T.C.

ISTANBUL AYDIN UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

SIMULATION OF AN ENERGY EFFICIENT BUILDING IN DIFFERENT GEOGRAPHICAL LOCATIONS USING ENERGY PERFORMANCE SOFTWARE

MASTER’S THESIS

Abdellatif Jamal Abdelrahman HAYAJNEH

Department of Mechanical Engineering

Mechanical Engineering Program

AUGUST, 2022

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AUGUST, 2022

ONAY FORMU

DECLARATION

I hereby declare with the respect that the study "Simulation of an Energy Efficient Building in Different Geographical Locations Using Energy Performance Software", which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the References. (18/07/2022)

Abdellatif Jamal Abdelrahman HAYAJNEH

FOREWORD

In the name of Allah, the Most Gracious and the Most Merciful.

All praise and blessings to Allah for the completion of this thesis. I thank God for all of the opportunities, hardships, and strength that have been bestowed upon me in order to complete the thesis.

First and foremost, I would want to express my gratitude to my supervisor, Prof. Dr. HASAN HEPERKAN, for his direction, understanding, patience, and, most significantly, for providing positive support and a warm attitude for me to complete this thesis. It has been a privilege and an honor to have him as my supervisor.

My heartfelt thanks go to all my family members. This thesis would not be achievable without the assistance of these individuals. I would like to thank my loving father, Dr. JAMAL HAYAJNEH, and my beautiful mother, Dr. DUA NASSAR, for their unconditional support during my journey.

A special thanks to Dr. MAHA LASHIN for her huge support and guidance during this thesis.

My heartfelt gratitude and appreciation go to all my colleagues and dear friends who stayed by me and supported me through thick and thin.

July, 2022 Abdellatif Jamal Abdelrahman HAYAJNEH

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ABSTRACT

Nowadays, energy is becoming the most important aspect of our lives; some countries are suffering from a lack of electricity, and by finding ways to reduce energy consumption, we could have a more energy efficient building, which would have a direct impact not only on individuals but also on the entire country. This thesis compares the impact of adding synthetic and natural thermal insulation materials on cooling and heating load to the exterior walls of two office buildings that are in two different geographic regions.

This study illuminates the role of natural and synthetic insulating materials in creating more energy-efficient building. This thesis will provide an overview of the significance of buildings and their energy use in two different scenarios, as well as a discussion of thermal insulation and many materials that might be employed depending on the qualities of each thermal insulation. The simulation program will run along with a demonstration of the research approach. While we will see the typical materials that are used in the building for each site, with the installation of different thermal insulation materials to identify and discuss the results, the study will be finalized by discussing the results and further recommendations for constructing more efficient buildings.

Keywords: Energy efficiency, Thermal insulation, Electricity, Energy consumption, Office building, Saudi Arabia, Turkey, Cooling load, Heating load.

ENERJİ PERFORMANSI YAZILIMI KULLANILARAK FARKLI COĞRAFİ LOKASYONLARDA ENERJİ VERİMLİ BİNA SİMÜLASYONU

ÖZET

Günümüzde enerji hayatımızın en önemli unsuru haline geliyor; bazı ülkeler elektrik sıkıntısı çekiyor ve enerji tüketimini azaltmanın yollarını bularak, sadece bireyler üzerinde değil, tüm ülke üzerinde doğrudan etkisi olacak daha enerji verimli bir binaya sahip olabiliriz. Bu tez, iki farklı coğrafi bölgede bulunan iki ofis binasının dış duvarlarına sentetik ve doğal ısı yalıtım malzemeleri eklenmesinin etkisini karşılaştırmaktadır.

Bu çalışma, daha enerji verimli bina oluşturmada doğal ve sentetik yalıtım malzemelerinin rolünü aydınlatmaktadır. Bu tez, binaların önemine ve iki farklı senaryoda enerji kullanımlarına genel bir bakış sunacak, ayrıca ısı yalıtımı ve her bir ısı yalıtımının kalitesine bağlı olarak kullanılabilecek birçok malzeme hakkında bir tartışma sunacaktır. Simülasyon programı, araştırma yaklaşımının bir gösterimi ile birlikte çalışacaktır. Simülasyon programını kullanarak her iki binaya çeşitli ısı yalıtımı malzemeleri uygulayıp simülasyon ederek, her malzemenin sonuçlarını elde etmek, ve daha sonra elde edilen sonuçları karşılaştırmak ve tartışmak, ve tartışmaya göre her iki binanın daha verimli hale getirilebilmesi için en uygun şartları belirlemek ve bu binalar için en uygun şartları tavsiyede bulunmak.

Anahtar Kelimeler: Enerji verimliliği, Enerji, Isı yalıtımı, Enerji tüketimi,Ofis binası, Suudi Arabistan, Türkiye, Soğutma yükü, Isıtma yükü.

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ABBREVIATIONS

BIM **:** Building Information Modeling.

EU **:** European Union.

SA **:** Saudi Arabia.

kW **:** Kilowatt.

DOE **:** Department of Energy.

ASHRAE **:** The American Society of Heating, Refrigerating and Air-Conditioning Engineers.

IEA **:** International Energy Agency.

ECRA **:** Electricity and Cogeneration Regulatory Authority.

NCM **:** National Center for Metrology.

SEC **:** Saudi Electric Company.

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I. INTRODUCTION

A. Buildings and energy consumption

Geometry and construction play an essential part in obtaining high energy performance when constructing new buildings (Gagliano et al., 2014). Buildings have an important role in a smart system that aims for more reliable and sustainable energy use (IEA. World Energy Outlook, 2015). They can enhance the rapid adoption of renewable technology, lowering energy consumption, carbon emissions, and operational costs while improving occupant comfort, contentment, health, and productivity (Omar, 2008). Energy should be used more efficiently to reduce energy consumption and greenhouse gas emissions (Kalliomäki, 2011).

Because buildings contribute for 30% to 40% of global energy consumption and 25% to 35% of global greenhouse gas emissions, the built environment plays an important role in improving energy efficiency (UNDP, 2009). In the European Union (EU), for example, the building industry consumes 40% of total final energy and emits 40% of total CO2 emissions. In 2006, the EU's average energy dependency grew to 56% (EUROSTAT, 2006).

For the period from 2020 to 2030, EU member states have set new strategic goals: a 40% reduction in greenhouse gas emissions compared to the levels of the 1990s, and a consumption of renewable energy by at least 32%; and at least 32.5% energy savings compared to the usual business scenario (European Commission, 2019). The energy performance of buildings affects not only energy consumption and costs, but also greenhouse gas emissions, occupant health and productivity, property value, poverty level and the bottom line of business Fig. 1 (Urge-Vorsatz et al., 2015).

Figure 1: The different Advantages of Energy Efficiency (IEA, 2014)

Recent studies in the field of building energy performance show that energy efficient deep renovation of existing building stock provides a large number of direct benefits in terms of energy savings, as well as many indirect benefits for society, such as lower unemployment and higher living standards. According to a study, Hungary's deep renovation program could generate up to 131,000 net new jobs by 2020. It is also worth mentioning that up to 38% of the job gains are due to indirect effects on other industries that supply the construction industry, as well as induced effects from higher employment levels' increased spending power (Urge-Vorsatz et al., 2015).

According to the study, electric appliances and lighting account for only 22% of overall energy consumption in the service sector, while they account for 12% in the residential sector. This means that when considering macroeconomic circumstances during building renovations, more attention should be paid to HVAC systems than to electrical energy consumption, and when comparing building types, attention to electrical energy consumption should be paid more in the service sector or public buildings than in the residential sector (EU Commission, 2011).

Anisah et al. used a variety of zero-cost energy-saving measures to reduce annual energy usage in Jakarta office buildings. They discovered that adjusting the room temperature, replacing light bulbs with LEDs, and upgrading the HVAC system's operating schedule had the highest potential for cost savings (Inayati, 2017).

B. Turkey's energy profile

In this period, Turkey ranks second after China in increasing demand for electricity and natural gas in the world. On the other hand, Turkey depends on imports for 74% of its energy demand (Altinay & Karagol, 2005). Energy demand is mostly provided using fossil fuel sources. Oil, natural gas, and coal are still the most consumed energy sources, although there have been investments in renewable energy recently (TIO, 2019). The following figure indicates Turkey’s final energy consumption by source from 1990 until 2019 in Tera joule.

