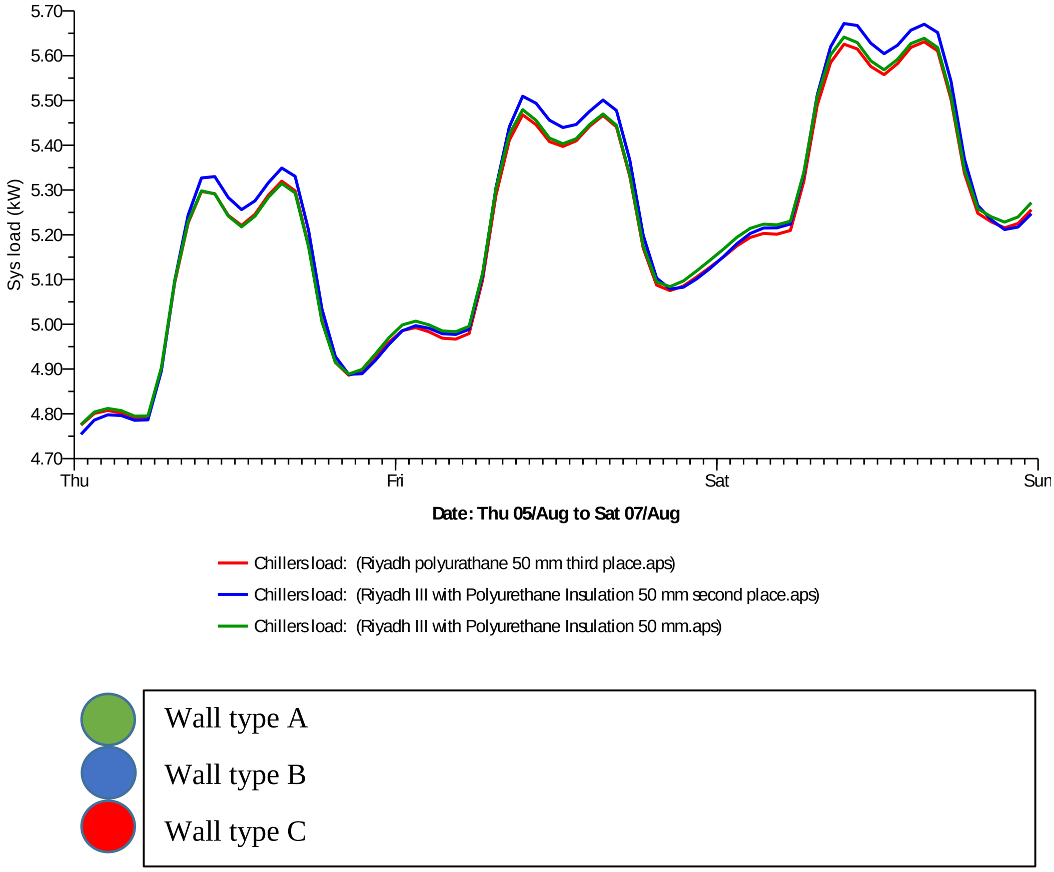


Figure 8.46: The cooling load results comparative between wall type A, B and C from 5th of August until 7th of August.

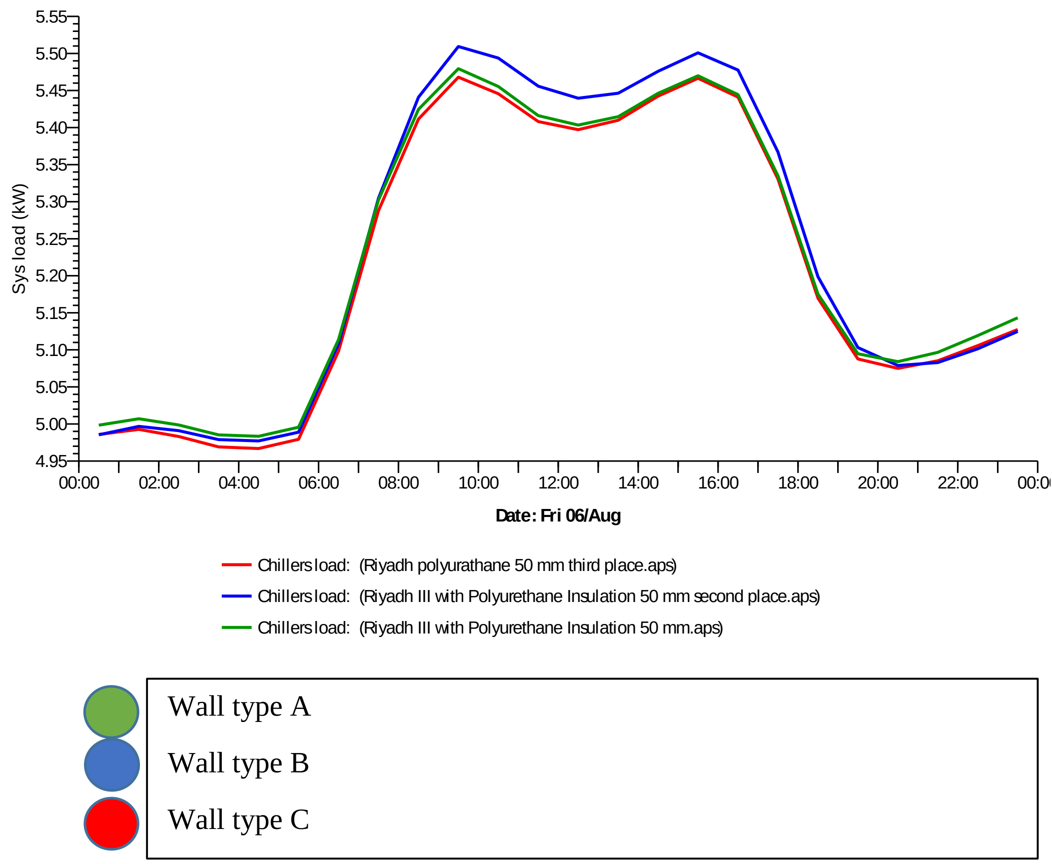


Figure 8.47: The cooling load results comparative between wall type A, B and C on 6th of August.

As shown above all types of walls (A, B and C) have a very similar performance on hottest days in general and on the 6th of July. All consumed less than 5.55 kW as a maximum load and the minimum load for this day is above 4.95 kW in the hottest day. The following table will make a comparison side by side to see which performed better on 6th of July and consumed less energy. All type of walls have the same thermal mass and the same type of the insulation but in different places. The figure 8.51 clearly shows that the best place for the thermal insulation is in the outer layer of the external wall. Wall type C shows a better result in terms of energy consumption for cooling load in Riyadh city. The following table 8.12 will compare the cooling load results between the external walls A, B and C.

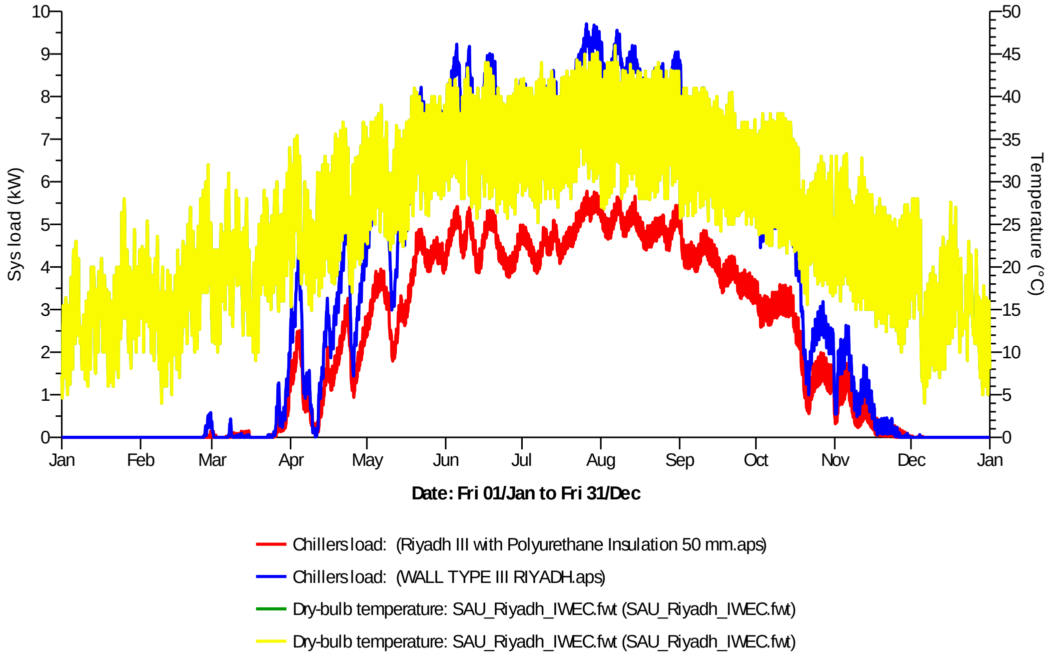
Table 8.12: The cooling load results comparative between wall type A, B and C on 06th of August.

Date	Time	Chillers load (kW)	Chillers load (kW)	Chillers load (kW)
		Riyadh polyurethane Insulation 50 mm third place (Wall Type C)	Riyadh III with Polyurethane Insulation 50 mm second place (Wall Type B)	Riyadh III with Polyurethane Insulation 50 mm (Wall Type A)
06 August	00:30	4.9859	4.9854	4.9984
	01:30	4.9927	4.9968	5.007
	02:30	4.9832	4.991	4.9987
	03:30	4.969	4.9789	4.9853
	04:30	4.967	4.9772	4.9834
	05:30	4.9794	4.9889	4.9956
	06:30	5.0984	5.1081	5.114
	07:30	5.2878	5.3045	5.3023
	08:30	5.4114	5.4409	5.4246
	09:30	5.4679	5.5093	5.4794
	10:30	5.4456	5.4937	5.4553
	11:30	5.4081	5.4558	5.416
	12:30	5.3971	5.4396	5.4033
	13:30	5.4099	5.4464	5.4147
	14:30	5.4425	5.4759	5.4462
	15:30	5.4665	5.5008	5.4698
	16:30	5.441	5.4776	5.4445
	17:30	5.3306	5.3669	5.3348
	18:30	5.1698	5.1987	5.1751
	19:30	5.0877	5.1032	5.0947
	20:30	5.0751	5.0789	5.0841
	21:30	5.0853	5.0828	5.0966
	22:30	5.1057	5.1014	5.1192
	23:30	5.1275	5.1249	5.1433
Total		**125.1351**	**125.6276**	**125.3863**

With the previous table, it is clear that thermal insulation in third place (wall type C) for external wall type III is slightly better. The data for the 6th of August for the building with external wall type C showed that it consumed 125.14 kW.

It is important to note that even in the middle of the day, when the temperature is higher and hitting the peak, the building with external wall type C still performed better.

The next following chart 8.48 will present energy consumption for air-conditioning for the whole year comparing wall type III with and without insulation.



Wall type III

Wall type A (wall type III with 0.50 polyurethane thermal insulation)

Figure 8.48: The cooling load results comparative between wall type III and wall type A from 1st of January until 31st of December.

Previous charts show better performance of wall type III with thermal insulation. Riyadh city is very hot in the summer and cold in winter. In summer temperature could reach up to 50 degrees centigrade and zero in winter. The cooling load will also increase when the temperature increases. The chart shows that the typical Saudi building without insulation will consume more energy and the cooling load will reach about 10 kW. On the other hand, the same type of external wall with Polyurethane Insulation the cooling load reached only 6 kW approximately as a maximum load recorded in IES dynamic simulation.

The following table will compare wall type III with Polyurethane insulation to the same wall without any type of insulation. The comparison will present the energy consumption for the cooling load in MWh for every month for each type and the total reduction that could be achieved with Polyurethane Insulation.

Table 8.13: The cooling load results comparative between wall type III and wall type A from 1st of January until 31st of December.

Date	**Chillers load (MWh)**	**Chillers load (MWh)**	**Total cooling load reduction percentage %**
	Riyadh III with Polyurethane Insulation 50 mm (wall type A)	WALL TYPE III RIYADH	
Jan 01-31	0	0	0%
Feb 01-28	0.001	0.022	95%
Mar 01-31	0.0737	0.1476	50%
Apr 01-30	1.0889	1.8562	41%
May 01-31	2.6476	4.5269	42%
Jun 01-30	3.2881	5.6289	42%
Jul 01-31	3.5481	6.0724	42%
Aug 01-31	3.6897	6.3164	42%
Sep 01-30	2.8684	4.929	42%
Oct 01-31	1.6698	2.8963	42%
Nov 01-30	0.3103	0.5562	44%
Dec 01-31	0.0003	0.0003	0%
Summed total	**19.186**	**32.9522**	**42%**

Table 8.13 shows that energy reduction up to 42% in total could be achieved by applying thermal insulation to the external wall. The same building and construction without the insulation consumes 32.952 MWh for the whole year while adding insulation cuts the energy consumption for cooling load to only 19.186 MWh. This table shows that adding the thermal insulation to the external wall (wall type III) increased the energy efficiency and reduced the cooling load.

The next part will make a comparison between three external walls all have an insulation. The location of the 50 mm Polyurethane Insulation is different in the external wall layers.

The following chart 8.49 will discuss if location of thermal insulation could help to save more energy for the whole year.

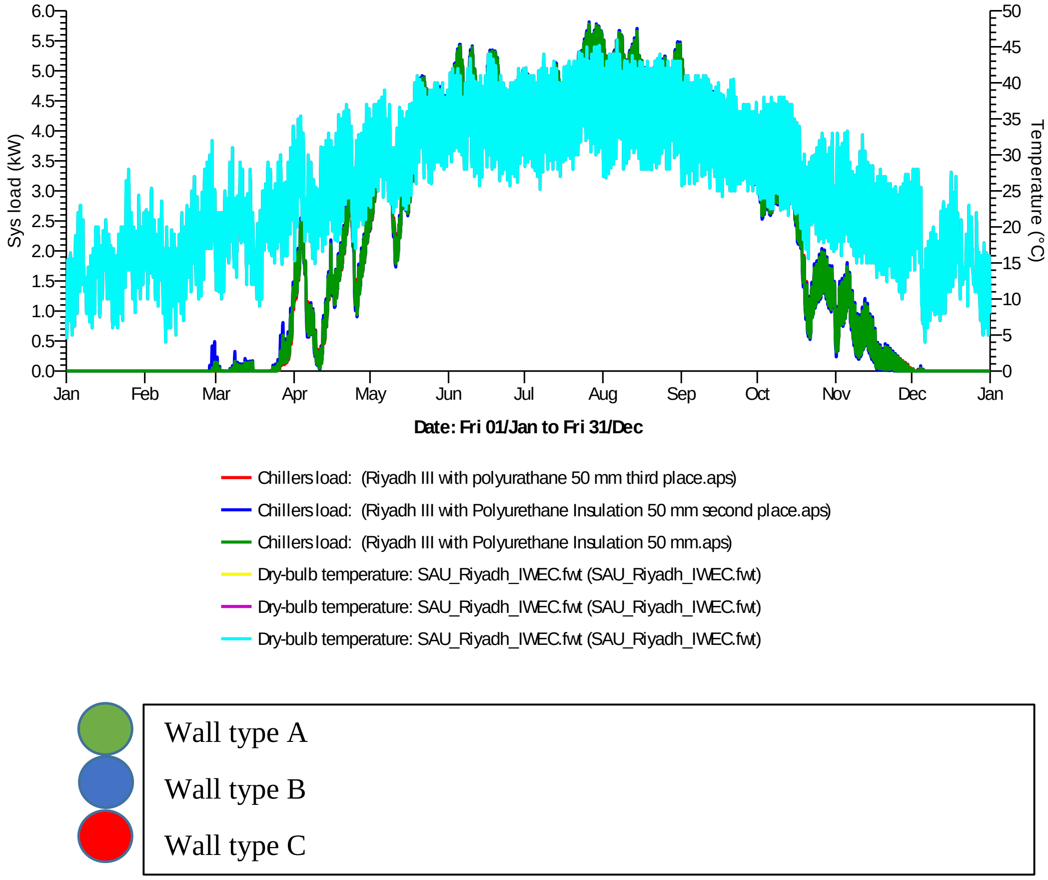


Figure 8.49: The cooling load results comparative between wall type A, B and C from 1st of January until 31st of December.

It is noticeable that all walls reduced energy consumption in comparison to the same wall without insulation. All external walls behaved almost the same in all seasons. To find out the slight difference a comparative table is required to see which one is better for the Riyadh city house.

Table 8.14: The cooling load results comparative between wall type A, B and C from 1st of January until 31st of December.

Date	Chillers load (MWh)	Chillers load (MWh)	Chillers load (MWh)
	Wall Type C	Wall Type B	Wall Type A
Jan 01-31	0	0	0
Feb 01-28	0.0002	0.0073	0.001
Mar 01-31	0.0635	0.0903	0.0737
Apr 01-30	1.0833	1.0916	1.0889
May 01-31	2.6416	2.6483	2.6476
Jun 01-30	3.2869	3.2875	3.2881
Jul 01-31	3.5454	3.5472	3.5481
Aug 01-31	3.6908	3.6882	3.6897
Sep 01-30	2.8715	2.8645	2.8684
Oct 01-31	1.6755	1.6658	1.6698
Nov 01-30	0.3139	0.3086	0.3103
Dec 01-31	0.0005	0.0005	0.0003
Summed total	**19.173**	**19.1997**	**19.186**

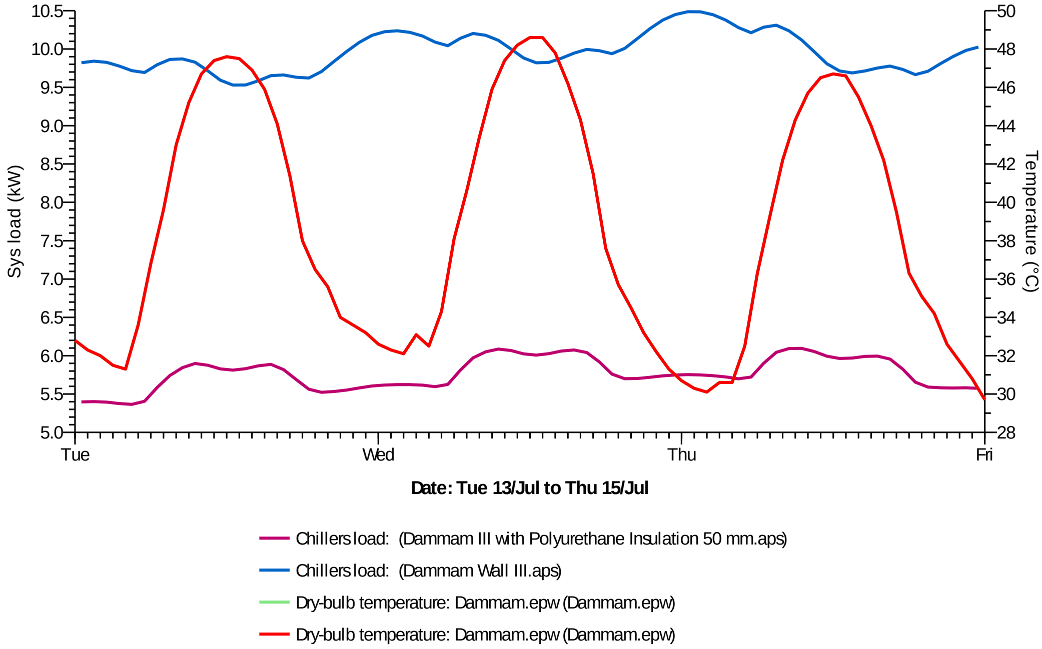
The table 8.14 shows that the result for cooling loads in each type are very close to each other. The typical residential building in Riyadh with external wall type C consumes less energy compared to other types. The result shows a slight decrease of energy consumption in total for a whole year. This research is looking to reduce and achieved the energy to the minimum in the building it is important to consider that the third place or location for thermal insulation (wall type C) is more useful for Riyadh city house. It shows that the best place for the 0.05 m of polyurethane in the outer layer of the external wall.

8.3.3 Simulation Analysis for the Typical Residential Building in Dammam City-Second Part

The last city as a location to study thermal insulation in external walls is Dammam city. This research aims to determine the impact of adding 50mm of polyurethane thermal insulation to the external wall of the typical Saudi house, and assessing the effect on the cooling load consumption. The dynamic simulation shows the difference in energy consumption for external wall type III without insulation and with insulation in several locations.

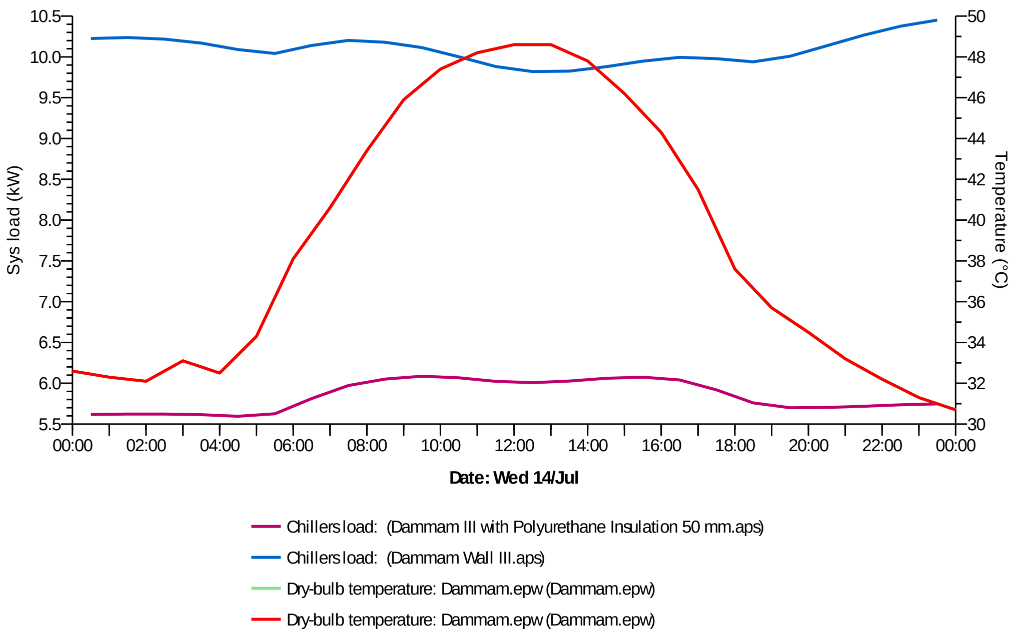
The IES simulation will performed for the whole year and presented in charts and tables showing the hottest days in this city and finally a full comparison.

The first charts 8.54 present an example of a very hot days in Dammam from 13-15 of July and make a comparison between two external walls, the first being wall III with no insulation and the other one with polyurethane 50 mm insulation (wall type A). The aim behind this is to show how much energy consumption could be reduced.



Wall type III
Wall type A (wall type III with 0.50 polyurethane thermal insulation)

Figure 8.50: The cooling load results comparative between wall type III and Wall type A from 13th of July until 15th of July.



Wall type III

Wall type A (wall type III with 0.50 polyurethane thermal insulation)

Figure 8.51: The cooling load results comparative between wall type III and Wall type A on 14th of July.

From 13-15 of July, the typical Saudi house with external wall type III (with no insulation) consumed between above 9.5 kW and up almost 10.5 kW. The cooling load for wall type III with polyurethane 50 mm insulation consumed between 5 to 6 kW. In 14th of July the difference is very clear. This day is considered to be the hottest day in Dammam as the temperature reached to 50 degrees centigrade which means the demand for air-conditioning will be very high. The cooling load reached to almost 10.5 kW as shown above but with thermal insulation only required less than 6 kW as a maximum load. The time lag between the cooling load and the outside temperature for both walls are similar but not identical. In addition, both walls have almost the same mass, materials and layers but the only difference is adding the polyurethane insulation to the wall A. Both walls succeeded in delaying the heat transfer for a quite a good time as they have a good thermal mass but adding the insulation to the wall helped to cut the heat transfer and increase the efficiency. The next table 8.15 compares the same external walls on the same date but in more detail to show the exact energy consumption for cooling load hour by hour.

Table 8.15: The cooling load results comparative between wall type III and Wall type A on 14th of July.

Date	Time	Dammam III with Polyurethane Insulation 50 mm (Wall Type A)	Chillers load (kW)	Dry-bulb temperature (°C)	Total cooling load reduction percentage %
	24:00:00		Dammam Wall III		
	00:30	5.6175	10.2249	32.6	45%
	01:30	5.6225	10.2373	32.3	45%
	02:30	5.622	10.2179	32.1	45%
	03:30	5.6154	10.1697	33.1	45%
	04:30	5.5961	10.0895	32.5	45%
	05:30	5.6256	10.0424	34.3	44%
	06:30	5.8127	10.1406	38.1	43%
	07:30	5.9722	10.2024	40.6	41%
	08:30	6.0509	10.1788	43.4	41%
	09:30	6.0868	10.1129	45.9	40%
	10:30	6.0673	10.0007	47.4	39%
14 July	11:30	6.0231	9.8826	48.2	39%
	12:30	6.0073	9.8199	48.6	39%
	13:30	6.0268	9.8253	48.6	39%
	14:30	6.0608	9.88	47.8	39%
	15:30	6.0747	9.947	46.2	39%
	16:30	6.0406	9.9947	44.3	40%
	17:30	5.9188	9.9774	41.5	41%
	18:30	5.7596	9.9387	37.6	42%
	19:30	5.7005	10.0077	35.7	43%
	20:30	5.703	10.1363	34.5	44%
	21:30	5.7186	10.2657	33.2	44%
	22:30	5.7367	10.3755	32.2	45%
	23:30	5.7477	10.4499	31.3	45%
Total		**140.2072**	**242.1178**		**42%**

The table 8.15 above shows that total energy saving is 42% for 14th of July this because of adding thermal insulation to the external wall. Cooling load was 242.12 kW in the hottest day in Dammam but with adding Polyurethane Insulation 50 mm to the external wall type III it makes the cooling load for this model only 140.21

kW. During the day chiller load reduced to 45% and achieved the maximum reduction.

Polyurethane Insulation 50mm is applied to the same wall but in different locations to see how the position of the insulation could add a further benefit to the wall.

The following chart 8.52 presents three external walls, all with insulation but in three different locations from 13th to 15th of July.

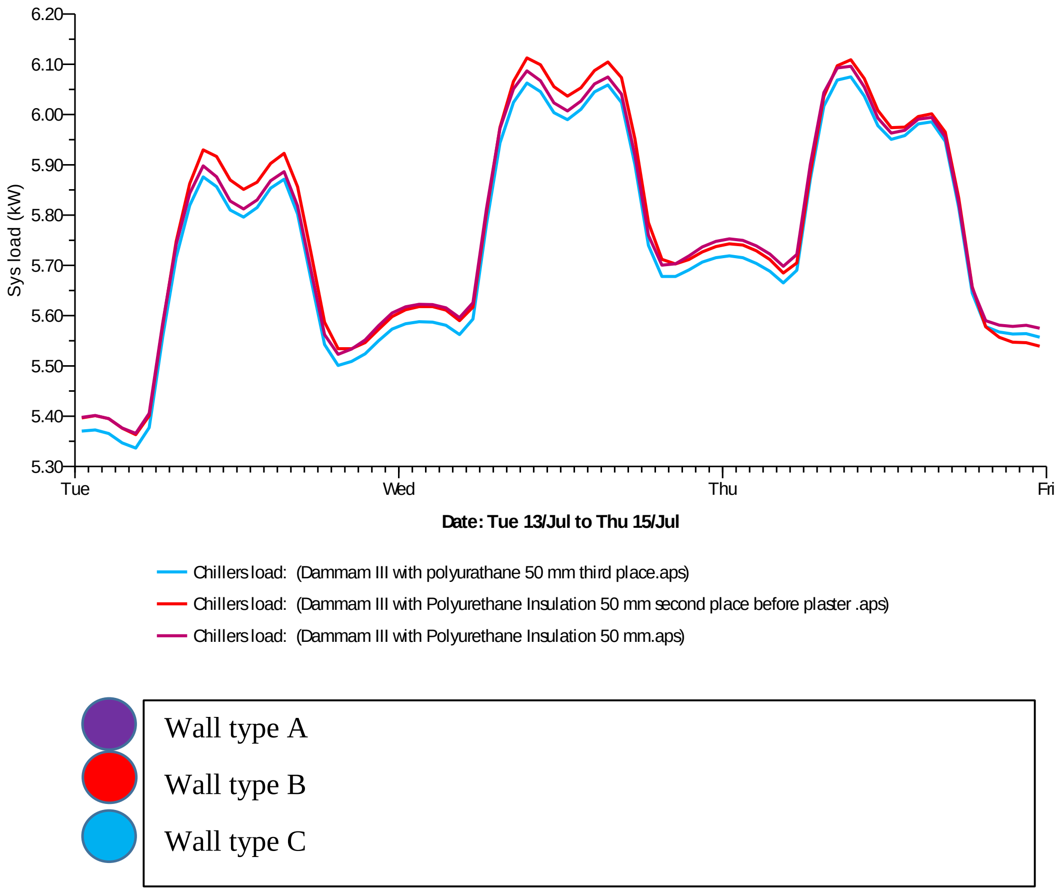


Figure 8.52: The cooling load results comparative between wall type A, B and C from 13th of July until 15th of July.

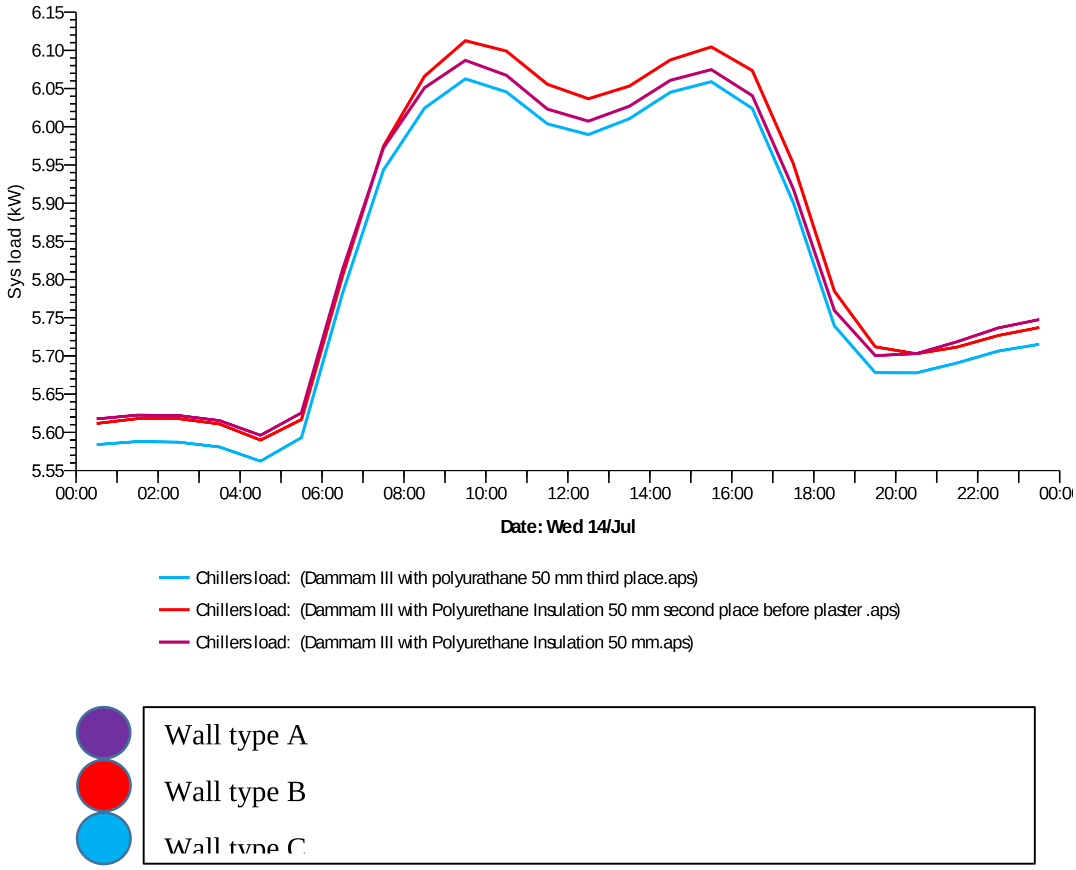


Figure 8.53: The cooling load results comparative between wall type A, B and C on 14th of July.

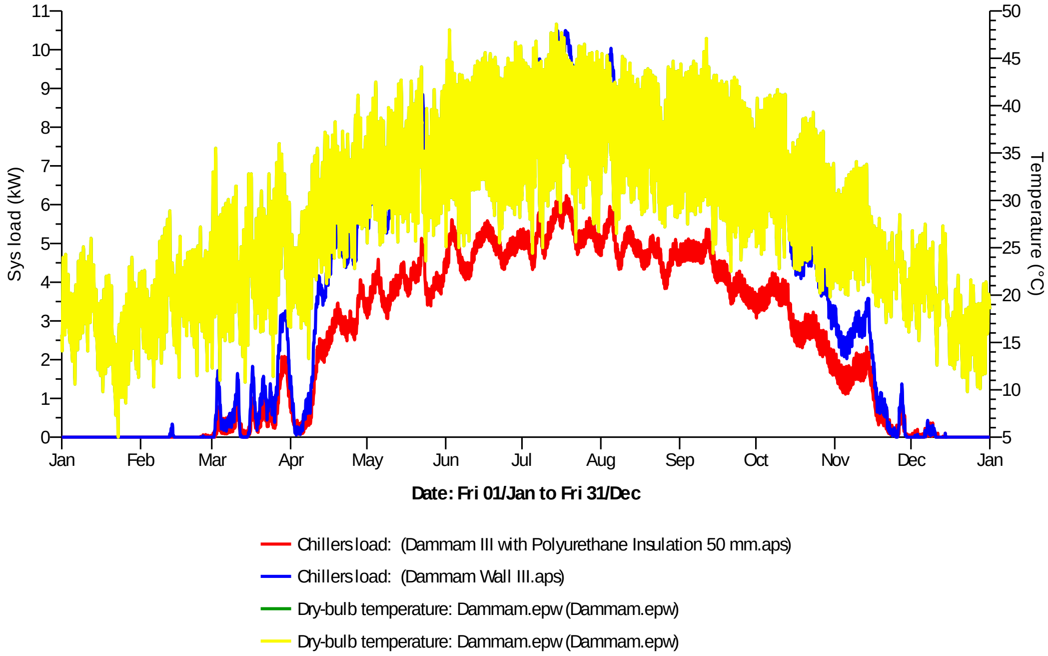
It is very clear that the performance for all types of external walls are almost the same. In specific hours the walls consumed exactly same amount of energy. The difference is very slight which means that it is difficult to decide in this stage which external wall is better. It is important to mention that all walls have the same materials, layers, u-values and thermal mass. The only difference is the place of the thermal insulation in each external wall. In fact, it is very clear the the best place for the 0.50 polyurethane thermal insulation in the outer layer of the external wall as shown in the previous figures that wall type C is more efficient regarding the cooling load reduction.

A further investigation is required to make the appropriate decision. The next table gives the details of each wall regarding to cooling load presented in kW.

Table 8.16: The cooling load results comparative between wall type A, B and C on 14th of July.

Date	Time	Chillers load (kW)	Chillers load (kW)	Chillers load (kW)
		Dammam III with polyurethane 50 mm third place(Wall Type C)	Dammam III with Polyurethane Insulation 50 mm second place (Wall Type B)	Dammam III with Polyurethane Insulation 50 mm (Wall Type A)
14 July	00:30	5.5839	5.6117	5.6175
	01:30	5.588	5.6179	5.6225
	02:30	5.5872	5.618	5.622
	03:30	5.5808	5.6109	5.6154
	04:30	5.5623	5.5899	5.5961
	05:30	5.5931	5.6168	5.6256
	06:30	5.7819	5.8048	5.8127
	07:30	5.9434	5.9744	5.9722
	08:30	6.0243	6.066	6.0509
	09:30	6.0627	6.1125	6.0868
	10:30	6.0456	6.099	6.0673
	11:30	6.0037	6.0555	6.0231
	12:30	5.9897	6.0367	6.0073
	13:30	6.0105	6.0533	6.0268
	14:30	6.0451	6.0875	6.0608
	15:30	6.0588	6.1044	6.0747
	16:30	6.0239	6.0735	6.0406
	17:30	5.9006	5.9517	5.9188
	18:30	5.7395	5.7849	5.7596
	19:30	5.678	5.712	5.7005
	20:30	5.6778	5.7028	5.703
	21:30	5.6908	5.7117	5.7186
	22:30	5.7064	5.7268	5.7367
	23:30	5.7153	5.7373	5.7477
Total		**139.5933**	**140.46**	**140.2072**

It is very clear that the result for energy consumption regarding Air-conditioning load is very close but the third position of thermal insulation (wall type C) in the external wall type III in the 14th of July has a better overall result according to the table. It is important to see how these external walls perform in the whole year not only on a specific hot day. Total energy saving is dependent on the total energy consumption. The next chart 8.54 compares two walls in order to find the most suitable external wall for the Saudi typical house in Dammam city. The first presents wall type III with no any type of insulation whereas the other one (wall type A) has the selected type of insulation for this research.



Wall type III

Wall type A (wall type III with 0.50 polyurethane thermal insulation)

Figure 8.54: The cooling load results comparative between wall type III and type A from 1st of January until 31st of December.

It is very noticeable that external wall with no insulation has an increased demand for energy. According to the chart above the cooling load for the typical Saudi house in Dammam with external wall type III (with no insulation) reached almost 11 kW in the summer season whereas the typical house with wall type A (wall with the insulation) reached only about 6 kW.

The exact megawatt of total energy consumption for each month and for the whole year in general will presented in the next table.

Table 8.17: The cooling load results comparative between wall type III and type A from 1st of January until 31st of December.

Date	Chillers load (MWh)	Chillers load (MWh)	MWh Reduction (Percentage %)
	Dammam III with Polyurethane Insulation 50 mm (wall type A)	Dammam Wall III	
Jan 01-31	0	0	0%
Feb 01-28	0.001	0.0061	83%
Mar 01-31	0.4116	0.7373	44%
Apr 01-30	1.4914	2.5442	41%
May 01-31	2.9275	5.0022	41%
Jun 01-30	3.5082	6.0204	42%
Jul 01-31	3.9287	6.7389	42%
Aug 01-31	3.5975	6.1777	42%
Sep 01-30	3.0923	5.318	42%
Oct 01-31	2.2357	3.8469	42%
Nov 01-30	0.7085	1.1948	40%
Dec 01-31	0.0156	0.0183	14%
Summed total	**21.918**	**37.6047**	**42%**

Adding 50 mm of Polyurethane Insulation makes a significant improvement to the external wall and helped to reduce the load for cooling 42%. Wall type III with no insulation consumed 37.604 MWh for a complete year. External wall III with the selected insulation in the other hand consumed 21.918 MWh. June, July, August and September considered to be the hottest months in Saudi Arabia and the insulation reduced cooling load to 42% in this summer season is a big success. This table confirmed that adding the thermal insulation to the external wall (wall type III) increased the energy efficiency and reduced the cooling load.

It is time now to look forward to save more energy be changing the location of 50 mm of Polyurethane Insulation and see if this could help in Dammam city.

The next following chart 8.55 will investigate to possibility of achieving a better result by the thermal insulation in a different place of the external wall and compare it to the previous result discussed previously.

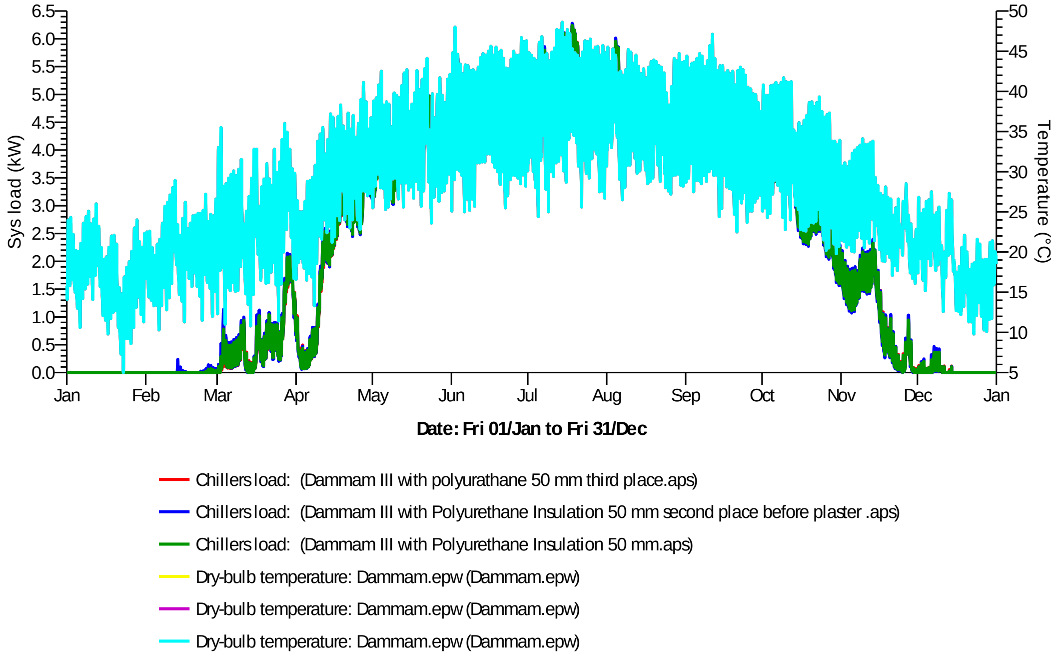


Figure 8.55: The cooling load results comparative between wall type A, B and C from 1st of January until 31st of December.

The result above shows that the comparison is not very clear at deciding which one has a better performance. All walls consumed zero kW in January for example and above 6 kW in July.

The next table will help to clear the image of each month cooling load consumption as well as total energy consumption for chiller load in the whole year.

Table 8.18: The cooling load results comparative between wall type A, B and C from 1st of January until 31st of December.

Date	**Chillers load (MWh)**	**Chillers load (MWh)**	**Chillers load (MWh)**
	Wall Type C	Wall Type B	Wall Type A
Jan 01-31	0	0	0
Feb 01-28	0.0005	0.0041	0.001
Mar 01-31	0.3982	0.4294	0.4116
Apr 01-30	1.4845	1.4951	1.4914
May 01-31	2.9253	2.9288	2.9275
Jun 01-30	3.506	3.5086	3.5082
Jul 01-31	3.929	3.9275	3.9287
Aug 01-31	3.5993	3.5962	3.5975
Sep 01-30	3.0951	3.0898	3.0923
Oct 01-31	2.2401	2.2325	2.2357
Nov 01-30	0.7132	0.7071	0.7085
Dec 01-31	0.0159	0.0171	0.0156
Summed total	**21.9071**	**21.9362**	**21.918**

The table 8.18 shows that wall type C (Polyurethane Insulation 50 mm in third place) for is considered to be the best option. According to the result in table above it is very important to say that the results for cooling load for all types are very similar but wall type C is a slightly better. All walls have the same construction materials, same layers, same insulation but in different places. Again, this explains that the best place for the thermal insulation in the outer layer in the external wall.

8.4 Simulation Chapter Summary and Conclusion

This was then input into the IES building energy simulation software for this typical house in three different climate zones, locations and cities (Riyadh, Jeddah and Dammam).

This IES simulation software revealed that using different construction materials for the external walls impacts on the building energy and cooling load. Most common types of external wall were applied to the typical Saudi house in three different cities and climate zones, and the most suitable external wall for the Saudi model is wall type III.

The addition of 50mm of Polyurethane thermal insulation to external wall type III significantly impacted on the building performance in terms of the cooling load. The reduction achieved in the cooling load satisfied the research goals and objectives, reducing the cooling load for the Saudi building typical building by over 30%. This reduction will inevitably benefit the environment, reducing CO_2 emissions. In addition, the Kingdom of Saudi Arabia can consequently reduce oil production for local purposes and increase oil exports. The future for the Kingdom looks bright with regard to reducing energy consumption and creating sustainable residential buildings.

The study found that thermal insulation (50mm of polyurethane) can be applied between any layers of external wall type III, resulting in significant reductions in energy consumption and cooling load. However, the optimum location for this layer of thermal insulation in external wall type III is in the outer layer between the stone and concrete layers.

Chapter 9

Conclusion

9.1 Thesis Summary

The following figure shows a summary of the thesis and the conclusion.

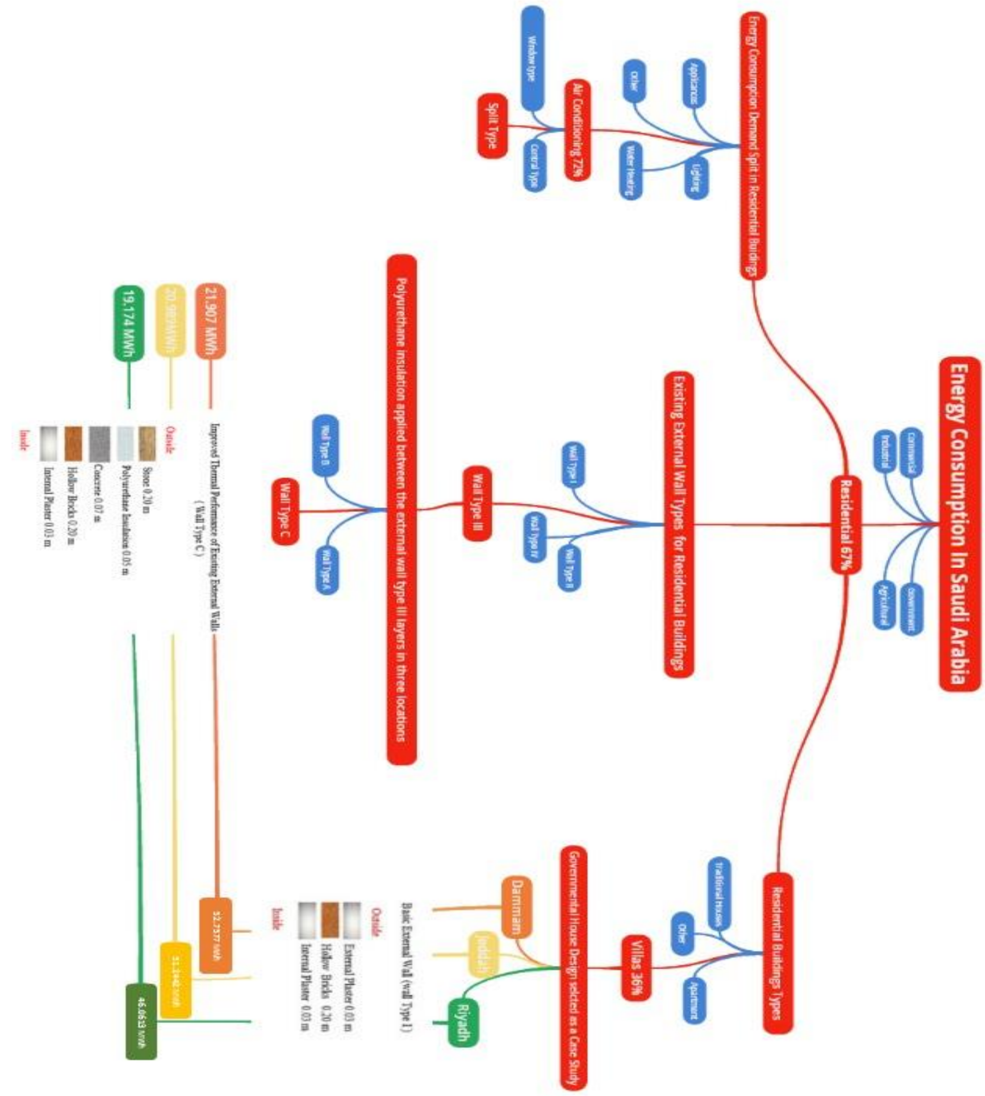


Figure 9.1: Thesis summary overview.

From the outset, this thesis has explained that the kingdom of Saudi Arabia is one the largest producers and exporters of petroleum liquids in the world. However, it also consumes a large amount of energy for local purposes, currently the equivalent of three million barrels per day, and this consumption is set to triple in the near future according to an OAPEC (Organization of Arab Petroleum Exporting countries) report.

Many factors have led to the dramatic increase in electricity consumption in Saudi Arabia, such as a lack of regulations and legislation, very cheap oil prices, and increased infrastructure, housing projects and projects in industrial cities. Other reasons include a high population growth rate, 3.2% according to the Ministry of Planning in 2010, building owners' lack of awareness and lack of culture energy-saving in buildings (further discussed in the survey results), and the impact of dynamic cultural changes on the design and energy performance. All of these factors mean that the country is facing very difficult challenges, especially for a country that is developing very rapidly.

The literature review discussed in-depth all types of buildings (residential, commercial and governmental) in Saudi Arabia regarding energy consumption in order to find out which type of building is the highest consumer of energy in the country. Using all the details gathered from various sources, it was found that residential buildings in the kingdom consume 67% of the total energy, which means that this type of building needs urgent development and should be considered as the major priority in this research.

Saudi residential buildings can be categorised into different types, such as villas, traditional houses, apartments, and duplexes. According to data gathered from the literature review, villas and apartments are the most common type of residential buildings, with one third of Saudis living in apartments. The total housing stock in 2010 was 4.6 million units and is expected to be around 7 million units by 2020.

Currently, the average household size in Saudi Arabia is 5.28 persons per occupied housing unit, and 66% of the Saudi population is aged under 30.

The residential buildings in the kingdom of Saudi Arabia depend heavily on air conditioning due to the hot weather in the majority of regions throughout most of the year. The power demand in residential buildings can be divided into different categories, such as water heating, lighting, appliance and air conditioning, but the study found that air conditioning accounts for over 70% of the energy consumption.

The survey results and the air conditioning chapter show that there are three main types of air conditioning that are predominantly used in the kingdom: window, split and central air conditioning types. All of these continue to rise in popularity in Saudi Arabia, with split air conditioners accounting for the highest demand. However, the survey revealed that most residential buildings use a combination of two types in a house: the split unit type and the window type.

Increasing energy consumption not only risks a crisis for non-renewable natural resources, such as oil and gas, but also harms the environment, which is already suffering from pollution, climate change and global warming.

It is evident that residential buildings in the kingdom are affected by several factors and are wasting a vast amount of energy, which could be saved and minimised in order to protect the environment and reduce the use of energy for local purposes. All of these factors led to the development of this study.

The second step in the thesis was to study the common thermal insulation and external wall materials in Saudi Arabia and adopt the possible methods to reduce energy consumption in the kingdom by at least 30%. The literature review mentioned that there are several strategies to reduce energy consumption across all types of buildings, such as repairing faults, reducing loads where possible, using efficient plants to service the load, and using efficient energy sources to operate the plant.

In addition, there are several factors and techniques that help and have a direct impact on saving building energy, such as: changing the building fabric, building service plant, controls, management of the building, and energy supply. Building materials, especially external wall materials and wall insulation, have a significant impact on energy in general and particularly on the cooling reduction. Therefore, this research started by presenting the common building construction materials that are used in Saudi residential buildings. Saudi Arabia has a variety of natural resources, such as all types of cement, concrete, bricks, marble, tiles, granite panels, reinforced steel, gypsum, ceramics, composite materials and glass. Cement is considered to be the most popular construction material in the country.

External walls in Saudi Arabia mainly consist of three basic layers: external cement plaster, hollow red clay brick, and interior cement plaster. The literature review mentioned that this is the most common type of external wall, though there are some other common external walls for residential buildings in the country that also contain stone and concrete.

All these types of external walls were used in the Integrated Environmental Solution (IES) simulation software to determine which one has the best energy performance and the minimum energy consumption in a selected residential building. Many of the common mistakes made in Saudi house design could be minimised by using modelling and simulation software, which has a variety of measures to manage energy and reduce electricity consumption.

A typical Saudi house was used in the simulation, which was selected as it represents the typical Saudi family and this model was provided by the Ministry of Housing in Saudi Arabia. The Saudi Ministry of Housing decided to build this house in all regions in the kingdom to help low and middle income families to own their own homes rather than renting, and afterwards Saudis pay the government a small monthly payment with no added profit. The Ministry of Housing is taking this step as 60% of Saudis do not own their homes and the Ministry of Housing announced that want to build 500,000 residential buildings to ease this shortage.

The Ministry of Housing in Saudi Arabia selected and designed this model because it reflects the size, customs and traditions of a Saudi family and the Arabic community. It is also designed to achieve the best engineering standards ideal for a home, such as: economic designs, ease of implementation, good distribution of the rooms, ideal room measurements, natural lighting and ventilation, flexibility and scalability in the future and, of course, privacy for the Saudi family.

This typical house includes two main floors, the first floor contains: guest room, dining room, kitchen, guest toilet, guest bedroom, toilet and living room.

The second floor contains the master bedroom including a private toilet, two bedrooms for children with a shared toilet, servant bedroom and toilet and expandable area.

This typical model is applied in three main locations in the kingdom of Saudi Arabia to investigate the energy consumption for this specific model and all possible methods to save energy and change the future in the country. Each location and zone has it is own weather, each one distinct from the others. These locations were selected because of their high population and the large numbers of residential buildings in the cities. The first city is Jeddah, in the west, which is located overlooking the Red Sea that separates Asia from Africa.

The second city is Riyadh, the capital and largest city of Saudi Arabia. It is also the capital of Riyadh Province, and belongs to the historical regions of Najd and Al-Yamama. It is situated in the centre of the Arabian Peninsula on a large plateau.

The last city in this thesis is Dammam, which is the largest city in the Eastern Province, and is located along the Arabian Gulf Coast.

IES dynamic simulation software was selected to best satisfy the research of the PhD and its aims and objectives regarding reducing energy consumption in Saudi residential buildings and saving energy. According to the IES software weather database, the simulation results shows that energy consumption for cooling loads peaks in the Saudi summer. July and August are considered to be the hottest months in the country, and specifically in the three selected cities of Jeddah, Riyadh and Dammam. During these months the temperature could increase and reach to 50 degrees centigrade, and the cooling load consumption can be up to 11kW in the summer season.

Therefore, this research studied the impact of construction and building materials on residential buildings in Saudi Arabia and the importance of selecting the right available, local construction materials for the external walls, as well as how adding thermal insulations can make a difference. It identified, after studying the most common external walls in Saudi Arabia in the literature review and from the IES simulation results, that the best available external wall type for the Saudi climate for almost all regions regarding energy consumption performance and cooling load is wall type III. This type contains 0.20 m of stone, 0.07m concrete, 0.20 m hollow bricks and 0.03m of plaster and, adding 50 mm of polyurethane thermal insulations to the external walls helped to save energy (over 40% in total) with regard to the cooling load. The following figures compare the thermal performance of the most common external walls in Saudi Arabia in terms of cooling load and show that wall type III gives the lowest cooling load.

The first figure compares four common walls in the hottest days in Jeddah city:

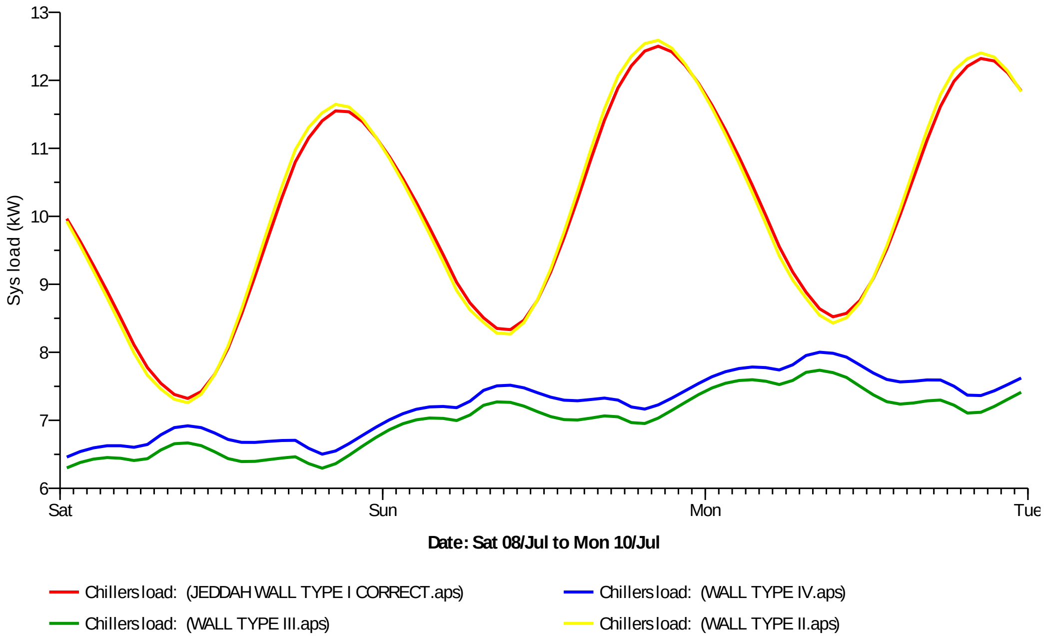


Figure 9.2: The comparative results of the cooling load from 8th of July until 10th of July for all external wall types in Jeddah.

The second figure compares the same wall types in the hottest days but this time in different region and different climate zone, Riyadh city:

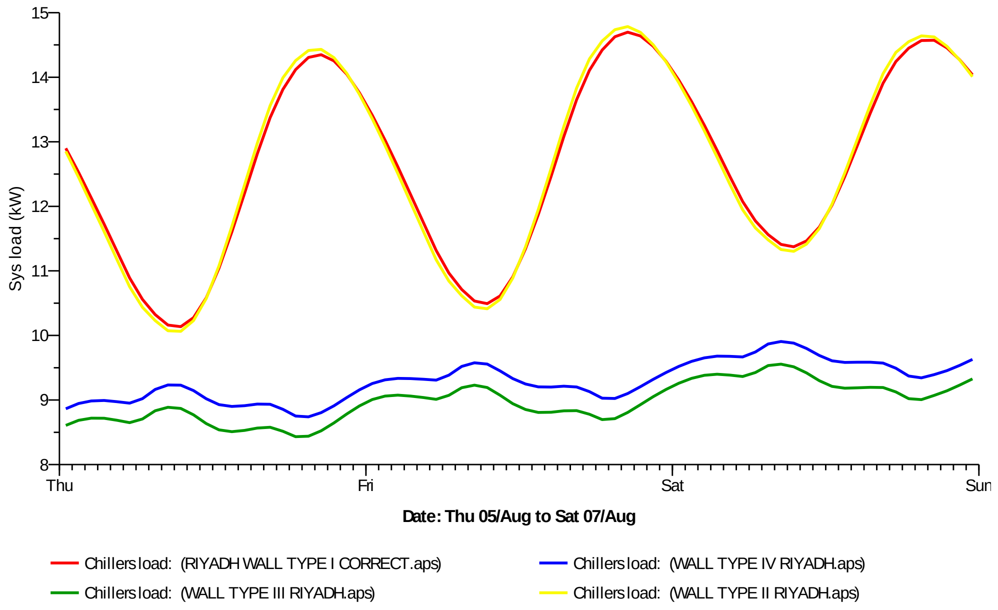


Figure 9.3: The comparative results of the cooling load from the 5th until the 7th of August for all external wall types in Riyadh

The last figure again compares these common external walls but in Dammam city:

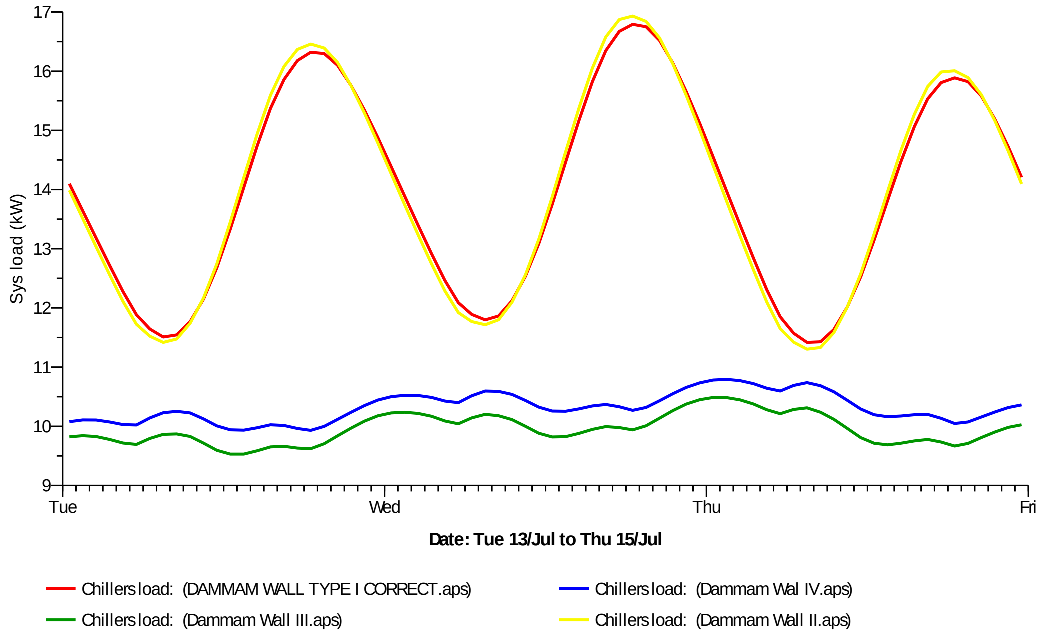


Figure 9.4: The comparative results of the cooling load from the 13th until the 15th of July for all external wall types in Dammam.

All the previous figures (9.2, 9.3 and 9.4) present a comparison between the most common external walls in Saudi Arabia regarding cooling load but in different regions, different climate zones and different cities. The hottest days were selected to compare the peak load for air-conditioning. It is very clear from the previous figures that wall types I and II have the worst thermal performance that led the heat to transfer very easily and result in high cooling load. Applying the external walls type III and IV to the residential building in these cities reduced the cooling load significantly and results in a better thermal performance for the residential building. However, the external wall type III shows better overall results regarding energy consumption for cooling load in Saudi cities.

Additionally, the simulation results for the typical house used show that altering the position of the thermal insulation in the external wall layers did not make a significant difference regarding the cooling load consumption, but the best place for the 50 mm of polyurethane insulation in wall type III in the outer wall layer between the stone and the concrete.

The following figures will present a comparison between three different walls, all having the same construction materials, u-values, thermal mass and polyurethane thermal insulation but in different locations. The aim was to test if the position of the thermal insulation could affect the cooling load and reduce the consumption. Three different locations selected for the insulation were close to the inside (wall type A), in the middle (wall type B), close to the outside (wall type C). The first figure compares these walls in Jeddah city in the hottest days:

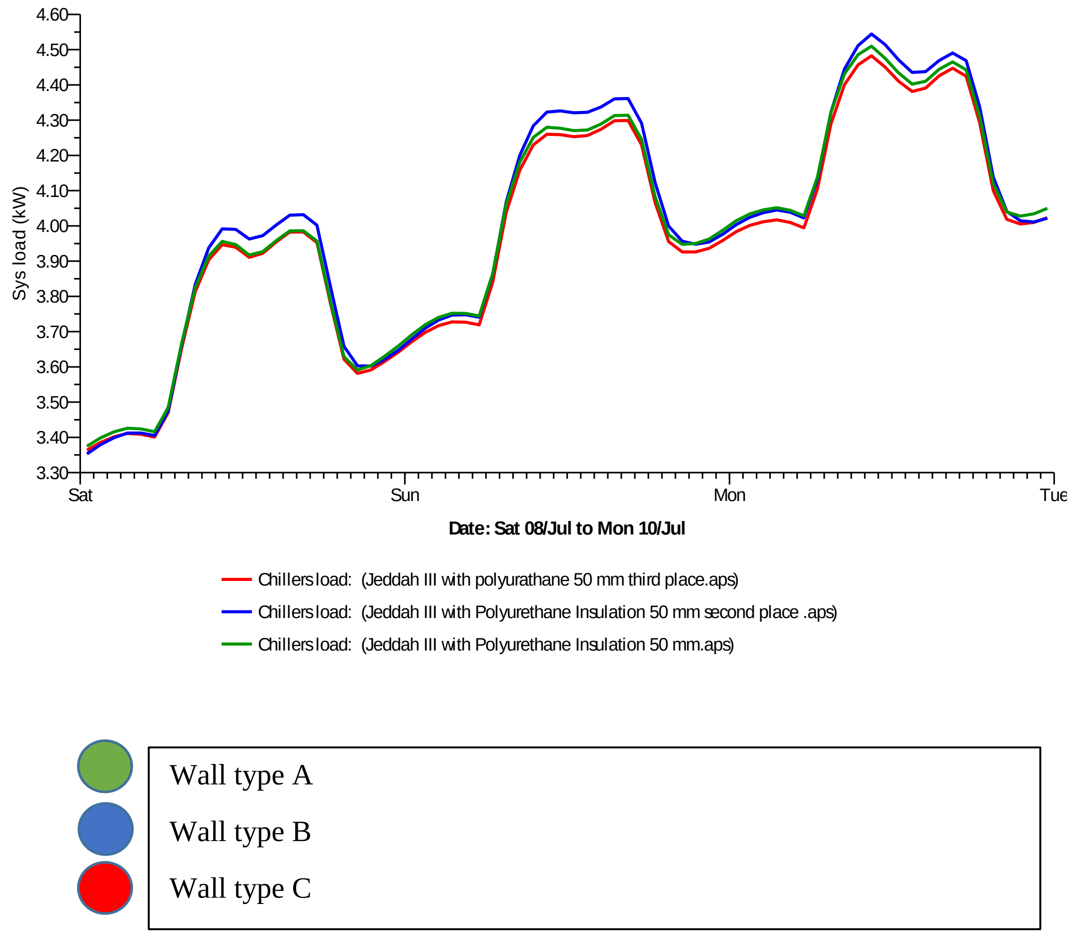
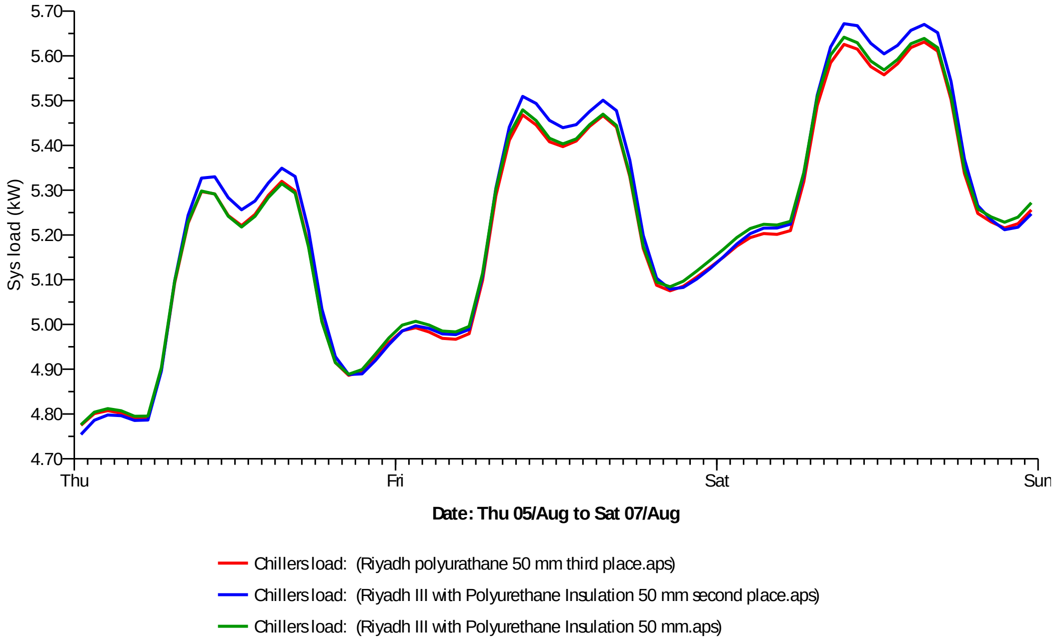


Figure 9.5: The cooling load results comparison between wall types A, B and C, from the 8th until 10th of July.

The second chart compares the same external walls but in the capital city Riyadh:



Wall type A

Wall type B

Wall type C

Figure 9.6: The cooling load results comparative between wall type A, B and C from 5th of August until 7th of August.

The last chart compares the external walls A, B and C in the hottest days in Dammam city:

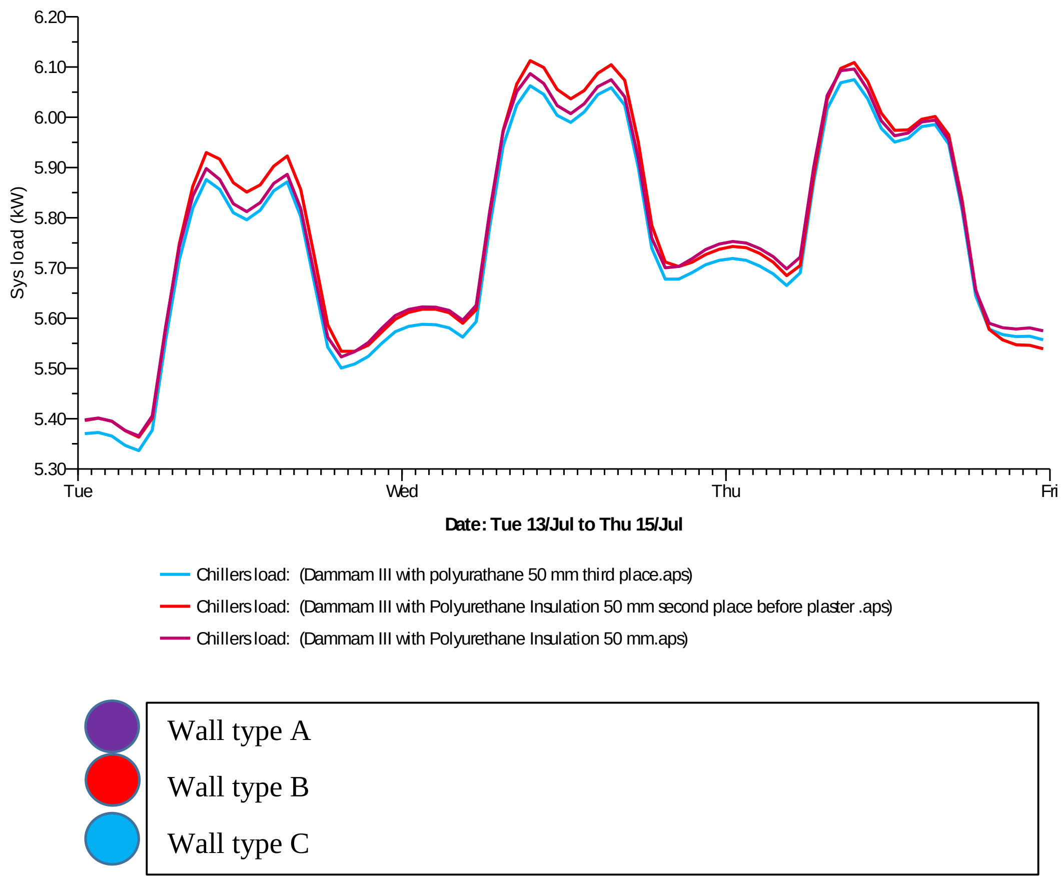


Figure 9.7: The cooling load results comparative between wall type A, B and C from 13th of July until 15th of July.

It is very clear that all types of the external wall performed similarly regarding the cooling load consumption on the hottest days but were not identical. Applying the insulation in the inner layer of the external wall showing good result but moving the insulation to the outer layer of the external wall saves more energy and reduced the cooling load to the minimum.

In fact, in Saudi Arabia the most common external is wall type I which is the basic wall and it is constructed of external plaster, hollow bricks and internal plaster. After applying this particular wall to the residential building, the simulation results for cooling load illustrated the total in MWh every year as follows:

- **51.2442** MWh in Jeddah
- **46.0613** MWh in Riyadh
- **52.7577** MWh in Dammam

But selecting the most appropriate external wall materials for this typical residential building as well as the right location for thermal insulation in the external wall will lead to a significant reduction in cooling load to the residential building as follow:

- **20.989** MWh in Jeddah
- **19.174** MWh in Riyadh
- **21.907** MWh in Dammam

Therefore, as an average the Saudi residential building for this specific model will consume approximately 50.02 MWh a year for cooling load but with all improvements and developments for the external wall, this building from this study it will consume only 20.36 MWh for cooling load as an average.

As a result of the decision of the ministry of Housing as well as the government for Saudi Arabia to build 500,000 units from this model, the energy consumption for cooling load will be approximately 25,010,533 MWh every year but it can be reduced to 10,180,000 MWh and save 59%.

As previously discussed, substantial energy savings could be made from simply upgrading the building envelope components of residential buildings in KSA. Evidently, energy efficiency improvements for residential buildings would benefit both homeowners and the Saudi government, as well as the environment.

9.2 Thesis Finding and Recommendations

1- The government of Saudi Arabia should develop building standards and regulations that suit the Saudi climate, culture and environment.

2- The Saudi government should introduce new laws to reduce energy and water consumption in order to decrease the overall consumption of natural resources and secure the future generation’s demand for natural resources

3- Saudi residential buildings should be a priority for developing, from both the Saudi government and building developers, as they consume 67% of the total energy consumption.

4- Thermal insulation is an influential factor in saving energy and could save up to 40% on the total energy consumption for residential buildings in the kingdom.

5- Saudis should learn from a young age the impact of energy consumption on the environment and increase their knowledge regarding all possible methods to save energy and protect the environment.
6- Selecting local and appropriate construction materials has a positive impact on energy consumption and the environment.
7- Saudis have demonstrated their willingness and desire to pay more for homes that consume less energy and are more environmentally-friendly.
8- The government could increase electricity prices for Saudis who consume more than their actual need.

9.3 Further Study

1- Wall type III could be developed by increasing the thickness of layers, which could affect and reduce energy consumption.

2- Changing the order of wall type III maybe result in reducing the energy consumption and cooling load.

3- It is possible that new sustainable building materials will develop locally and can be used in buildings, thereby changing the kingdom's future.

4- Adding shading devices also could make a minor or significant impact on building energy.

5- The first step in reducing energy consumption in residential buildings in Saudi Arabia is the design. A better design will help to maintain a sustainable environment; thus a better residential design is needed.

6- Adding plants will help to reduce heat on building facades and they should be included in the design.

7- A further area for research could involve selecting light colours externally and internally for walls, which is also important to reduce sunlight absorption.

8- Further investigation in window sizes and the type of glass to use in buildings will improve the building performance regarding the energy consumption and cooling load.

9-Using renewable energy (e.g. Wind, solar, geothermal, hydroelectric, and biomass) as a main solution to reduce energy consumption will provide substantial benefits for the climate, health, and the economy, especially for Saudi Arabia, a country that has a high amount of natural resources, such as **s**olar radiation.

Appendix A: This appendix shows the results of a detailed climatic analysis of Jeddah, Riyadh and Dammam cities using IES software. The appendix will start by presenting the climatic chart of Jeddah city as follow:

1-Simulation Analysis for the Typical Residential Building in Jeddah City

1.1 Wall Type I

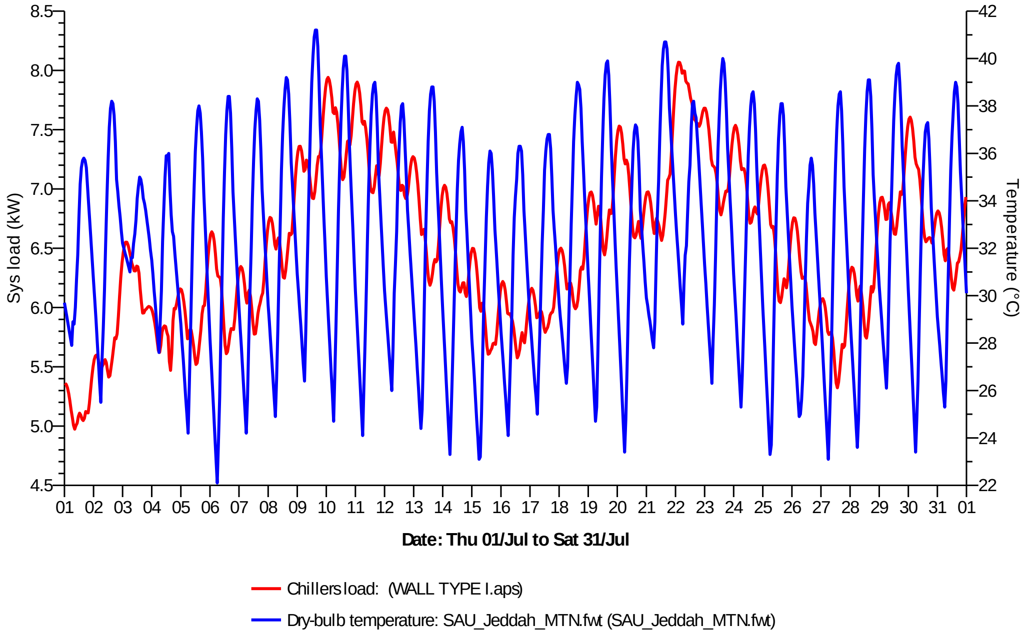


Figure 1: The result of the cooling load from 1st of July until 31st of July in Jeddah city for the external wall type I.

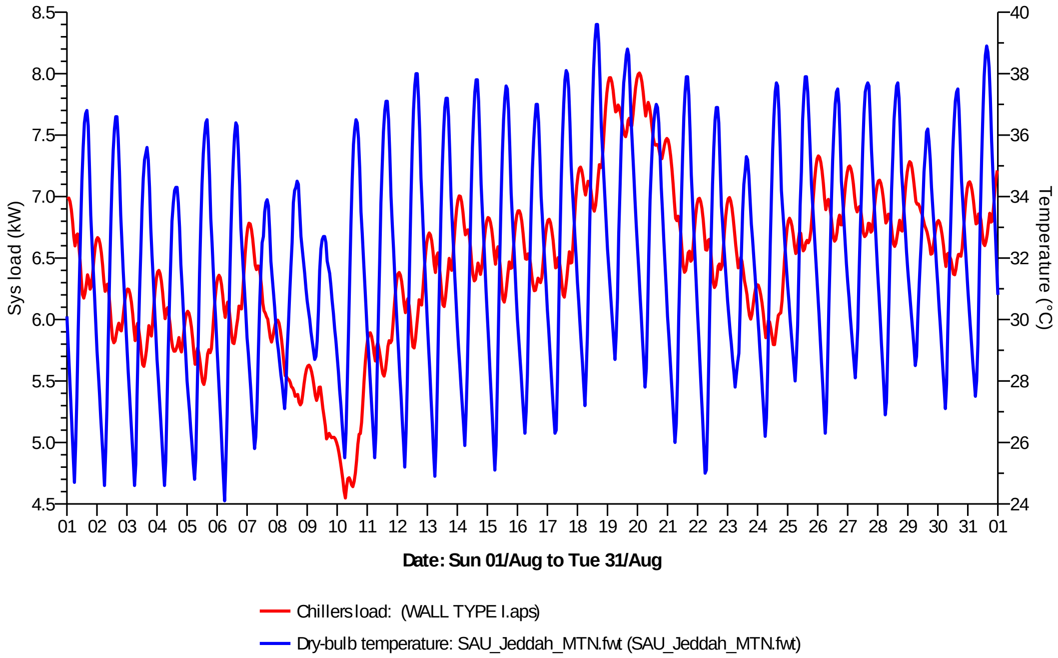


Figure 2: The result of the cooling load from 1st of August until 31st of August in Jeddah city for the external wall type I.

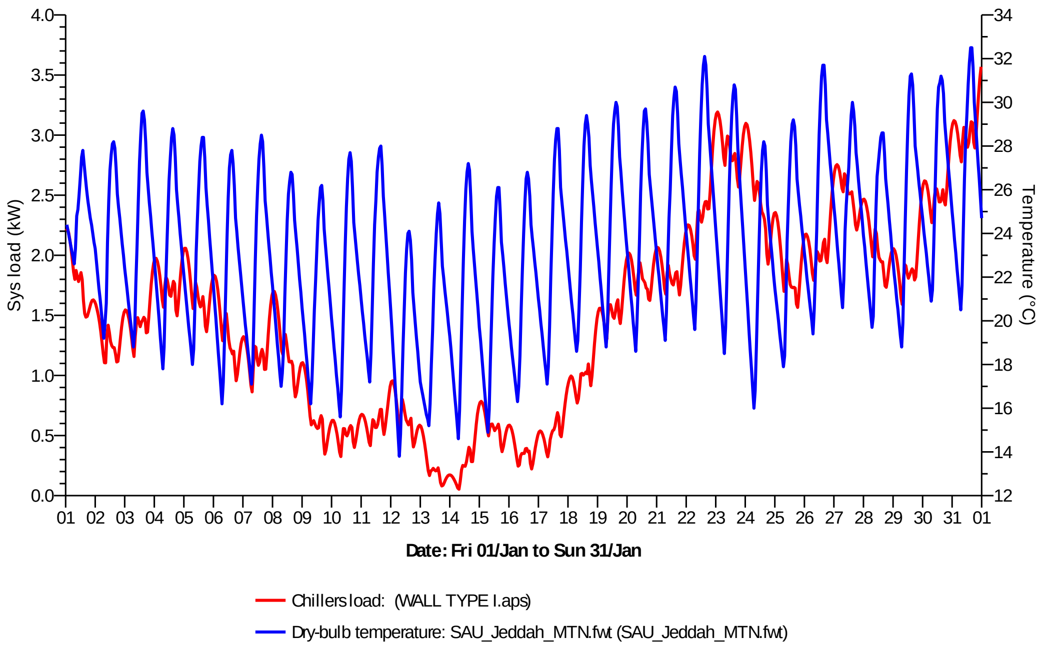


Figure 3: The result of the cooling load from 1st of January until 31st of January in Jeddah city for the external wall type I.

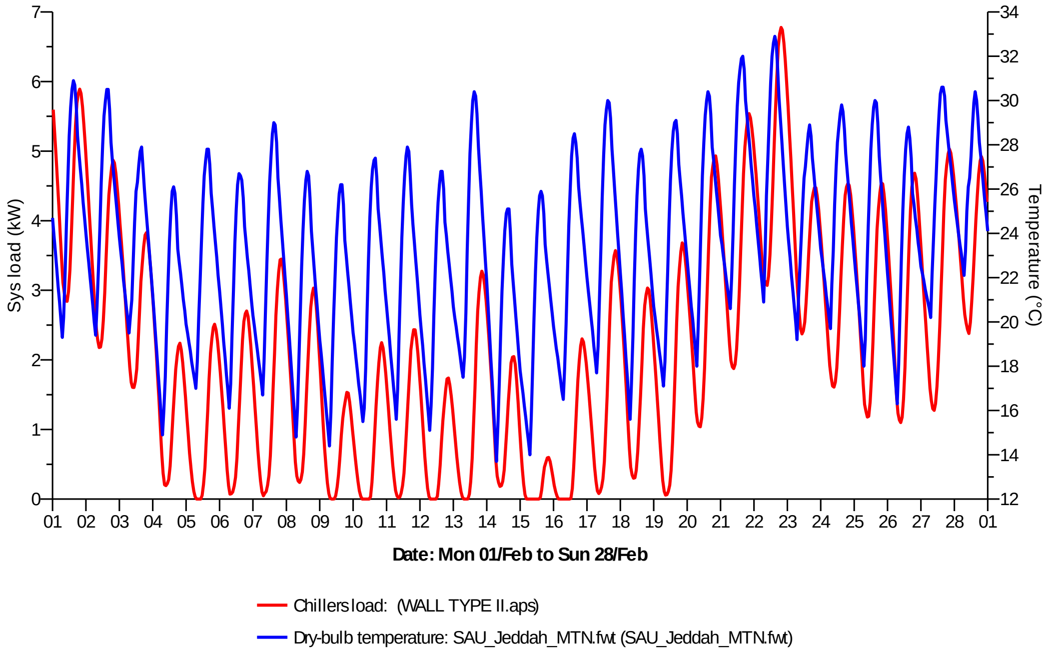


Figure 4: The result of the cooling load from 1st of February until 28th of February in Jeddah city for the external wall type I.

1.2 Wall Type II

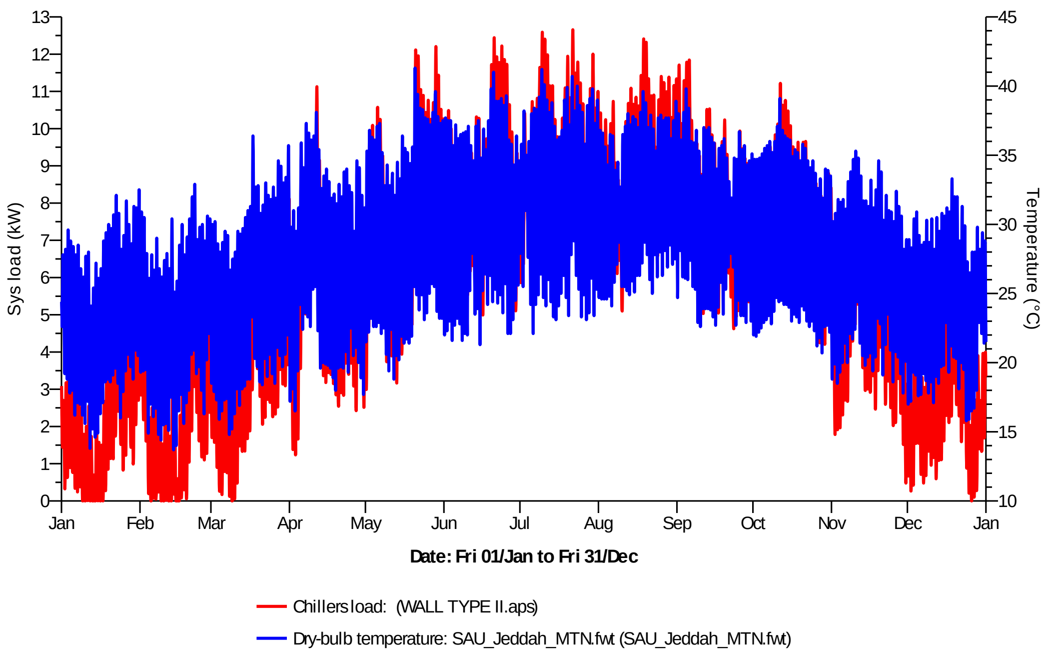


Figure 5: The result of the cooling load from 1st of January until 31st of December in Jeddah city for the external wall type II.

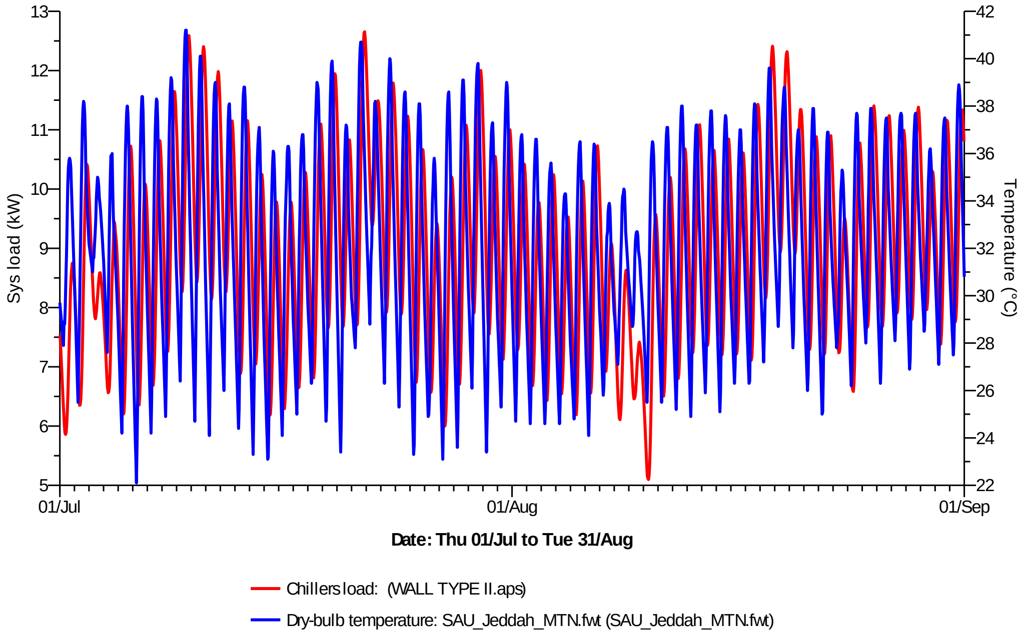


Figure 6: The result of cooling load from 1st of July until 1st of September in Jeddah city for the external wall type II.