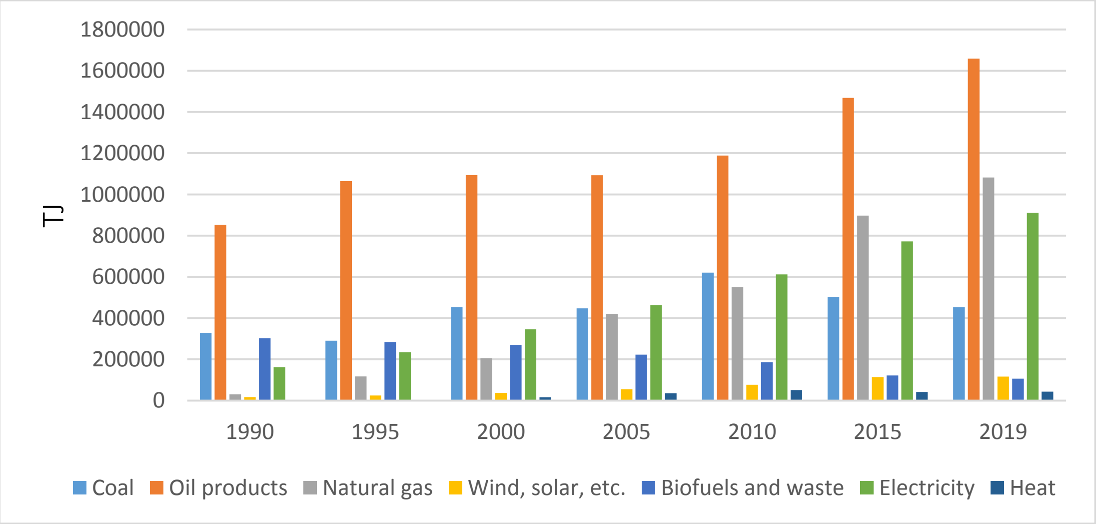


Figure 2: Turkey’s total final energy consumption by source in Tera joule (IEA, 2020)

While Turkey imports 93.2% of oil and 99.2% of natural gas consumption (TABO, 2018) and because of the volatility of oil and gas prices, such a large amount of imports puts pressure on the country's economy. Among the countries from which natural gas and oil are imported, Russia, Iran, Iraq, and Azerbaijan stand out. About 23% of the oil is imported from Iraq, 19% from Russia, and 17% from Iran. Besides, 53% of natural gas is imported from Russia, 17% from Iran, and 14% from Azerbaijan (TABO, 2018). According to the data collected by the IEA, the energy consumption in TWh for Turkey between the periods of 1985 and 2020 is as shown in Fig. 2.

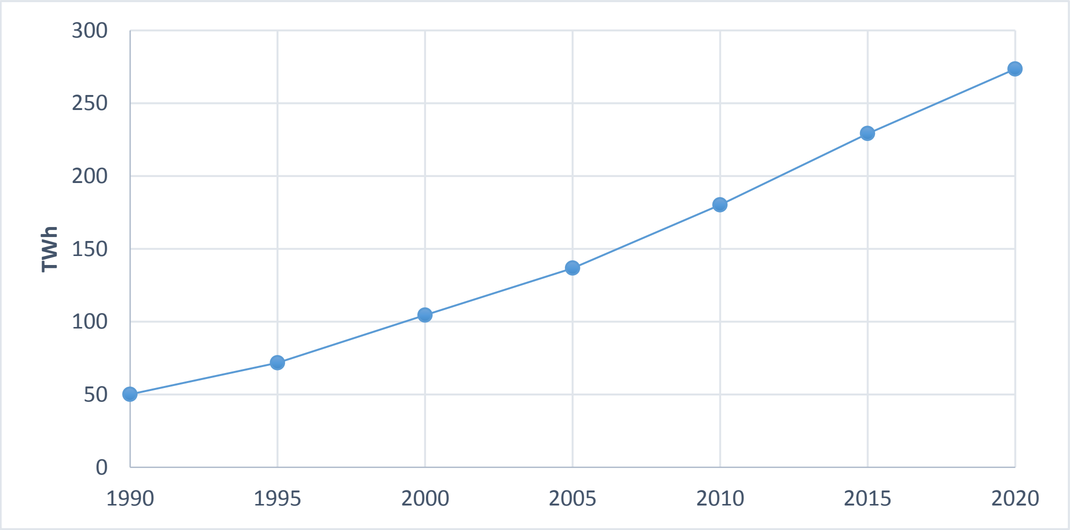


Figure 3: Turkey's electricity energy consumption in TWh from 1990 to 2020 (IEA, 2020)

In Turkey, buildings account for a growing portion of total energy consumption, now accounting about for half of total energy consumption. According to WEC Commercial buildings demand year-round space heating and cooling (World Energy Council, 2002). According to 2017 data, Turkey consumed 289 billion kWh of electricity per year, placing it among the top twenty energy-consuming countries in the world (Riddell et al., 2019).

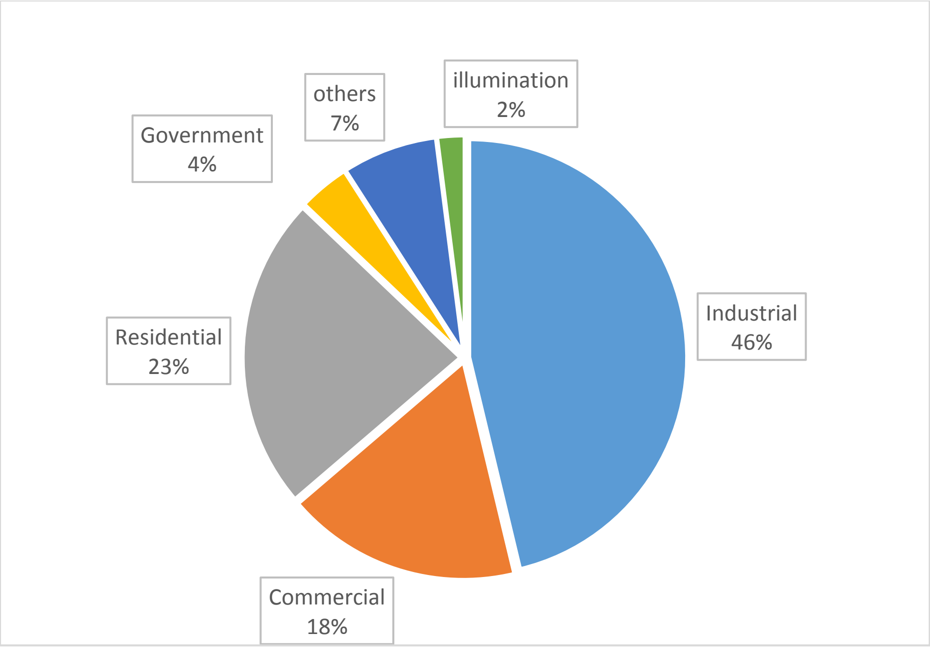


Figure 4: Energy consumption by building type Turkey in 2020 (TEDC, 2021)

Since the mid-1990s, completely air-conditioned office buildings have been significant commercial electricity end-users. As a result, reducing energy consumption for space cooling and heating in buildings is a critical step in Turkey's efforts to conserve energy and preserve the environment. Studying the factors that influence office building energy efficiency and the energy characteristics of building systems is necessary for a better understanding of energy-saving design principles and operational techniques. It is now possible to evaluate these issues comprehensively and methodically using computer modeling techniques and detailed building energy simulation software (Clarke, 2001).

C. Saudi Arabia energy profile

While Saudi Arabia is one of the world's fastest-growing countries, with an annual economic growth rate of 6.8 percent, the country's annual primary energy consumption has increased in recent years, rising from 3.88 MWh/capita in 1980 to 9.14 MWh/capita in 2014 (EIA 2014; ECRA, 2014). In 2014, Saudi Arabia generated 281.1 GWh of electricity, a 6.8 percent increase. The amount generated has more than doubled since 2007 (ECRA 2014, 2007). In 2012, Saudi Arabia was the world's largest oil producer and the second largest holder of crude oil reserves. Saudi Arabia's economy is heavily reliant on fossil fuels. According to the Organization of Petroleum Exporting Countries, fossil fuel exports accounted for over 90% of total Saudi export earnings in 2011 (OPEC). Its GDP ranks 20th worldwide (WDI, 2012).

Saudi Arabia is the world's sixth largest consumer of oil and natural gas. It is one of ten countries in the world with higher energy usage than the worldwide average. Saudi Arabia consumed approximately 129.7 million tons of oil in 2012 representing 3.1 percent of total world consumption, whereas it consumed 92.5 million tons of natural gas in 2012, representing 3.1 percent of the total global consumption. In 2009, industries consumed half of total energy consumption (Alyousef & Abu-ebid, 2011). Fig. 5 shows the total final energy consumption by source in terajoule.

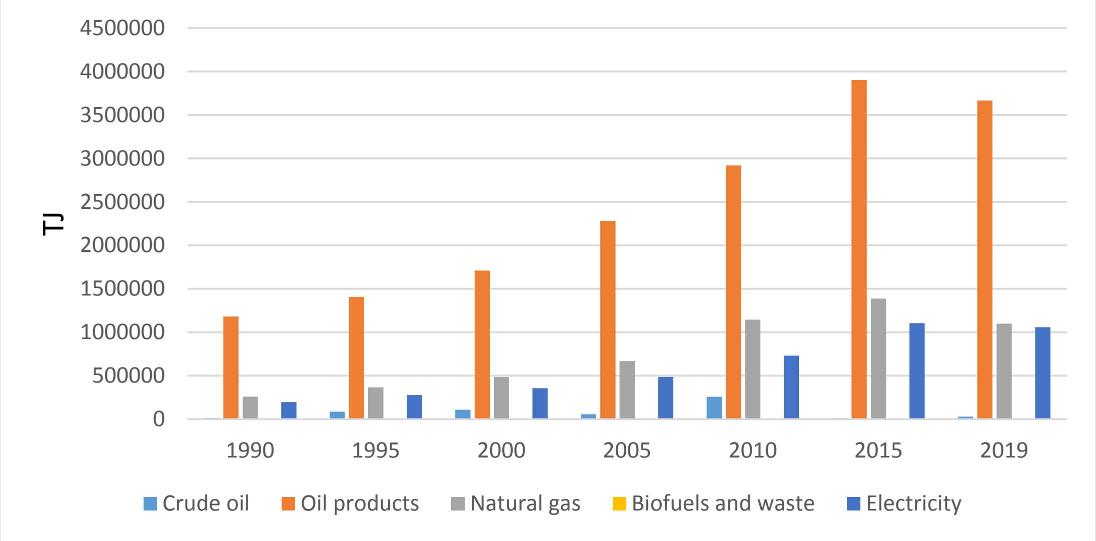


Figure 5: Saudi Arabia total final energy consumption by source in Terajoule (IEA, 2020)

Saudi Arabia consumed approximately 24 million tons of the total 708.8 million tons of energy production and imports during 2018 (IEA, 2017). The Kingdom has an annual rate of 1.54% of population growth that is directly proportional to the annual rate of growth in Energy consumption (Alrashed & Asif, 2012).

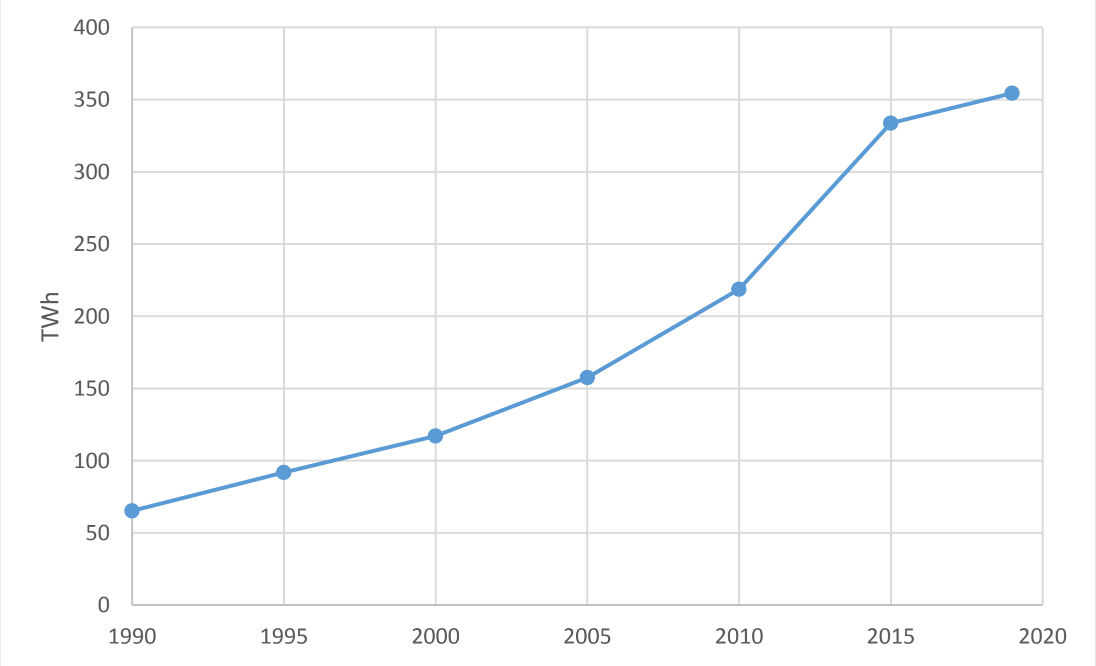


Figure 6: Saudi Arabia's electricity energy consumption in TWh between 1990 and 2019 (IEA, 2020)

The thesis consists of five different sections. The first part of the thesis provides the introduction, which presents the background of the current study, the motivation for conducting this study, and objectives. Secondly, the literature review is presented in which the gap of the study is emphasized. This provides the basis for undertaking the current study. The third chapter discusses the research methodology, including the steps followed in conducting this study. The fourth chapter provides the findings of the study. The fifth chapter is on the discussion and conclusion of the thesis work.

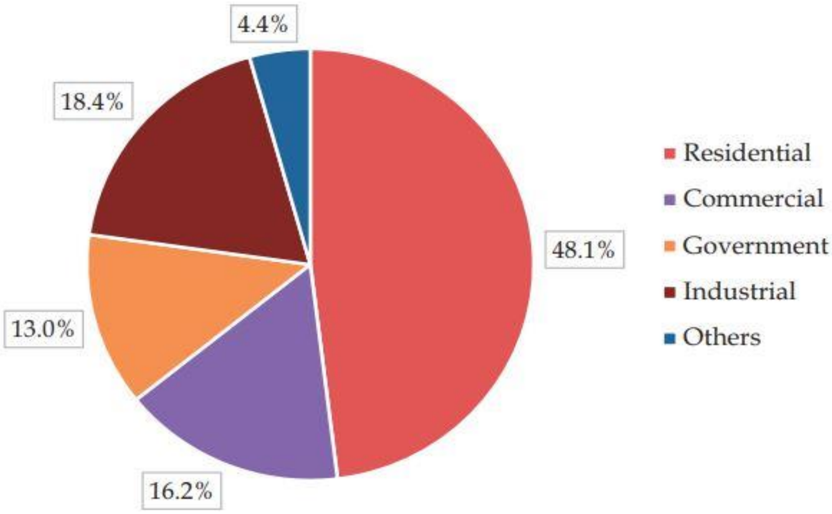


Figure 7: Total electrical energy consumption per sector in Saudi Arabia in 2017 (SEC, 2017)

The purpose of this thesis is to investigate the effect of various thermal insulation materials and their reactions in diverse climatic regions, as well as their role in reducing energy demand on two office buildings using energy simulation software to calculate cooling and heating loads when insulations are applied into the exterior walls.

This thesis faces challenges of the climate change of each location in summer and winter and how it would affect the overall energy demand.

II. LITERATURE REVIEW

In this part of the work, a general idea about thermal insulation, old studies about the several types of thermal insulation, and the difference between each type of building insulation material and their thermal properties were discussed.

Thermal insulation is an important contributor and a clear practical and logical first step towards achieving energy efficiency, especially in structures that are loaded with envelopes and located in adverse climatic conditions. So, what is thermal insulation? Thermal insulation is a material or mixture of materials that, when used properly, slows the rate of heat transfer by conduction, convection, and radiation. Due to its high thermal resistance, it slows down the passage of heat in and out of the building (ASHRAE, 2001).

A. The Mechanism of Thermal Insulation

Heat naturally moves from a warm environment to a cooler environment. In winter, heat travels instantly from all heated living quarters to the outdoors, as well as to attics, garages, and adjacent unheated basements - wherever there is a temperature difference. During the summer heat is transferred from outside to inside the house. To maintain comfort, your heating system must replace heat lost in winter, and your air conditioner must remove heat gained in summer. By generating an effective resistance to heat movement, insulated ceilings, walls, and floors lower the amount of heating or cooling necessary (DOE, 2002).

1. Thermal resistance

Insulation is evaluated in terms of thermal resistance, which shows how well it resists heat flow. The higher the insulating performance, the higher the R-value. Thermal insulation's R-value is determined by thickness, density, and the type of material. R-value is expressed in $m^2 * K/W \ (ft^2 \cdot °F \cdot h/BTU)$ (DOE, 2002).

2. Thermal conductivity

Thermal conductivity is the time rate of steady-state heat flow (W) through a unit area of 1 m thick comparable material in a direction perpendicular to the isothermal levels, as caused by the unit temperature difference (1 K) across the sample. The SI unit for thermal conductivity K is $W/m * K$ (Btu/h-ft-F or Btu-in/hrft2-F) (ASTM, 1997).

B. Insulation building materials

As shown in Fig. 8 below, the types of thermal insulation for building materials are classified in three major categories based on synthetic substitute, base of origin, and availability, but the focus of this study will be on conventional and sustainable materials.