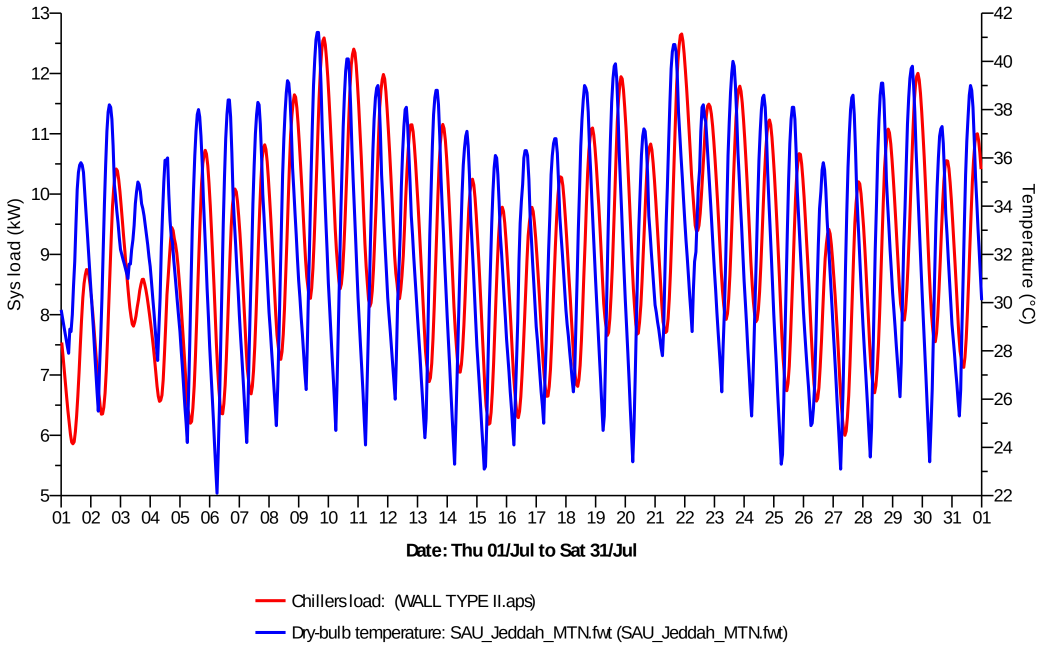


Figure 7: The result of the cooling load from 1st of July until 31st of July in Jeddah city for the external wall type II.

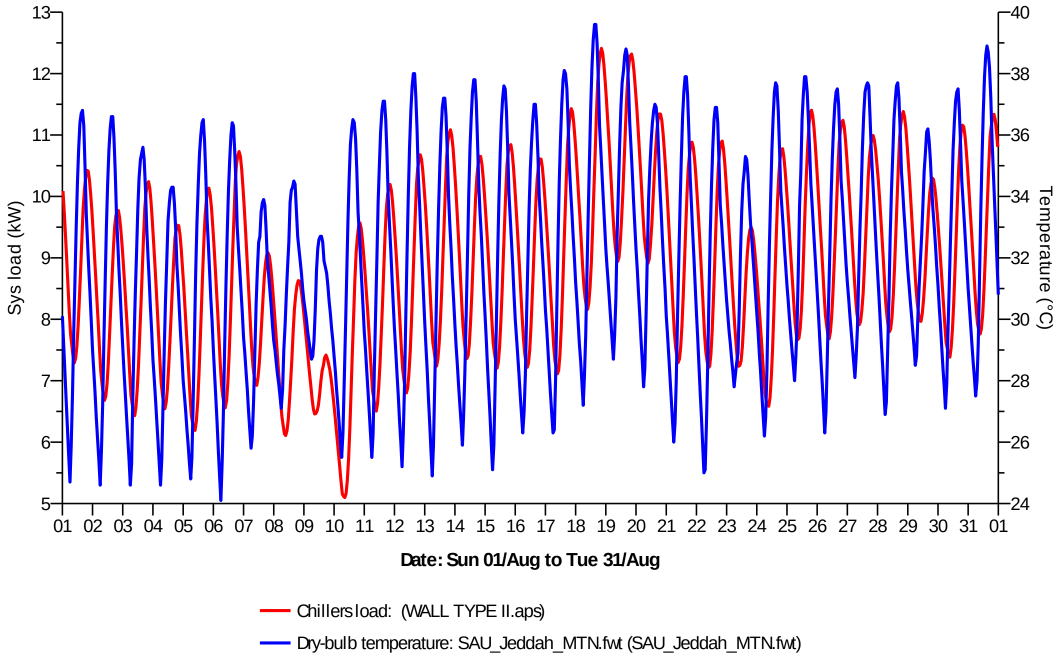


Figure 8: The result of the cooling load from 1st of August until 31st of August in Jeddah city for the external wall type II.

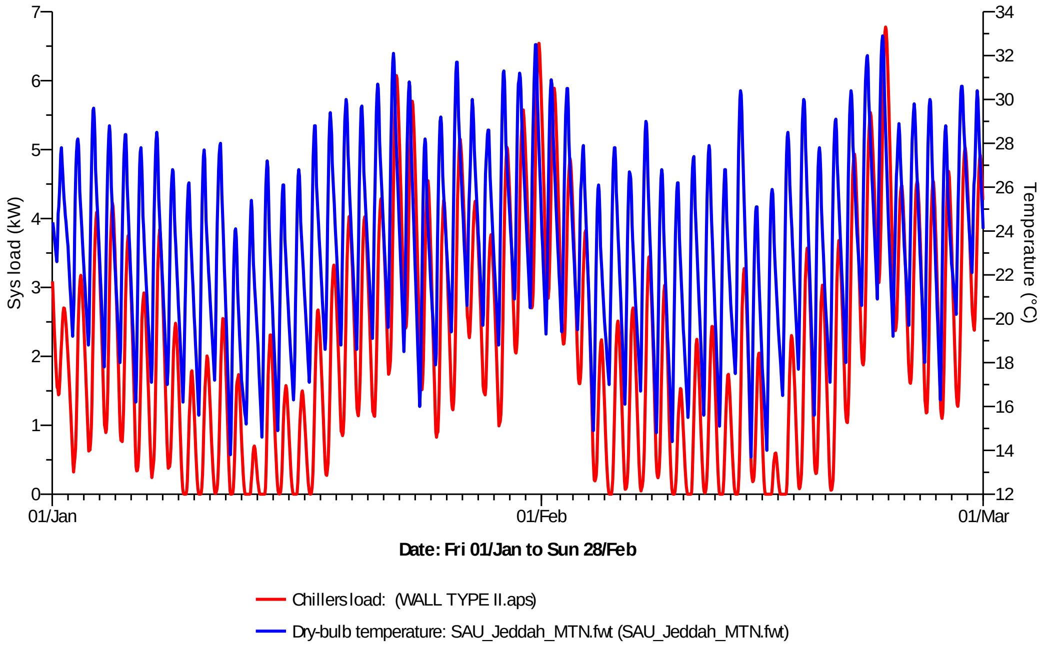


Figure 9: The result of cooling load from 1st of January until 28th of February in Jeddah city for the external wall type II.

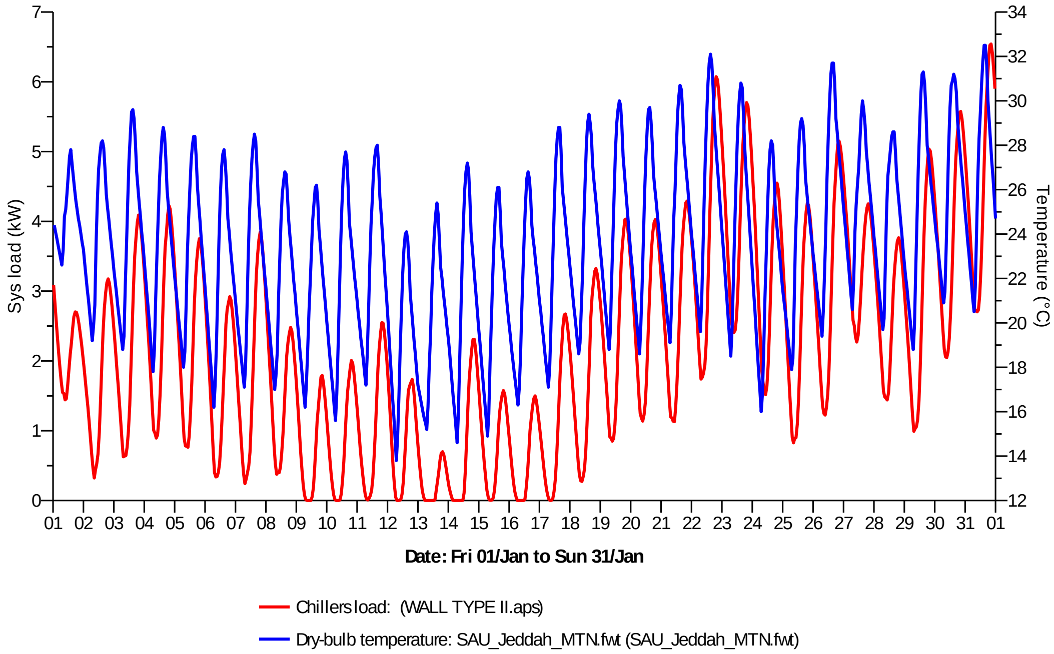


Figure 10: The result of cooling load from 1st of January until 31st of January in Jeddah city for the external wall type II.

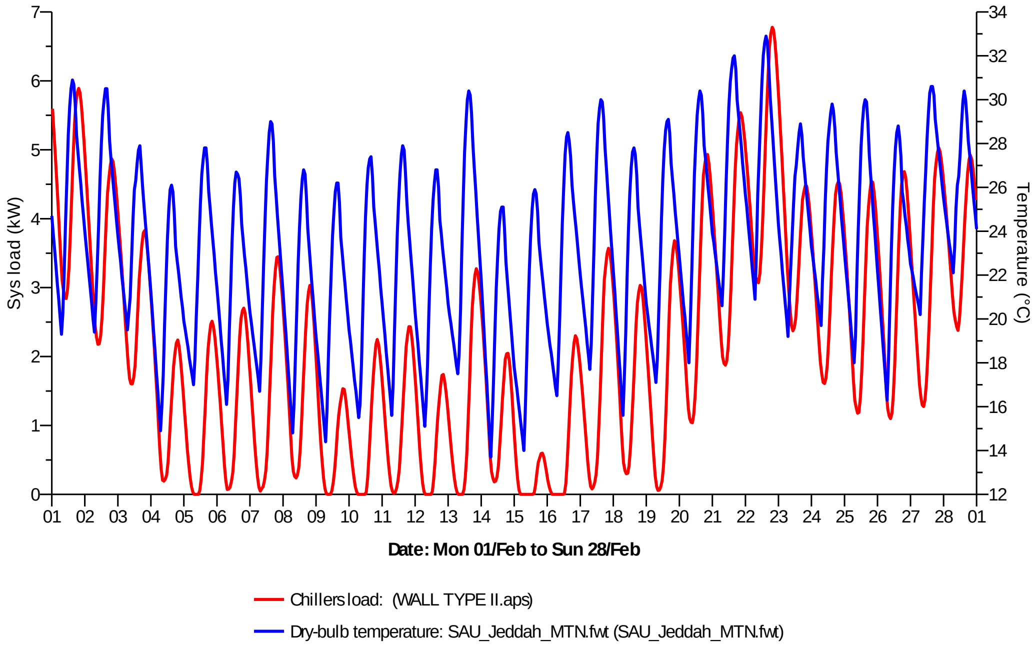


Figure 11: The result of cooling load from 1st of February until 28th of February in Jeddah city for the external wall type II.

1.3 Wall Type III

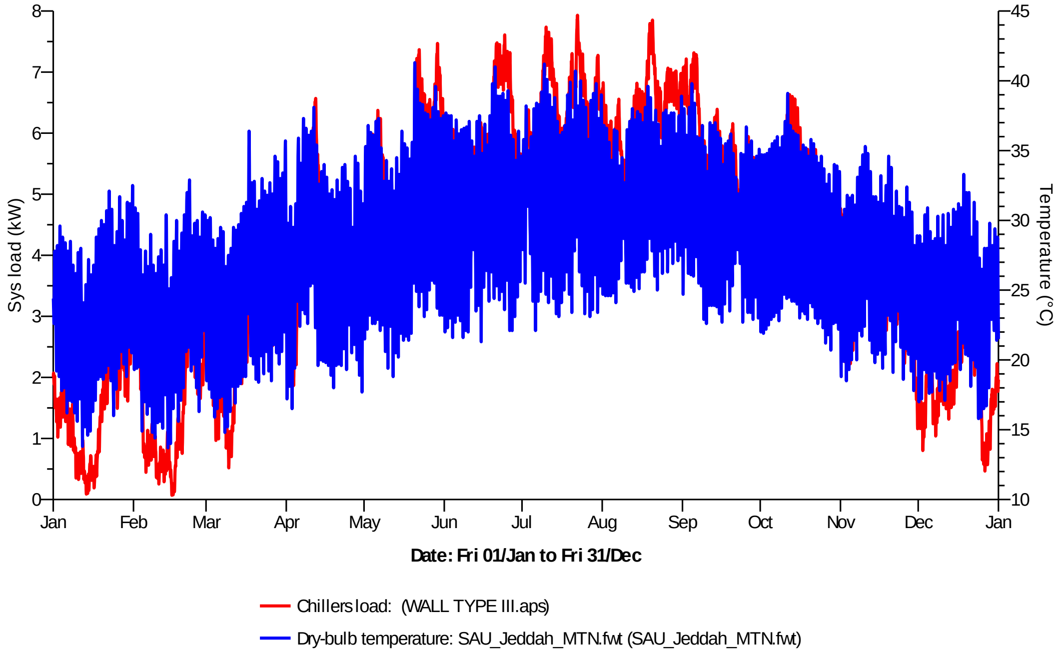


Figure 12: The result of the cooling load from 1st of January until 31st of December in Jeddah city for the external wall type III.

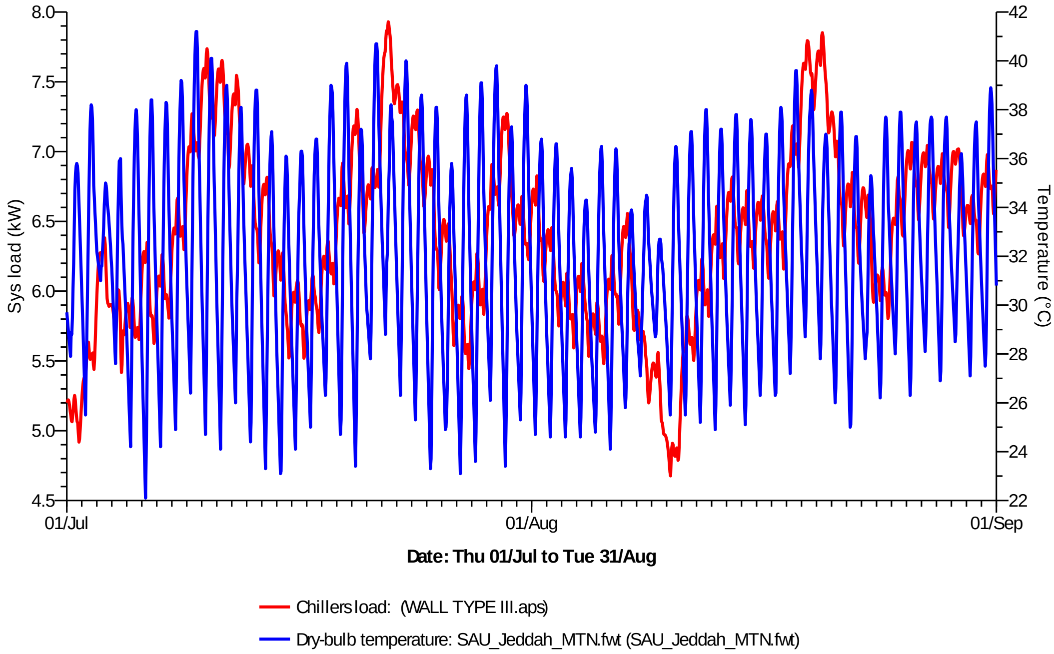


Figure 13: The result of the cooling load from 1st of July until 1st of September in Jeddah city for the external wall type III.

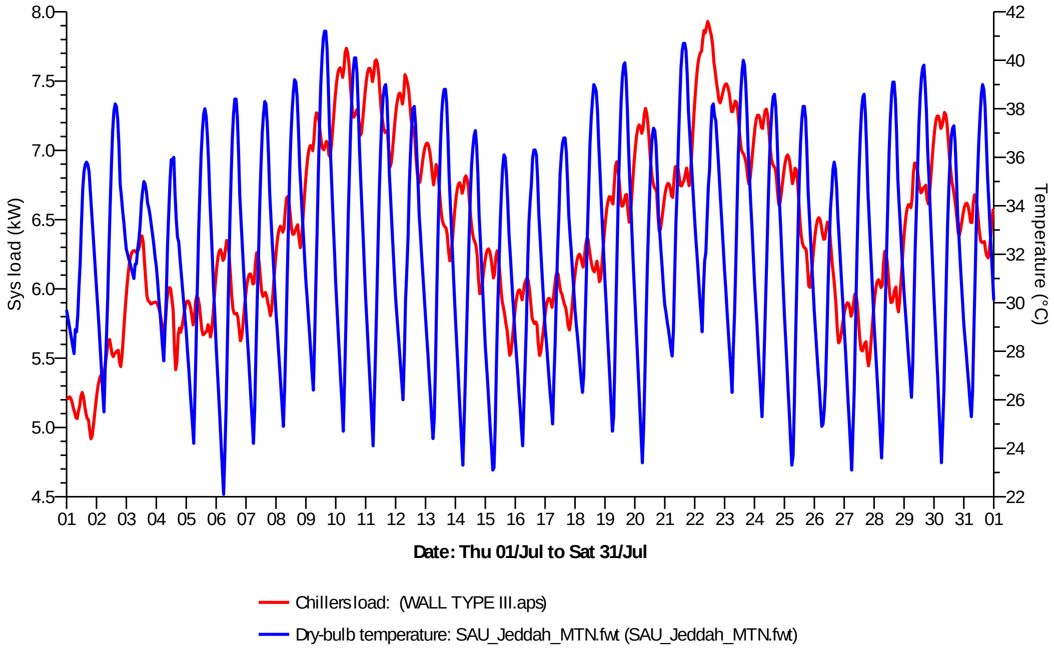


Figure 14: The result of the cooling load from 1st of July until 31st of July in Jeddah city for the external wall type III.

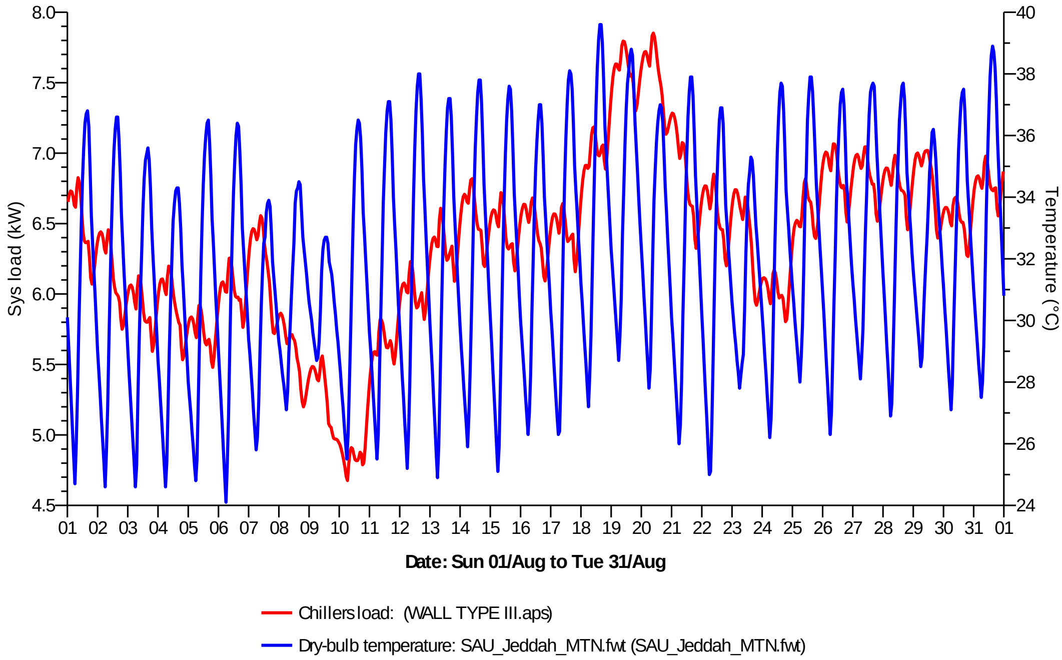


Figure 15: The result of the cooling load from 1st of August until 31st of August in Jeddah city for the external wall type III.

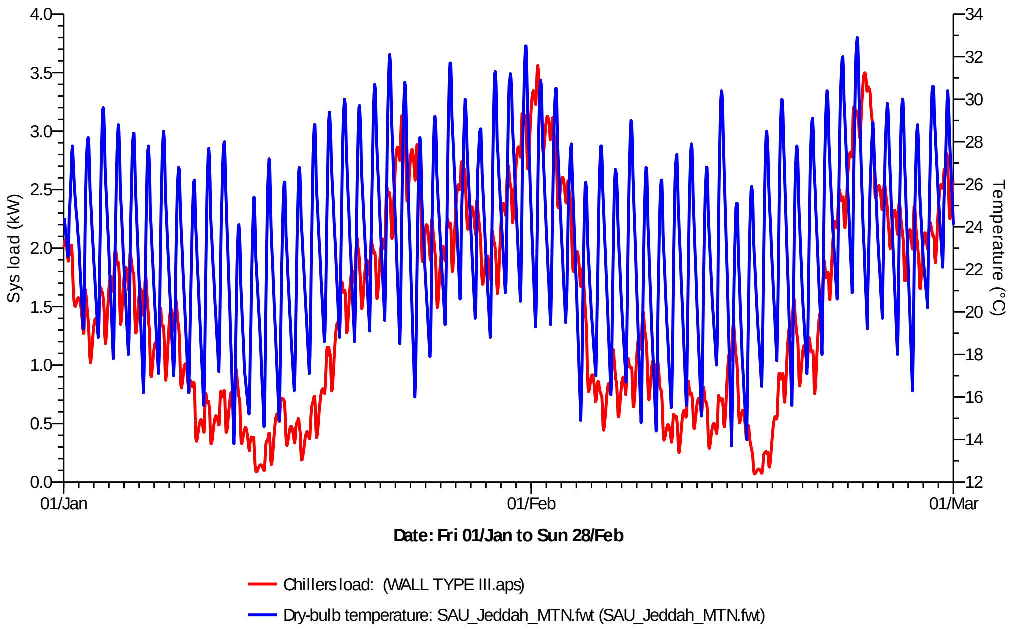


Figure 16: The result of the cooling load from 1st of January until 28th of February in Jeddah city for the external wall type III.

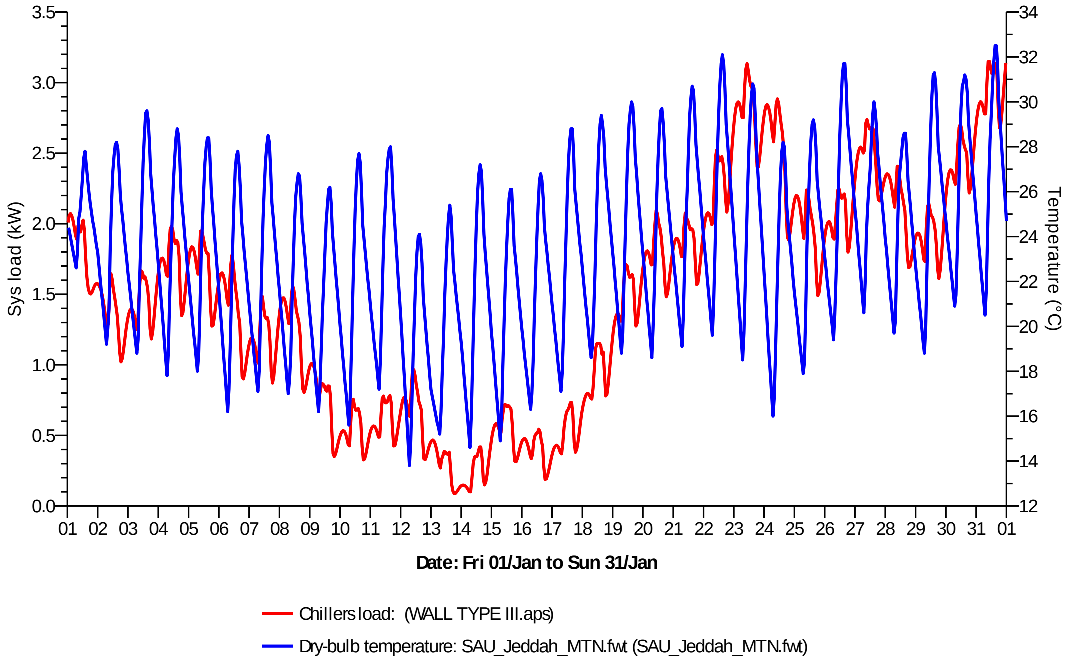


Figure 17: The result of the cooling load from 1st of January until 31st of January in Jeddah city for the external wall type III.

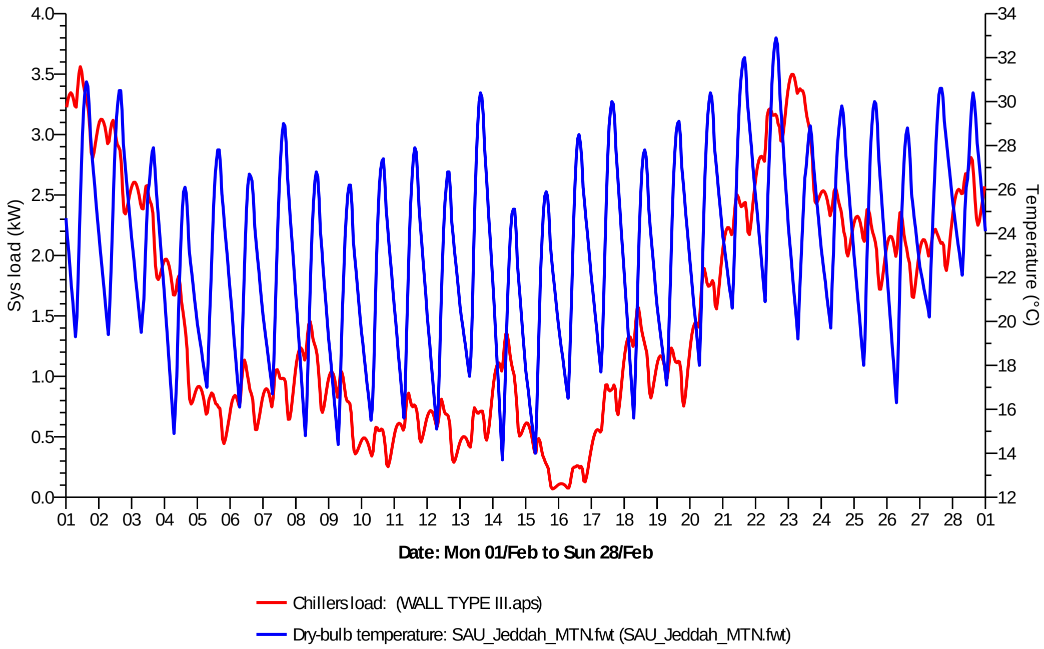


Figure 18: The result of the cooling load from 1st of February until 28th of February in Jeddah city for the external wall type III.

1.4 Wall Type IV

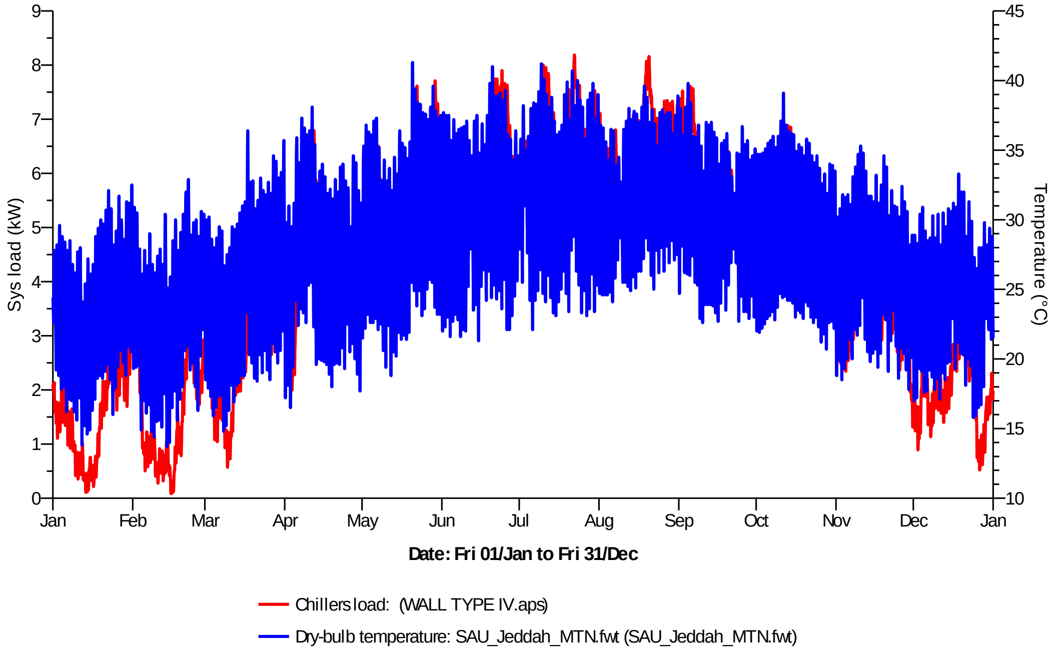


Figure 19: The result of cooling load from 1st of January until 31st of December in Jeddah city for the external wall type IV.

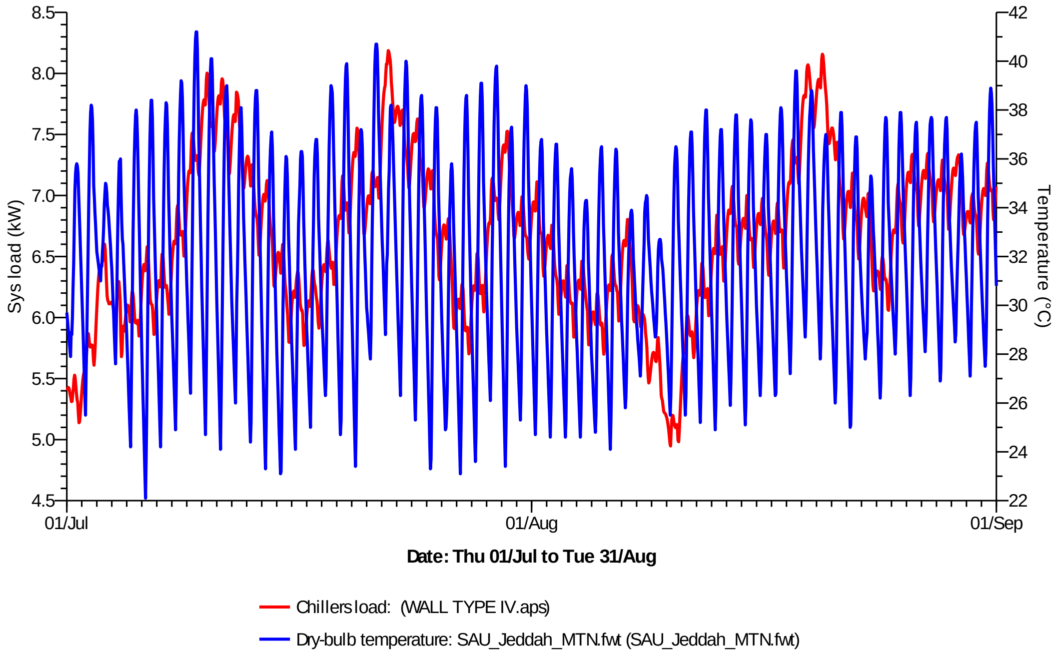


Figure 20: The result of cooling load from 1st of July until 31st of August in Jeddah city for the external wall type IV.

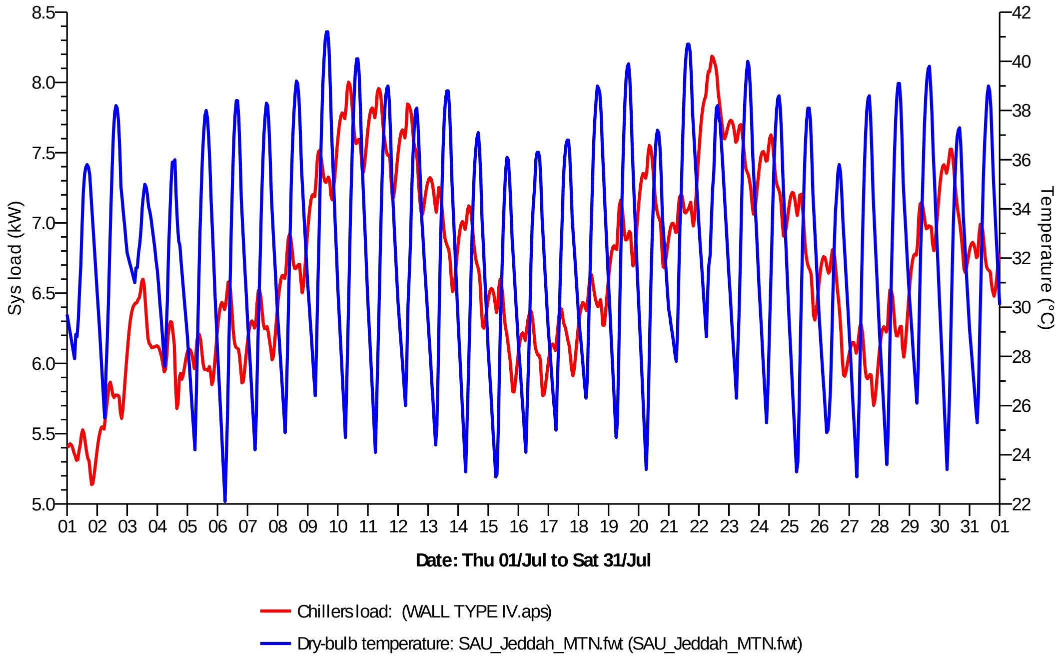


Figure 21: The result of cooling load from 1st of July until 31st of July in Jeddah city for the external wall type IV.

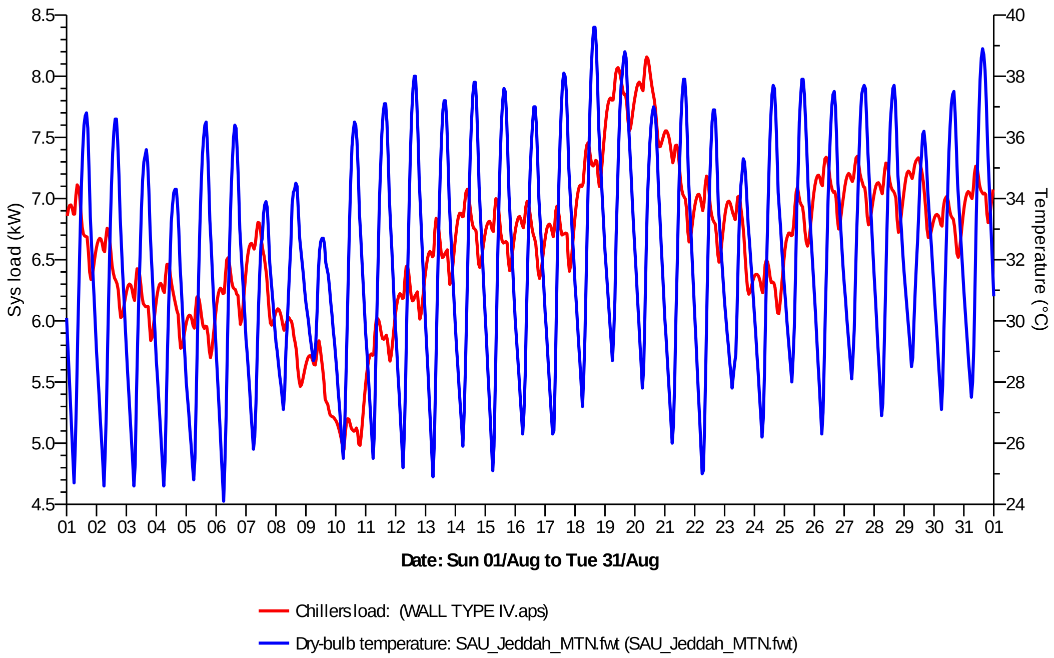


Figure 22: The result of cooling load from 1st of August until 31st of August in Jeddah city for the external wall type IV.

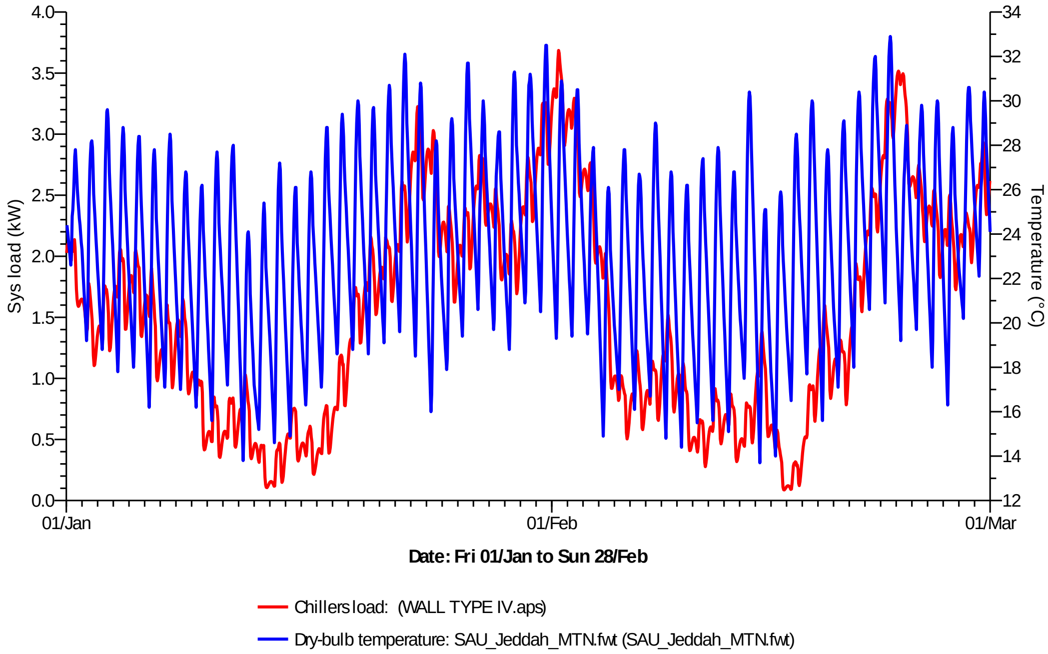


Figure 23: The result of cooling load from 1st of January until 28th of February in Jeddah city for the external wall type IV.

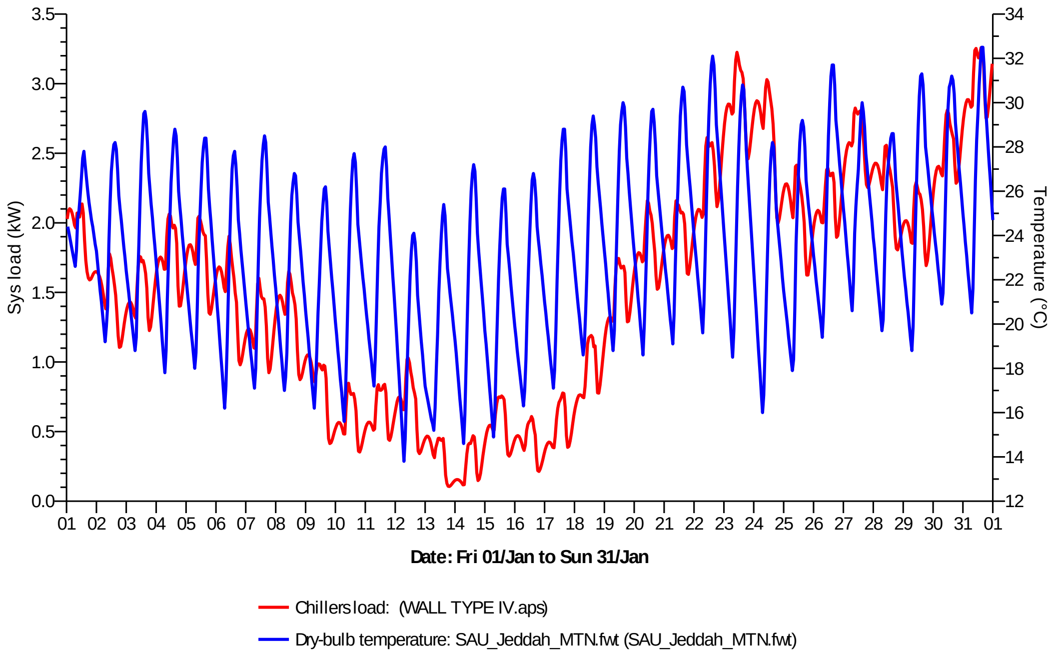


Figure 24: The result of cooling load from 1st of January until 31st of January in Jeddah city for the external wall type IV.

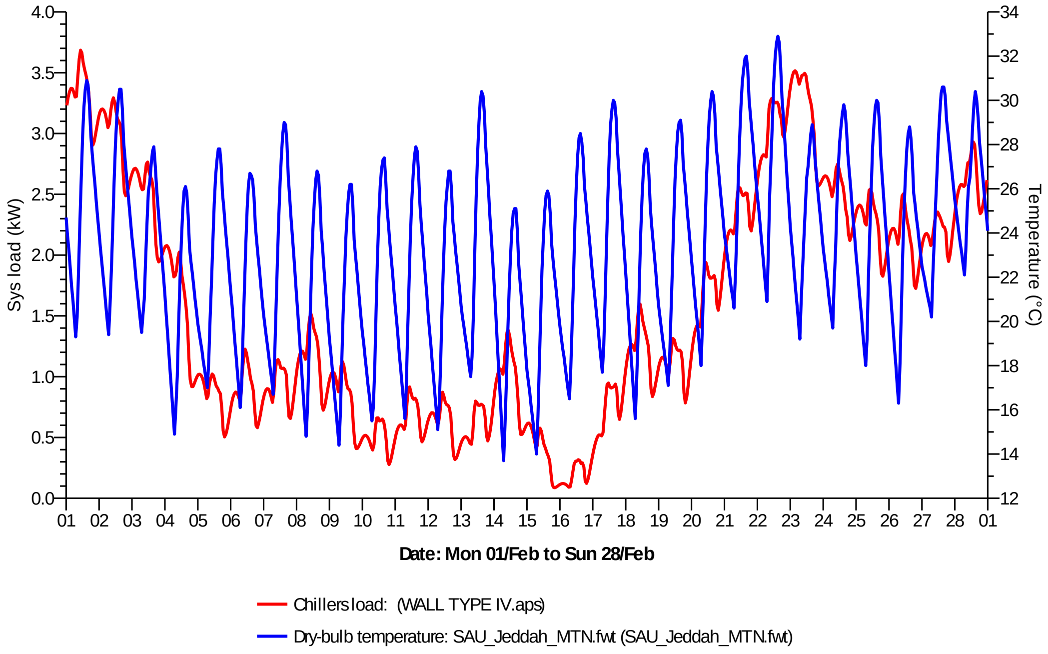


Figure 25: The result of cooling load from 1st of February until 28th of February in Jeddah city for the external wall type IV.