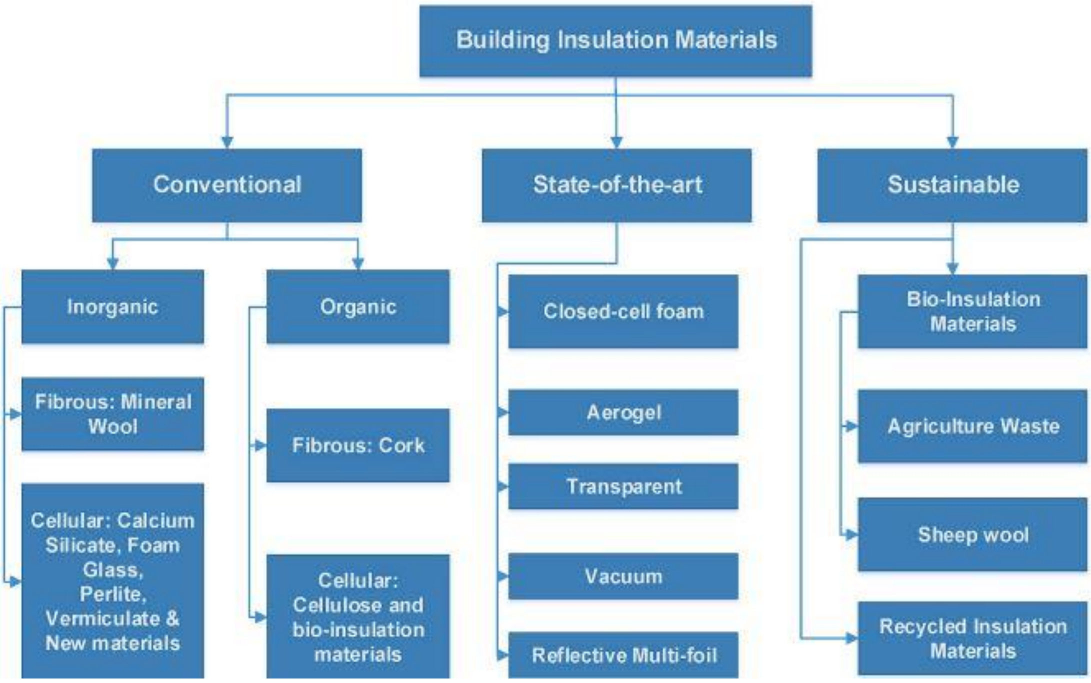


Figure 8: Classification of insulation types (Kumar et al., 2020)

C. Conventional insulation materials

Conventional insulation materials are currently used in buildings and are commercially available, which can be classified as organic and inorganic materials, and are explained further below (Kumar et al., 2020).

1. Organic insulation materials

a. Polystyrene

Expanded (XPS) and extruded (EPS) insulation polystyrene are commercially available. They are made of organic cellular plastic. To manufacture expanded polystyrene insulation, microscopic polystyrene (a byproduct of crude oil) is heated with water vapor, combined with an expansion agent (i.e., propane) (Fig 9). Extruded polystyrene, on the other hand, is produced by extruding a molten mixture of polystyrene and foaming agent through a pressure release nozzle (Cai et al., 2017).

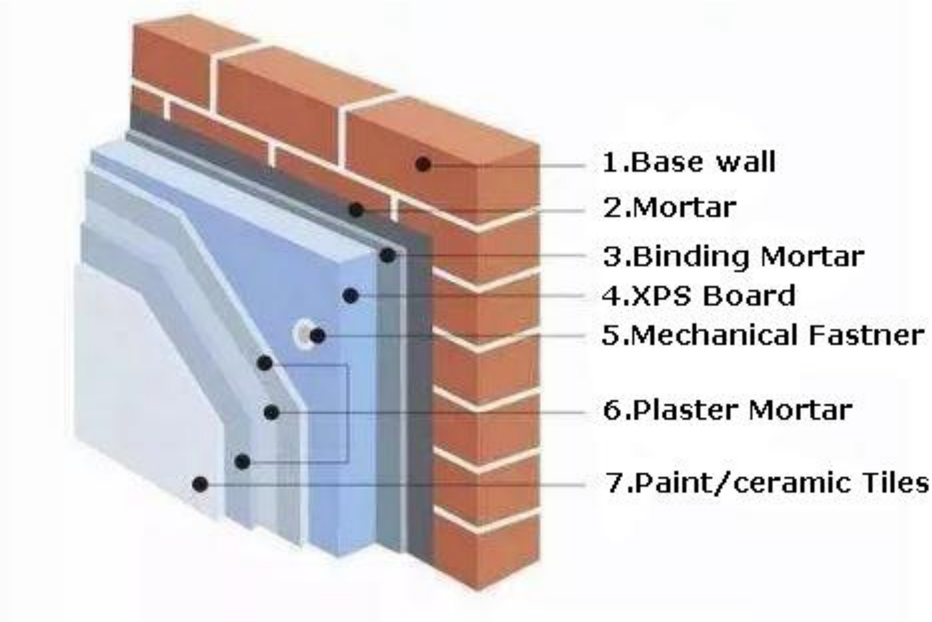


Figure 9: Structural composition of thermal insulation exterior wall (Ali, 2021).

b. Polyurethane (PUR) and Polyisocyanurate (PIR)

Polyurethane and Polyisocyanurate are produced by the interaction of isocyanate and polyols. During the expansion process, the expansion gases are filled into the closed pore. As a result, it is employed in openings (window fill and door air gaps) and in an envelope (Somarathna et al., 2018).

c. Cellulose

To improve thermal characteristics, cellulose is made of recycled paper (Fig 10), wood fiber, and borax acid. They are commercially available as cavity fillers and board and batt for envelopes (Lopez Hurtado et al., 2016).

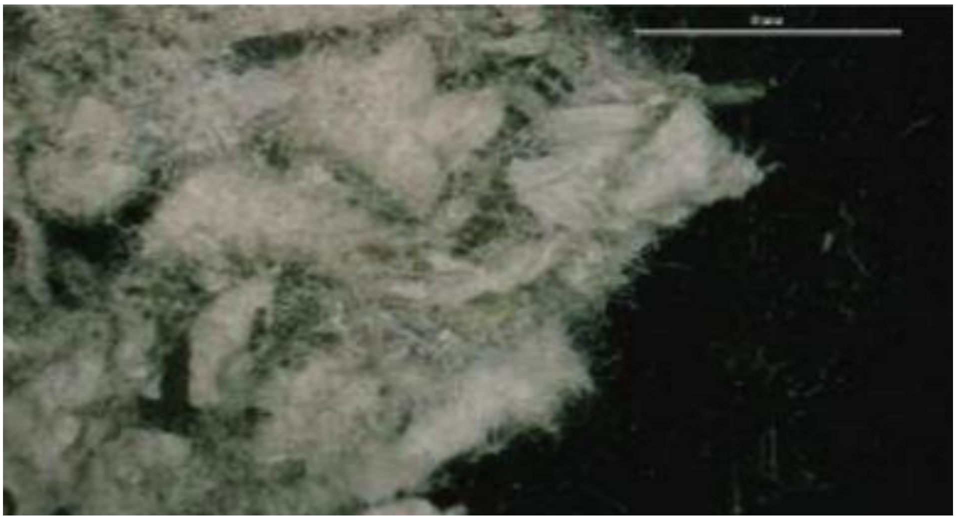


Figure 10: Microscopic scan of cellulose fibers, 10X magnification (Somarathna et al., 2018)

d. Cork

The cork oak is used to make cork insulators (Fig 11). It is commercially available as a filler material and as an insulation board. Because of its strong thermal resistance and compressive strength, it can withstand structural loads without surrendering thermal characteristics (Hernandez-Olivares et al., 1999).

Figure 11: Insulation cork Board glued to gypsum plasterboard in an Internal TICS (GYPTEC, 2012)

2. Inorganic insulation materials

a. Fibrous insulation materials

Mineral wool is a type of inorganic fiber insulation made up of rock, glass, and slag wool. Cullet, quartz sand, diabase, and basalt are used to make them. These materials are commercially available in batt and board form. Mineral wool boards that are denser and tougher are employed in floor, wall, and roof applications, whilst mineral wool batts that are lighter and softer are used in frame houses and other applications (Villasmil et al., 2018).

b. Inorganic cellular insulation materials

Calcium silicate, foam glass, perlite, and vermiculite are examples of inorganic cellular insulation materials. Chalk, sand, cellulose fibers, cullet, dolomite, oxide (aluminum and silicon), and magnesium-aluminum silicate are their basis materials. Because of their large porosity, foamed insulators have low thermal conductivity, which reduces mechanical strength while improving hygroscopic properties (Abu-Jdayil et al., 2019).

D. Sustainable insulation materials

Among the three kinds of insulation, sustainable insulating materials have the lowest environmental impact during the manufacturing stage. These materials are further classified into two types: the first type is natural insulating materials obtained from agricultural and forest leftovers, as well as sheep wools, while the second type is materials made from recycled insulation. It should be emphasized that the term "sustainable" is specifically used regarding lower embodied energy and carbon of these materials (Kumar et al., 2020).

1. Natural insulating materials made from agricultural and forest waste

For date production, the date palm (Phoenix dactylifera) is planted in semi-arid locations. Leaves, petioles (13 per plant per year), and bunches (seven per plant per year) are often considered as waste Fig. 12. Agoudjil et al. (2011) reported that around 1,200,000 tons of petioles, 410,000 leaves, and 300,000 bunches are generated annually worldwide, based on FAO official data.

Agoudjil et al. (2011) examined the thermal insulation capabilities of these materials after they were converted to fibers because of their wide availability. The influence of palm date type and the difference between petioles and bunches-based material were investigated using six samples. The fiber direction was also evaluated. Thermal conductivity of 0.072 W/mK was found in the best-performing materials (Agoudjil et al., 2011).