2-Simulation Analysis for the Typical Residential Building in Riyadh City

2.1 Wall Type I

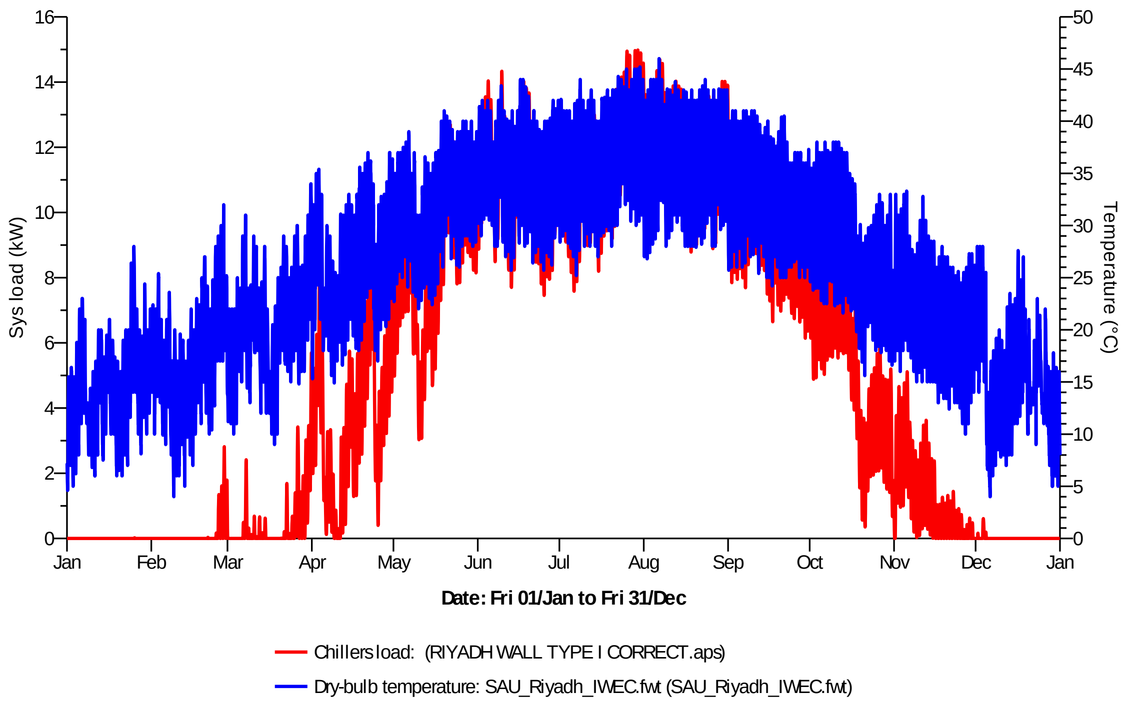


Figure 26: The result of cooling load from 1st of January until 31st of December in Riyadh city for the external wall type I.

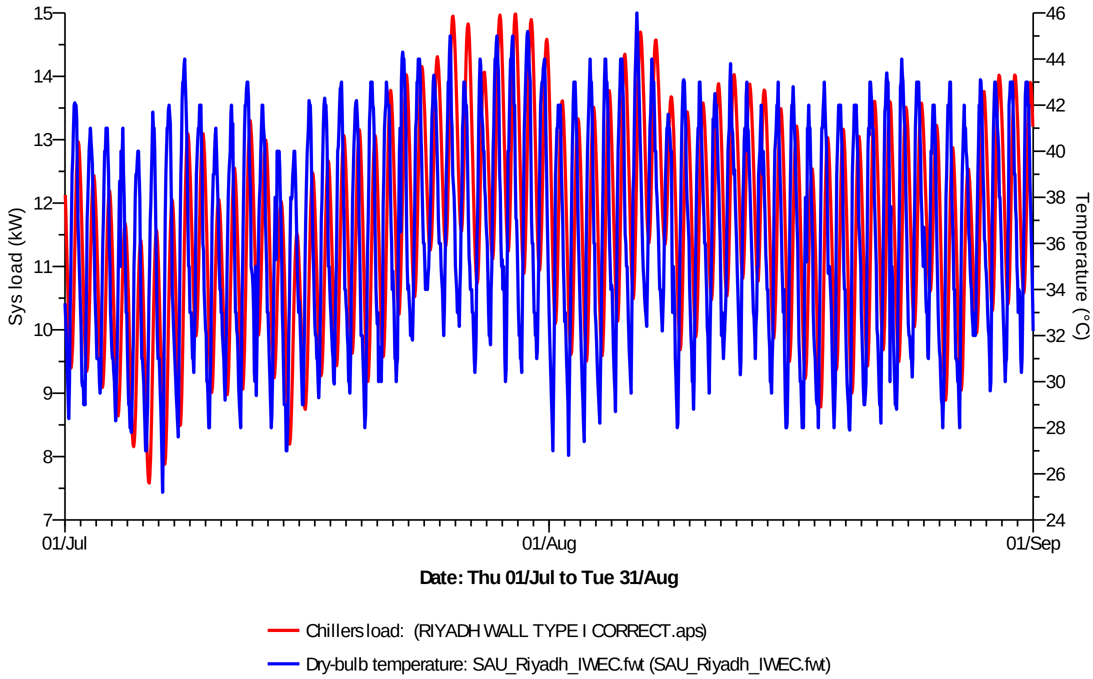


Figure 27: The result of cooling load from 1st of July until 31st of August in Riyadh city for the external wall type I.

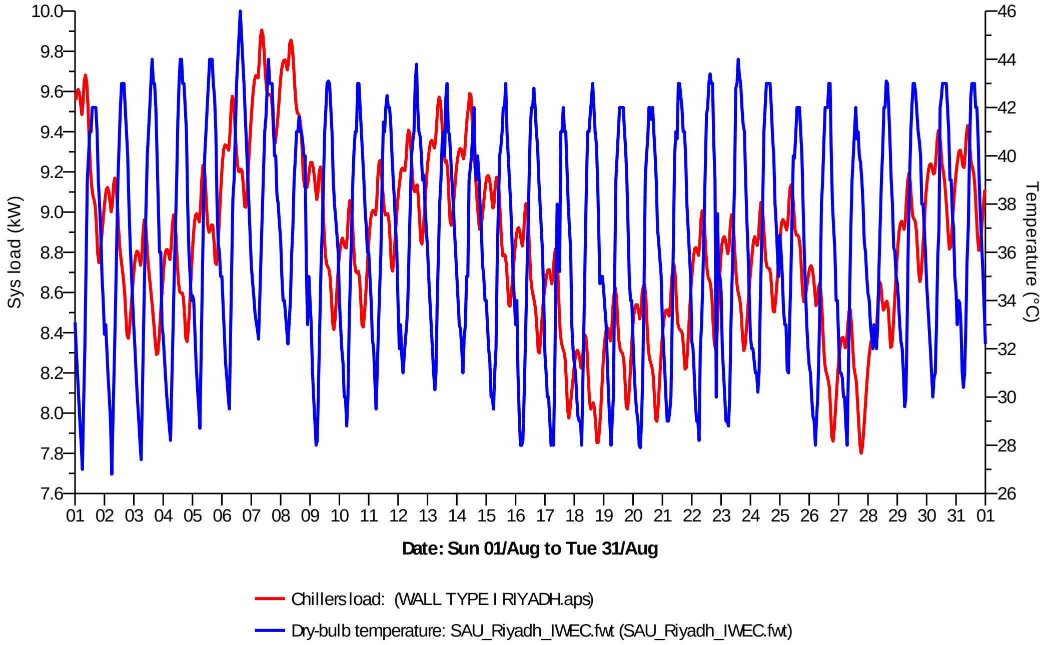


Figure 28: The result of cooling load from 1st of August until 31st of August in Riyadh city for the external wall type I.

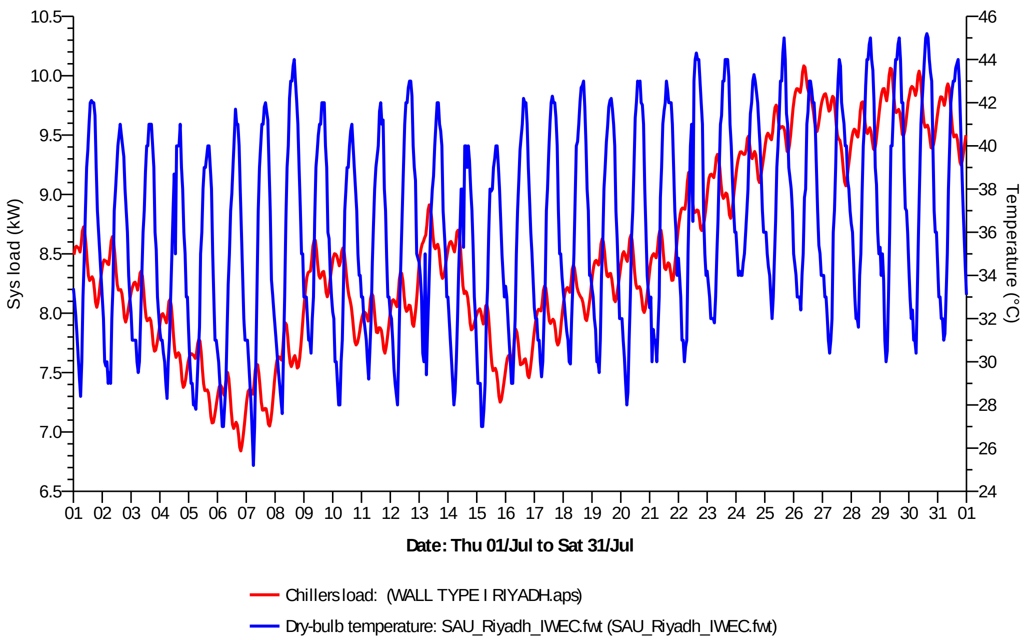


Figure 29: The result of cooling load from 1st of July until 31st of July in Riyadh city for the external wall type I.

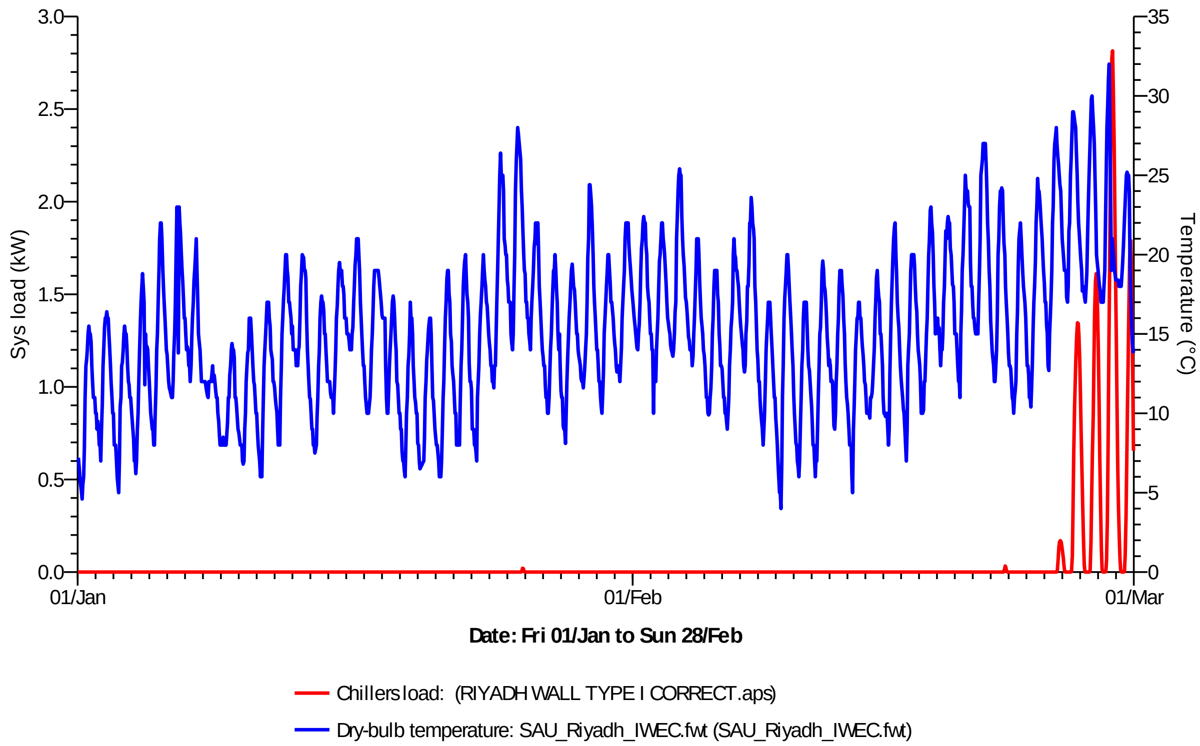


Figure 30: The result of cooling load from 1st of January until 28th of February in Riyadh city for the external wall type I.

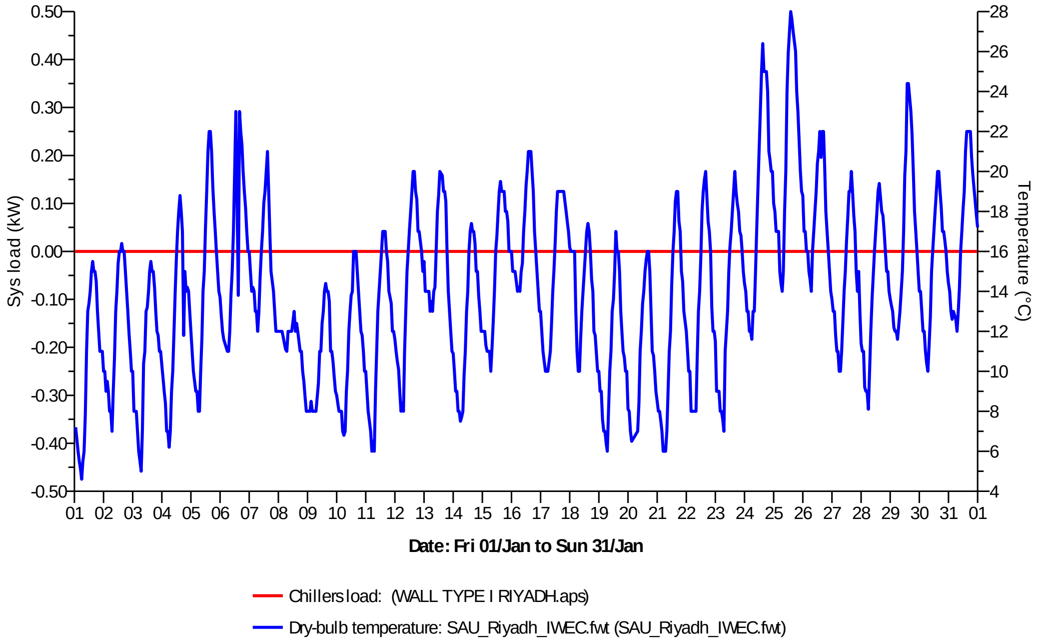


Figure 31: The result of cooling load from 1st of January until 31st of January in Riyadh city for the external wall type I**.**

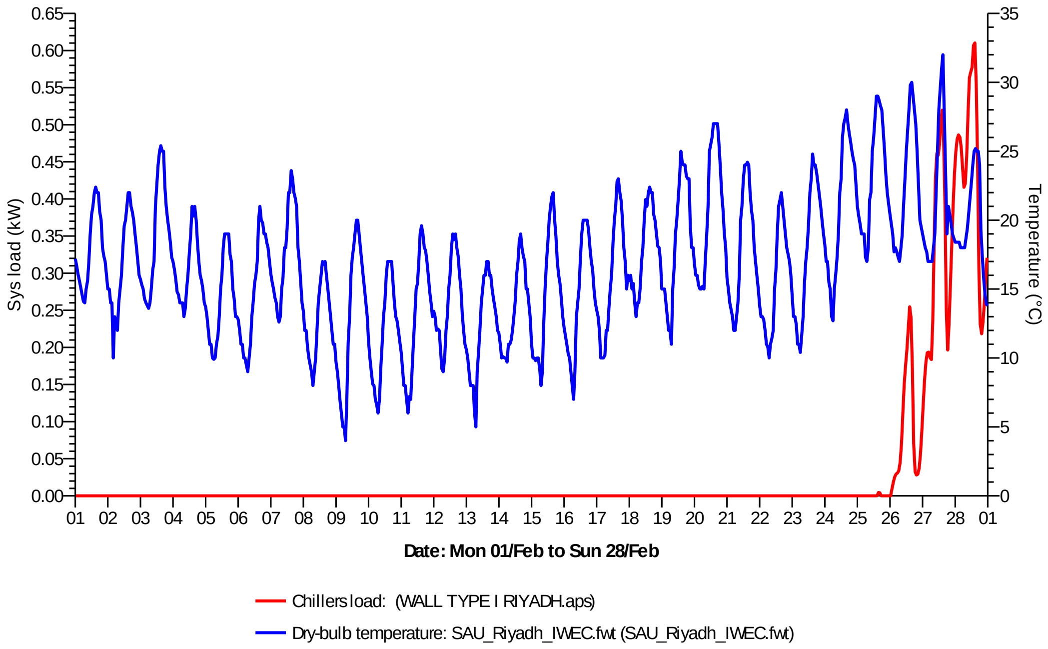


Figure 32: The result of cooling load from 1st of February until 28th of February in Riyadh city for the external wall type I.

2.2 Wall Type II

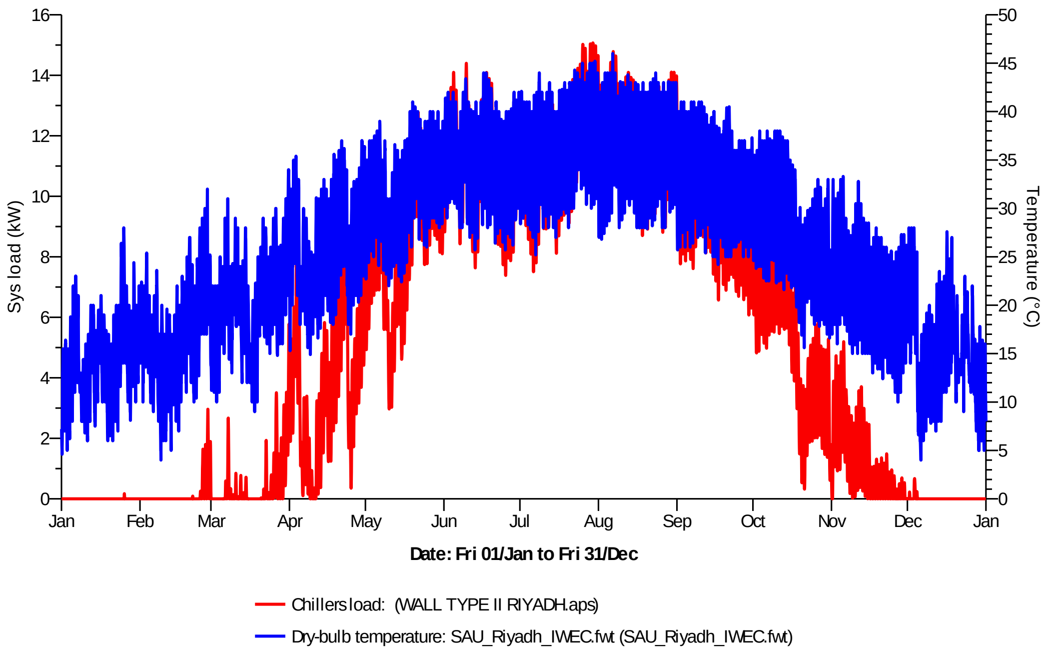


Figure 33: The result of cooling load from 1st of January until 31st of December in Riyadh city for the external wall type II.

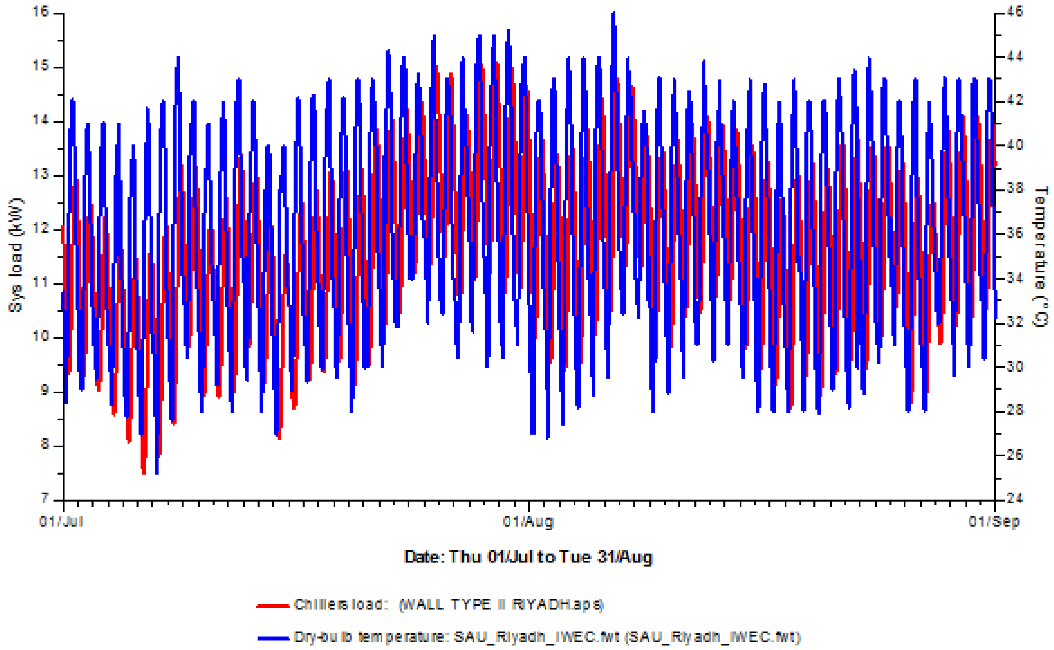


Figure 34: The result of cooling load from 1st of July until 31st of August in Riyadh city for the external wall type II.

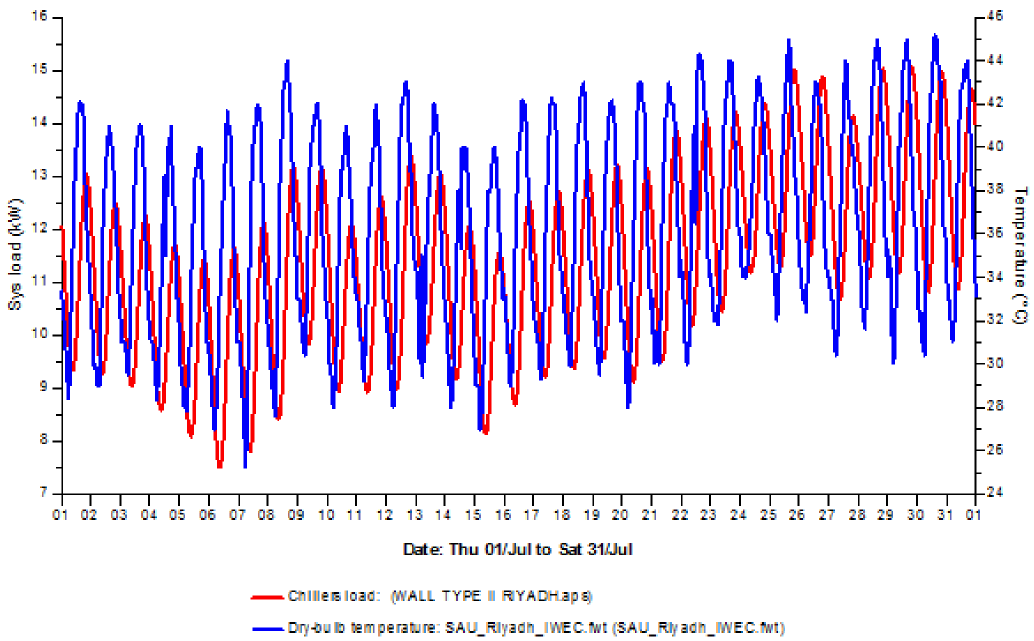


Figure 35: The result of cooling load from 1st of July until 31st of July in Riyadh city for the external wall type II.

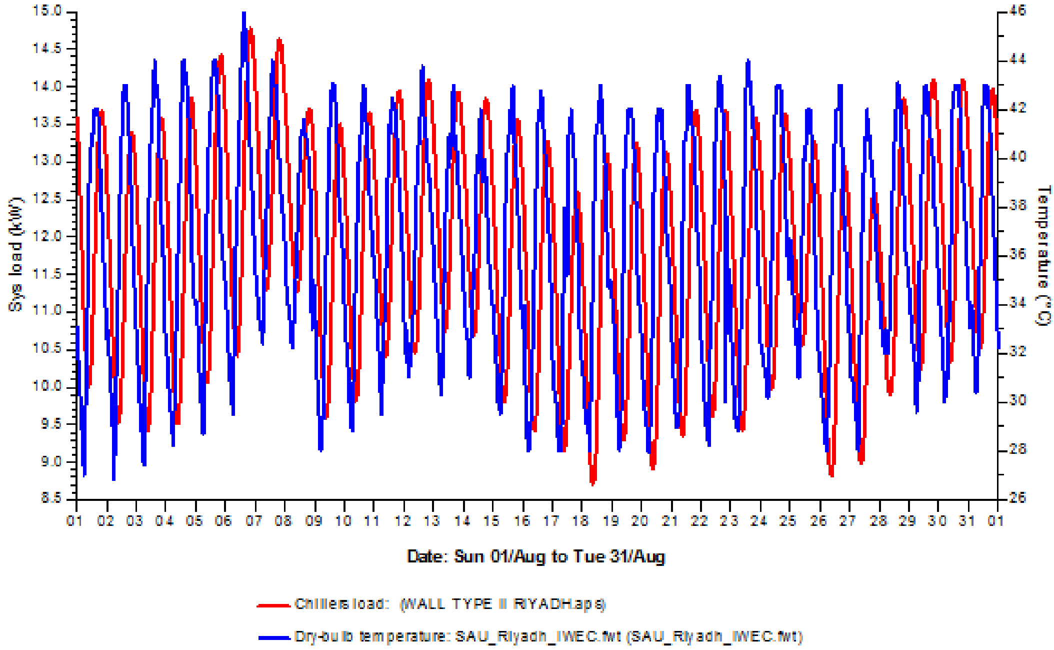


Figure 36: The result of cooling load from 1st of August until 31st of August in Riyadh city for the external wall type II.

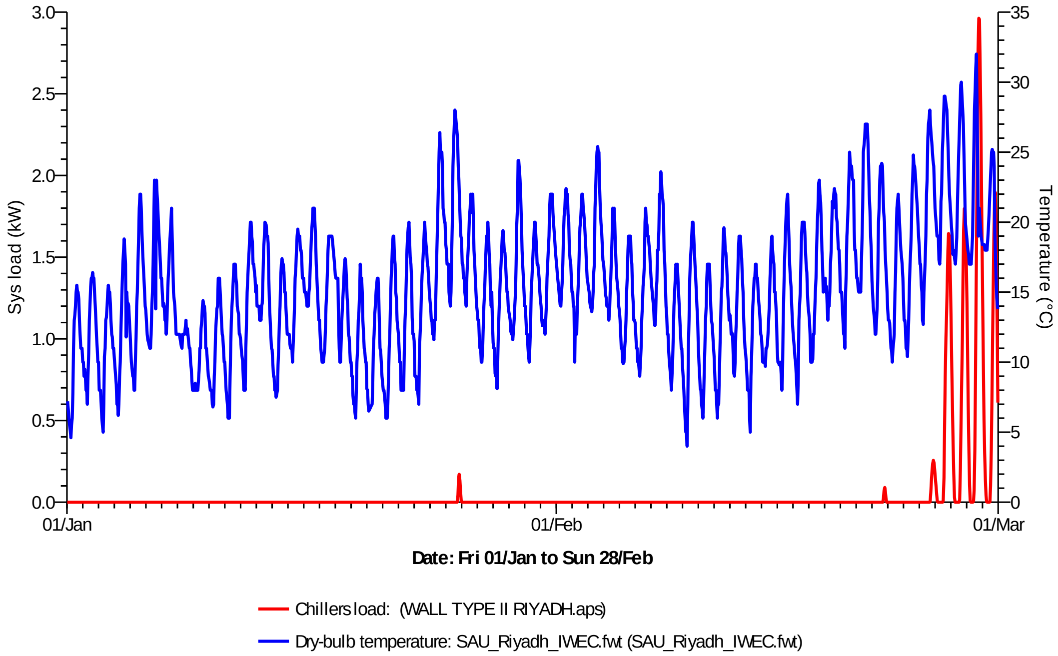


Figure 37: The result of cooling load from 1st of January until 28th of February in Riyadh city for the external wall type II.

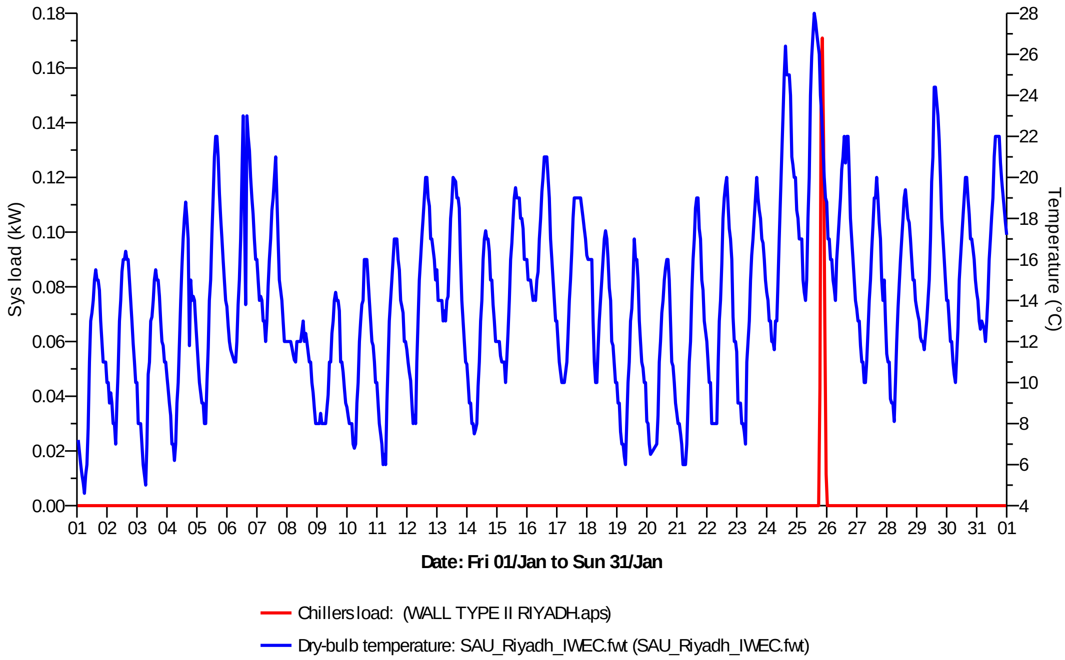


Figure 38: The result of cooling load from 1st of January until 31st of January in Riyadh city for the external wall type II.

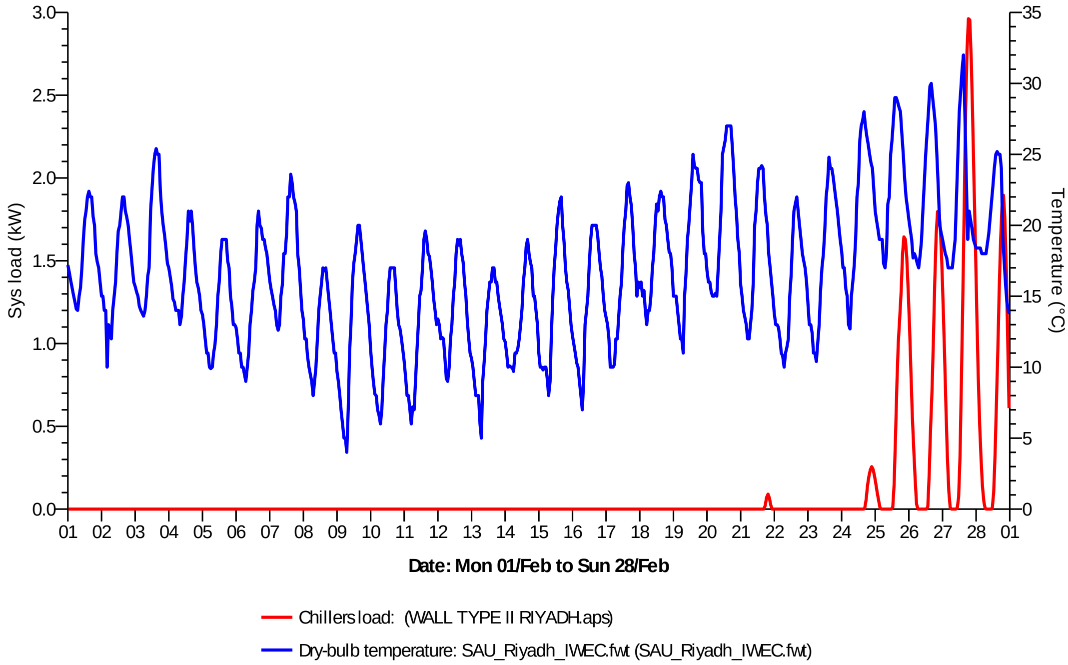


Figure 39: The result of cooling load from 1st of February until 28th of February in Riyadh city for the external wall type II.

2.3 Wall Type III

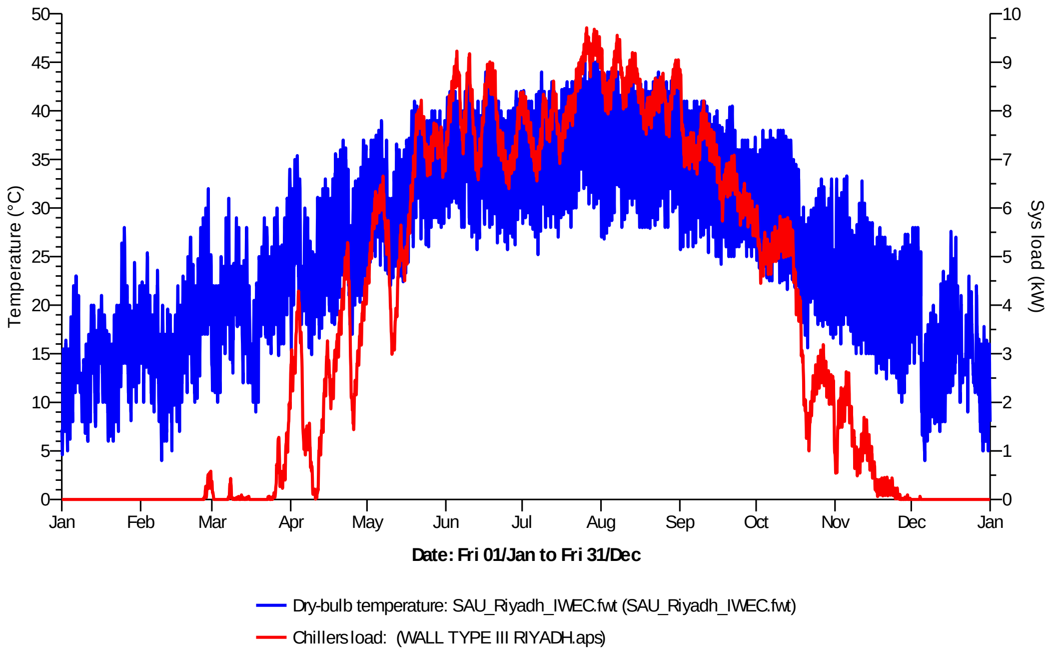


Figure The 40: Result of cooling load from 1st of January to 31st of December in Riyadh city for the external wall type III.

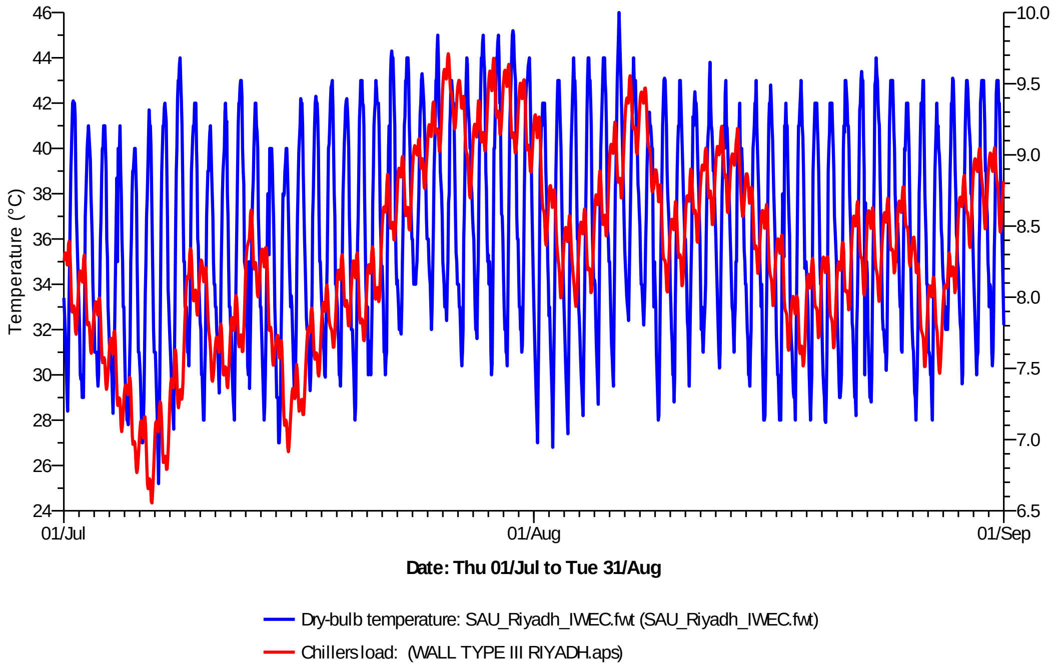


Figure 41: The result of cooling load from 1st of July until 31st of August in Riyadh city for the external wall type III.

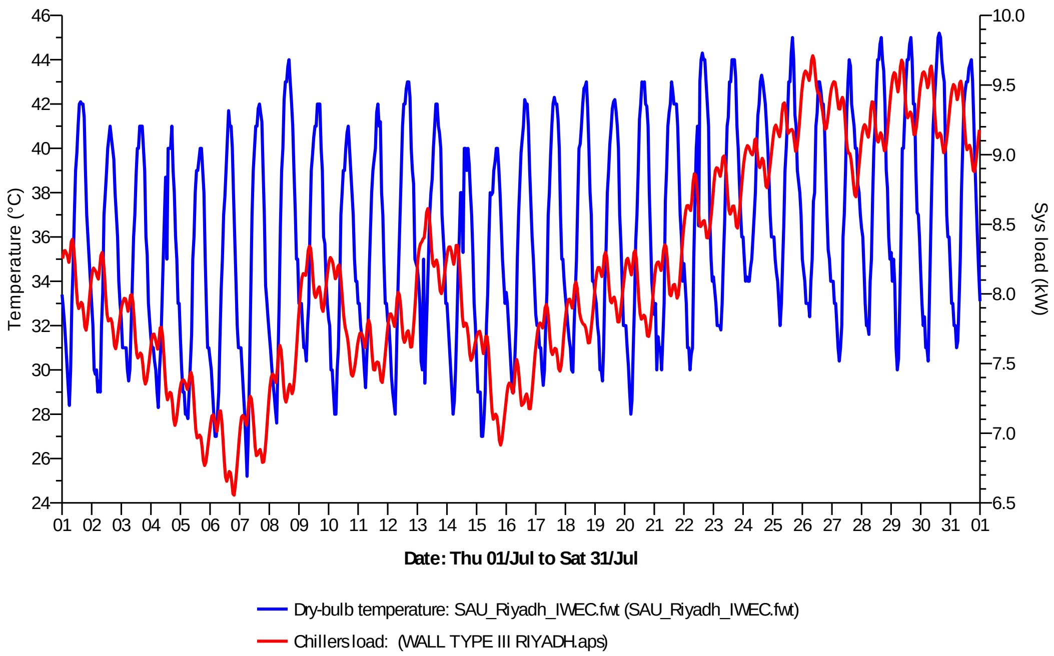


Figure 42: The result of cooling load from 1st of July until 31st of July in Riyadh city for the external wall type III.

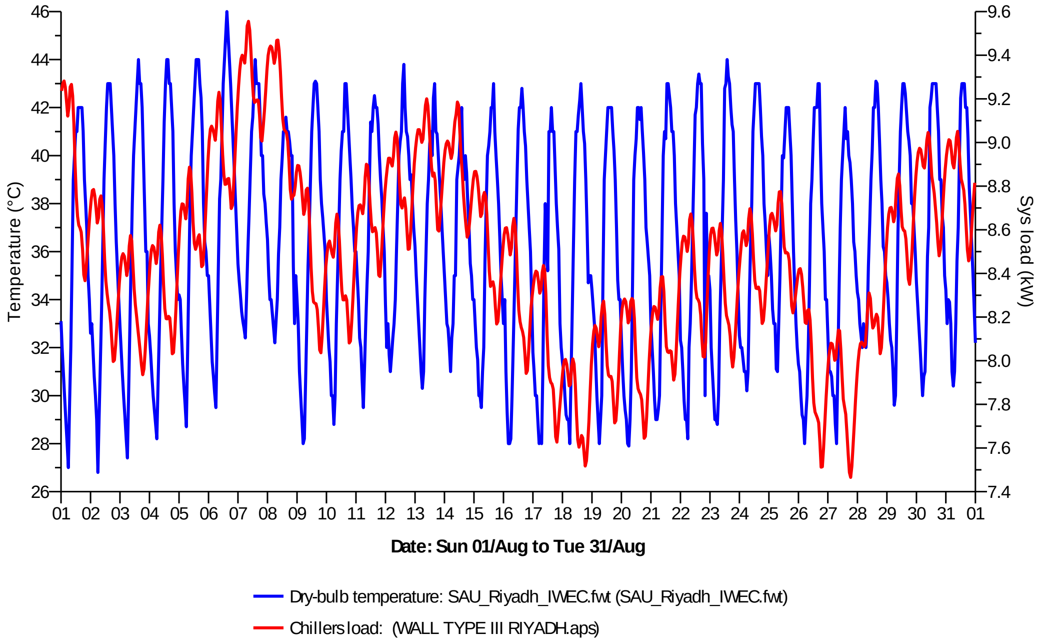


Figure 43: The result of cooling load from 1st of August until 31st of August in Riyadh city for the external wall type III.

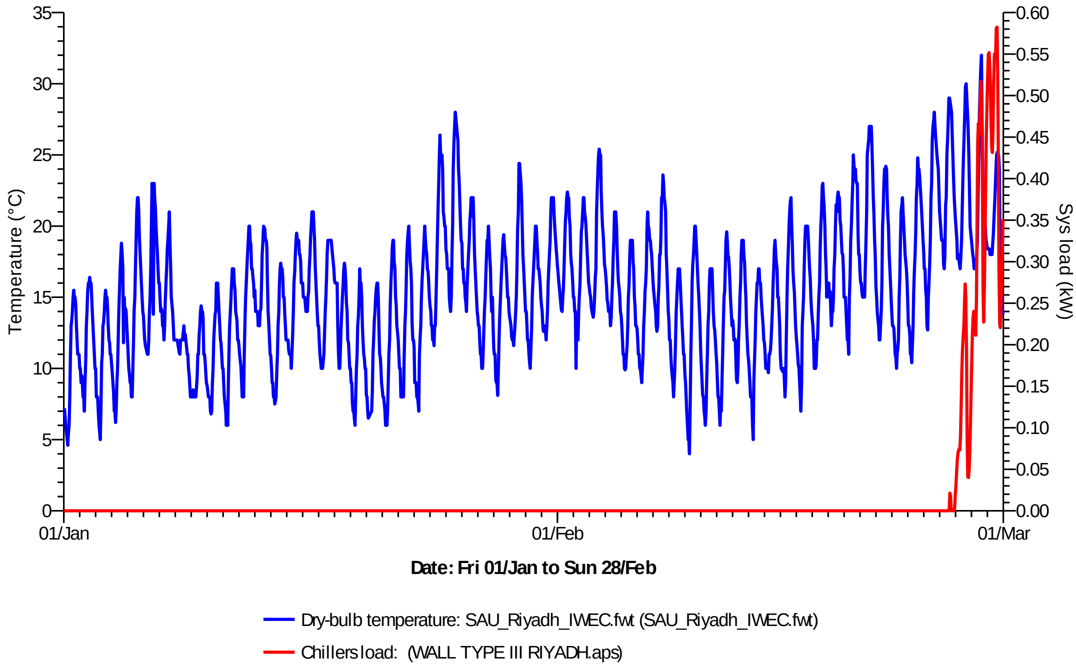


Figure 44: The result of cooling load from 1st of January to 28th of February in Riyadh city for the external wall type III.

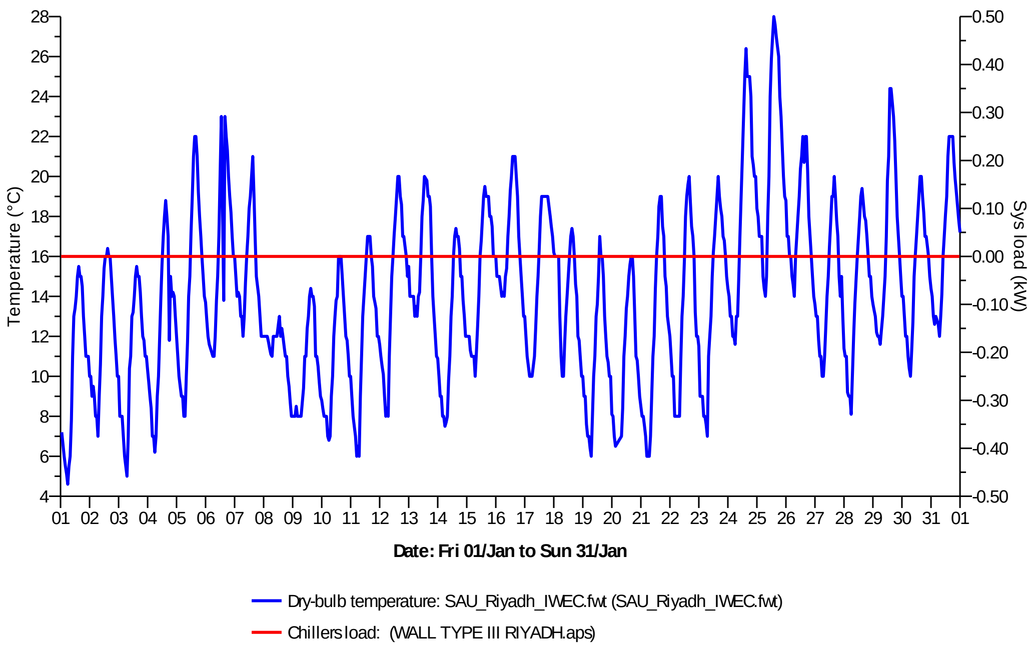


Figure 45: The result of cooling load from 1st of January to 31st of January in Riyadh city for the external wall type III.

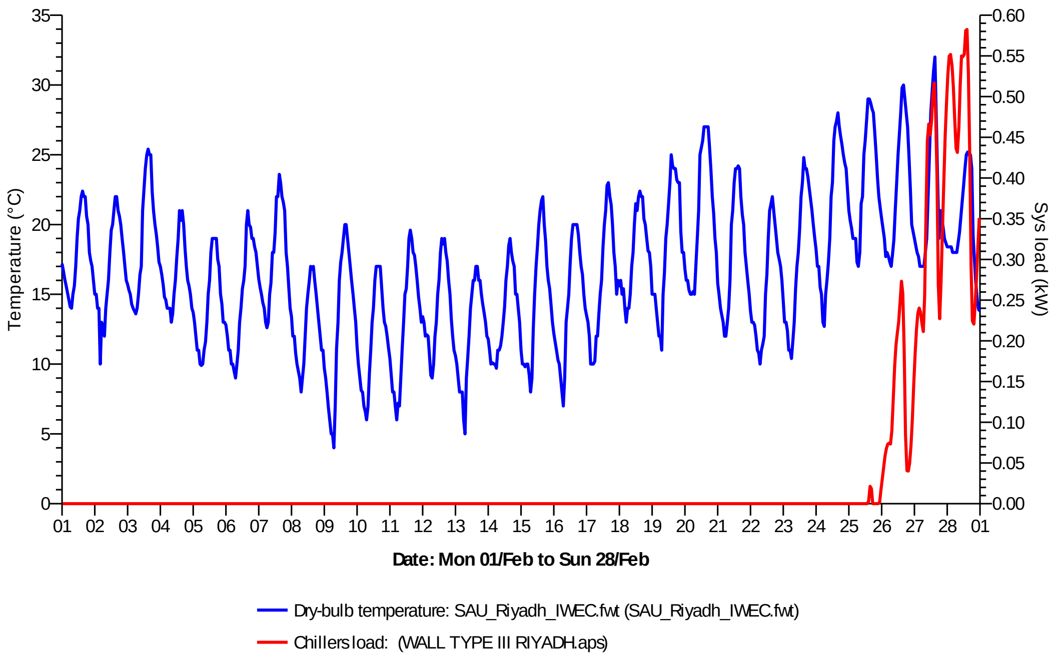


Figure 46: The result of cooling load from 1st of February to 28th of February in Riyadh city for the external wall type III.

2.4 Wall Type IV

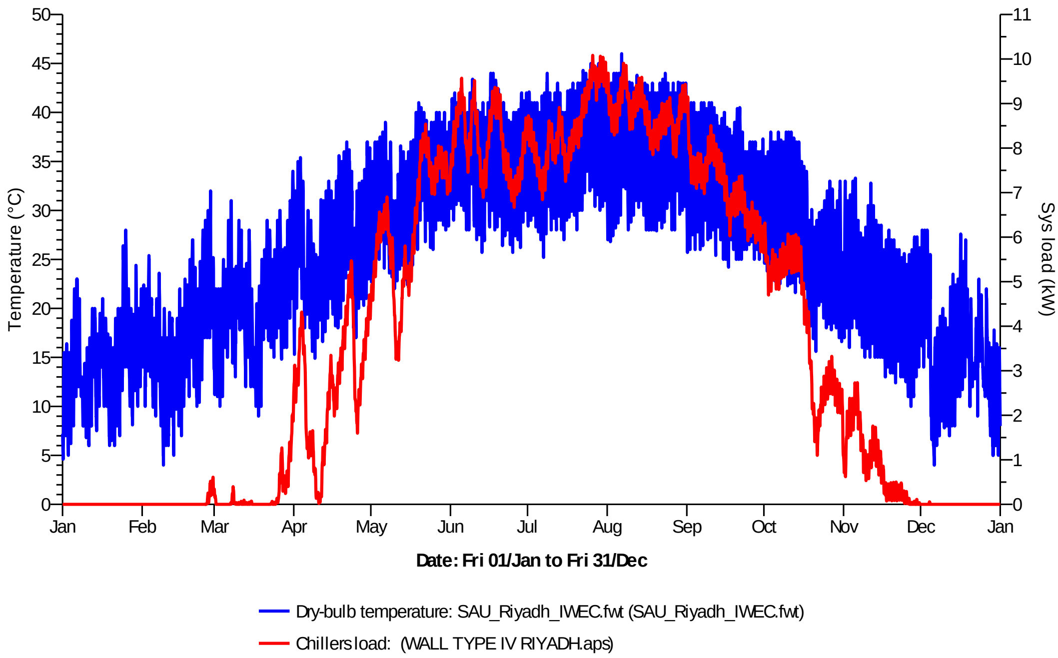


Figure 47: The result of cooling load from 1st of January until 31st of December in Riyadh city for the external wall type IV.

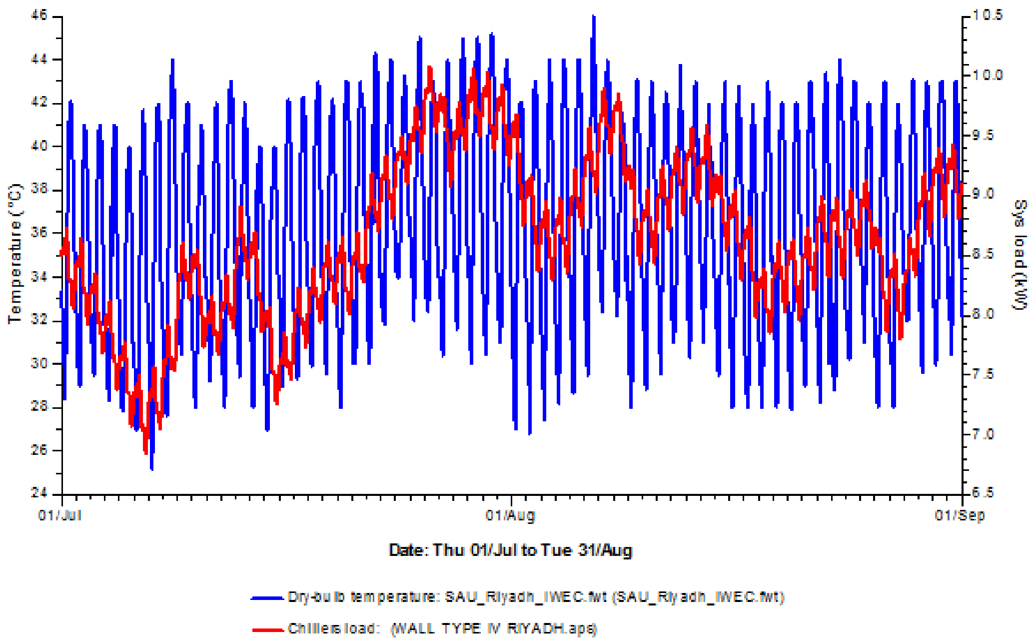


Figure 48: The result of cooling load from 1st of July until 31st of August in Riyadh city for the external wall type IV.

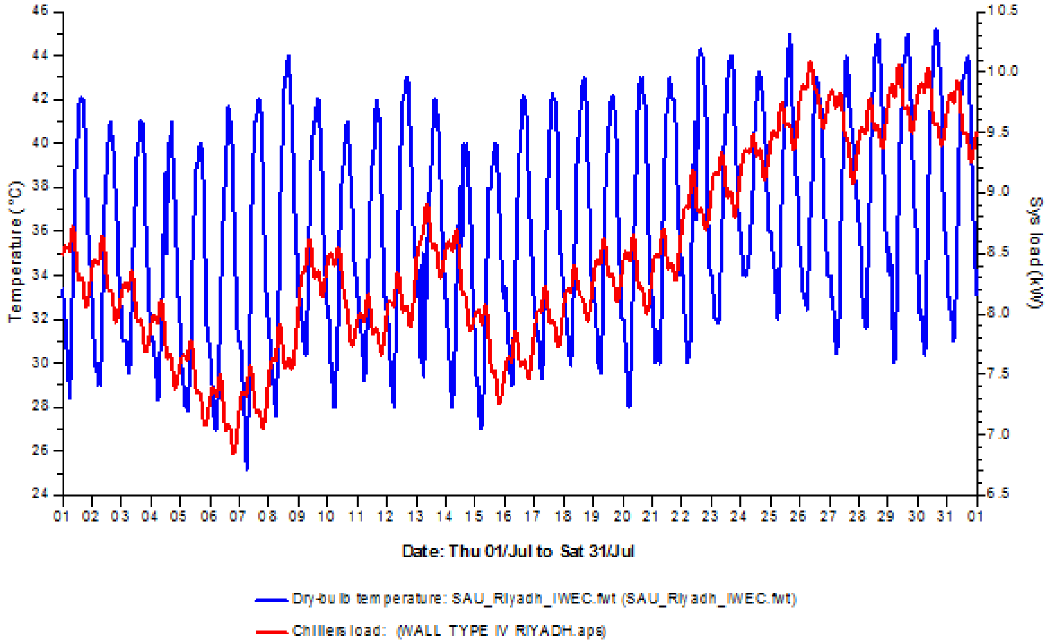


Figure 49: The result of cooling load from 1st of July until 31st of July in Riyadh city for the external wall type IV.

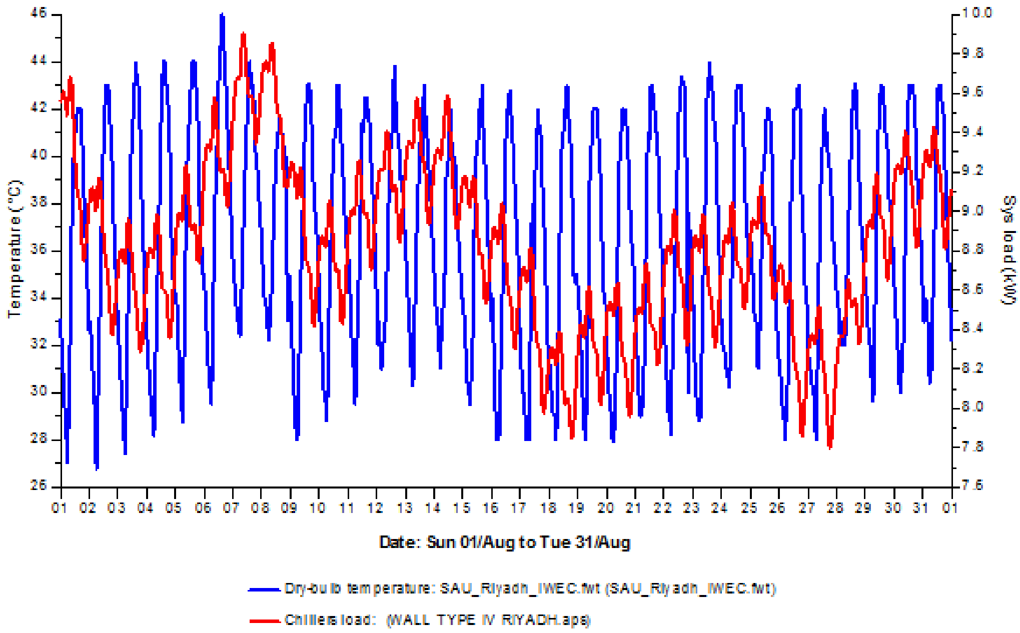


Figure 50: The result of cooling load from 1st of August until 31st of August in Riyadh city for the external wall type IV.

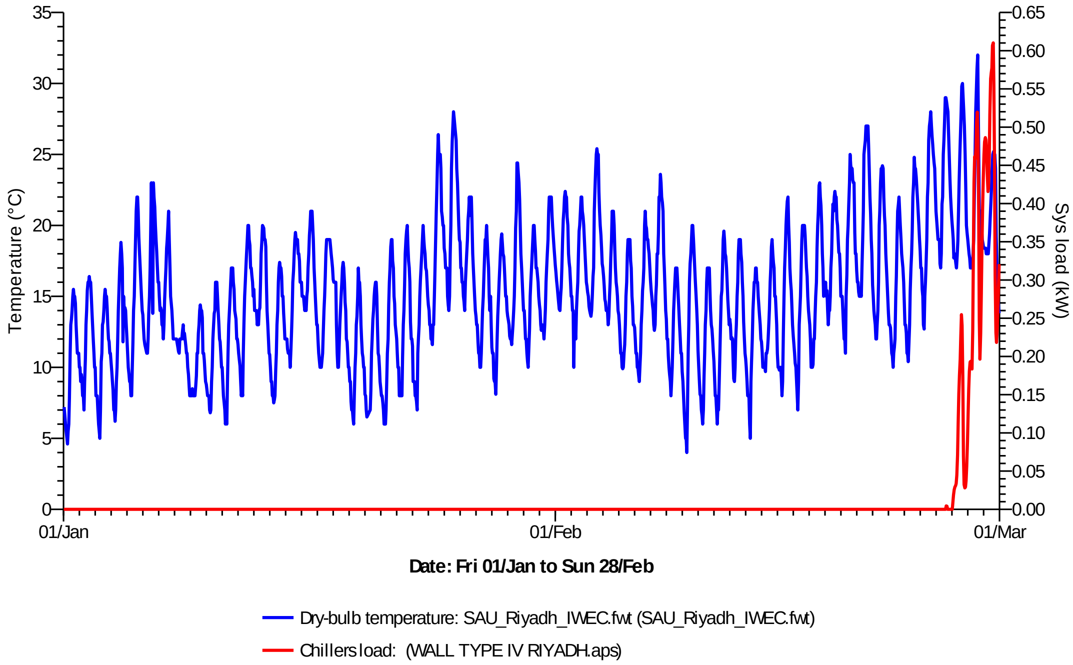


Figure 51: The result of cooling load from 1st of January until 28th of February in Riyadh city for the external wall type IV.

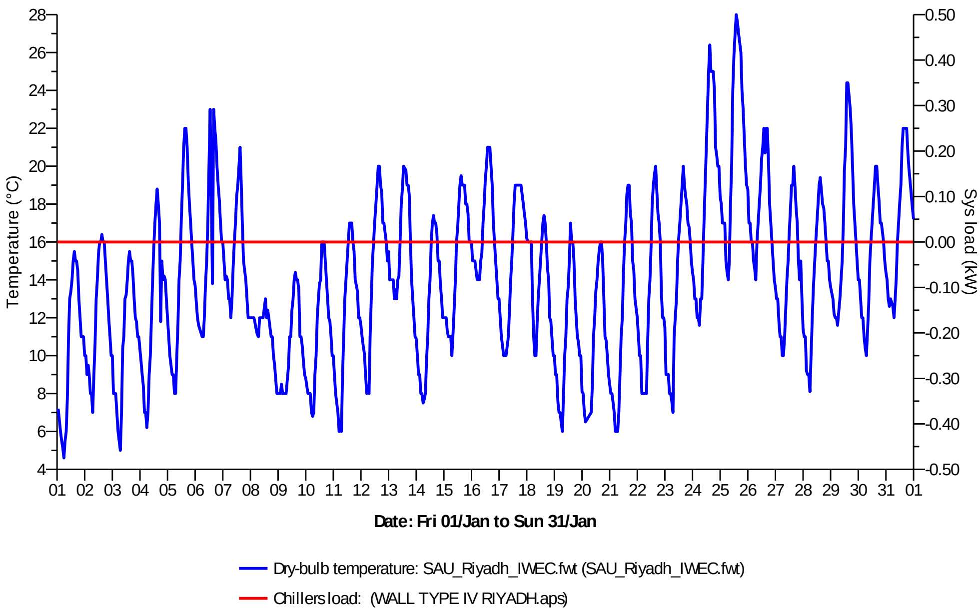


Figure 52: The result of cooling load from 1st of January until 31st of January in Riyadh city for the external wall type IV.

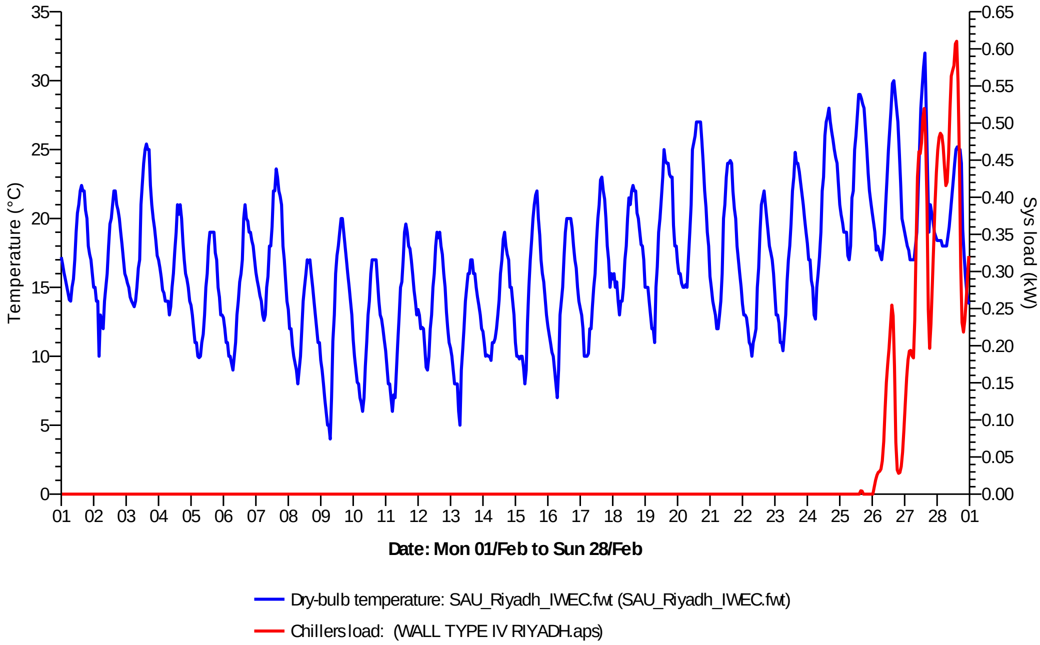


Figure 53: The result of cooling load from 1st of February until 28th of February in Riyadh city for the external wall type IV.

3-Simulation Analysis for the Typical Residential Building in Dammam City

3.1 Wall Type I

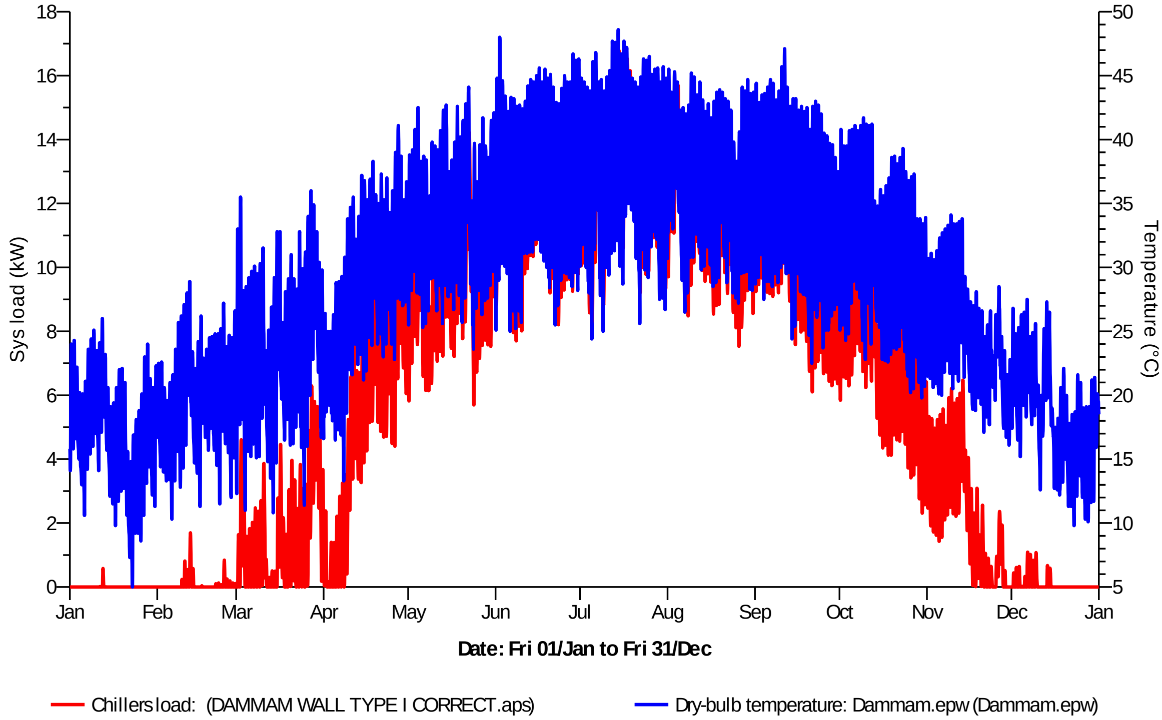


Figure 54: The result of cooling load from 1st of January until 31st of December in Dammam city for the external wall type I.

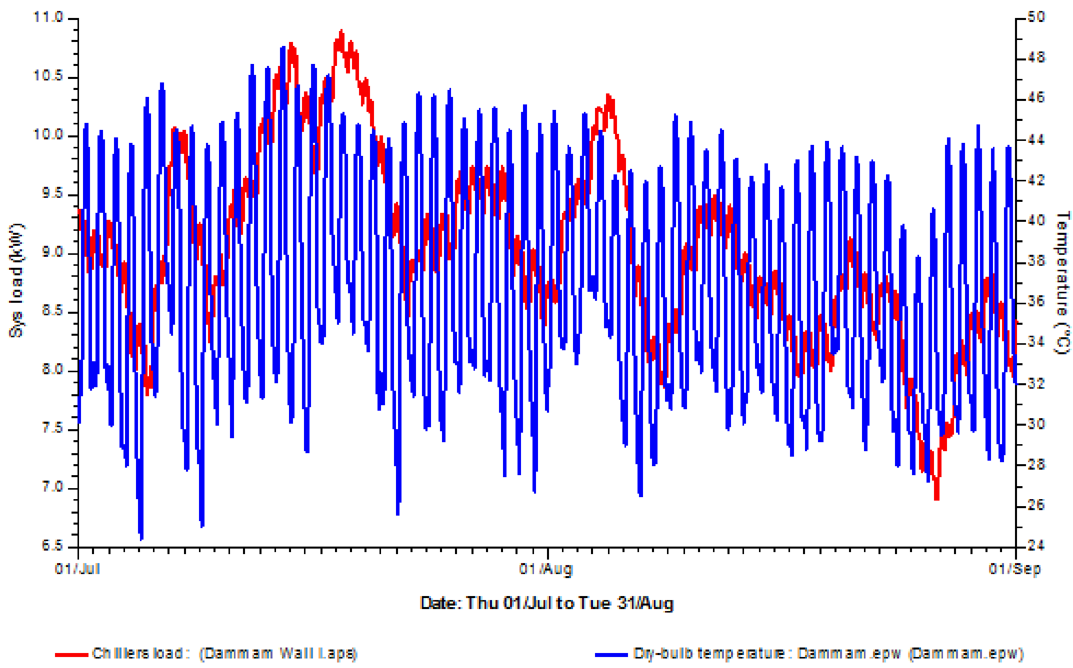


Figure 55: The result of cooling load from 1st of July until 31st of August in Dammam city for the external wall type I.

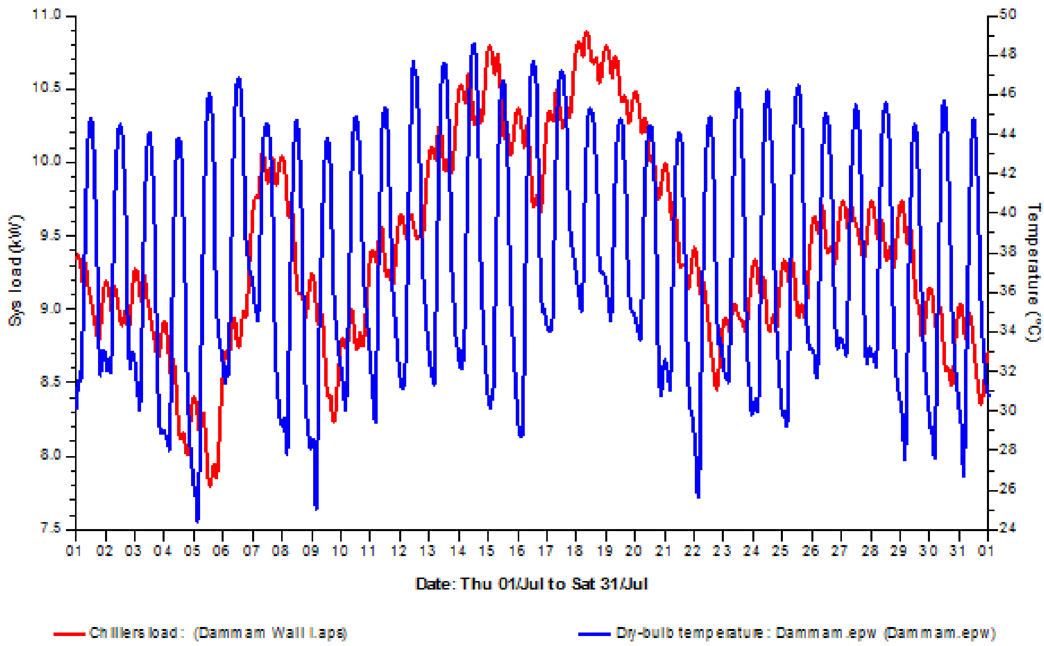


Figure 56: The result of cooling load from 1st of July until 31st of July in Dammam city for the external wall type I.

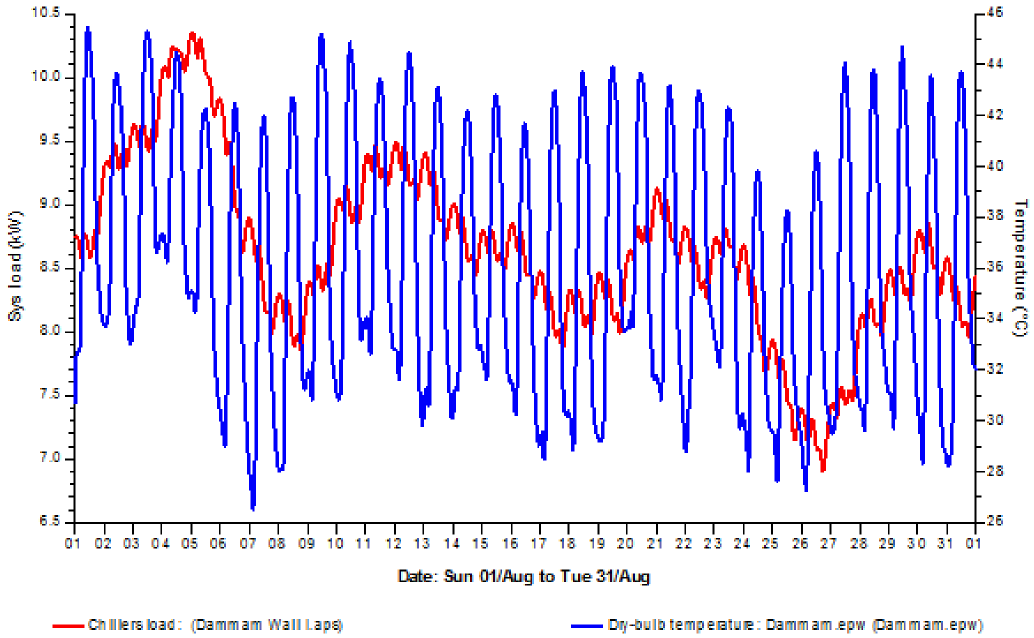


Figure 57: The result of cooling load from 1st of August until 31st of August in Dammam city for the external wall type I.

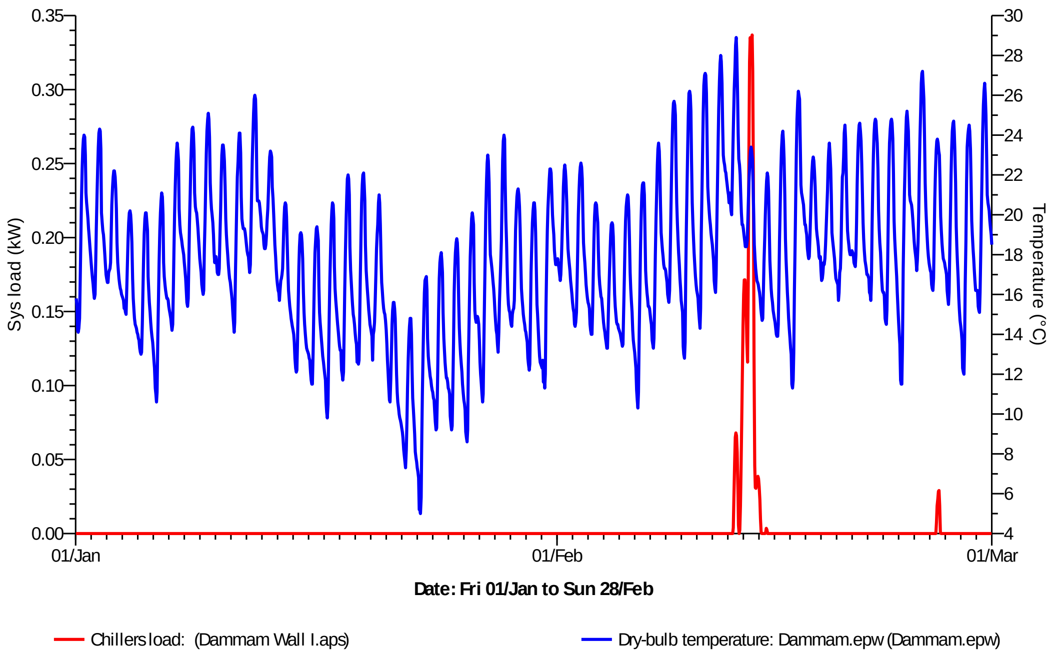


Figure 58: The result of cooling load from 1st of January until 28th of February in Dammam city for the external wall type I.

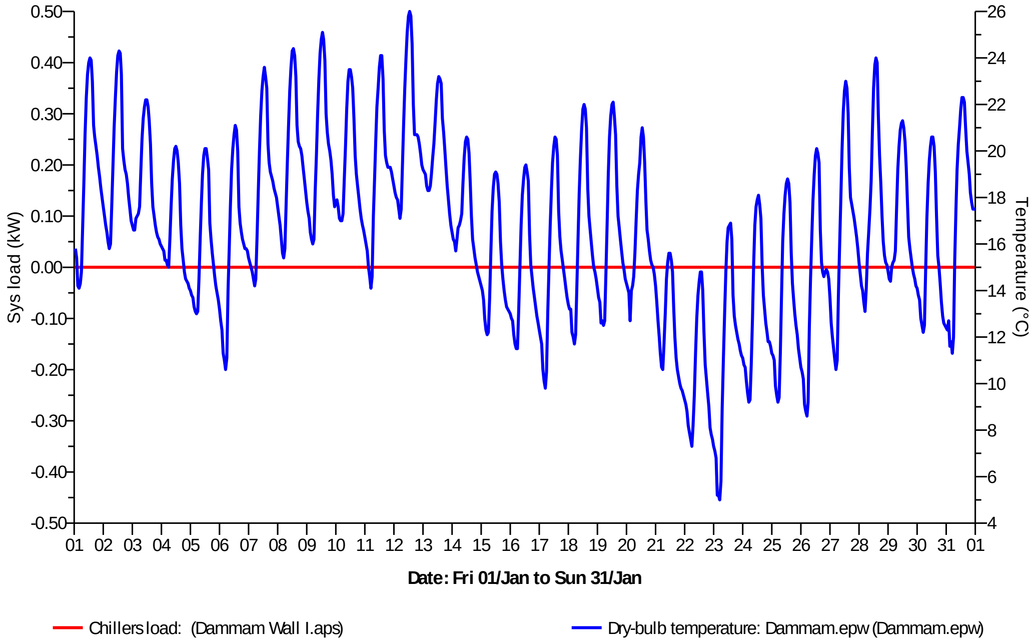


Figure 59: The result of cooling load from 1st of January until 31st of January in Dammam city for the external wall type I.

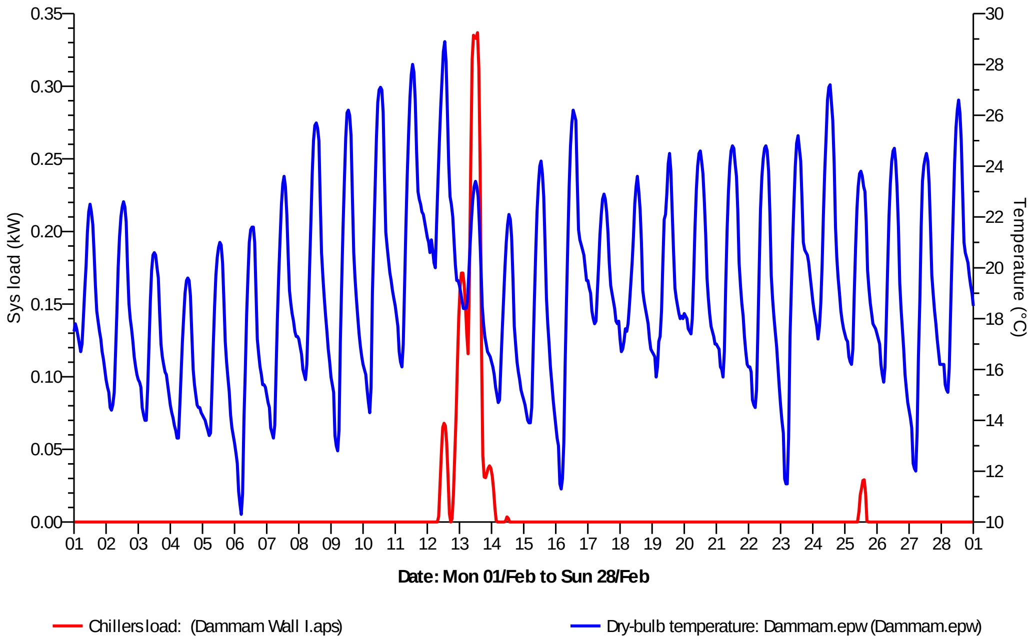


Figure 60: The result of cooling load from 1st of February until 28th of February in Dammam city for the external wall type I

3.2 Wall Type II

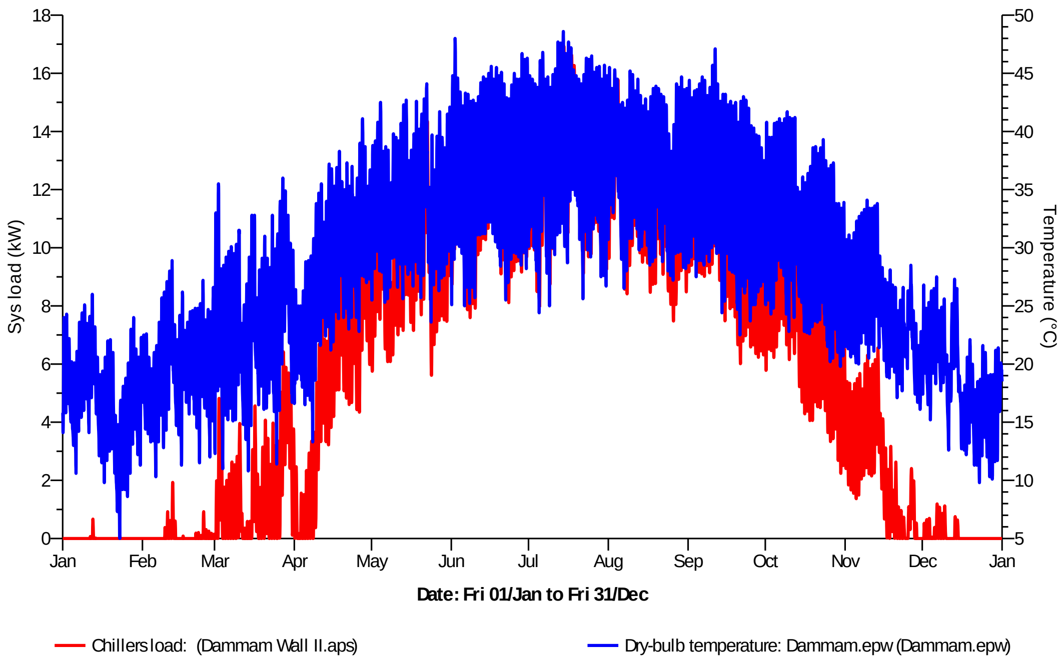


Figure 61: The result of cooling load from 1st of January until 31st of December in Dammam city for the external wall type II.

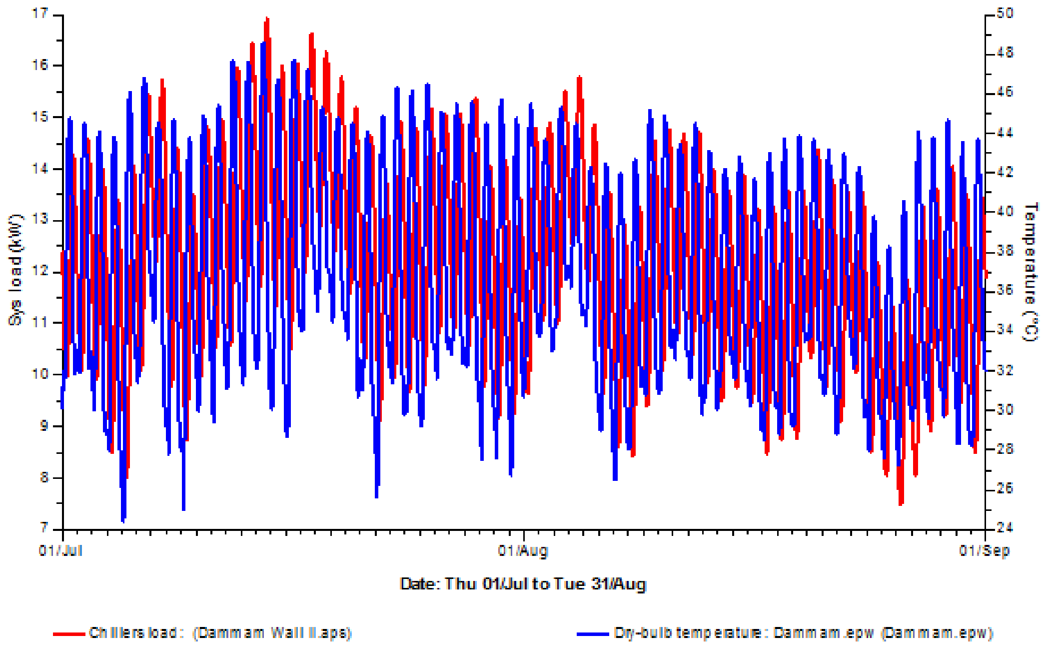


Figure 62: The result of cooling load from 1st of July until 31sy of August in Dammam city for the external wall type II.

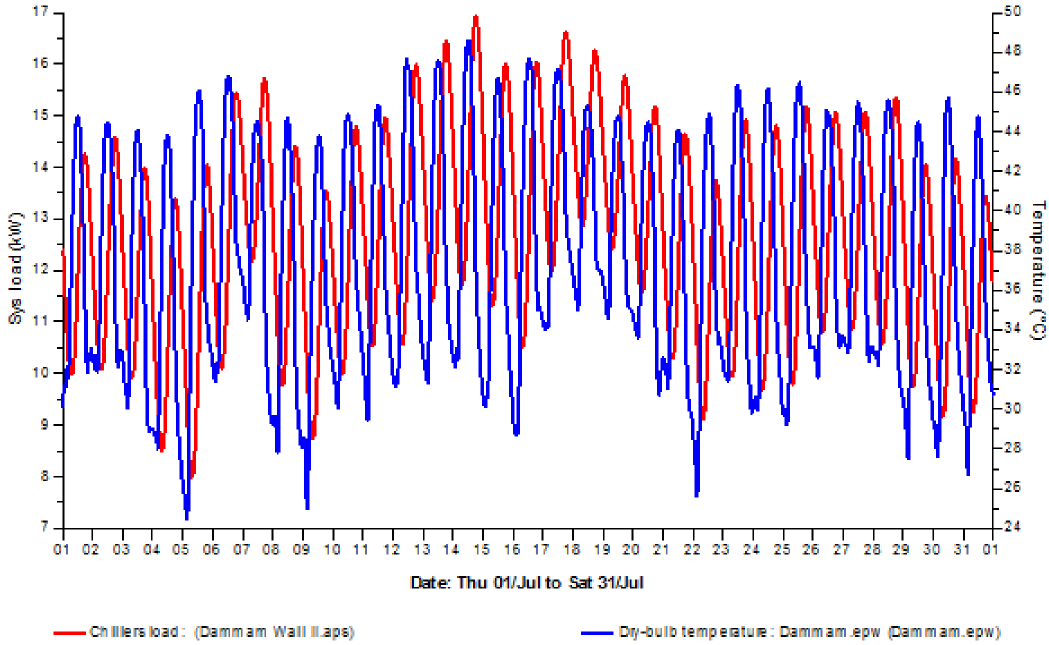


Figure 63: The result of cooling load from 1st of July until 31st of July in Dammam city for the external wall type II.

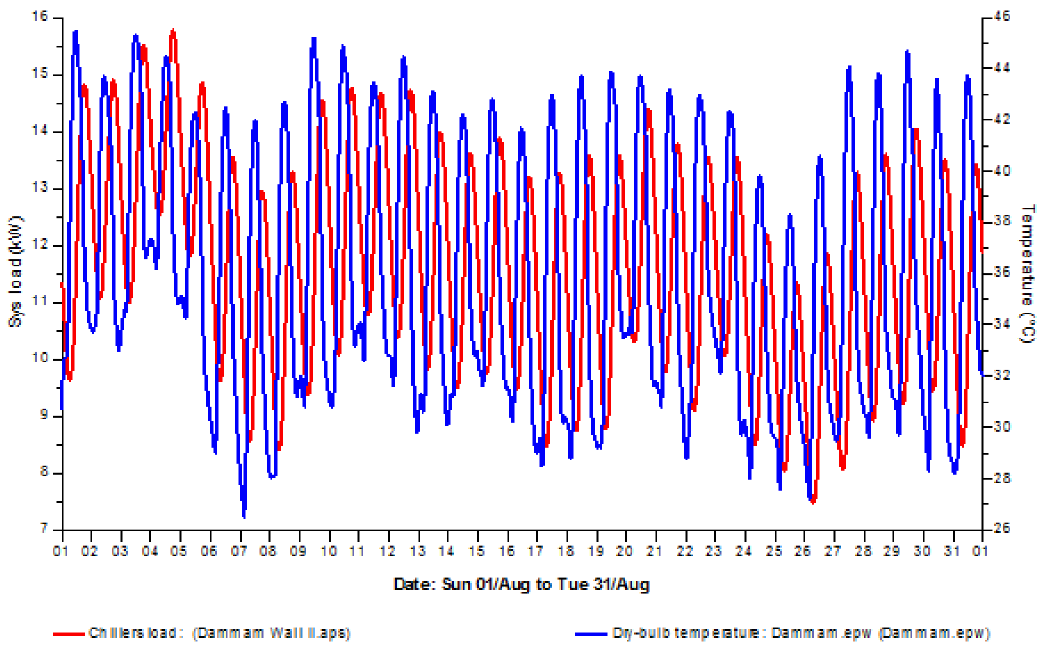


Figure 64: The result of cooling load from 1st of August until 31st of August in Dammam city for the external wall type II.