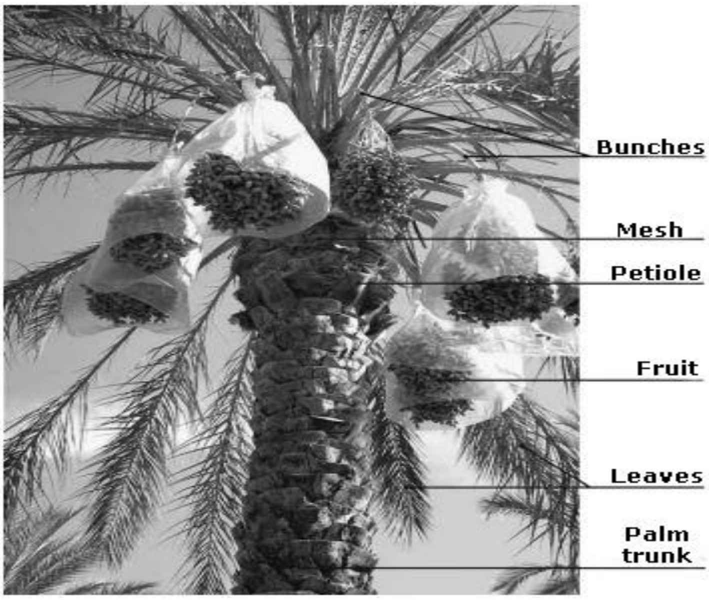


Figure 12: Different parts of the date palm tree (Agoudjil et al., 2011)

Khedari et al. (2004) created a low-cost insulation panel out of durian peel and coconut coir. They discovered that a low-cost insulating particleboard panel with a thickness of 10 mm and a 90:10 ratio of durian peel and coconut coir had an ideal thermal conductivity ranges from 0.0728 to 0.1342 W/ (m K).

Another low-cost insulation particleboard panel was produced utilizing Miscanthus and Sunflower stalk Fig. 13 (Eschenhagen et al., 2019). Using high-frequency hot pressing, Zhou et al. (2010) created a binderless cotton stalk fiber (BCSF). BCSF has a similar density and thermal conductivity to vermiculite and expanded perlite. Prabhakaran et al. (2014) prepared the vertical faced reed panels and crossed them for testing their acoustic properties (D’Alessandro et al., 2016).

(a) (b)

Figure 13: (a) Miscanthus fiber panel. (b) Sunflower stalk fiber panel (Eschenhagen et al., 2019).

For a passively controlled indoor environment, Nguyen et al. (2017) created a bio-insulation fiberboard out of bamboo fibers, bone glue, and sodium lignosulfonate (Nguyen et al., 2017). Previous research has also produced insulation particleboards from bagasse, cotton stalks (Zhou et al., 2010), oil palm fibre (Agoudjil et al., 2011), pineapple leaves (Kumfu et al., 2012), durian Peel (Khedari et al., 2004), rice and wheat husk (Muthuraj et al., 2019), sansevieria fibre (Ramanaiah et al., 2011), sunflower stalks (Fig 14) (Binici et al., 2013), straw bale (Sabapathy et al., 2019), kenaf core(Xu et al., 2004), natural fibres (Damfeu et al., 2016), corn Cobs(Paiva et al., 2012), wood waste(Fig 11) (Barreca et al., 2019), silkworm cocoons (Zhang et al., 2013), sisal (Kalaprasad et al., 2000), hemp (Griffiths et al., 2012), banana (Annie Paul et al., 2008), cork (Barreca et al., 2018), narrow-leaved Cattail (Luamkancganaphan et al., 2012) and coconut coir (Khedari et al., 2004).

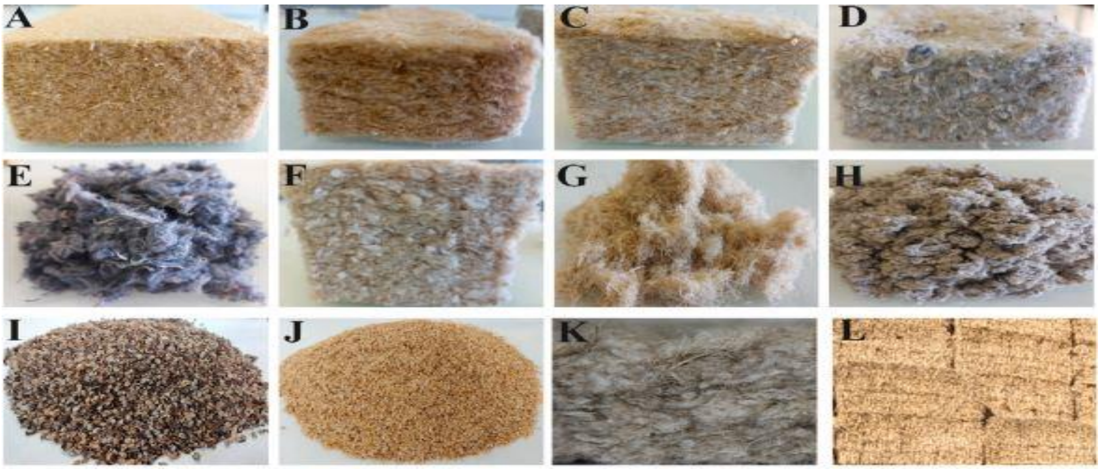


Figure 14: Several biomass-based insulating materials and products: a) wood hardboards, b) wood medium-density fiberboard, c) hemp panel, d) cellulose wadding panel, e) recycled textiles in loose-fill, f) mixed fibers (cotton/flax/hemp) panel, g) hemp fibers, h) cellulose wadding in loose-fill, i) buckwheat husks, j) millet husks, k) flax panel, l) wheat straw bales (Rabbat et al., 2022).

2. Natural insulation materials based on sheep wool

Sheep wool has many physical properties that make it a great sustainable building insulation material, including strength, hygrothermal, acoustic, fire resistance, organically controlling the indoor atmosphere, and low embodied energy and carbon (Johnson N. et al., 2003). Nevertheless, Ye et al. (2006) discovered that the heat conductivity of hemp and sheep wool was the same at a given density.

The sheep wool insulation batt Fig. 15, on the other hand, is four times the price of fiberglass insulation due to high labor costs, and 40 percent of the wool is lost during the production process. It is not fully commercialized because of a lack of efficient local wool collection (Bosia et al., 2015). The thermophysical properties and design of the prepared sheep wool insulation samples were evaluated (Zach et al., 2012). The highest sound absorption frequency lowers and the sound absorption coefficient increases as insulation thickness increases. The lightweight insulation samples were more sensitive to temperature changes than the denser insulation samples. Furthermore, because sheep wool has up to 30% hygroscopicity, it may absorb a large amount of water vapor without increasing thermal conductivity. As a result, it maintained sorption humidity up to 20% with little fluctuations in thermal conductivity under the relative humidity range of 30-60% at 23 °C.

Figure 15: Sheep wool and its applications in building construction. (Zach et al., 2012)

1. Recycled insulation materials

Sustainable insulating materials are also manufactured from recycled or industrial waste to reduce the energy involved and carbon and to redirect garbage from landfills (Patnaik et al., 2015). Mix recovered polystyrene fibers and waste wool in equal parts to create an insulating material for the structures. The materials generated absorb 70% of accident noise in the 50-5700Hz frequency range and have sufficient moisture resistance when wet without compromising thermal or acoustic performance (Abdul Qadir et al., 2012).

The thermal and mechanical properties of natural rubber compounds have been improved by mixing varying amounts of waste rubber. Thermal properties were similar to those of other known insulators, but the cost was reduced by 80%. (Ayadi et al., 2011). Grinding the remaining glass particles with 1% CaCO3 gave good insulation (0.03 W/m/K) and acoustic properties (15 dB). The thermal conductivity and density of commercial fiberglass-based recycled insulating materials ranged from 0.038 to 0.050 W/m/K and 100-165 kg/m3, respectively (Asdrubali et al., 2015). The thermal conductivity and density of recycled cotton and textile waste were determined to be 0.039-0.044 W/m/K (Binici & Aksogan, 2014) and 0.034-0.053W/m/K (Tilioua et al., 2015). 2018), accordingly.

E. Insulation material properties

In the following tables, the properties of each material are presented.