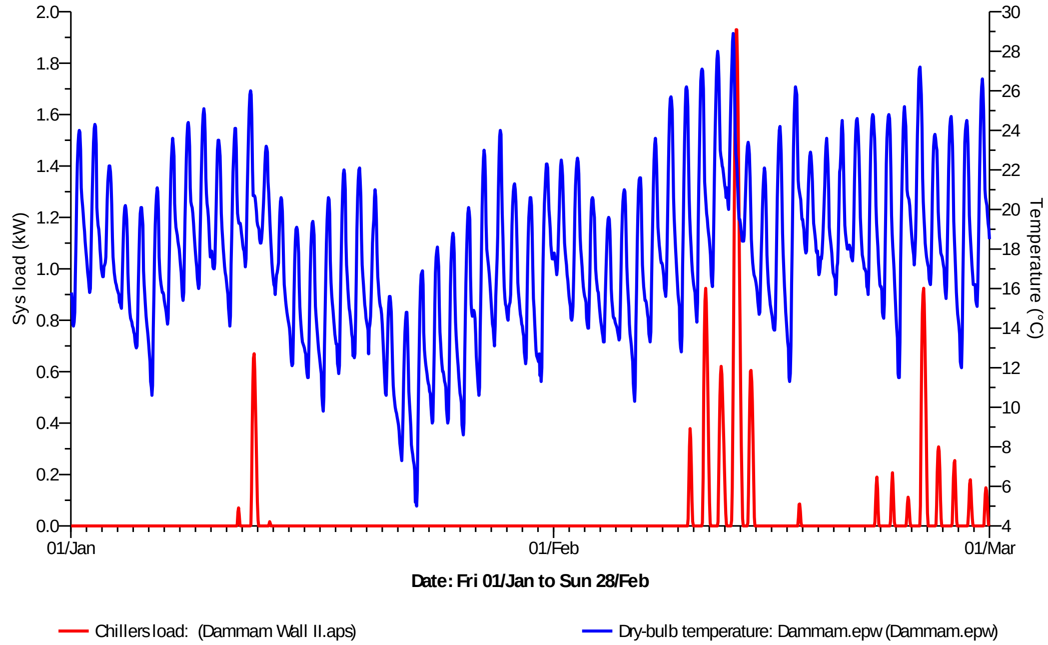


Figure 65: The result of cooling load from 1st of January until 28th of February in Dammam city for the external wall type II.

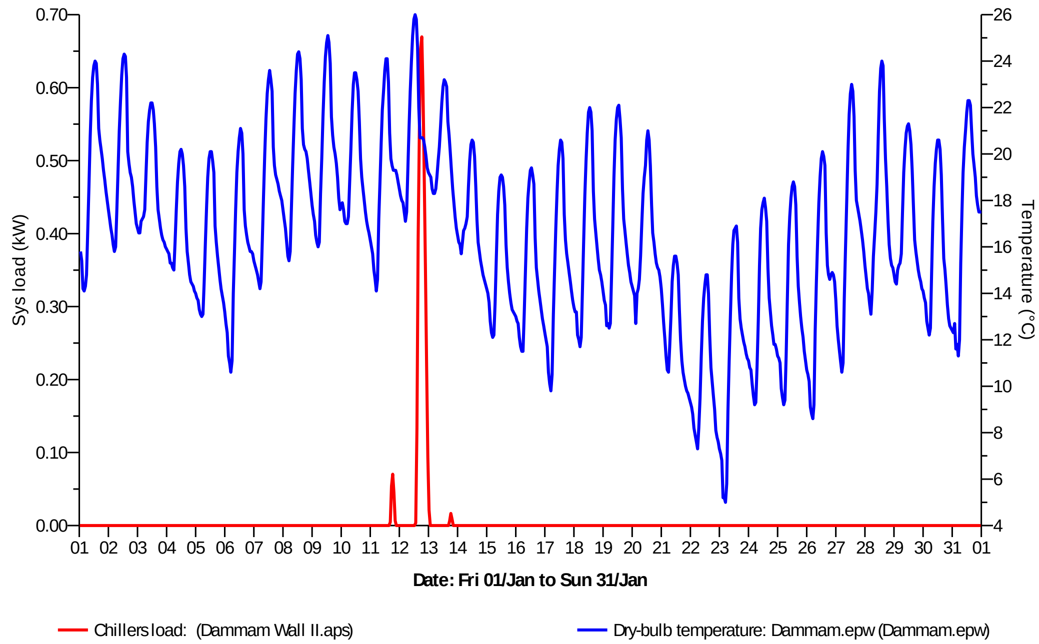


Figure 66: The result of cooling load from 1st of January until 31st of January in Dammam city for the external wall type II.

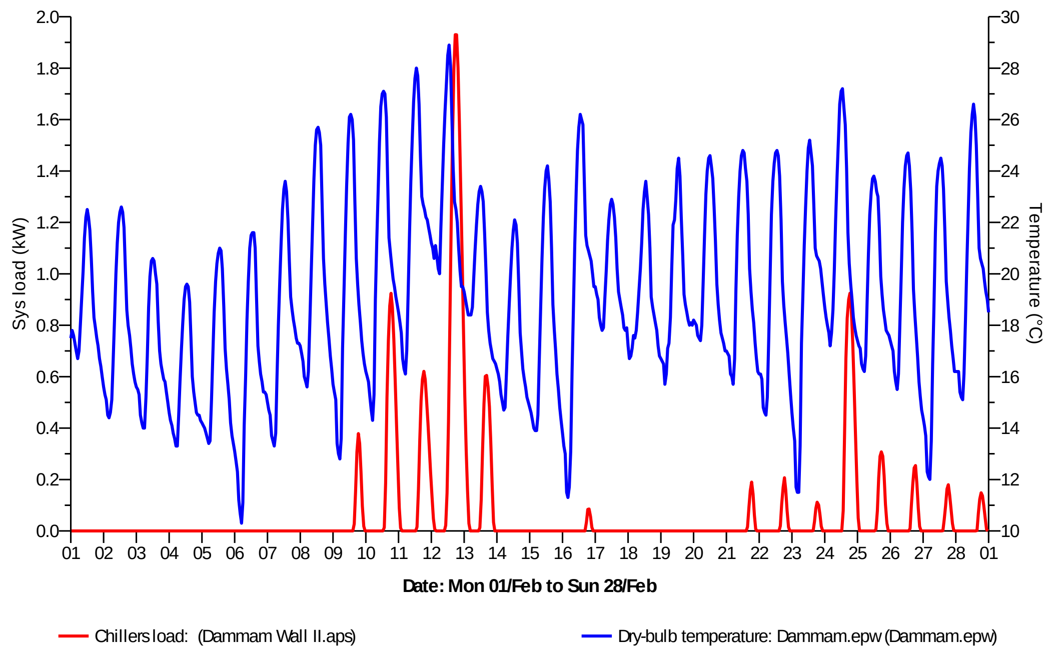


Figure 67: The result of cooling load from 1st of February until 28th of February in Dammam city for the external wall type II.

3.3 Wall Type III

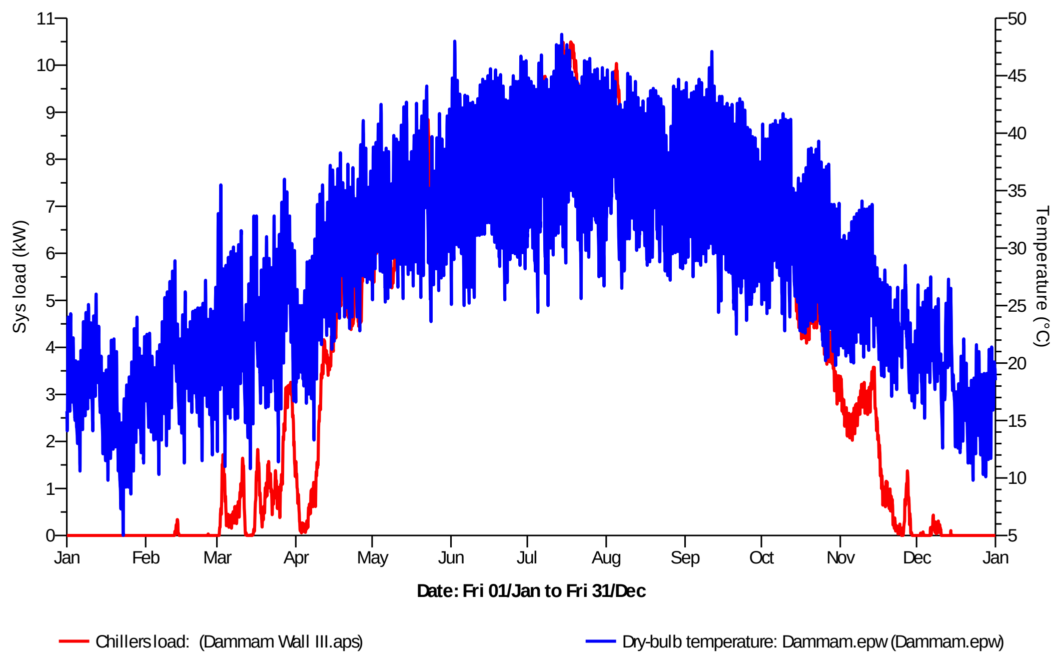


Figure 68: The result of cooling load from 1st of January until 31st of December in Dammam city for the external wall type III.

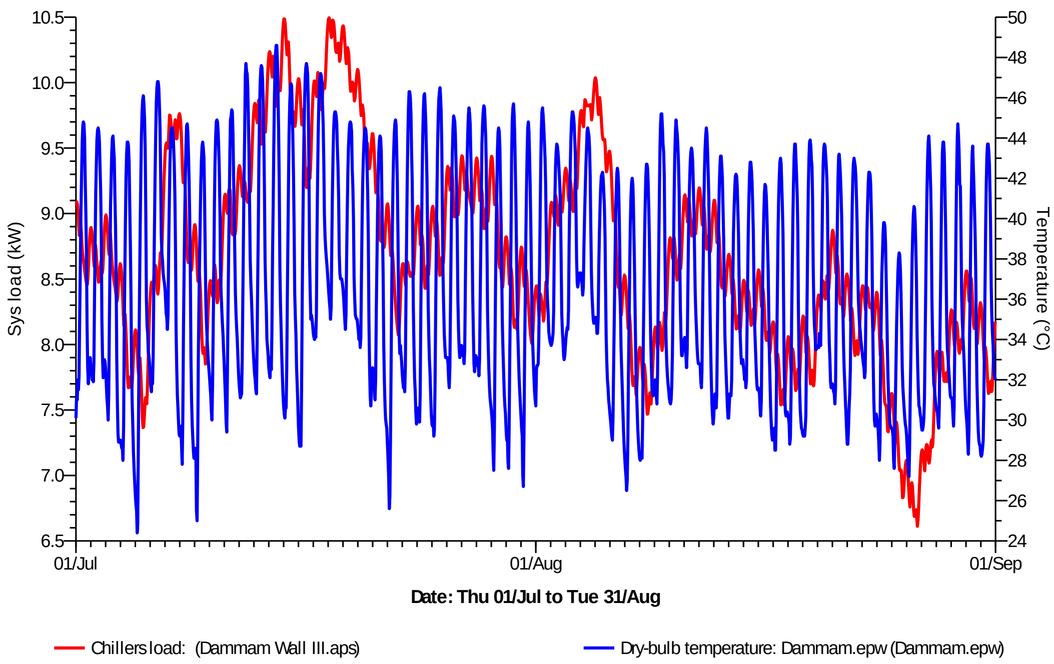


Figure 69: The result of cooling load from 1st of July until 31st of August in Dammam city for the external wall type III.

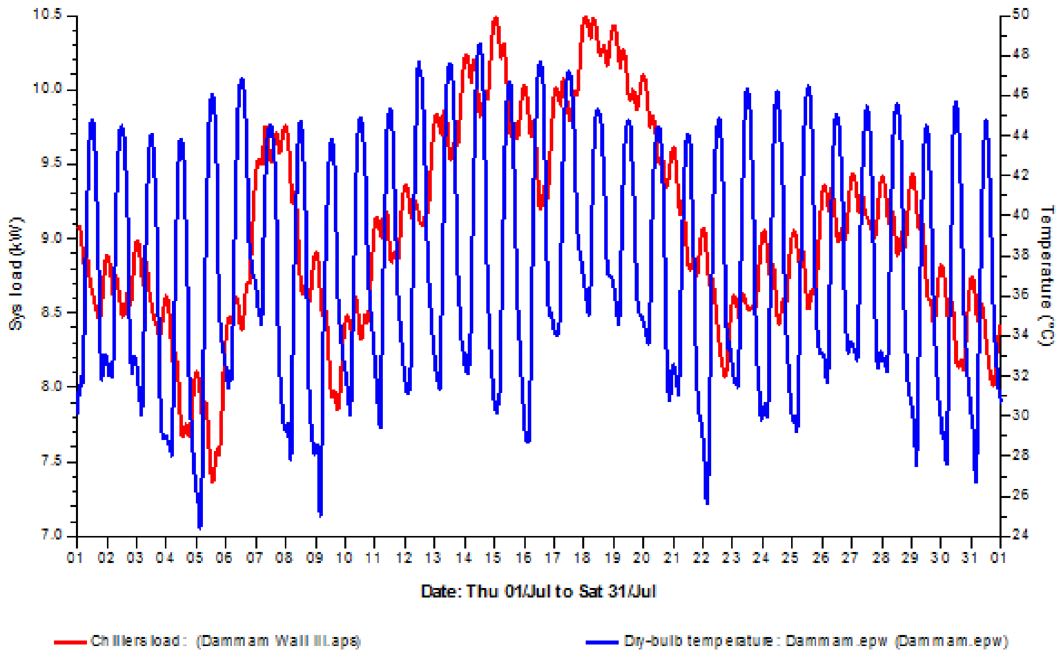


Figure 70: The result of cooling load from 1st of July until 31st of July in Dammam city for the external wall type III.

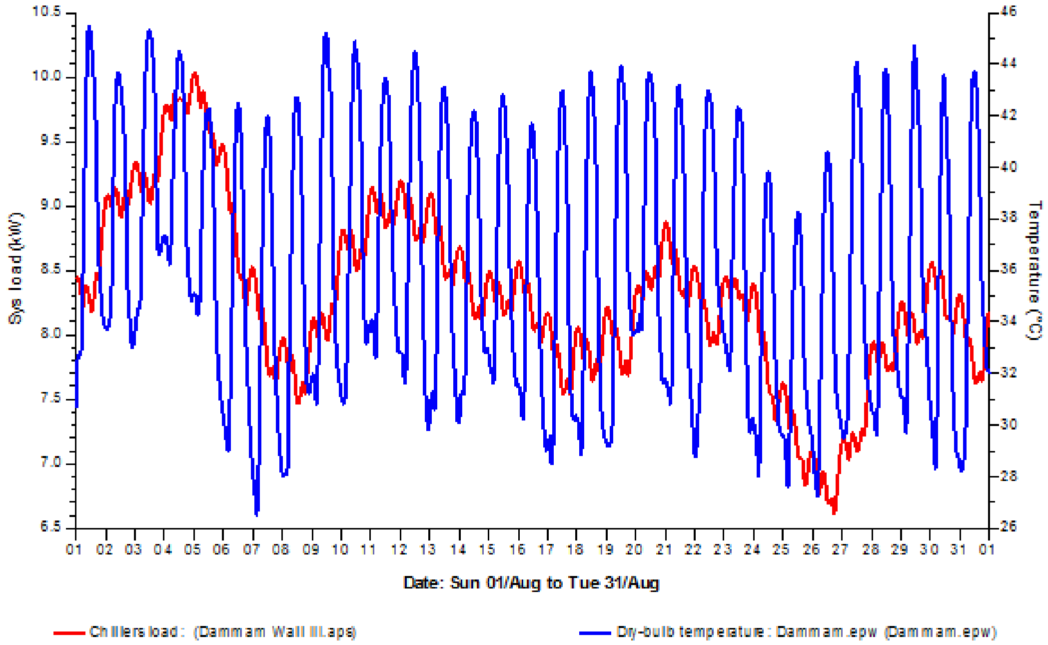


Figure 71: The result of cooling load from 1st of August until 31st of August in Dammam city for the external wall type III.

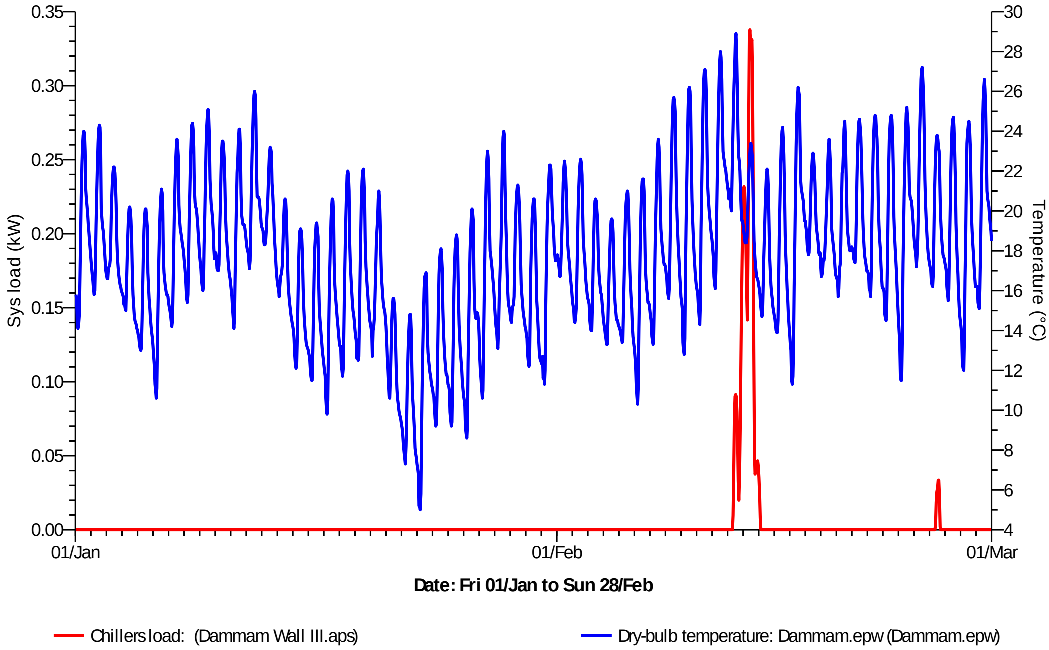


Figure 72: The result of cooling load from 1st of January until 28th of February in Dammam city for the external wall type III.

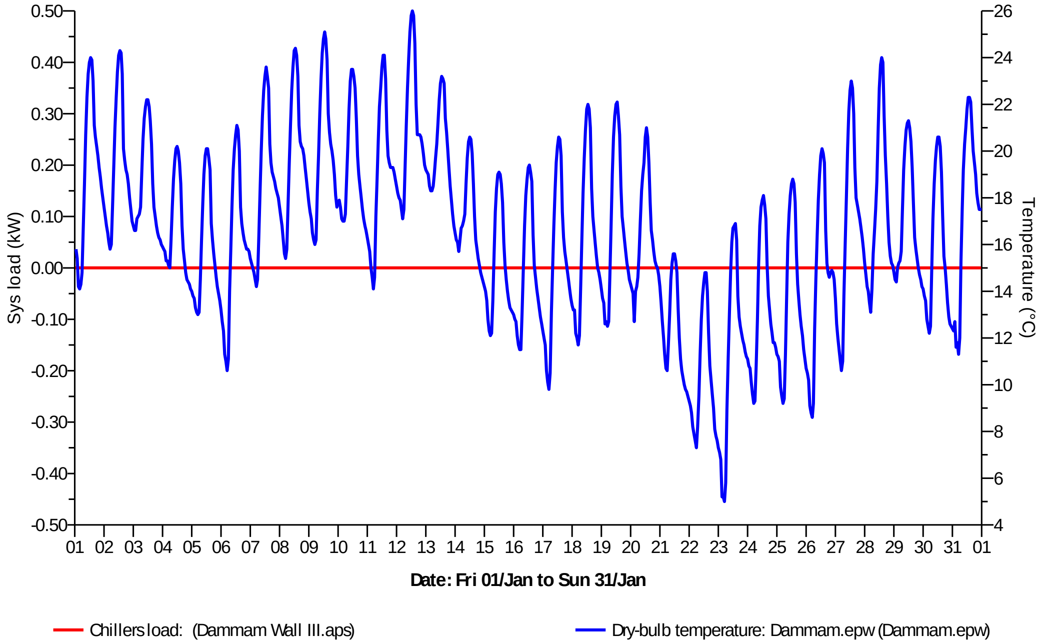


Figure 73: The result of cooling load from 1st of January until 31st of January in Dammam city for the external wall type III.

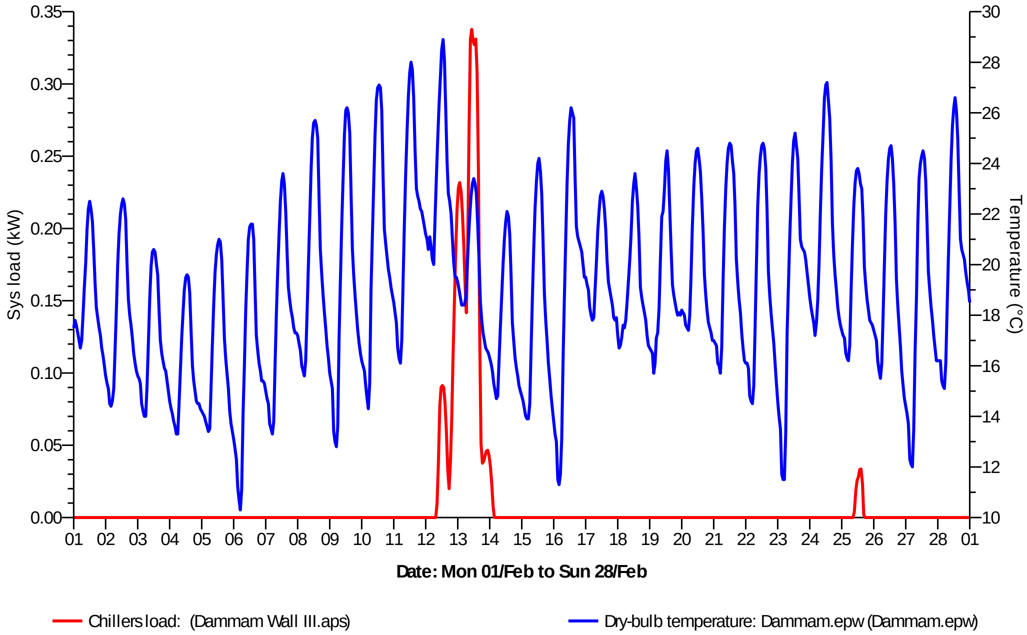


Figure 74: The result of cooling load from 1st of February until 28th of February in Dammam city for the external wall type III.

3.4 Wall Type IV

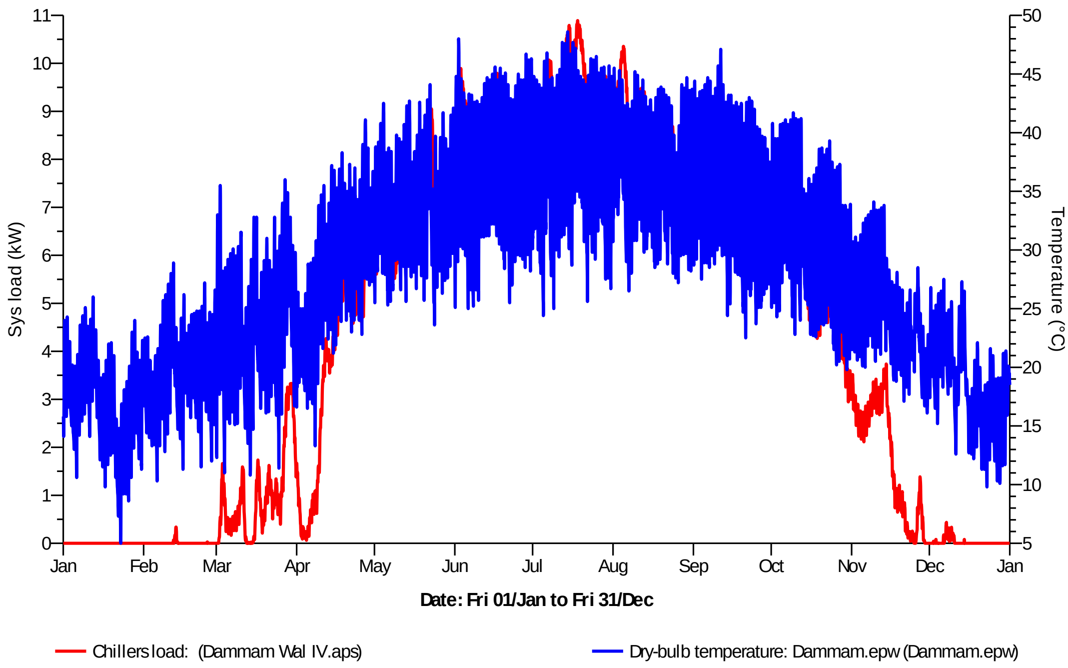


Figure 75: The result of cooling load from 1st of January until 31st of December in Dammam city for the external wall type IV.

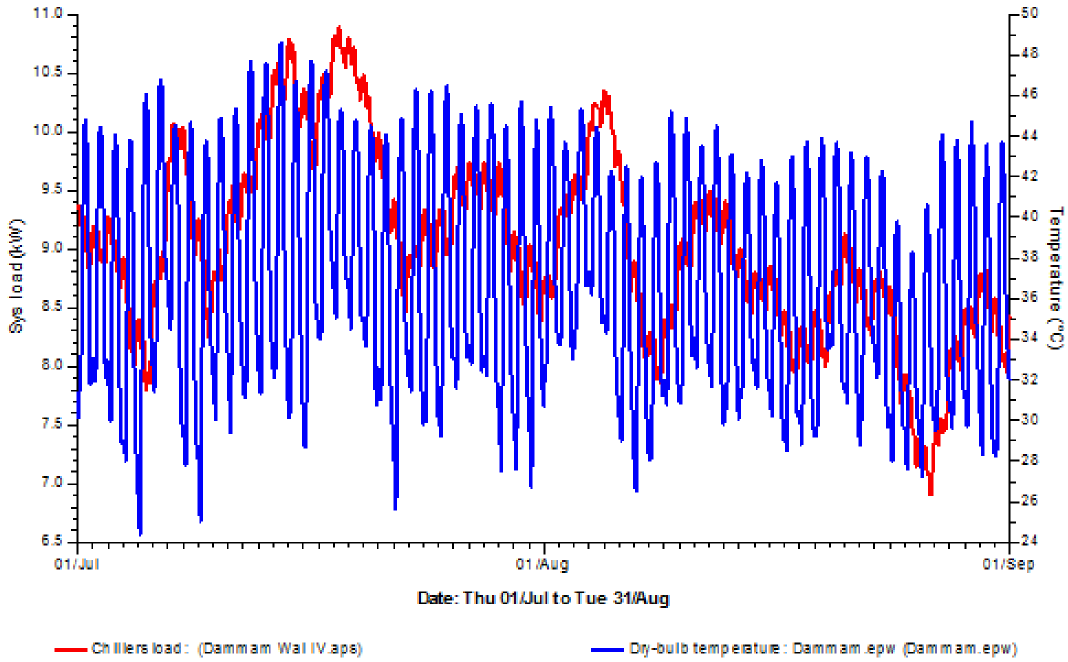


Figure 76: The result of cooling load from 1st of July until 31st of August in Dammam city for the external wall type IV.

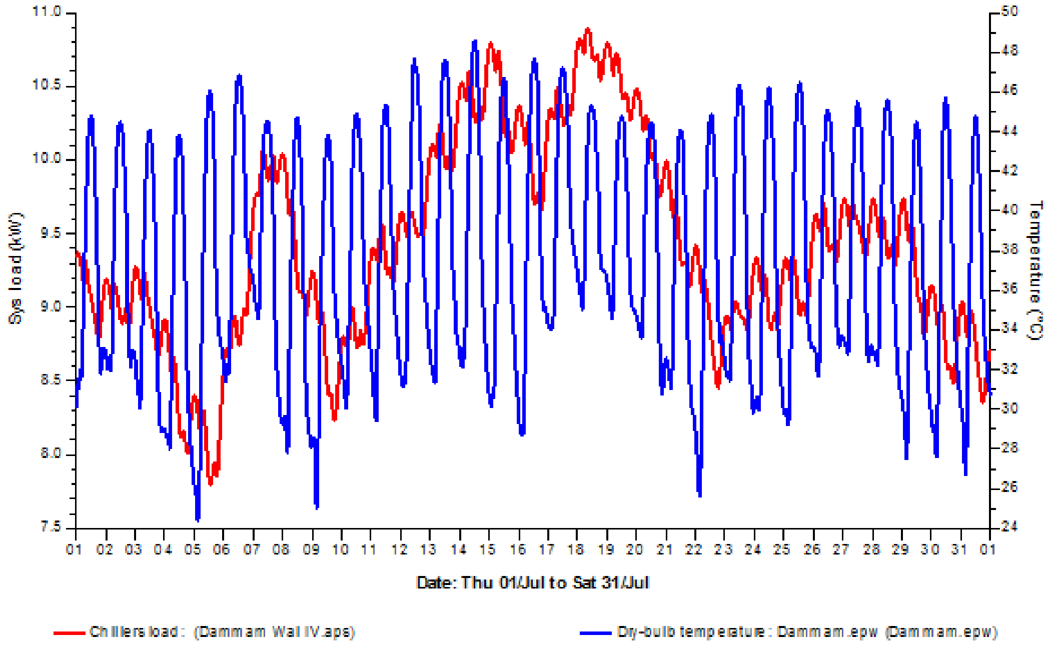


Figure 77: The result of cooling load from 1st of July until 31st of July in Dammam city for the external wall type IV.

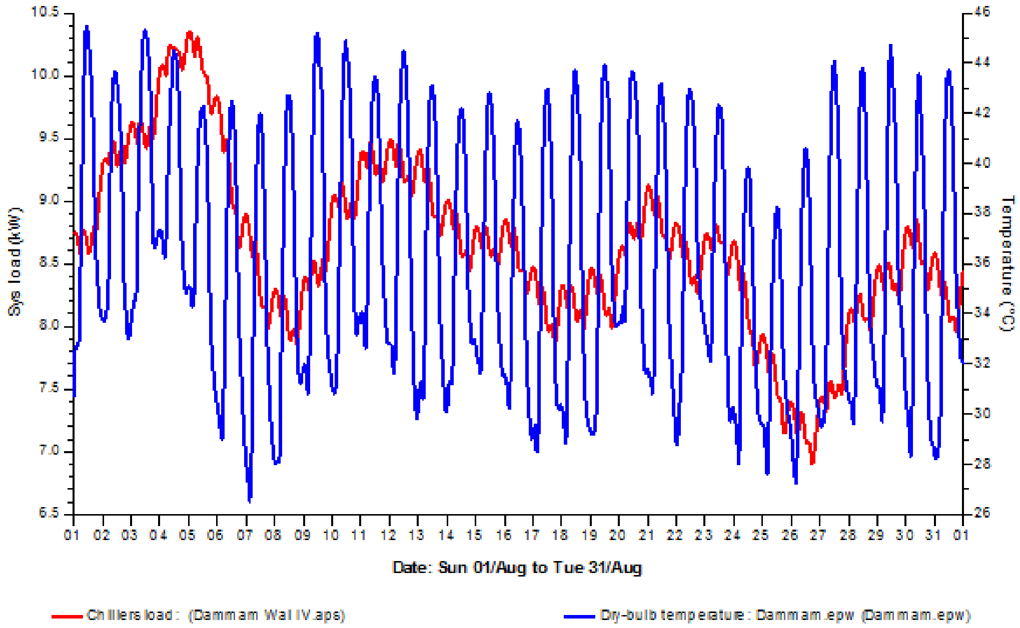


Figure 78: The result of cooling load from 1st of August until 31st of August in Dammam city for the external wall type IV.

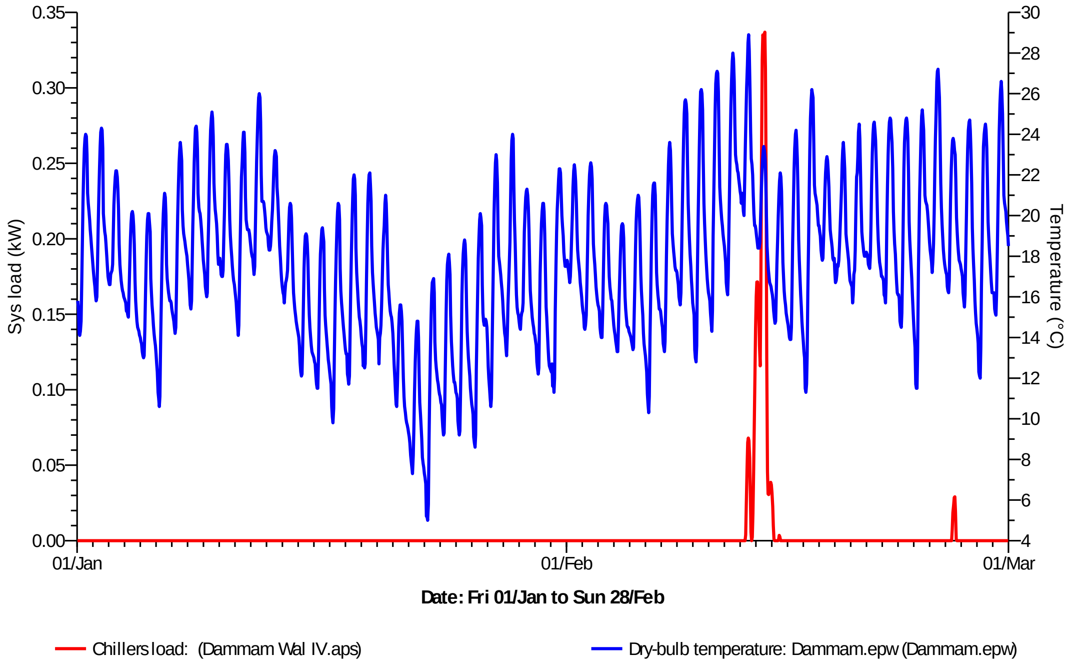


Figure 79: The result of cooling load from 1st of January and 28th of February in Dammam city for the external wall type IV.

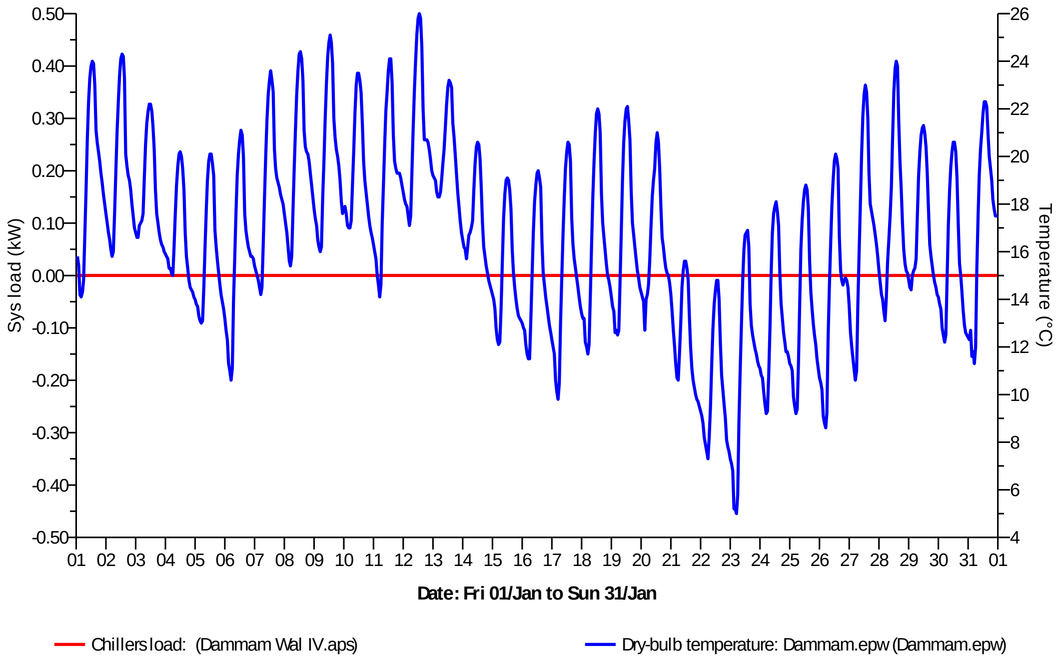


Figure 80: The result of cooling load from 1st of January until 31st of January in Dammam city for the external wall type IV.

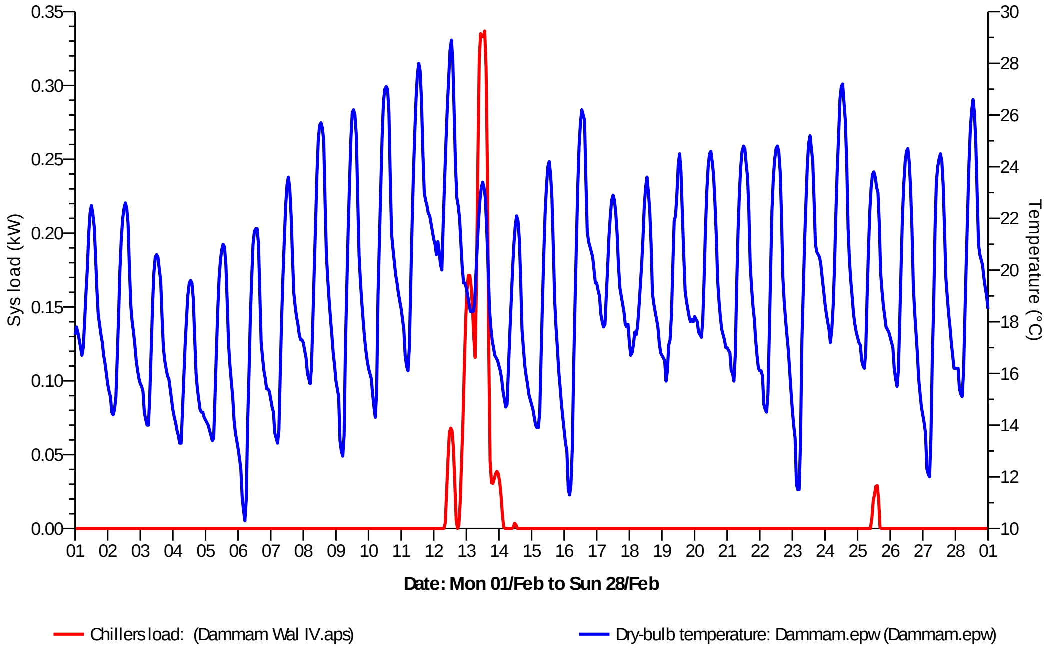


Figure 81: The result of cooling load from 1st of February until 28th of February in Dammam city for the external wall type IV.

Appendix B: Interview Guide and Field Trip Report: This appendix shows a copy of the field trip report as well as the questions sheets for each interview.

Field Trip Report 2013

Green Residential Buildings in Saudi Arabia

Case Study

(The impact of construction and building materials on energy in the Saudi residential buildings)

(Interviews analysis)

01/06/2013 - 31/08/2013

Wasim Jamil A. Lasker

Supervisors

Dr/ Doug Harris
Heriot Watt University

Dr/ Nezar Hashem
Taibah University

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Contents

Acronyms/Abbreviations

HMM Holy Makkah Municipality

SEC Saudi Electricity Company

KACST King Abdulaziz City of Science and Technology

SGB Saudi Green Building Council

KAUST king abdullah university of science and technology

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1.0 Introduction

1.1 Overview

1.1.1 Context of the case study

This case study was undertaken as part of PhD studies "The impact of construction and building materials on energy in the Saudi residential buildings" from several governmental/ private companies in different cities in Saudi Arabia.

1.1.2 Aims of the field trip

The principal aims of the field trip is to understand the present situation of the Saudi residential buildings in the kingdom,explore the most common type of Saudi residential building , find out the methods to build green buildings in Saudi Arabia from specialists point of view, find out how to change the current situation of residential buildings to consume less energy consumer, to know if the Saudi government has plans to save the environment and reduce energy consumption, and finally, to know if Saudi government or companies are following specific building regulation and standards or or the government has its own version.

1.1.3 Field Trip Plan

The field trip started from 01/06/2013 until 31/08/2013. The visits were to different cities and different governmental/ private companies in the kingdom of Saudi Arabia.

The field trip plan was formulated to consider two main sections, Interviews with Engineers, Architects and Representatives who work in this required field and data collection. Collection data aim to collect required data in the PhD studies without meetings or interviews. Moreover, analysis and reporting as an ending stage. Report will consider just the interviews part as it mentioned below:

Activity	Location	Interview date
Visit Makkah Municipality	Makkah- Saudi Arabia	07-06-2013
Saudi Electricity Company	Jeddah- Saudi Arabia	14-06-2013
King Abdulaziz City of Science and Technology	Riyadh-Saudi Arabia	14-07-2013
Saudi Green Building Council	Riyadh-Saudi Arabia	15-07-2013
King Abdullah city	Thuwal -Saudi Arabia	21-07-2013

1.1.4 Field trip changes and limitations

In fact, few changes happened as a result of delay to get an appointments from few companies. Moreover, few companies refused to do interviews. Therefore, an other interviews and meetings with other companies prepared because they were ready to co-operate to fill data needed in PhD research.

2.0 Field Interviews

This report will discuss each visit by presenting the questions that the interviewee been asked during the meeting and his answers. The report organized to give an overview of government/private company. After that an introduction and finally the interview section.

2.1 Name of Visit: Makkah Municipality

Location: Makkah- Saudi Arabia

Date: 07-06-2013

Name of Interviewer: Wasim Jamil Lasker

Name of Interviewee: Engineer Ahmed Al Zhrani.

Position: Site Engineer

Industry: Public Sector

Employees: 3,000

Annual Revenue: Under $100 Million

أمانة العاصمة المقدسة

Purpose of visit: Collecting data about the types of Saudi Residential Buildings.

2.1.1 Overview

Holy Makkah Municipality (HMM) is a government organization of Saudi Arabia.

The organization runs more than 30 business applications that address the needs of major municipal operations and services, such as issuing licenses for construction and professionals, and managing the municipality's financial, human resources, and payroll processes. However, its legacy systems had limited integration, driving the need to

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transform and deliver most municipal services as e-services. HMM wanted to use the latest technologies and focus on best practices and methodologies, such as those developed for the Information Technology Infrastructure Library (ITIL), business process modeling (BPM), and program management organization (PMO).

Holy Makkah Municipality established a multichannel platform, based on Oracle's Siebel Customer Relationship Management (CRM) 8.1 and other Oracle products to automate processes, ensure digital collaboration with engineering offices, and enhance the quality of the services it delivers to professionals and the public. HMM also integrated Siebel with the geographical information system developed by Oracle Partner Omnix International, which produces geographical information on top of a map of the Makkah region to complement discrete reports and substantially enhance HMM's analytical capabilities.

2.1.2 The Interview section

The interview was with a representative of Makkah Municipality in the main building. Few questions been asked to fill the data needed in PhD studies. The interview started by asking about the average of the Saudi family members to know the size of the Saudi family and residential space required.The answerwas five persons as an average in the Saudi family. The next question was about the number of residential buildings in Saudi Arabia recently. The interviewee provided a table explain the numbers of residential buildings in Makkah region as follows:

City / Town / Village	Numbers of residential buildings
Jeddah	702547
Makkah	291468

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City / Town / Village	Numbers of residential buildings
Taif	177408
Qunfza	54170
Allith	23936
Rabee	18600
Algamom	18269
Klhis	11759
Alkamel	4878
Al Khurma	7949
Rance	8005
Turba	8698
Total for Makkah region	1327667

The following question was about the expected percentage for increasing numbers of Saudi residential buildings in the next 10 years. It is very difficult to answer this question he said.

The types of residential buildings was the next question as this question is very important in this field of study. Theinterviewee mentioned that the country of Saudi Arabia has four types of residential buildings as following : Apartments blocks four storey, Apartments blocks two storey, Duplexes and Houses (villas), and he reported that all regions in the kingdom has the same categories of residential buildings.

To focus on the most type of residential building in the kingdom in this study the interviewee asked What is the most prefered type of residential buildings in Saudi Arabia? He replied without doubt houses are the most preferred type in Saudi Arabia as they are the most existing type of Saudi residential buildings.

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The last question with Makkah municipality representative was about the average, of the prices for owning/ renting residential flat/ villa/ other and if there is any government facts to support the answer. For owning flats it is start from 350,000 SR = 58,333 GBP, Houses on the other hand start from 1000,000 SR = 166,666 GBP. renting is different from a city and from a place to another so it is difficult to tell. and yes we do have a governmental facts to support the answer he said.

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الشركة السعودية للكهرباء
Saudi Electricity Company

2.2

Name of Visit: SEC (Saudi Electricity Company)

Location: Jeddah branch-Saudi Arabia

Date: 14-06-2013

Name of Interviewer: Wasim Jamil Lasker

Name of Interviewee: Sami Refaee

Position: Electrical Engineer

Purpose of visit: Collect data about energy consumption/demand and methods to save energy in Saudi buildings.

2.2.1 Overview

On 05/04/2000, our company was established as a Saudi joint stock company with a paid-up capital of SR 33,758,632,650 (Thirty three billion seven hundred fifty-eight million six hundred thirty-two thousand six hundred and fifty Saudi Riyals). This amount divided into 675,172,653 shares (Six hundred seventy-five million, one hundred seventy-two thousand six hundred and fifty-three shares).

This achieved by virtue of the Cabinet Order No. 169 Dated 11/08/1419H. which stipulated the merger of all Saudi electricity companies in the Central, Eastern, Western and Southern Regions in addition to the ten small companies operating in the north of the Kingdom as well as all other electricity operations managed by The General Electricity Corporation, into a single joint stock company which is now known as Saudi Electricity Company. After the accomplishment of the merger process, we adopted a gradual, systematic approach to the re-development and consolidation of the organizational structure of the Company to make sure constant provision of the electric power services, taking into consideration maintaining the electricity system's reliability, the quality service provided to our customers and ensuring the human resources adaptability to change to meet our strategic goals and our shared vision.

At the beginning of 2002, the Board of Directors approved the new phase-based organizational structure, which was mainly designed by specialized activities including the organizational units (Electricity activities), related activities and supporting services to reinforce our overall performance on the level of all our activities. This helps us to set out the future orientations required for the potential wide-ranging change.

On 01/01/2003, the phase-based organizational structure was put into effect in addition to the application of the second level of the structure. The sectors and departments specified and their respective job descriptions outlined. Thereafter, we completed the job descriptions related to all organizational levels.

In the First Of January 2012, National Grid sa Was established, With the aim of liberating the industry of electricity; and forming specialized companies to create competitive environment, Improving performance, and reducing the cost. As a result the structure of the Saudi Electricity Company amended As follow:

2.2.2 The Interview Section

The second interview was with a representative of Saudi Electricity Company (SEC) in Jeddah branch. The interviewee was asked several questions to get the required data.

The first question in this interview was about the reason that make Saudi government just depending on oil for the last decades. The interviewee replied, Saudi Arabia is a very rich of oil , it is the main source for energy and finally, it is very cheap to use local energy purposes.

The following question was about the major energy-saving concern for Saudi electricity company. The representative explained that the major concern is cooling systems, because it is constitutes to be the main energy consumption in Saudi Arabia.

The next question was about the most months that consume energy in the year in the kingdom. He replied that 80 % of power in Saudi Arabia being consumed between June and October.

It is very important to know if Saudi electricity company has plan or strategies to reduce energy consumption that depend on oil. Therefore, interviewee been asked to answer this question. He answered Yes, using renewable energy and we have a several contracts with different companies and organizations to get the benefits of renewable energy, specially solar power.

The other important question was if Saudi electricity company has expectations for electricity demand in the nearest future. He said yes, electricity demand will almost triple within 20 years to 120,000 megawatts by 2032 from around 46,000 in 2010.

the next question to the representative is to know if Saudi government still just want to depend on oil to produce energy in the next 10 years. The answer is no , Saudi government wants a diversity energy, because of continually rapidly growing demand of energy.

SEC representative been asked about the methods to reduce energy consumption of an existing Saudi residential building.He answered the question and mentioned that The easiest way is to apply them insulation walls, roofs, shade devices, and to have windows that help to decrease heat in houses.

The last question in this interview was if Saudi government has any of kind co-operation with an international company. The answer was yes, with JETRO (Japan External Trade Organisation).

2.3

Name of Visit: KACST (King Abdulaziz City of Science and Technology)

Location: Riyadh-Saudi Arabia

Date: 14-07-2013

Name of Interviewer: Wasim Jamil Lasker

Name of Interviewee: Ahmad Al Ghazi

Position: Architectural Engineer

Purpose of visit: Collect data related about Energy strategies and plans for the future in the Kingdom of Saudi Arabia.

2.3.1 Overview

King Abdulaziz City for Science and Technology (KACST) is an independent scientific organization administratively reporting to the Prime Minister. KACST is both the Saudi Arabian national science agency and its national laboratories. The science agency function involves science and technology policy making, data collection, funding of

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external research, and services such as the patent office. KACST has currently over 2500 employees. Based on is charter 31.I.2.1.985, KACST's main responsibilities summarized as follows:

Main Responsibilities:

1. Propose a national policy for the development of science and technology and develop strategies and plans necessary to implement them.

2. Coordinate with government agencies, scientific institutions and research centers in the Kingdom to enhance research and exchange information and expertise.

3. Conduct applied research and provide advice to the government on science and technology matters.

4. Support scientific research and technology development.

5. Foster national innovation and technology transfer between research institutes and the industry.

6. Foster international cooperation in science and technology.

Strategic Objectives

- A sustained planning mechanism for all scientific disciplines.
- Scientifically knowledgeable and capable government agencies.
- A developed R&D infrastructure with fully functioning centers of excellence in all scientific disciplines.
- Strong interaction between the private sector and research centers.
- Regional leaders in patent ownership and issuance. Advanced incubator systems and output.
- World leaders in strategic technologies including water and oil and gas.
- Enhanced interaction networks between all scientific agencies.

2.3.2 The Interview Section

The Thired interview was with a representative of King Abdulaziz City of Science and Technology (KACST) in the main building in Riyadh . The interviewee was asked many different questions to get the needed data for the research.

The first question in this interview was about the reasons that made the development of energy technology so important to Saudi Arabia. The KACST representative said that energy is one of the crucial drivers of the nation's development and economic growth. The demand for energy in the Kingdom is a challenge for the nation to keep up with. It is estimated that the demand for electricity alone is increasing by over 6% a year. Science has to offer many different solutions to keep pace with this growing demand.

The representative asked to give his point of view about the most types of building that consume the most of energy in the country. The representative pointed that based on their research it is very clear that residential buildings are the most energy consumer. They consume 53% of the total energy.

The next question was if KACST has plans about increasing demand of energy in the kingdom and reducing damage to environment. Yes they do have plans to develop solar-powered using advanced nanotechnologies, because by using this devices the cost will be less than 30 halals oer kwh (about half UK pennie).

After that, the question was if KACST always interested in renewable energy, and about the renewable energy resources in the Kingdom. He replied that the Kingdom receives 105 trillion kilowatts of sunlight per day, which means that Saudi Arabia gets some of the most intense sunlight exposure on the planet. The country listed as one of the top five places in the world for potential photovoltaic generation of electricity. That means that sunlight rather than oil may prove to be the Kingdom's greatest natural resource.

The following question was about the methods that Saudi Arabia is using to reduce its energy consumption. He said The key to reducing energy consumption in the Kingdom is reduction of 'Peak Load'. Currently in Saudi Arabia, around 10 % of all electricity generated and 25 % of distribution infrastructure, are used for just 400 hours per year, that's around 6% of the time – this period of time is known as peak load. New technologies promise to provide much-needed relief in this area by better informing customers of how they can reduce their demand in peak load times, and of the tangible immediate benefits they can receive financially and environmentally in terms of lower bills and improved air quality. Even a small reduction in peak load can result in savings of billions of dollars in infrastructure investment. Peak demand forecast is expected to grow by over 60% until 2021.

An important question was the next about the ways and methods to improve the energy efficiency of existing buildings based on their researches and experience.

the representative replied that Green building reduces energy consumption in many ways. First, the embodied energy of the building can be reduced through efficient design, use of recycled and local materials, and recycling construction waste. Second, green building design reduces a building's energy consumption over its lifetime. Strategically placing windows and skylights can eliminate the need for electrical lighting during the day. A whole house fan can cool the house overnight, rather than relying on air conditioning. High quality insulation reduces temperature regulation costs in both summer and winter.

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Additionally, houses can maximize passive heating and cooling. South facing windows with overhangs can reduce heating costs by 20 to 30%, and prevailing breezes, shading, and natural plantings can keep houses cooler in the summer. And, going one step further, it is possible to create zero energy buildings these are structures with an onsite source of renewable energy such as solar panels or wind turbines.

The last question was if KACST collaborating with international partners in developing energy technology. Interviewee answered that KACST Energy Technology Program is working with scientists and organizations around the world. The 2012 Saudi Energy Efficiency Workshop was organized in partnership with the US National Renewable Energy Laboratory, and is working on another project focusing on sustainable resources with MIT, in their joint Centre of Excellence for Complex Engineering Systems.

2.4

Name of Visit: Saudi Green Building Council

Location: Riyadh-Saudi Arabia

Date: 15-07-2013

Name of Interviewer: Wasim Jamil Lasker

Name of Interviewee: Saad Al Harthy

Position: Architectural Engineer

Purpose of visit: Collecting data about green buildings projects in the Kingdom.

2.4.1 Overview

SAUDI GREEN BUILDING FORUM is an initiative under the appointment of King Abdullah bin Abdulaziz of Saudi Arabia Royal Decree No. 7095/mb dated 5/10/1431 A.H., inaugurated by the official patronage of His Royal Highness Prince Dr. Mansourbin Miteb bin Abdulaziz, Ministry of Municipalities & Rural Affairs. The SGB FORUM's Conference, Education, Resources and Projects developed under the leadership of faisal alfadl PARTNERS permitted by Royal Decree Approved by the Ministry of Commerce & Industry 2010-2013.

SGB FORUM's Goals/ Objectives are: Aid the development of laws and regulations promote Green Building initiatives in Saudi Arabia; Promote the comprehensive collection of standards and systems for Green Buildings in the Kingdom; Define Building Information Modeling based on Green Building guidance; Strengthen relations among industry stakeholders; Deliver information, analysis and insights through high-quality workshops; Promote Green Building concepts and find positive policies relevant to Saudi Arabia and the region that preserves the urban heritage while incorporating new advancements; Build a cultural awareness of Green Building and sustainability initiatives.

SGB FORUM's Conference identify the emerging investment and employment opportunities associated with Green Building, strategically aligned in-conjunction with Government and Non-Government in addition to private sector sponsors from national and international organised by MEED® events.

SGB FORUM Education is recognized by the U.S. Green Building Council as an Authorised Education Delivery Partner run by USGBC® Faculty to provide LEED® Workshop sessions out of Riyadh, Saudi Arabia serving globally.

SGB FORUM Projects are supported by fa Engineering Consultants with leading consultants for high performance and efficient buildings pursing certification.

SGB FORUM Resources are presented by leading sponsors developers, contractors and vendors active in the delivery of sustainable eco-friendly Goods and Services.

2.4.2 The Interview Section

The Fourth interview was with a representative of Saudi Green Building Council (USGBC) in Riyadh. The aim of the interview is to Collect data about green buildings projects in the Kingdom.

The first question in this interview was about SGBC aims. The representative of SGBC informed that the aims of SGBC is to transform the way buildings are designed, built and maintained by leading the way in promoting, advising and educating all stake holders to carry out best practices to meet environmental sustainability.

The second question was about to know if there is any green building existing in the kingdom of Saudi Arabia. Theinterviewee replied to the question by saying yes, KAUST

(King Abdullah University for Science and Technology) is a very good example that Saudi Arabia do have green buildings.

The aim of following question is to know if Saudi Green Building Council established its version of regulations and standards and to know the references that Saudi Green Building Council use. He said. until now the answer is no. They are using different references such as: World Green Building Council, United States Green Building Council,Green building councilinstitute,Canadian green building council, Environmental protection Agency, American Society of Heating, Refrigerating and Air Conditioning Engineers, Abu Dhabi Urban planning council, UAE green building council.

The next question is to know if the Saudi Green Council has regulations and standards for all different categories of buildings. The representative said yes of course.

After that, a question was about the type of Green Building Rating Systems does the Council use, and the reasons of this selection. He answered LEED, because of the agreements between them.The interviewee said that until now there is nothing official but we have private sponsors

such as:

1- AL-Jazeera Factory For Paints

2- BOUDL, Hotels & Hotel Suites

3- Durrat Amiyadh for Real Estate Development

4- Herfy Food Services Co. Ltd.

An important question the interviewee been asked if Saudi government has a plans to protect the environment and to have more green buildings. He said well in fact, we know that the Saudi government is working very hard to have a sustainable and green buildings in future.

Next question was about if there any specific construction materials or methods to achieve green buildings in Saudi Arabia.

The representative replied that there are many materials and methods to achieve a sustainable and green buildings in the Kingdom. We are still in the research field and we don't have a complete answer.

An important question was the following to know the main steps to change an existing Saudi residential building to be more environmentally friendly and sustainable. He replied that the main step is to study the current situation of the residential buildings. After that, is to know what are the main methods and changes that should done. Finally, take an action and use the available methods.

The last question was to know if the Saudi Green Council has strategies to encourage residents, companies and government to change homes to be green in the future. The representative of SGBC said that he think that it is very important first to raise public awareness, provide training & Education, Helping the construction industry transform to the green building requirements Encourage building materials manufactures and suppliers to produce and supply environmentally responsible products. Promote green labeling.

2.5

Name of Visit: Visit King Abdullah city (king abdullah university of science and technology)

Location:Thuwal -Saudi Arabia

Date: 21-07-2013

Name of Interviewer: Wasim Jamil Lasker

Name of Interviewee: Tariq Rahbini

Position: Construction Engineer

Purpose of visit: Get data about the sustainable buildings inside the campus.

2.5.1 Overview

Location: Thuwal, Kingdom of Saudi Arabia

Building type(s): Campus

New construction

5,340,000 ft2 (496,000 m2)

Project scope: multiple buildings

Suburban setting

Completed September 2009

Rating: U.S. Green Building Council LEED-NC, v.2.2–Level: Platinum

King Abdullah University of Science and Technology (KAUST) is a new international, graduate-level research university established to drive innovation in science and technology and to support world-class research in areas such as energy and the environment. KAUST's new campus is the Kingdom of Saudi Arabia's first LEED certified project and the world's largest LEED Platinum project.

The design team responded to a set of extraordinary challenges. In the context of an extremely hot, humid climate, theywere asked to create a low-energy, highly sustainable project. The team was challenged to create a contemporary work of architecture that would resonate with the global scientific community while being firmly rooted in local Saudi culture. Finally, the team was asked to design an institution of the highest physical quality at a historically unprecedented speed—from conception to completion in just three years.

Because the research and development of renewable resources drives KAUST's research agenda, sustainable development is integral to KAUST's overall mission. By integrating sustainable measures into the site planning, the community, the building design and the campus operations, the university is demonstrating new ways to build in the region and promoting responsible stewardship of the environment.

As multiple design teams worldwide worked in tandem at a high-speed, a core group developed concepts to guide their efforts and integrate sustainability. The team employed five strategies that borrow from local culture and traditions to solve environmental issues:

1. Structured like traditional Arabic cities, the campus is compressed as much as possible to decrease the amount of exterior envelope exposed to the sun and reduce outdoor walking distances.

2. As found in a traditional souk, or Arabic market, shaded and passively cooled circulation thoroughfares are characterizedby dramatic light and social spaces.

3. The Arabic Bedouin tent inspired designers to create a monumental roof system that spans across building masses to block sun on building facades and into the pedestrian spine, to facilitate natural ventilation and to filter light. Solar panels covering the surface capture the sun's energy.

4. Passive ventilation strategies of the traditional Arabic house influenced the design of iconic, solar-powered wind towers that harness energy from the sun and wind to passively create airflow in pedestrian walkways.

5. Similar to Arabic screening called 'mashrabiya,' the campus shades windows and skylights with an integral shading system that reduces heat loads while creating dramatic dappled light.

2.5.2 The Interview section

The interview was with a representative of king abdullah university of science and technology (KAUST) in Thuwal . Theinterviewee was asked few questions to fill the data needed in PhD studies.

The interview started by asking about the green building projects in King Abdullah city. He replied that the buildings in campus are sustainable (LEED certified and earned platinum certification).

The next question is to know if the buildings in campus are from different buildings categories. He answered the question by saying Yes, university campus, town center, multi family residential and single family residential.

The following question in the interview is to know how did these buildings achieved LEED green building rating system. He said by designing low-energy buildings, sustainable projects, and comfortable place. In fact, KAUST earned 52 of the 53 required credits.

After that the interviewee asked if King Abdullah city project asked foreigners or local companies to complete the green buildings project in the city. The interviewee replied that KAUST designed by HOK'S Bill Odell (HOK'S Bill O'dell is an architect and director of HOK'S science and technology group). Bill Odel used Building Information Modeling (BIM). The project took 28 months.

The representative of KAUST asked about the possible ways and methods to change current Saudi cities and buildings to bemore friendly to environment. The representative answered that it is possible to change current Saudi cities and buildings to be more friendly to environment by construct buildings use low energy be more sustainable.

An important question the interviewee asked about the limitations that could not help Saudi residents to decide to change their homes to be green.He said that he thought Saudi residents need first to rise the awareness and understand importance of green buildings.

The last question in this interview was if the Saudi government has a future plan to establish more sustainable cities such as King Abdullah city or change current cities. The answer was that the kingdom of Saudi Arabia will use both methods in the future.

3.0 conclusion

The field trip shows that the population in Saudi Arabia is increasing very fast as the demand for power and electricity. In addition, very cheap oil in the kingdom made Saudis to behave badly in using energy and not to give any attention to environmental damages.

These issues reflected as well in Saudi residential buildings and caused huge amount of energy consumption. From the interviewees answers it is very clear that most of Saudi regions are suffering cooling loads in their homes as most of the regions in Saudi Arabia are hot and humid. Saudi electricity company mentioned that electricity demand will almost triple within 20 years to 120,000 megawatts by 2032 from around 46,000 in 2010 which mean that this issue need an urgent study and suitable solutions to avoid any increase of energy demand especially that residential buildings consume more than 50 % of energy consumption in the kingdom.

In fact, the government of Saudi Arabia started to take these issues into consideration. King Abdullah university for science and technology is a good example to represent the new generation of buildings which are more friendly to environment and consume less energy. KAUST campus got LEED certificate but this project alone is not enough. The Saudi government need to move very fast to change the current situation of residential buildings and new buildings. In addition, Saudi municipalities need suitable building regulations and building standards to change the future of construction in the country.

Finally, most of the engineers in the interviews pointed to several stages and steps to have a green future and change the current situations of buildings such as raise public awareness, provide training & Education, Helping the construction industry transform to the green building requirements Encourage building materials manufacturers and suppliers to produce and supply environmentally responsible products, Promote green labeling.

Appendixes

4.1 Field Trip Time Table

4.2 Field Trip Interview Forms

Green Residential Buildings in Saudi Arabia

(The impact of construction and building materials on energy in the Saudi residential buildings)

Wasim Jamil A. Laskar

2013/2014

The following table outlines the proposed schedule to carry out and complete research :

Activity	Object	Location	Means of transport	Start date	Completion date	Staying over night
Multiple visits to Faculty of Environmental Design , King Abdulaziz University	Collecting data about construction types, building materials, design and all environmental issues for Saudi residential buildings	Jeddah-Saudi Arabia	Private car	01-06-2013	31-08-2013	Home
Visit Makkah Municipality	Collecting data about the types of Saudi Residential Buildings **(interview)**	Makkah-Saudi Arabia	Private car	07-06-2013	13-06-2013	Home

Activity	Object	Location	Means of transport	Start date	Completion date	Staying over night
Visit Saudi Electricity Company	Collect data about energy consumption/ demand and methods to save energy in Saudi buildings **(Interview)**	Jeddah-Saudi Arabia	Private car	14-06-2013	30-06-2013	Home
Visit Jeddah Municipality library	Find the standards and regulations for Saudi residential buildings	Jeddah-Saudi Arabia	Private car	01-07-2013	08-07-2013	Home
visit King Abdulaziz City of Science and Technology	Collect data related about Energy strategies and plans for the future in the Kingdom of Saudi Arabia **(Interview)**	Riyadh-Saudi Arabia	Airplane and Taxi	09-07-2013	14-07-2013	Hotel
Visit Saudi Green Building Council	Collecting data about green buildings and projects done in the Kingdom **(Interview)**	Riyadh-Saudi Arabia	Airplane and Taxi	15-07-2013	20-07-2013	Hotel

Activity	Object	Location	Means of transport	Start date	Completion date	Staying over night
Visit King Abdullah city	Get data about the sustainable buildings inside the campus **(Interview)**	Thuwal-Saudi Arabia	Private car	21-07-2013	31-07-2013	Friend home
Visit several architecture design companies	Get different residential projects in Saudi Arabia (Flats, Villas) and study building materials, construction and energy	Jeddah-Saudi Arabia	Private car	01-08-2013	31-08-2013	Home

Notice

1- Please note that Thursday and Friday are an official holiday in Saudi Arabia that all government buildings and most of companies are closed.

2- Please note that a small report will be send to you explaining the work done every two weeks.

Contact details

1- Makkah Municipality

Location: Kingdom of Saudi Arabia - Makkah
Postal Code: 21955
Phone: +966225739555- 25735228
Fax: +966225748633

Email: info@holymakkah.gov.sa
Web Site:www.holymakkah.gov.sa

2- Saudi Electricity Company

Location: Kingdom of Saudi Arabia - Jeddah Branch
Po Box 9299
21413
Phone: +966(2)6500005
Facsimile: +966(2)65341
E-mail Address: necmg@se.com.sa
Website: http://www.se.com.sa

3- Jeddah Municipality

Location: Kingdom of Saudi Arabia - Jeddah
P.O.Box: 7607
Postal Code: 211
Phone: +966 (0)2-6149999
Email: info@jeddah.gov.sa
http://www.jeddah.gov.sa

4- King Abdulaziz City of Science and Technology

Location: Kingdom of Saudi Arabia - Riyadh
P.O Box 6086, Riyadh 11442
Phone: +966 (1) 4883555
Fax: +966 (1) 4813274

http://www.kacst.edu.sa

5- Saudi Green Building Council

Location: Kingdom of Saudi Arabia - Riyadh
P.O.Box 60322/ 11545
Phone: +966 (0)1-4603460
Fax: +966 (0)1-4190461
Email: info@saudi-gbc.org
Website: www.saudi-gbc.org

6- King Abdullah of Science & Technology University

Location: Kingdom of Saudi Arabia- Thuwal
P.O. Box :23955-6900
Phone: +966 (0)2-808 3428
Email: online@kacst.edu.sa
public@kacst.edu.sa
Web site: www.kaust.edu.sa

4.2 Field Trip Interview Forms

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Field work interview form

(The Impact of Construction and Building Materials on Energy for Saudi Residential Buildings)

Name of Visit: Makkah Municipality

Location: Makkah- Saudi Arabia

Date: 07-06-2013

Name of interviewer: Wasim Jamil Lasker

Name of Interviewee: Engineer Ahmad Al Zhrani
Purpose of visit: Collecting data about the types of Saudi Residential Buildings

Question	Answer
On average, how many members in Saudi family? are there any government data to support the answer ?	5 Members ... yes
Recently, what is the number of residential buildings in Saudi Arabia ? are there any government data to support the answer ?	Jeddah- 702547 Makkah- 291458 Taif - 177409 Qunfza - 54170 Allith - 23935 Rabee - 18600 Algamom - 18269 Klhis - 11759 Alkamel- 4878 Al Khurma - 7943 Ranee - 8005 Turba - 8698 Total for Makkah region- 1327667
what is the expected percentage for increasing numbers of Saudi residential buildings in the next 10 years? are there any government data to support the answer ?	It is very diffcult to answer this question .... No
What are the types of Saudi residential buildings? are there any government data to support the answer ?	Apartment blocks four storey Apartment blocks Two storey Duplex House

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Field work interview form

Question	Answer
Is the kingdom of Saudi Arabia has different types of residential buildings according to different regions or all parts of the kingdom has the same types?	No the same types
What is the most prefered type of residential buildings in Saudi Arabia? why? are there any government data to support the answer ?	Houses
on average, what is the prices for owning/ renting residential flat/ villa/ other ? are there any government data to support the answer ?	Flats start from 350,000 SR = 58,333 GBP Houses start from 1000,000 SR = 166,666 GBP Yes
Are there any sort of information that would be helpful to add in this field of study?	

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HERIOT WATT UNIVERSITY

Field work interview form

(The Impact of Construction and Building Materials on Energy for Saudi Residential Buildings)

Name of Visit: SEC (Saudi Electricity Company)

Location: Jeddah branch-Saudi Arabia

Date: 14-06-2013

Name of Interviewer: Wasim Jamil Laskar

Name of Interviewee: Sami Refaee

Purpose of visit: Collect data about energy consumption/demand and methods to save energy in Saudi buildings.

Question	Answer
Why Saudi government just depending on oil for the last decades?	Because the country is very rich of oil and it is very cheap to use for local purposes.
What is the major energy saving concern of Saudi electricity company? Why?	The major concern is cooling systems, because it is constitutes to be the main energy consumption in Saudi Arabia.
Which months of the year are the most consumer of building energy?	80 % of power in Saudi Arabia being consumed between June and October.
Does the Saudi electricity company has plan or strategies to reduces energy consumption that depend on oil?	Yes, using renewable energy and we have a several contracts with different companies and organizations to get the benefits of renewable energy, specially solar power.
Does the Saudi electricity company has expectations for electricity demand in the future?	Yes, electricity demand will almost triple within 20 years to 120,000 megawatts by 2032 from around 46,000 in 2010.
Does the kingdom just want to depend on oil in the next 10 years? why?	No, The kingdom wants a diversity energy, because of growing demand.

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Field work interview form

Question	Answer
How to reduce energy consumption of an existing Saudi residential building?	The easiest way is to apply them insulation walls, roofs, have shade devices, and to have windows that help to decrease heat in houses.
Does the government of Saudi Arabia has any of kind co-operation with an international company?	Yes, with JETRO (Japan External Trade Organization).

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Field work interview form

(The impact of Construction and Building Materials on Energy for Saudi Residential Buildings)

Name of Visit: KACST (King Abdulaziz City of Science and Technology)

Location: Riyadh-Saudi Arabia

Date: 14-07-2010

Name of interviewer: Wasim Jamil Lasker

Name of interviewee: Ahmed Al Ghazi

Purpose of visit: Collect data related about Energy strategies and plans for the future in the Kingdom of Saudi Arabia

Question	Answer
Why is the development of energy technology so vital to Saudi Arabia?	Energy is one of the crucial drivers of the nation's development and economic growth. The demand for energy in the Kingdom is a challenge for the nation to keep up with. It is estimated that the demand for electricity alone is increasing by over 6% a year. Science has to offer many different solutions to keep pace with this growing demand.
From your point of view, which type of buildings in Saudi Arabia is the most energy consumer?	Based on our research it is very clear that residential buildings are the most energy consumer. They consume 53% of the total enrgy.
Does KACST has plans regarding increasing demand of energy in the kingdom and reducing damage to environment ?	The answer is yes, we have plans to develop solar powered using advanced nanotechnologies, because by using this devices the cost will be less than 30 halals per kw/h (about half UK pennies).
As KACST always intrested in renewable energy, what is Saudi Arabia's best renewable energy resource?	In fact,he Kingdom receives 105 trillion kilowatts of sunlight per day, which means that Saudi Arabia gets some of the most intense sunlight exposure on the planet. The country is listed as one of the top five places in the world for potential photovoltaic generation of electricity. That means that sunlight rather than oil may prove to be the Kingdom's greatest natural resource.

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Field work interview form

Question	Answer
How is Saudi Arabia reducing its energy consumption?	The key to reducing energy consumption in the Kingdom is reduction of 'Peak Load'. Currently in Saudi Arabia, around 10 % of all electricity generated and 25 % of distribution infrastructure, are used for just 400 hours per year, that's around 5% of the time – this period of time is known as peak load. New technologies promise to provide much needed relief in this area by better informing customers of how they can reduce their demand in peak load times, and of the tangible immediate benefits they can receive financially and environmentally in terms of lower bills and improved air quality. Even a small reduction in peak load can result in savings of billions of dollars in infrastructure investment. Peak demand forecast is expected to grow by over 60% until 2021.
How can you improve the energy efficiency of existing buildings?	Green building reduces energy consumption in numerous ways. First, the embodied energy of the building can be reduced through efficient design, use of recycled and local materials, and recycling construction waste. Second, green building design reduces a building's energy consumption over its lifetime. Strategically placing windows and skylights can eliminate the need for electrical lighting during the day. A whole house fan can cool the house overnight, rather than relying on air conditioning. High quality insulation reduces temperature regulation costs in both summer and winter. Additionally, houses can maximize passive heating and cooling. South facing windows with overhangs can reduce heating costs by 20 to 30%, and prevailing breezes, shading, and natural plantings can keep houses cooler in the summer. And, going one step further, it is possible to create zero energy buildings, these are structures with an onsite source of renewable energy such as solar panels or wind turbines.
Is KACST collaborating with international partners in developing energy technology?	KACST Energy Technology Program is working with scientists and organizations around the world. The 2012 Saudi Energy Efficiency Workshop was organized in partnership with the US National Renewable Energy Laboratory, and is working on another project focusing on sustainable resources with MIT, in their joint Centre of Excellence for Complex Engineering Systems.

Field work interview form

(The Impact of Construction and Building Materials on Energy for Saudi Residential Buildings)

Name of Visit: Saudi Green Building Council

Location: Riyadh-Saudi Arabia

Date: 15-07-2013

Name of Interviewer: Wasim Jamil Lasker

Name of Interviewee:

Purpose of visit: Collecting data about green buildings projects in the Kingdom

Question	Answer
What is the Saudi Green Building Council? what are the main targets of the council?	SGBC aims to transform the way buildings are designed, built and maintained by leading the way in promoting, advising and educating all stake holders to implement best practices to achieve environmental sustainability.
Are there any green building in the Kingdom of Saudi Arabia?	Yes, KAUST (King Abdullah University for Science and Technology) is a very good example.
Does the Saudi Green Building Council established its version of regulations and standards? what are the references that Saudi Green Building Council use?	Until now the answer is no. They are using different refrences such as: World Green Building Council, United States Green Building Council,Green building council institute,Canadian green building council, Environmental protection Agency, American Society of Heating, Refrigerating and Air Conditioning Engineers, Abu Dhabi Urban planning council, UAE green building council
Does the Saudi Green Council has regulations and standards for all different categories of buildings? if not, what are they? and why?	Yes.
Which type of Green Building Rating Systems does the Council use? why?	LEED, because of the agreements between them.

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Field work interview form

Question	Answer
Does the Saudi government support the Green Council in any way?	Until now there is nothing official but we have private sponsors such as: 1- AL-Jazeera Factory For Paints 2- BOUDL, Hotels & Hotel Suites 3- Durrat Arriyadh for Real Estate Development 4- Herfy Food Services Co. Ltd.
Does the Saudi government has a future plans to protect the environment and to have more green buildings?	In fact, we know that the Saudi government is working very hard to have a sustainable and green buildings in future.
Are there any specific construction materials or methods to achieve green buildings in Saudi Arabia?	There are many different materials and methods to achieve a sustainable and green buildings in the Kingdom.. We are stil in the research field and we dont have a complete answer.
What are the main steps to change an existing Saudi residential building to be more environmentally friendly and sustainable?	The main step is to study the current situation of the residential buildings. After that, is to know what are the main methods and changes that should done. Finally, take an action and use the available methods.
Does the Saudi Green Council has a strategies to encourage residents, companies and government to change homes to be green in the future? if yes, what are they?	I think it is very important to raise public awareness, provide training & Education. Helping the construction industry transform to the green building requirements. Encourage building materials manufactures and suppliers to produce and supply environmentally responsible products. Promote green labeling.

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Field work interview form

(The Impact of Construction and Building Materials on Energy for Saudi Residential Buildings)

Name of Visit: Visit King Abdullah city

Location: Thuwal -Saudi Arabia

Date: 21-07-2013

Name of Interviewer: Wasim Jamil Lasker

Name of Interviewee: Tariq Rahbini

Purpose of visit: Get data about the sustainable buildings inside the campus

Question	Answer
What are the green building projects in King Abdullah city?	The whole buildings in campus are sustainable (LEED certified and earned platinum certification).
Are the buildings in campus from different buildings categories? what are they?	Yes, university campus, town center, multi family residential, single family residential and golf course.
How did these buildings achieved LEED green building rating system?	By designing low-energy buildings, sustainable projects, and comfortable place. In fact, KAUST earned 52 of the 53 required credits.
Did King Abdullah city asked foreigners or local companies to complete the green buildings project in the city?	KAUST designed by HOK'S Bill Odell (HOK'S Bill O'dell is an architect and director of HOK'S science and technology group). Bill Odel used Building Information Modeling (BIM). The project took 28 months.
Is it possible to change current Saudi cities and buildings to be more friendly to environment? how?	Yes, by low energy and sustainable buildings
What are the limitations that could not help Saudi residents to change their homes to be green?	I think Saudi residents need first to rise the awareness and understand importance of green buildings.

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Field work interview form

Question	Answer
Does the Saudi government has a future plan to establish more sustainable cities such as King Abdullah city or change current cities?	yes, and i believe that the kingdom of Saudi Arabia will use both methods.

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Appendix C: The survey: this appendix shows a copy of the survey questions, by using google chrome, regarding energy consumption in Saudi residential buildings.

Energy Consumption in Saudi Residential Buildings (استهلاك الطاقة في المباني السكنية السعودية)

The aim of this survey is to find out how Saudis use air conditioning in homes, what is the system type of air conditioning, how Saudis concern about energy consumption and electricity bills and all other issues regarding to air-conditioning

والهدف من هذه الدراسة هو معرفة كيف يستخدم السعوديين و المقيمين تكييف الهواء في منازلهم، ماهو نوع نظام تكييف الهواء المستخدم، وما هو مدى قلق السعوديين بشأن استهلاك الطاقة وفواتير الكهرباء وجميع المسائل الأخرى المتعلقة بتكييف الهواء.

Required *

Optional questions (اسئلة اختيارية)

The first part of the survey is about an optional several questions that will help in the research but is not compulsory.

الجزء الاول من الاستبيان عبارة عن عدة اسئلة إختيارية تساعد في البحث ولكنها ليست الزامية

1 . **What is your gender?**
ماهو جنسك ؟

Mark only one oval.

- Male (ذكر)
- Female (انثى)

2. **What is your age?**
ما هو عمرك ؟

Mark only one oval.

- 12-17 years old
- 18-24 years old
- 25-34 years old
- 35-44 years old
- 45-54 years old
- 55-64 years old
- 65-74 years old
- 75 years or older

3. **What is your educational level ?**
ماهو مستواك التعليمي ؟

Mark only one oval.

- Less than high school (اقل من الثانوية)
- High school (الثانوية)
- Bachelor degree (البكالوريوس)
- Postgraduate (دراسات عليا)

4. **What is your income average in Saudi rial ?**
ما هو متوسط دخلك الشهري بالريال السعودي ؟

Mark only one oval.

- No income
- under 8000 SR
- 8001- 12000 SR
- 12001-16000 SR
- 16001-20000 SR
- 20000 and above
- Other: ____________

Compulsory questions (اسئلة اجبارية)

Compulsory questions are very important and indeed need it in the research and must be answered.
الاسئلة الاجبارية في غاية الاهمية بالتاكيد في مجال البحث و يجب الرد عليها.

5. **Where do you live ?** *

أين تسكن ؟

Mark only one oval.

- Riyadh (الرياض)
- Jeddah (جدة)
- Dammam (الدمام)
- Other: ____________

6. **What is your home type ?** *

ماهو نوع منزلك ؟

Mark only one oval.

- Flat (شقة)
- Villa (فيلا)
- Duplex villa (فيلا دوبلكس)
- Other: ____________

7. **How many rooms in your house?** *

كم عدد الغرف في منزلك ؟

Mark only one oval.

- Only one room (غرفة واحدة فقط)
- 2-3 rooms
- 4-5 rooms
- 6-7 rooms
- 8-9 rooms
- 10-11 rooms
- Other: ____________

8. **Do you own/ rent your house ?**

هل تملك منزلك ام تستأجره ؟

Mark only one oval.

- I own the house (املك المنزل)
- Rented house (مستأجر)
- Living with family (اسكن مع العائلة)
- Other: ____________

9. How many persons you live with? *
كم عدد الاشخاص الساكنين معك ؟

Mark only one oval.

- ◯ Only me
- ◯ 1-3 persons
- ◯ 4-6 persons
- ◯ 6-8 persons
- ◯ more than 8 persons

10. What type of air-conditioning do you have? *
ما هو نوع التكييف الخاص بك ؟

Mark only one oval.

- ◯ Window Air Conditioner (مكيف الشباك)
- ◯ Split Air Conditioner (مكيف السبليت)
- ◯ Central Air Conditioning System (مكيف مركزي)
- ◯ Window Air Conditioner and Split Air Conditioner (مكيف شباك و مكيف سبليت معا)
- ◯ Other: ____________________

11. How many air conditioning units you have at home?
كم عدد وحدات تكييف الهواء لديك في المنزل ؟

Mark only one oval.

- ◯ 1-3
- ◯ 4-6
- ◯ 6-8
- ◯ 8-10
- ◯ 10-12
- ◯ more than 12

12. How do you set the air conditioning usually ? *
كيف تقوم بضبط اعدادات التكييف عادة ؟

Mark only one oval.

- ◯ Low (منخفض)
- ◯ Medium (متوسط)
- ◯ High (عالي)

13. Do you know your monthly electricity bill ? *
هل تعلم فاتورتك الشهرية لاستهلاك الكهرباء ؟

Mark only one oval.

- ◯ Yes (نعم)
- ◯ No (لا)
- ◯ Sometime (بعض الاحيان)

14. Do you know your electricity usage in kWh? *
هل تعلم مقدار إستهلاكك من الكهرباء بالكيلواط ؟

Mark only one oval.

- Yes (نعم)
- No (لا)
- Sometime (بعض الاحيان)

15. How many hours you use air-conditioning daily in summer season? *
كم عدد ساعات إستخدامك لمكيف الهواء خلال فترة الصيف ؟

Mark only one oval.

- 0-6 Hours
- 6-12 Hours
- 16-18 Hours
- 18-24 Hours

16. How many hours you use air-conditioning daily in winter season? *
كم عدد ساعات إستخدامك لمكيف الهواء خلال فترة الشتاء ؟

Mark only one oval.

- 0-6 Hours
- 6-12 Hours
- 16-18 Hours
- 18-24 Hours

17. Which room you use the air-conditioning most of the time? (you can tick more than one option) *
اي غرفة تستخدم فيها التكييف معظم الوقت ؟ بامكانك اختيار عدة اجابات لهذا السؤال

Check all that apply.

- Living room (غرفة المعيشة)
- Bed room (غرفة النوم)
- Guest room (غرفة إستقبال الضيوف)
- Kitchen (المطبخ)
- Servant room (غرفة الخادمة)
- All rooms (جميع الغرف)

18. Do you concern to turn air-conditioning off when not in use? *
هل تهتم لاغلاق مكيف الهواء عنما لا تحتاجه ؟

Mark only one oval.

- Yes (نعم)
- No (لا)
- Sometime (بعض الاحيان)

19. Do you feel that sometime air-conditioning in the summer is not cooling enough? *

هل تشعر بعض الاحيان ان مكيف الهواء خلال فترة الصيف لا يبرد كفاية ؟

Mark only one oval.

- Yes (نعم)
- No (لا)

20. Why do you turn off the air-conditioning ? (you can tick more than one option) *

لماذا تقوم باغلاق جهاز التكييف ؟ بامكانك اختيار اكثر من اجابة لهذا السؤال

Check all that apply.

- [ ] Because it is a habit when I leave the room or the house.(لانها عادة عندما اغادر الغرفة او المنزل)
- [ ] Because the weather is cold sometimes. (لان الجو بارد في بعض الاحيان)
- [ ] To save energy in house and protect the environment.(لاحافظ على الطاقة و احمي البيئة)
- [ ] To reduce the electricity bill. (لاخفض فاتورة الكهرباء)

21. Do you feel that sometime you need to turn off the air-conditioning as room is too cold suddenly and after few minutes you need to turn it on again? *

هل تشعر بعض الاحيان انك تضطر لاغلاق جهاز التكييف بسبب برودة الغرفة المفاجأة ثم تضطر لاعادة تشغيله مرة اخرى بعد دقائق محدودة ؟

Mark only one oval.

- Yes
- No

22. Do you know that using energy could harm our environment ? *

هل تعلم ان استهلاك الطاقة قد يضر بالبيئة ؟

Mark only one oval.

- Yes I know (نعم اعلم)
- No I don't know (لا اعلم)

23. Do you know any simple methods to save energy and money regarding to air-conditioning? *

هل تعلم بعض الطرق البسيطة لتخفيض الطاقة في النزل و خصوصا التكييف ؟

Mark only one oval.

- Yes I know (نعم اعلم)
- No I don't (لا اعلم)

24. Are you going to reduce using of the air-conditioning if the electricity bill is going to increase in the future ? *

هل ستقوم على تقليل استخدامك لمكيف الهواء ما اذا زادت فاتورة الكهرباء في المستقبل ؟

Mark only one oval.

- Yes (نعم)
- No (لا)

25. **Would you pay for more expensive house that has better energy efficiency methods that will help to reduce the electricity bills in the future?** *
هل ستدفع لمنزل اغلى يمتلك طرق ممتازة لترشيد استهلاك الطاقة والتي بالتاكيد من شانها ان تقلل فواتير الكهرباء في المستقبل ؟

Mark only one oval.

- Yes (نعم)
- No (لا)
- Im not sure (لا اعلم)

26. **If you know any simple method to save energy and money in your home please specify** *
اذا كنت تعرف بعض الطرق لتخفيض استهلاك الطاقة و ايضا تقليل فاتورة الكهرباء الرجاء ذكرها

27. **If you have any comments please feel free to fill the box below.**
اذا كانت لديك اي ملاحظات الرجاء لا تتردد في ملء المستطيل ادناه

Thanks for your valuable time

اشكركم لوقتكم الثمين

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Appendix D: 3rd Annual International Conference on Architecture and Civil Engineering (ace 2015): This appendix shows a copy of the conference paper that held in Singapore on 13-14 April 2015.

(*The Impact of Construction and Building Materials on Saudi Residential Buildings*)

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Abstract— **the population of Saudi Arabia has been increasing rapidly over the last few years, resulting in a massive need for homes and energy. Residential buildings in the Kingdom of Saudi Arabia consume more than 70% of the total building energy consumption. The construction materials of the buildings have a significant impact on the energy consumption of residential buildings in Saudi Arabia, and major savings in air-conditioning energy can be made by adopting the appropriate construction type. (Abstract).**

GHW (Gigawatt- Hours), ebpd (Equivalent Barrels Per Day), toe (Ton Oil Equivalent), KWh (kilowatt-hour), GDP (Gross Domestic Product), bbl/d (Barrels Per Day), KACST (King Abdulaziz City for Science and Technology), SEC (Saudi Electricity Company).