Table 1: Conventional material properties (inorganic)

Material	Temperature (◦C)	Density (kg/m^3)	Thermal conductivity (λ) (W/m K)	Reference
Rock wool (natural rock)	-100-750	30–180	0.033–0.045	Al-Homoud, 2005 D’Alessandro et al., 2016 Abu-Jdayil., 2019 Papadopoulos, 2005 Pfundstein et al., 2012 Karamanos et al., 2008 Wieland et al., 2000.
Glass wool	-100-500	13–100	0.03–0.045	D’Alessandro et al., 2016 Abu-Jdayil., 2019 Papadopoulos, 2005
Calcium silicate	300	115–300	0.045–0.065	Pfundstein et al., 2012
Cellular glass	−260–430	115–220	0.04–0.06	Pfundstein et al., 2012
Vermiculite	700–1600	70–160	0.046–0.07	Zhang, 2011) Pfundstein et al., 2012 Al-Homoud, 2005
Ceramic	N. A.	120–560	0.03–0.07	Pfundstein et al., 2012

N. A.: Not available

Table 2: Conventional material properties (organic)

Material	Temperature (◦C)	Density (kg/m^3)	Thermal conductivity (λ) (W/m K)	Reference
Expanded Polystyrene (EPS)	−80–80	15–35	0.035–0.04	Al-Homoud, 2005 D'Alessandro et al., 2016 P. Jelle, 2011 Papadopoulos, 2005 Pfundstein et al., 2012
Extruded Polystyrene (XPS)	−60–75	25–45	0.03–0.04	Al-Homoud, 2005 D'Alessandro et al., 2016 P. Jelle, 2011 Papadopoulos, 2005 Pfundstein et al., 2012
Polyisocyanurate (PIR)	−20–100	30–45	0.018–0.028	D'Alessandro et al., 2016 Omar et al., 2009
Cellulose fibers	60	30–80	0.04–0.045	Al-Homoud, 2005 D'Alessandro et al., 2016 P. Jelle, 2011 Pfundstein et al., 2012
Cork	N. A.	100–120	0.037–0.043	Sierra-Perez et al., 2018 Silvestre et al., 2016 Sierra-Perez et al., 2016 Robin et al., 2014

N. A.: Not available

Table 3: Natural insulation materials (agricultural, forest waste and sheep wool)

Material	Temperature	Density	Thermal conductivity	Reference

	(◦C)	(kg/m^3)	(λ) (W/m K)	
Sheep wool	130–150	25–30	0.04–0.045	Pfundstein et al., 2012
Cotton fiber	100	20–60	0.035–0.06	Pfundstein et al., 2012
Rice straw	24	154–168	0.046–0.056	D’Alessandro et al., 2016
Hemp fiber	100–120	20–68	0.04–0.05	Pfundstein et al., 2012
Bagasse fiber	160–200	70–350	0.046–0.055	D’Alessandro et al., 2016 Panyakaew & fotios., 2011
Coconut fiber	180–220	70–125	0.04–0.05	Pfundstein et al., 2012 D’Alessandro et al., 2016 Panyakaew & fotios., 2011
Flax	N. A.	20–80	0.03–0.045	Pfundstein et al., 2012
Wood wool	110–180	350–600	0.09	Pfundstein et al., 2012
Wood fibers	110	30–270	0.04–0.09	Pfundstein et al., 2012
Date palm	N. A.	187-389	0.072–0.085	Agoudjil et al., 2011 Chikhi et al., 2013

N. A.: Not available

Table 4: Recycled material

Material	Density (kg/m^3)	Thermal conductivity (λ) (W/m K)	Reference

Cotton (recycled)	25–45	0.039–0.044	Inno-Therm, 2020
Recycled glass	450	0.031	Ayadi et al., 2011
Recycled PET	30	0.0355	Intini & Kühtz, 2011
Recycled textile and paper	433	0.034–0.039	Ricciardi et al., 2014
Recycled textile fibers (Polyester and polyurethane)	440	0.044	Briga-Sá et al., 2013
Recycled textile fibers (synthetic)	200–500	0.041–0.053	Valverde et al., 2013

N. A.: Not available

III. METHODOLOGY

In this chapter, we are going to discuss the methodology that was used to conduct this work. It starts by explaining the type of building that was used in this study, then the number of different types of thermal insulation used to analyse and compare each sort of wall insulation.

Then the selection procedure for the thermal insulation will be summarized, and the different study cases for each location will be presented. Eventually, an overview of the program used to simulate the buildings will be provided, including the procedure used in the program to calculate the heating and cooling load for the various types of thermal insulation for each case, as well as the mathematical operation used in the program to calculate heating and cooling load, as well as the classification of the material used in this research.

The current research is about analysing the different types of thermal insulation materials that are used for exterior walls and how they effect in the total energy consumption especially in heating and cooling load in commercial buildings. In the following Fig. 16 the selection procedure for thermal insulation will be presented.

Figure 16: Thermal insulation selection procedure

A. Case studies

In this part of the chapter, the two case studies will be presented. Location, temperature, wind, and the average rainfall through the year will be specified for each case. Starting with Istanbul, Turkey, and then moving to Riyadh, Saudi Arabia.

1. Case study 1 (Istanbul-Turkey)

As a result of this geomorphological aspect, Turkey has various climatic zones as shown in Fig. 17. Anatolia's mountain ranges extend west to east, parallel to the north and south coasts. From west to east, the altitude progressively rises. These variances result in different types of pasture and changes in range practices (Koc et al., 2015).

Figure 17: Climate zones of Turkey (Deggin, 2021)

The following sections are descriptions of the four major climate zones and their various range types:

a- Mediterranean Climate Zone

The Mediterranean climate zone extends from the Mediterranean and Aegean Sea coastlines to the Taurus Mountain range, which runs parallel to the Mediterranean shore. The climate is defined by pleasant, rainy winters and hot, dry summers, with annual precipitation varying between 600 and 1100 mm (Atalay, 1997).

b- Black Sea Climate Zone

The Black Sea Climate Zone stretches from west to east between the Black Sea coast and the Black Sea Mountains' foothills. The annual precipitation in the west is approximately 550 mm and progressively climbs to 2,200 mm in the east (Atalay, 1997).

c- Marmara Transition Zone

The Marmara region has a transitional climate between the Mediterranean and Black Sea climates; annual precipitation is around 600 mm and is distributed relatively uniformly throughout the year, while plant water stress is frequently significant in late July and August due to the hot weather (Atalay, 1997).

d- Continental Climate Zone

Moreover, half of the country is covered by the continental climatic zone. The natural vegetation and climate patterns differ amongst the subdivisions of the continental climatic zone. The following are the general characteristics of these subdivisions. (Atalay, 1997).

1) Southeastern Anatolia Subdivision

This climatic divide of southeastern Anatolia is found in southeastern Turkey Fig. 17 on the high plains (500-1000 m) that stretch into Syria Fig. 18. The average annual precipitation is around 500 mm, with the majority of it falling from autumn through spring. During the sweltering summer (daily high temperatures of over 40°C in July and August), there is hardly little precipitation (Atalay, 1997).

2) Eastern Anatolia Subdivision.

The Eastern Anatolia region of east-central Turkey Fig. 18 is a high plateau (North & Thinsep 1500 m) with mountain ranges ranging in height from 2,000 m to 3,000 m (Mount Ararat 5137 m; Fig 18). The annual precipitation fluctuates between 400 and 650 mm, with the majority falling from October until spring (Atalay, 1997).

3) Central Anatolian region

The Central Anatolian region Fig. 17 encompasses 18.5 million hectares, including approximately 6 million hectares of pastures. Although there are mountainous places categorized as pastures, the altitude of the pasture ranges between 500 m and 1500 m. The average annual precipitation is around 400 mm, with the majority falling from October through spring. Summer precipitation deficits limit plant output on cropland and pastureland alike (Atalay, 1997).

Istanbul is Turkey's largest city, with a population of over 16 million people and an area of 5461 km^2. With these characteristics, Istanbul is Turkey's most populated and dense metropolis, with nearly 20% of the country's population living within its borders.

Istanbul is divided into two halves by the Bosporus as shown in Fig. 18, which connects the Black Sea to the Marmara Sea (TurkStat 2018). The warm & hot session starts at the end of June with 21.1 ◦C, while the cold session starts in November with 11.9 ◦C as shown in Table 5. The hottest month of the year is August with 23.9 ◦C while the coldest is January with 5.7 ◦C (EUC, 2021).

Figure 18: Turkey’s latitude and longitude map (WM, 2017)

In Table 5, an average monthly rainfall & temperature for Istanbul is presented. According to TR ministry of environment, urbanization, and climate change.

Table 5: Average monthly temperature & rainfall (Istanbul) (EUC, 2021)

Month	Temperature in ◦C	Average Monthly Total Rainfall (mm)
January	5.7	84.3
February	5.8	69.6
March	7.4	60.5
April	11.6	46.9
May	16.5	29.8
June	21.1	27.6
July	23.8	21.4
August	23.9	25.2
September	20.4	38.1
October	16.0	66.5
November	11.9	81.0
December	8.1	97.2

The following Fig. 19 specifies the location of istanbul, the diverse rock types as well as the volcanic areas around it.

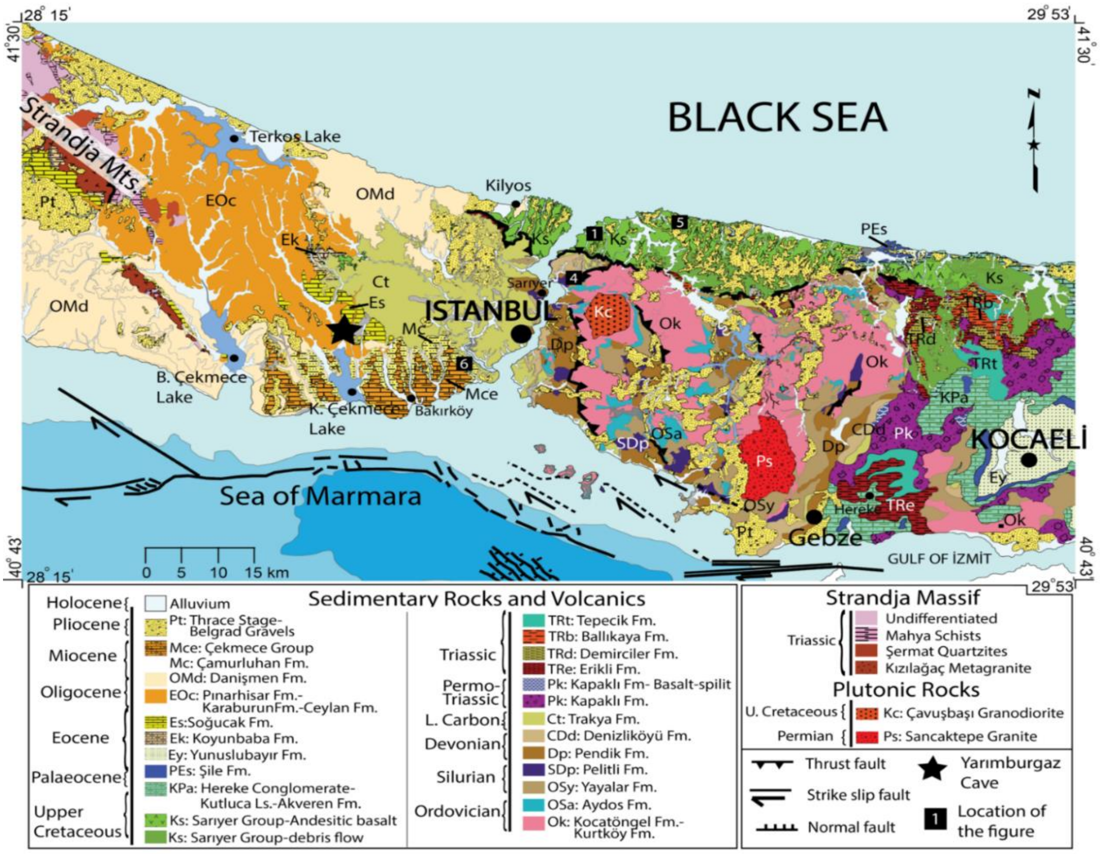


Figure 19: Geological map of Istanbul and its surroundings (Lom et al, 2016)

2. Case study 2 (Riyadh-Saudi Arabia)

The region of (SA) has gotten little attention. Brief and reliable climatic data for the Arabian Peninsula (AP) have been supplied, demonstrating that the AP has a diverse climate spectrum. From the Asir region of southern Australia's snows to the Persian Gulf's extreme dampness, from the blistering heat of the Empty Quarter to the monsoon rains in Al-Qarrah Governorate Dhofar.

SA has a diverse topography surface and covers large regions (approximately 2,250,000 km^2), accounting for nearly 80% of the AP. Saudi Arabia's latitude ranges from 15.5°N to 32.5°N, and its longitude ranges from 32°E to 55°E. The Empty Quarter (Empty Quarter) is located in Southeast South Asia's eastern and southeastern regions, as depicted in Fig. 20 (Walter and Lieth, 1967, Muller, 1982, Moore, 1986).

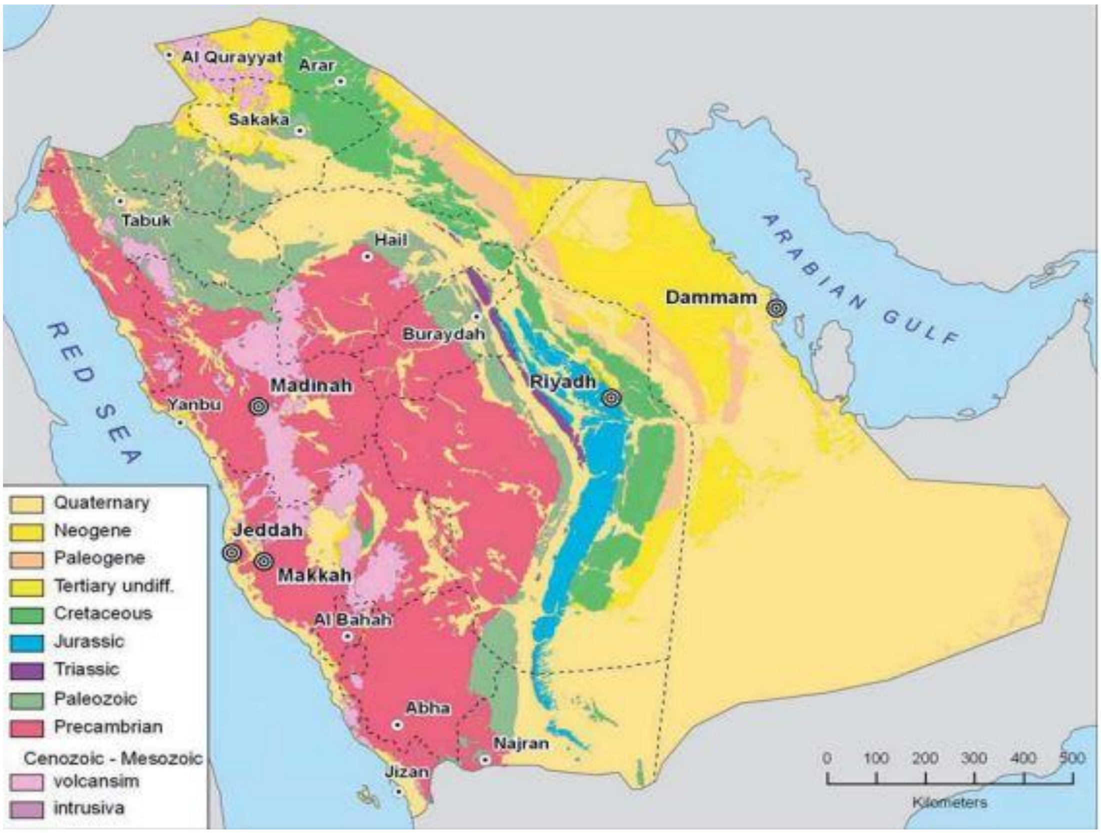


Figure 20: Simplified geological map of the Kingdom of Saudi Arabia (Al Saud & Rausch, 2012)

Because of the large changes in spatiotemporal temperatures, the country is divided into various climatic zones. According to the Köppen classification, most of SA region is hot and dry, with little rainfall and high temperatures (Al-Jerash, 1985, Al-Taher, 1994). On the other hand, the southwestern region of Saudi Arabia is classified as semi-arid (Köppen, 1936).

Irregular, heavy rainstorms happen on only a few days in a year and only in some areas of the SA. Therefore, the SA is considered one of the driest countries in the world. With the exclusion of the southwestern coast, the SA climate is described by extreme heat throughout the day, a sudden fall in temperature at night, and little, irregular precipitation. The aridity index classifies the study region as having desert conditions and a water deficit except the mountainous regions, which can be described as semiarid (Subyani & Al-Modayan, 2010).

While Riyadh is the capital city of the Kingdom of Saudi Arabia, it is located in the Riyadh region in latitude 24.7N and longitude 46.8E, roughly 600 meters above sea level and flowing eastward. Riyadh has evolved from a small-enclosed town to a modern city occupying an area of 3115 square kilometers, including 15 municipalities, and home to more than 6.5 million people in 2017 (MMRA, 2021). Summer Maximum temperature in Riyadh typically exceed 43.7◦C (Philip & Lau, 2013).

Figure 21: Saudi Arabia latitude, longitude and major cities and towns (WM, 2017)

In Table 6, an average monthly rainfall & temperature for Riyadh are presented. According to National Center for Metrology.

Table 6: Average monthly temperature & rainfall (Riyadh) (NCM, 2022)

Month	Temperature in ◦C	Average Monthly Total Rainfall (mm)
January	14.2	14.8
February	16.8	8.3
March	24.5	19.9
April	30.0	23.7
May	36	5.6
June	34.1	0
July	35.3	0
August	35.2	0
September	32.8	0
October	27.5	1.5
November	20.4	20
December	15.7	13.5

B. Software

The use of new methods and software is one of the most important tools that structural engineers use nowadays to stay ahead of the competition. Engineers are constantly looking for new ways to improve and keep pace with today's economy, reaching new heights in aspects such as productivity, coordination, and problem solving. (Building Information Modeling) BIM can assist with these crucial elements. The main advantage that BIM offers is the ability to integrate smart objects into the model (Hunt, 2013). BIM is the process of developing, collecting, and utilizing building information throughout its life cycle. While CAD design offers information modeling includes information about the building or information created in a database. The fundamental benefit of BIM over other modeling software is the availability of information about the building or structure, which may be used at various phases including architectural design, engineering calculations, construction, maintenance, and rebuilding (Ignatova, 2011).

These smart objects contain all the data about a particular component, from the geometric properties to the way they interact with other components, making the entire model very informative. Structural engineers can make use of BIM in various ways, as the model can be constantly updated with any changes in design or general specifications, while keeping all data as accurate as possible. BIM is changing the way we treat and perceive components. It has a serious impact on the design of activities such as conceptual design and structural analysis. BIM ensures that design and drafting errors are reduced and thus provides lower design cost and improved productivity (Hunt, 2013).