I. Introduction (Heading 1)

The Kingdom of Saudi Arabia is one of the most energy consuming countries in the Middle East and worldwide. Increases in both the population and building construction in the country are the main reasons for increases in the demand for energy. Recent statistics have confirmed that energy consumption will triple over the next few years.

The Saudi government is engaged in developing appropriate methods to reduce energy consumption and move to a lower carbon economy in the near future.

Residential Buildings in the Kingdom of Saudi Arabia consume approximately 70 percent of the total building energy consumption. Therefore, Saudi residential buildings require urgent development to become less energy-intensive and more environmentally-friendly. In this respect, the study will investigate the recent situation of Saudi residential buildings in terms of a set of elements such as energy consumption, design, construction and building materials, using the Saudi field and several case studies.

II. BACKGROUND

The country of Saudi Arabia occupies a territory of 2,149,690 sq. km. (829,995 sq. mi.), slightly more than one-fifth of the size of the continent of the United States. The capital city Riyadh has a total population of around 4.7 million people. However, there are other large cities, including Jeddah (with a population of around 3.2 million), Makkah (with a population of around 1.5 million), and Dammam/Khobar/Dhahran (with a population of around 1.6 million).

III. Climate of Saudi Arabia

The climate of Saudi Arabia may be described as arid with extreme fluctuations in temperature in interior of the country. Likewise, humidity and high temperatures are common along coastal regions (TounGlobe, 2012).

IV. Saudi Population

The annual population growth rate (2011 EST) is estimated at 1.536%. The main ethnic group is Arab (90% of native pop) and Afro-Asian (10% of native pop). The religion is Islam with Arabic as the official language. Various indicators are as follows: Education: Literacy is around 78.8% (Male 84.7%, Female 70.8%). Health: the infant mortality rate (2011 EST) is 16.16 deaths / 1,000 live births. Life expectancy: Male 72 years, Female 76 years. With regard to the work force: 7.3 million, about 80% foreign workers (2011 EST). Industry: 21.4% services (including government) 71.9 % and Agricultural 6.7 % (YoumGlobe, 2012).

V. Saudi Economy

It goes without saying that the discovery of oil in Saudi Arabia was one of the defining moments in the country's history. As such, oil was first discovered in Saudi Arabia in the early 1930's by a team of us geologists. However, it is important to note that large-scale production of oil did not commence until after the end of the second world war.

It is very clear that this oil wealth has enabled the rapid industrialization and urbanization of the Saudi Arabian economy, and has helped to transform the kingdom into a living embodiment of technological advancement (Michigan State University, 2012).

VI. ENERGY CONSUMPTION IN SAUDI ARABIA

As a result of cheap energy prices and the hot climate, the country depends on heavily air-conditioned buildings (The Economist Intelligence Unit Limited, 2010). Table 1 gives energy consumption totals from 2000 to 2020 in Gulf countries.

TABLE 1. Energy consumption totals, millions tons of oil equivalent, GCC countries, 2000-2020 (The Economist Intelligence Unit Limited, 2010).

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Bahrain	8.8	8.9	9.1	9.6	9.8	10.7	11.4	12.0	12.7	13.2	13.8	14.3	14.9	15.4	16.2	16.8	17.5	18.3	[illegible]	19.9	20.7
Kuwait	21.4	20.0	21.0	22.8	23.9	25.4	26.9	28.1	29.8	30.9	31.7	33.8	34.3	35.4	36.9	38.4	39.9	41.4	42.8	44.6	46.4
Oman	8.4	8.7	9.1	9.6	9.6	12.7	14.1	14.3	15.3	16.1	17.1	18.1	19.2	20.3	21.5	22.8	24.2	25.7	27.2	28.8	30.6
Qatar	14.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Saudi Arabia	114.6	123.3	127.1	133.9	144.2	153.2	160.1	169.0	179.1	187.8	[illegible]	198.8	[illegible]	[illegible]	246.2	[illegible]	274.3	[illegible]	306.2	323.4	[illegible]
UAE	42.3	43.3	46.8	47.7	50.3	52.4	55.9	60.6	66.3	67.0	70.1	73.7	77.8	82.2	87.8	91.7	96.7	102.3	107.9	113.9	120.2
GCC Total	210.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

In Saudi Arabia, the total energy consumption in 2010 was about 212,263 Gigawatt-hours (GHW) and, in the last few years, there has been a rapid growth in the electricity demand, with an estimated increase of 2015.7 GWH per annum (Al-Ghamdi and. Al-Feridah, 2011). In fact, every sector in the Kingdom consumes huge amounts of energy every year, but residential buildings are the major consumer, using 108,627 GWH or 67% of the total consumption, as shown in figure 2 (Al-Ghamdi and Al-Feridah 2011).

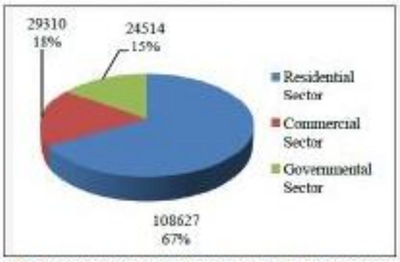

Figure 2. Energy consumption by different sectors in the Kingdom of Saudi Arabia in 2010 (Al-Ghamdi and Al-Feridah 2011).

The power demand in Saudi Residential buildings is divided into different categories, such as lighting, water heating, air conditioning, appliances and other sources; air-conditioning is responsible for the majority of consumption, as shown in figure 3.

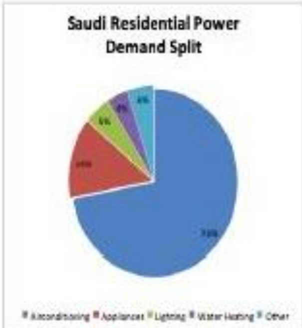

Figure 3. Saudi residential power demand split (Zawya, 2012).

In fact, Saudi Arabia has proved to be the top consumer of energy, with its energy consumption increasing to around three million ebpd (equivalent barrels per day) from 2.92 million ebpd (equivalent barrels per day). Oil products are the chief element of the energy mix consumed by the country (Saudi energy consumption swells: Oapec, 2011).

VII. CAUSES LEADING TO INCREASED DEMAND FOR POWER AND ELECTRICITY IN SAUDI ARABIA

Saudi Arabia was the largest producer and exporter of the total of petroleum liquids in the world in 2010. In the production of crude oil, it ranked second, only behind Russia. The economy of the country is highly dependent on the production of crude oil, with 80-90 percent of the total revenue accounted for by the export revenue obtained from oil production. The country has focused its attention on increasing oil production since the production target has been *achieved* (Saudi Arabia, 2011).

Studies reflect that the causes leading to the increasing demand for power in the country can be associated with;

· The population of the country increasing rapidly by 3.2% per annum (Ministry of Planning, 2010).
·The increase in the number of connections to customers.
·The development in industrialization and development projects.
·The expansion of electricity supply to villages located in remote areas.
·The behavior of consumers being affected by low tariffs, leading to increasing wastage of energy, causing a rising demand for electricity. (Obaid, 2011).

The energy sold to subscribers amounted to 114,161 GWh in 2000 while at the end of 2010 it was 212,236 GWh, an increase of 86% (Al-Ghamdi & Al-Feridah, 2011). Table 4 shows the increase in electricity consumption for different sectors, from 2000 to 2010, in Saudi Arabia.

TABLE 4. Increase of consumption of electric power from year 2000 to 2010 in Saudi Arabia (Al-Ghamdi, S. & A.K. Al-Feridah 2011).

	Year 2000(GWh)	Year 2010(GWh)	Increased (GWh)	Increased(%)
Residential	56,063	108,627	52,564	93.7%
Commercial	9,969	29,319	19,35	194.0%
Governmental	13,869	24,514	10,645	76.4%
Total	79,901	162,46	82,559	364,1%

It is very clear that there was a huge increase in energy consumption between the years 2000 and 2010, and households are the major reason for this increasing electricity demand. Encouraging people to change their behavior to reduce electricity consumption is very difficult, while increasing the production of electricity is much easier (Hertog and Luciani, 2009). A further example showing the increase in energy use in different sectors between 2002 and 2006, including agriculture, is shown in Figure 5.

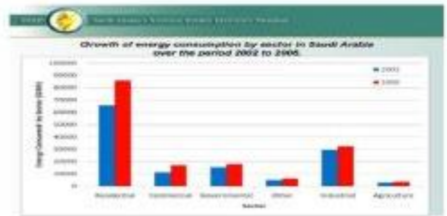

Figure 5. Growth of energy consumption by sector in Saudi Arabia 2002-2006 (Hertog and Luciani, 2009).

Figure 5 shows that the residential sector is growing most rapidly and, therefore, any measures to reduce residential energy consumption would produce good dividends in reducing overall consumption.

VIII. ENERGY EFFICIENCY AND CARBON DIOXIDE IN SAUDI BUILDINGS.

In fact, if the government of Saudi Arabia does not react very quickly and start to cut energy consumption, it will result in the country burning 850 million barrels of oil each year, until the year 2030, which is equal to 30% of its total production. Therefore, the government needs to develop more efficient buildings and alternatives, such as the use of renewable energy (Burgess, 2012).

The Saudi Arabia Energy Efficiency Center is the center that is in charge of the technology and policies necessary for energy efficiency and energy conservation. The National Energy Efficiency Program set eight objectives in the year 2008, focused on the reduction of electricity intensity, and including activities such as energy audits, supporting the industry, efficient use of oil and gas, the introduction of efficiency labels and standards for applications, and codes of construction, as well as technical management and guidance. The plan aims to:

•reduce the electricity intensity by 30 per cent between 2005 and 2030;

•halve the peak demand growth rate of the 2000 -2005 period by 2015.

Saudi Arabia's primary energy consumption per capita is four times higher than the world average; at 6.8 toe (ton oil equivalent) total energy consumption per capita in 2009, compared with the world average of 1.8 toe (ton oil equivalent) total energy consumption per capita, and it is growing faster than the GDP (Gross Domestic Product).

In the power sector, although the emission factor for power generation (CO_2 emission per kWh produced) has been falling, it is still high. In 2009 it reached 750 gCO_2 per kWh, which is 1.5 times higher than the world average. The energy and CO_2 intensity trends in the country reflect the fact that the country's consumption of energy is rising faster than the GDP (Gross Domestic Product) of the country. This, in turn, is increasing the energy intensity, which is different from the common trend that can be observed in other countries of the world. It has been observed that this rising trend can be associated with the dependency of the development of the country on energy intensive industries, along with a standard of living with high demands on energy use in buildings and transport that is further promoted by low energy prices. (Saudi Arabia- Energy Efficiency Report, 2011). Table 6 shows changes in CO_2 emissions from 1990 until 2011 for a range of countries including Saudi Arabia (Olivier, Janssens and Peters, 2012).

TABLE 6. CO_2 emissions in 2011 (million tonnes CO_2) and CO_2/capita emissions, 1990–2011 (tonne CO_2/person) (Olivier, J., Janssens, G. and Peters, J., 2012).

Country	Emissions 2011	Per capita emissions				Change 1990-2011	Change 1990-2011 in %	Change in CO_2 1990-2011 in %	Change in population 1990-2011, in %
		1990	2000	2010	2011				
Annex I°									
United States	[illegible]	19.7	20.8	17.8	17.3	-2.4	-12%	8%	19%
EU27	[illegible]	9.2	8.4	7.8	7.5	-1.7	-18%	-12%	6%
Germany	[illegible]	12.9	10.5	10.2	9.9	-3	-23%	-21%	4%
United Kingdom	[illegible]	10.3	9.3	8.1	7.5	-2.8	-27%	-20%	8%
Italy	[illegible]	7.5	8.1	6.8	6.7	-0.8	-11%	-4%	7%
France	[illegible]	6.9	6.5	6.1	5.7	-1.2	-17%	-9%	10%
Poland	[illegible]	8.2	7.5	8.8	9.1	0.9	11%	11%	-1%
Spain	300	5.9	7.6	6.5	6.4	0.5	8%	24%	16%
Netherlands	[illegible]	10.8	10.6	10.5	9.8	-1	-9%	3%	11%
Russian Federation	[illegible]	16.5	11.3	12.4	12.8	-3.7	-23%	-25%	-4%
Japan	[illegible]	9.5	10.1	10	9.8	0.3	3%	7%	3%
Canada	[illegible]	16.2	17.9	16	16.2	0	0%	24%	19%
Australia	[illegible]	16.0	18.6	17.9	19.0	3	19%	57%	24%
Ukraine	[illegible]	14.9	7.2	6.7	7.1	-7.8	-52%	-58%	-14%
Non-Annex I									
China	[illegible]	2.2	2.8	6.6	7.2	5	227%	287%	19%
India	[illegible]	0.8	1.0	1.5	1.6	0.8	100%	198%	39%
South Korea	[illegible]	5.9	9.7	12.2	12.4	6.5	110%	141%	11%
Indonesia	[illegible]	0.8	1.4	2	2.0	1.1	122%	219%	39%
Saudi Arabia	[illegible]	10.2	13.9	15.8	16.5	6.3	63%	161%	60%
Brazil	[illegible]	1.5	2.0	2.2	2.3	0.8	55%	108%	34%
Mexico	[illegible]	5.7	5.8	5.9	5.9	0.2	5%	41%	37%
Iran	[illegible]	3.7	5.2	5.4	5.5	1.8	49%	100%	37%
South Africa	[illegible]	7.3	6.9	7.7	7.2	-0.1	-1%	35%	37%
Taiwan	[illegible]	6.2	10.5	11.7	11.6	5.4	88%	119%	17%
Thailand	[illegible]	1.8	2.7	3.5	3.5	1.7	96%	135%	18%

Finally, it is very important to mention that conservation of energy in the power sector has been targeted by The National Energy Efficiency Program, which focuses on the improvement of steam system efficiency through energy audits and supporting energy-efficient boilers. The efficiency of the power sector (thermal power plants) has been seen to have increased on a regular basis, rising from 27 percent to 31 percent from 1990 till 2009. This improvement has been possible due to the increasing contribution of gas-fired facilities. The National Energy Efficiency Program also incorporates energy audits in the industrial sector accompanied with the encouragement of high-efficiency motors (Saudi Arabia- Energy Efficiency Report, 2011).

IX. FIELD TRIP STUDY

A field trip was undertaken to study the impact of construction and building materials on energy in Saudi residential buildings by gathering opinions from several governmental/ private companies in different cities in Saudi Arabia.

A. Aims of the field trip

The principal aims of the field trip were to:

- Understand the present situation of Saudi residential buildings in the Kingdom;
- Explore the most common type of Saudi residential buildings;
- Find out the methods to build green buildings in Saudi Arabia from specialists' points of view;
- Find out how to change the current situation of residential buildings to consume less energy;
- Determine whether the Saudi government has plans to save the environment and reduce energy consumption;
- Establish if the Saudi government or companies are following specific building regulations and standards, or if the government has its own version.

The field trip involved visits to different cities and governmental/ private companies in the Kingdom of Saudi Arabia.

B. Field trip results and analysis

1) The oil of Saudi Arabia

Saudi Aramco is the largest oil company in the world as regards both oil reserves and production and it plays a central role in the oil and gas field in Saudi Arabia. Within Saudi Arabia, responsibility for then oil and natural gas sector lies with both the Ministry of Petroleum and Mineral Resources, which oversees national planning around energy and minerals, and the Supreme Council, which brings together industry experts, government ministers and members of the royal family to create policies regarding petroleum and natural gas, as well as overseeing Saudi Aramco's strategic planning.
During a visit to the Saudi Electricity Company, a representative of the company said that Saudi Arabia has a wealth of oil, which is therefore the main energy source. Furthermore, as a result of low local oil prices, it is anticipated that Saudi Arabia will continue to rely on oil for the next few decades.

Statistics show that, in 2012, Saudi Arabia generated an average of 11.6 million bbl/d (Barrels Per Day) of petroleum, 9.8 million bbl/d of crude oil and 1.8 million bbl/d (Barrels Per Day) of natural gas liquids (NGL) (eia, 2013). Research by Burgess (2012) stated that Saudi Arabia will continue to burn 850 million barrels of oil per year until 2030 and, although there is no fear of running out of oil as Saudi Arabia is the global leader in oil production, there would be a significant loss of potential revenue.

2) The average Saudi family size and number of residential buildings.

In Saudi Arabia the size of the average family has decreased, from 6.08 persons per household in 1992, to 5.84 persons per household in 2010. This change in the demographics of the country will lead to increasing demand for residential buildings in the future, consequently benefitting construction and building material companies (Kawach, 2010).
In response to a question regarding the size of modern Saudi families, a representative of Makkah municipality in Makkah city stated that nowadays an average Saudi family has five persons. The interviewee provided a table explaining the number of residential buildings in the Makkah region, as follows (Table 7).

Table 7. Number of residential buildings in Saudi Arabia.

City/ Town/ Village	Numbers of Residential Buildings
Jeddah	702547
Makkah	291468
Taif	177408
Qunfza	54170
Allith	23936
Rabee	18600
Algamom	18269
Khlis	11759
Alkamel	4878
Al Khurma	7949
Ranee	8005
Turba	8698

Total of Makkah Region	1327667

A report estimating the number, size and type of housing in Saudi Arabia for the next twenty years, by Dr Fahad Al Ariqi, Dr Adnan Al Shiha and Dr Jamal Slagor, gives the number of residential buildings and population in each region in the Kingdom of Saudi Arabia in 1992 as follows:

Table 8. Residential buildings and population in each region in the kingdom of Saudi Arabia in 1992.

Region	Number of Housing	Classification Area	City	Population
Makkah	811199	Big	Makkah	965697
			Jeddah	2046251
			Taif	416121
			Qunfadah	15536
			Qias	
R i y a d h	611499		Riyadh	2776096
			Duwadimi	37871
			Arwa	1927
Sharqia	372274		Dammam	823345
			Qatif	98920
			Akighimih	1452
Asir	221315	Medium	Abha	112316
			Bareq	4062
			Alqariah	
Madinah	196235		Madinah	608295
			Badr	19778
			Muhylih	
Jazan	140092		Jazan	56565
			Alkhobh	2014
			Alkhbl	
Qassim	120543		Bridah	248636
			Albakriah	16928
			Alfowarah	3131
Tabuk	77908	Small	Tabuk	292555
			Taima	18066
			Alalirah	
Hail	66313		Hail	176757
			Turbah	2730
			Qifar	
Baha	55790		Baha	15587
			Alhujrah	2262
			Muhdara	
Najran	49386		Najran	90983
			Bran	1517
			Aljfah	
Aljouf	39136		Sakaka	65793
			Sawyer	5653
			Alaeikih	1588
Northern Border	26725		Arar	108055
			Alauqh	6451

			Aldbdb	
Total	2788413			

Another study done by the Central Department of Statistics for the government of Saudi Arabia shows households and individuals by source of electricity in 2007, as follows:

Table 9. Households and individuals by source of electricity in 2007.

Year	Housing Demand	Housing	Deficit in the supply of housing
2013	113766	104469	-9297
2014	126818	109579	-17239
2015	137873	114939	-22934
2016	149147	120562	-28586
2017	160640	126459	-34181
2018	172157	132645	-39512
2019	183846	139133	-44713
2020	210477	145939	-64537
2021	238467	153078	-85389
2022	267892	160566	-107325
Total projected demand for housing in Saudi Arabia for the next ten years 1761083			
The total expected supply of housing in Saudi Arabia for the next ten years 1307370			
Gap demand/ supply of housing for the next ten years -453,713			

A recent study estimated the deficit in housing units in Saudi Arabia over the next ten years to be more than 453 thousand units, where demand is expected to be about 1.76 million units versus an estimated .32 million units (Dahlan, 2013).

It is anticipated that the deficit in housing units in 2016 will reach up to 28.5 thousand, while in 2022; it will reach 107 thousand units. According to a study by the University of Business and Technology in Jeddah, the rapid growth of housing demand in Saudi Arabia is a result of the rapidly increasing Saudi population between the ages of 25 and 44 (Dahlan,2013).

The following table shows size of the demand and supply of housing units in Saudi Arabia over the next 10 years.

Table 10. The demand and supply of housing units in Saudi Arabia over the next 10 years.

Administrative Area		Total	Non-Coal	Other	Private Generator	Private Network	Public Network
Ar-Riyadh	Housing Units	637162	1903	0	1730	3046	640483
	Households	637162	1903	0	1730	3046	640483
	Individuals	4221262	3592	0	7112	17107	4191441
Makkah Al-Mukarramah	Housing Units	737311	2573	700	5677	22613	696748
	Households	737311	2573	700	5677	22613	696748
	Individuals	3566060	11458	567	11057	75252	3029949
Al-Madinah Al-Munawwarah	Housing Units	218761	7733	0	4946	8738	197344
	Households	218761	7733	0	4946	8738	197344
	Individuals	1256362	35531	0	18060	48071	1199200
Al-Qaseem	Housing Units	121718	3508	0	435	993	117574
	Households	121718	3508	0	435	993	117574
	Individuals	890764	26480	0	1405	1007	859890
Eastern Region	Housing Units	459875	361	128	753	5892	452741
	Households	459875	361	128	753	5892	452741
	Individuals	2768176	1542	969	2329	22820	2752616
Aseer	Housing Units	245683	7958	410	2556	7206	227135
	Households	245683	7958	410	2556	7206	227135
	Individuals	1543614	19425	592	9868	29154	1485451
Tabouk	Housing Units	98545	4566	155	1104	3196	89090
	Households	98545	4566	155	1104	3196	89090
	Individuals	638852	26025	2322	3933	20544	582033
Hail	Housing Units	65447	3208	196	422	1171	58450
	Households	65447	3208	196	422	1171	58450
	Individuals	487795	19120	1230	3036	7526	456875
Northern Borders	Housing Units	33342	329	0	274	1351	31388
	Households	33342	329	0	274	1351	31388
	Individuals	258315	2358	0	1775	8098	243483
Jazan	Housing Units	134602	4536	275	4366	1740	142742
	Households	134602	4536	275	4366	1740	142742
	Individuals	1004829	28614	3324	47540	15409	956548
Najran	Housing Units	52481	1275	90	1509	764	48843
	Households	52481	1275	90	1509	764	48843
	Individuals	577346	3308	525	11414	2779	552253
Al-Baha	Housing Units	50736	871	134	315	795	48581
	Households	50736	871	134	315	795	48581
	Individuals	341418	5879	577	2005	6060	325104
Al-Jouf	Housing Units	38761	599	0	127	309	37666
	Households	38761	599	0	127	309	37666
	Individuals	333429	5179	0	986	3312	323032
Total	Housing Units	2922524	39914	2126	24638	59061	2796783
	Households	2922524	39914	2126	24638	59061	2796785
	Individuals	18133570	199259	10446	119486	255901	17548478

In comparative form, the above tables clearly show that the number of housing units is increasing and will double, or more, in some regions in the next 20 years.

3) *Types of Saudi residential buildings*

For the purposes of this study, it is important to define the types of residential buildings in Saudi Arabia and, information from the Makkah municipality shows that there are four categories of residential buildings in Saudi Arabia, as follows: Four-storey apartment blocks, Two-storey apartment blocks, Duplexes (attached houses) and houses (Villas). Of these varieties, villas are the most popular type of residential buildings.

The Saudi Ministry of Housing website provides details about a typical Saudi house (villa) as follows:

Table 11. The Ground floor includes:

Name of the room	Size
Guest room	4x6
Dining room	3,8x5
Kitchen	3x4
Men Toilet	1,7x2
Bed room	3.8x4.6
Toilets	2x2.8
Living room	4x4,6

Table 12. The First floor includes:

Name of the room	Size
Main Bed Room	4x6 with toilet 1,7x2,2
First Bed Room	3,8x5
Second Bed Room	3,8x4,6
Servant Room	1,5x2,3 with toilet 1,2x1,5

The floor plan, elevations and perspectives, according to the Saudi Ministry of Housing, are as follows:

Figure 13. Ground floor plan (Saudi ministry of housing, 2014).

Figure 14. Second Floor Plan (Saudi Ministry of Housing, 2014).

Figure 15. Building Elevations (Saudi Ministry of Housing, 2014).

Figure 16. Building Perspective 1 (Saudi Ministry of Housing, 2014).

Figure 17. Building Perspective 2 (Saudi Ministry of Housing, 2014).

Figure 18. Building Perspective 3 (Saudi Ministry of Housing, 2014).

The Makkah municipality representative stated that, as regards the prices of residential buildings in Saudi Arabia, flats start from 350,000 SR (58,333 GBP) and houses start from 1000,000 SR (166,666 GBP).

Residential buildings energy consumption and cooling loads

Information from a representative of KACST (King Abdulaziz City for Science and Technology) showed that Saudi residential buildings alone consume approximately 53% of the total energy used in the country.

An SEC (Saudi Electricity Company) representative explained that cooling systems in residential buildings are a major source of energy consumption as they often operate 24 hours a day due to the climate. The consumption is also higher due to poor quality insulation and building materials used in the buildings.

The highest energy consumption takes place between June and October, which are the hottest months.

The future of energy in Saudi Arabia

The Kingdom of Saudi Arabia has recently developed strategies to use renewable energy sources and SEC is now at the point of concluding contracts with various companies and organizations in order to benefit from this new energy source in the future.

Moreover, the KACST representative said that Saudi Arabia receives 105 trillion kilowatts-hours of solar energy each day. Thus, Saudi Arabia is one of the top countries worldwide for potential photovoltaic generation of electricity.

The Government of Saudi Arabia is looking for investors to support its $109 billion plan to develop a solar energy sector that would be able to provide 30 percent of its electricity by 2032 (Burgess, 2012).

A consultant at the King Abdullah City for Atomic and Renewable Energy, Maher al Odan, explained that the aim is to develop 41,000 megawatts of solar power within the timeframe of the next two decades: 25,000 MW will be generated from solar thermal plants, by using heliostatic mirrors to reflect the sun's rays onto a central tower which, in turn, heats a fluid to drive a turbine, and another 16,000 MW will be generated using photovoltaic panels..

Al-Odan states, "We are not only looking for building solar plants. We want to run a sustainable solar energy sector that will become a driver for the domestic energy for years to come." (Burgess, 2012).

Khalid al-Suliman, the Vice President of Ka-care, added that an additional 21,000 megawatts of power will come from nuclear, wind, and geothermal sources.

Burgess (2012) mentions that there is a strong incentive to reduce dependency on oil as 'The state could generate an internal rate of return of approximately 12 percent if it built a PV plant and sold the displaced oil on the international markets."

4) The future of electricity demand in the kingdom

It is anticipated that, due to both the rapidly increasing population and the increasing number of residential houses, the electricity demand in Saudi Arabia will almost triple to 120, 000 megawatts by 2032, from the demand of 46,000 megawatts in 2010 (Husain,2011). Consequently, Saudi Arabia will face a serious problem in the future, requiring the government to either provide more energy or find solutions to reduce energy consumption, particularly in residential buildings.

A KACST (King Abdul-Aziz City of Science and Technology) representative explained that the electricity demand alone is increasing by more than 6% per year.

In order to address the problem by reducing demand, the Saudi government has been working to establish a Saudi version of building standards and regulations in order to change the current energy efficiency of residential buildings as well as new buildings. These changes will result in reduced energy consumption in the kingdom and increase the quality of buildings in general.

5) Methods to reduce energy consumption in the Saudi residential buildings

The SEC representative explained that there are numerous different methods that can be used in buildings, such as wall and roof insulation, shading devices for elevations, as well as considering window sizes.

The KACST representative indicated several other methods to reduce energy consumption including efficient design, using recycled and local materials, and recycling construction waste. Green building design reduces the energy consumption in a building over its lifetime. By strategically placing windows and skylights, the need to use electric lights during the day can be avoided. Moreover, a residence can be cooled through the use of a whole house fan overnight, reducing the dependency on air conditioning. The cost of regulating the interior temperature, both in summer and winter, can be reduced through the use of both high quality insulation and passive heating and cooling. In addition, heating costs can be reduced by by 20 to 30% with the use of south-facing windows, and houses can be kept cooler in summer by taking advantage of prevailing breezes, shading and natural plantings. Going beyond this, there is the opportunity to build zero energy buildings, which are structures with their own renewable energy source, such as solar panels or wind turbines, onsite.

Conclusion

It is clear that the Saudi population is increasing very rapidly, and along with it the demand for power and electricity. In addition, the availability of very cheap oil in the Kingdom has created a relaxed attitude towards energy efficiency and environmental issues.

This lack of concern is reflected in the design of Saudi residential buildings, consequently resulting in huge energy consumption. From the interviewees' answers it is very clear that most Saudi regions are suffering high cooling loads in their homes, as most of the regions in Saudi Arabia are hot and humid. The Saudi Electricity Company mentioned that electricity demand will almost triple within 20 years, to 120,000 megawatts by 2032 from around 46,000 in 2010, which means that this issue needs urgent study to find suitable solutions to avoid any increase in energy demand.

The government of Saudi Arabia has already started to take these issues into consideration. King Abdullah University for Science and Technology is a good example representing the new generation of buildings which are more environmentally-friendly and consume less energy. The KAUST campus succeeded in winning LEED certification but this project alone is not enough, and the Saudi government needs to move quickly to change the current situation of residential buildings and new buildings. In addition, Saudi municipalities need suitable building regulations and building standards to change the future of construction in the country.

Finally, most of the engineers in the interviews pointed out that steps are being taken towards a green future and to change the current situation in buildings, such as raising public awareness, providing training and education, helping the construction industry transform to meet the green building requirements, encouraging building materials manufacturers and suppliers to produce and supply environmentally responsible products, and promoting green labeling.

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Appendix E: International Journal of Housing Science and Its Applications: This appendix presented a journal article submitted to the international journal of housing science and its applications on 2015**.**

On-site measurements of thermal performance of a residential building in a hot-arid region

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ON-SITE MEASUREMENTS OF THERMAL PERFORMANCE OF A RESIDENTIAL BUILDING IN A HOT-ARID REGION

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ABSTRACT

Many residential buildings in hot climates use a huge amount of energy to run the air conditioning in order to maintain comfortable conditions for the occupants. This study of a domestic building in Libya used detailed monitoring and analysis of the measured data with a view to devising a strategy for reducing energy consumption and carbon emissions.

Keywords - Building Energy; Architectural design; Energy saving in building; Overheating

1. Introduction

Because of the impact on climate change there is a growing need for building services engineers and architects to design buildings which not only provide comfort for the occupants but also minimize the consumption of fossil fuels and resultant greenhouse gas emissions in the process of heating and cooling (1).

Architects have stepped away from simple vernacular designs towards designs characterized by heavy energy consumption both in terms of construction and operation. It is estimated that 50%

of all energy resources consumed across our planet relate to operation and control of the indoor environment of buildings, which are heavily dependent on mechanical systems. The scale of this energy consumption represents a major problem facing the world, thus the need for energy conservation has become one of the main concerns for architects. However, many modern buildings in hot-arid areas are constructed with no consideration given to energy consumption, or their relationship with the climate. The use of new building technologies often results in failure to achieve thermal comfort, and consequently leads to an increase in energy consumption as mechanical cooling is needed, whereas many traditional buildings achieve comfort with little or no energy use.

2. Energy consumption in Libya

Although Libya is an oil producing country, there is an energy crisis in Libya for the following reasons:

- Extensive use of conventional energy sources leading to their depletion, and the increase in the individual annual consumption of electrical energy.
- Most of the energy consumption is from relatively inefficient non-renewable sources, while the use of renewable sources is still in the foundation stages.
- Energy consumption is on the increase annually.

The growth in electricity generation in Libya amounted to more than 50% in the ten years from 2000 to 2010 (2), with total CO_2 emissions of around 60 million tonnes per year (55% due to oil and 45% due to Natural gas). One of the reasons consumption continues to rise is the low cost of electricity; RCREEE (3) showed that electricity consumption per capita in Libya is 6 times that in Morocco, while the price per unit in Morocco is 5 times that in Libya.

3. Background

Buildings, in addition to offering shelter and fulfilling aesthetic requirements, should provide conditions of comfort for their occupants. During summer in hot climate regions, buildings are exposed to high intensities of solar gain, which may result in over-heating, causing discomfort to the users. Under these conditions, cooling the building is very important. Cooling processes include a range of measures from simple natural cooling techniques such as solar gain control, evaporative cooling and natural ventilation, to mechanical systems, i.e. air conditioners (4).

Designers use a range of technologies to reduce the amount of energy that buildings need for cooling. Early cooling system technology involved natural methods such as breezes flowing through windows, water evaporating from trees and fountains, as well as large amounts of stone and earth absorbing daytime heat. These ideas were developed over thousands of years as an integral part of all building designs and are known as "passive cooling". By engaging passive cooling techniques in new buildings, the designer can often eliminate the need for mechanical cooling or at least reduce the size and cost of the equipment. In this work we aimed to monitor the actual performance of an existing building, with a view to recommending techniques for improving conditions and reducing electricity consumption.

4. Methodology

This work presents part of a larger research programme whose overall aim is to study the thermal performance of domestic buildings in Tripoli, with a view to offering design recommendations for reducing the cooling load and energy consumption.

The first part, presented here, consists of analysing monitored data from sensors located in and outside a residential building recording temperature, humidity and electricity consumption from 05/07/2013 to 16/08/2013. In addition, temperature readings for the four facades were taken every two hours throughout the day, for walls and glazing for each floor using an infra-red camera. In a later part of the work, detailed computer simulation of the thermal performance will be carried out in order to determine strategies to reduce the energy load.

Below follows an introduction to the climate of Tripoli and a description of the case study building.

5. Climatic analysis of Tripoli city

Tripoli city lies on the far north of the continent of Africa overlooking the Mediterranean Sea. The ordinates of the city are latitude 32° 47" N and longitude 13° 04" E respectively. Tripoli is classified as a hot dry climate, this type of climate usually being found at latitudes between 20° and 35°, and the main shelter issue is overheating. The mean summer temperatures are around 25°C but can reach a maximum of 45°C; clear nocturnal skies can cool temperatures down as -10°C.

Furthermore, the building studied is located in the city of Tripoli, which incidentally is only 21Km north of the area where the hottest air temperature ever was recorded, 58°C, (5). Table 1 shows the yearly average weather condition readings covering rain, average maximum daily temperature and average minimum temperature.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Record high °C	28	33	38	41	43	44	46	44	45	41	36	31
Average High °C	16	17	19	22	24	27	29	30	29	27	23	18
Average low °C	8	9	11	14	16	19	22	22	22	18	14	9
Record low °C	1	3	4	6	6	10	16	17	15	10	6	1
mm rainfall	81	46	28	10	5	0	0	0	10	41	66	94

Table 1 Ambient Conditions in Tripoli

6. The Case Study

The case study residential building has a rectangular plan and was built in 1999. The building is two storeys high with a total height of 8 m. The ceiling height is 3.5 m. The ground floor is 1m above street level and the roof has a sill of one metre.

The floor area is approximately 700 m^2 for the first floor; this includes two flats, each of which has two bedrooms, two living rooms, two bathrooms, and a kitchen. The second floor is also divided into two flats, each of these having three bedrooms, two living rooms, a kitchen and three bathrooms. It is occupied as a multifamily residence and the ground and first floors are as shown in figure 1.

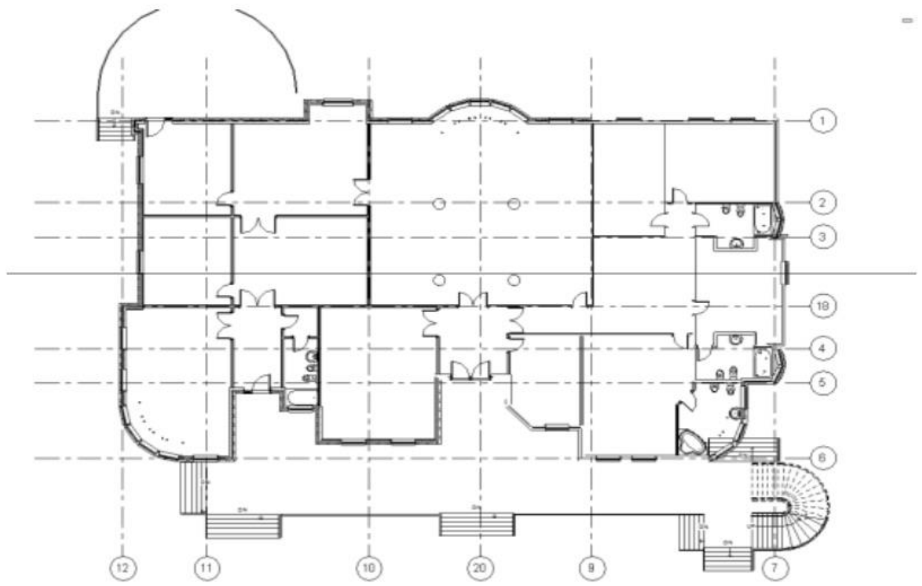

Figure 1Plan of the building

7. Results and Analysis

A field study including temperature, humidity and electricity consumption measurements was carried out and results from the study were gathered and analysed. The building was monitored continuously for 45 days, and the results clearly showed that there were two peak days; in between these days there is a sharp drop in temperature, otherwise the average temperature range is between 27°C-33°C. Three typical days were selected for detailed study, the first being the peak day 21/07/2013, the second day having a low temperature (09/07/2013), and finally a mid-temperature day (08/08/2013). The outside air temperatures for the three days are shown in figure 2.

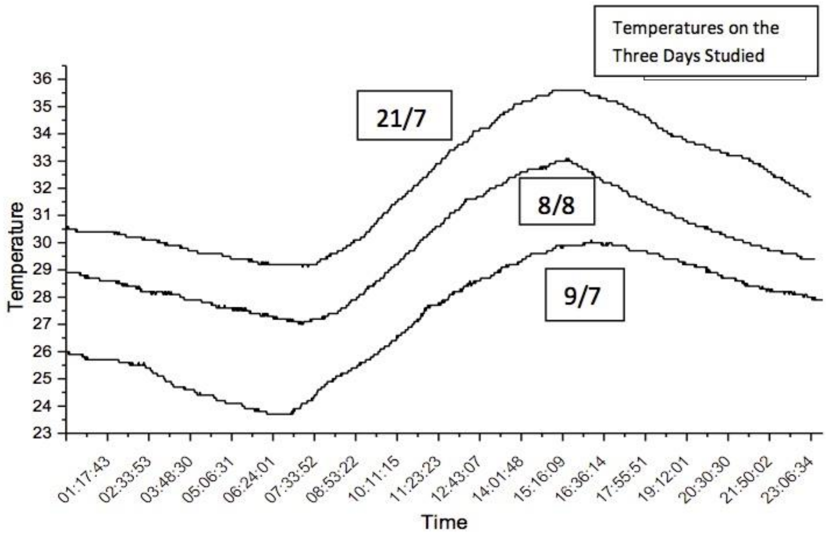

Figure 2 Outdoor air temperatures for the days studied

Figure 3 shows the outdoor temperature and that in the main rooms on the 9th of July, when the external temperatures ranged between 24°C and 30°C. The shaded areas indicate when the air conditioning was operating. Note that rooms located on the ground floor, i.e. flat 1 and 2, have a fairly steady temperature, while the room located on the west side in flat 2 is almost one degree higher than the room on the east side in flat 1. Furthermore, in flat 3 the room temperature drops at approximately the same rate as the drop in external temperature early in the morning, and rises with the rise in external temperature; at 27°C the air conditioning is switched on and starts cooling. While the temperature initially drops by about 0.5°C in about 20 minutes, the average cooling rate in this period is about 1°C per hour, at the same time as the outside temperature is rising at about 1.5°C per hour. As soon as the A/C is switched off the temperature rises slowly as the direct sun is now away from that part of the building. As for the room in flat 4, (with no air conditioning), the temperature is stable at around 31°C and is higher than the outside temperature. It is located on the second floor and the west side.

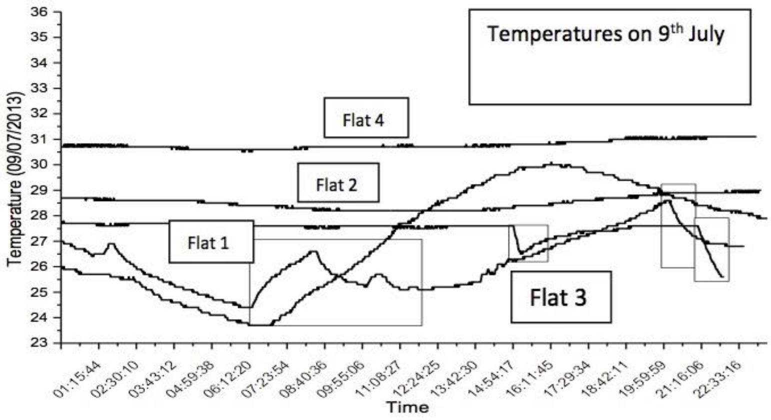

Figure 3 Main room temperatures on the 9th July

Considering now the rather hotter day of the 21st of July, the room in flat 4 (West side, upper storey) is as usual higher than the other rooms with average temperature of 33°C to 34°C, and flat 2 (West side, lower storey) is stable at around 31°C (Figure 4). In flats 1 and 3 (East side, lower and upper) the rise and fall in temperature as a result of switching the air conditioning off and on can also be seen, and it is evident that even over a period of several hours, even as the air temperature is falling the air conditioning does not bring the temperature in flat 3 below 26°C. The temperature rises rapidly when it is switched off (over 3°C in 1 hour) against a rising outside temperature of around 30°C.

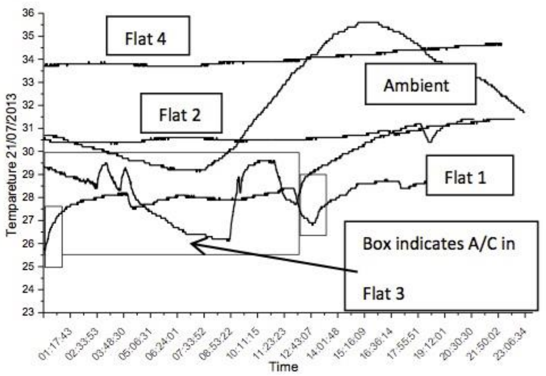

Figure 4 Main Room Temperatures on 21st July. Box Indicates A/C in Flat 3.

The upper storey suffers from high solar gain through the roof, which is not insulated.

Figure 5 shows that the living room temperatures on the 9th of July for flats 1, 2 and 3 are on average between 27°C and 29°C, except in the living room in flat 1 where the peak day temperature in the late afternoon temperature dropped two degrees, while the living room in flat 4 is above the outside temperature at around 31°C.

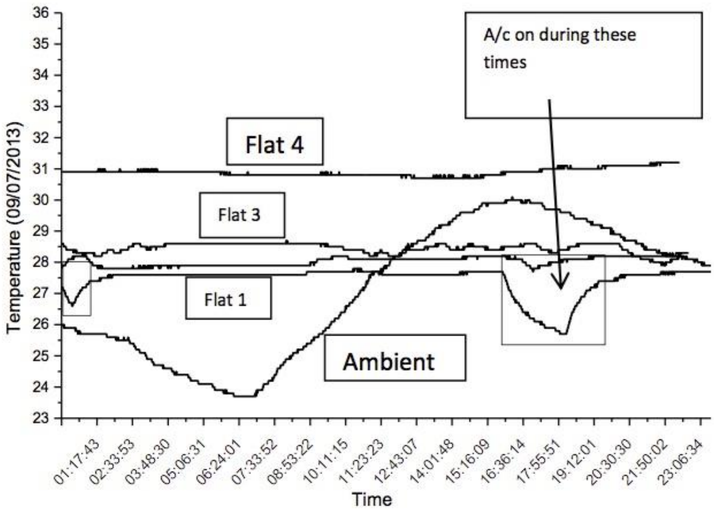

Figure 5 Living room Temperatures for the 9th July

The last space studied is the kitchen, which is no less important than the rest of the flat elements as it is occupied for a large part of the day. Figure 6 shows the kitchen temperatures on the 9th of July for all flats, and it is clear that the kitchen in flat 1 is stable at slightly above 28°C, and falls to a minimum of around 26°C when the air conditioning is running, after which it rises to around 28°C once more; furthermore the temperatures in the kitchen in flat 3 were stable and reasonably low due to the fact that the air conditioning was running almost continuously. Note that the temperature climbs suddenly in the last hours of the day even though the external temperatures fall, due to the time lag and the air conditioning being switched off. As for the kitchen in flat 4, as before, the temperature is stable at around 32°C, and is higher than the temperature outside the building: note again that that the temperature is out of phase with the outdoor temperature by about 5 hours due to the time lag induced by the thermal mass of the building materials.

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