The analysis was conducted using one of the BIM platforms Revit. Revit is currently the most popular BIM solution. Unlike older design software, Revit is highly advanced and can generate 3D models automatically from 2D drawings. The software provides insights into projects, facilitates accurate prototyping and real-time scheduling. Revit is a diverse design software, most architects and engineers have used such diversity before, which means that the basics of Revit should be familiar. The real difference is that Revit focuses more on the architecture sector. Where software like Maya and 3DS Max offer general modeling functionality, Revit caters to the specific needs of architects and engineers. Of course, the software also includes BIM. You can enter data that will affect the look of your forms (Coorey, 2020). Not only does Revit software enable virtual modeling, or the creation of a virtual model of a building (as shown in the following figures) or infrastructure before it is built on-site, but it can also help you with many other things, such as the following (Autodesk Inc., 2022).

1. Avoiding rework 2. Reducing costs 3. Detecting issues before construction begins on-site

In the following models, an overview of the interface of the architecture plan from AutoCAD for the main building plan that were used for both study cases in the project, as well as architecture and mechanical templates for Revit software, including wall assembly, mechanical and architectural virtual models will be presented.

The following figures indicates the building floors that been taken from AutoCAD drawings, the building is consistent of 4 floors with a different celling height, starting with the ground floor & the first floor with 5 m celling height as shown in figures Figs. 22 and 23, respectively, while second floor & the third floor with 4 m celling height is shown in figures Figs. 24 and 25, respectively.

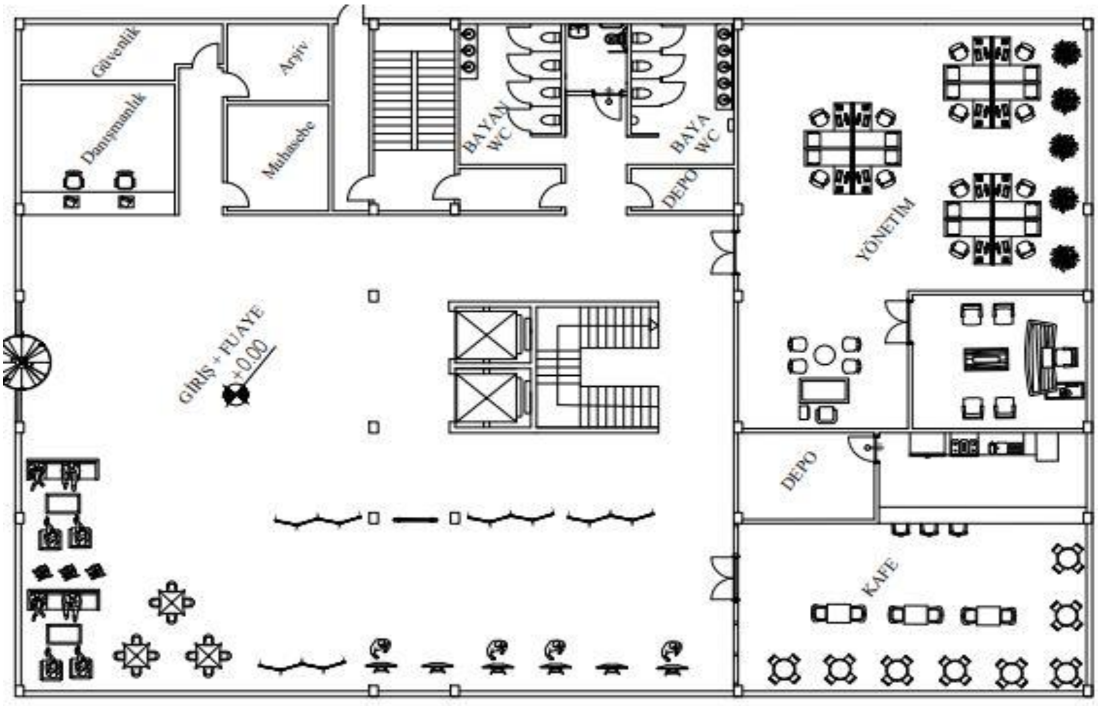


Figure 22: The ground floor of the architectural plan (AutoCAD, 2019)

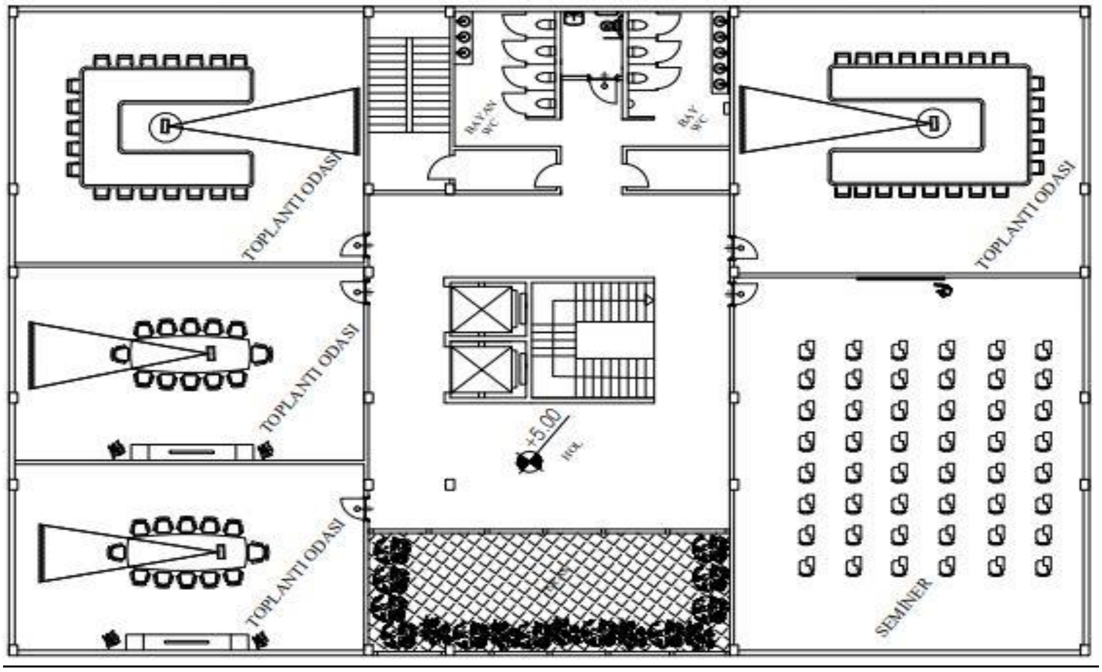


Figure 23: The first floor of the building (AutoCAD, 2019)

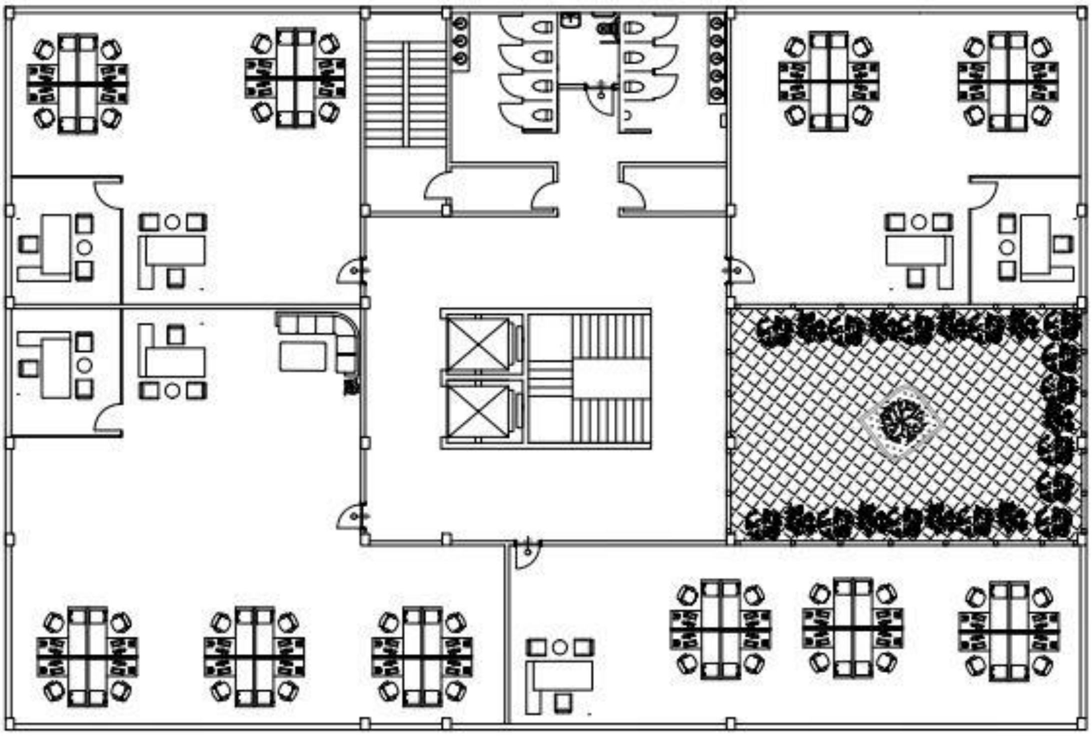


Figure 24: The second floor of building (AutoCAD, 2019)

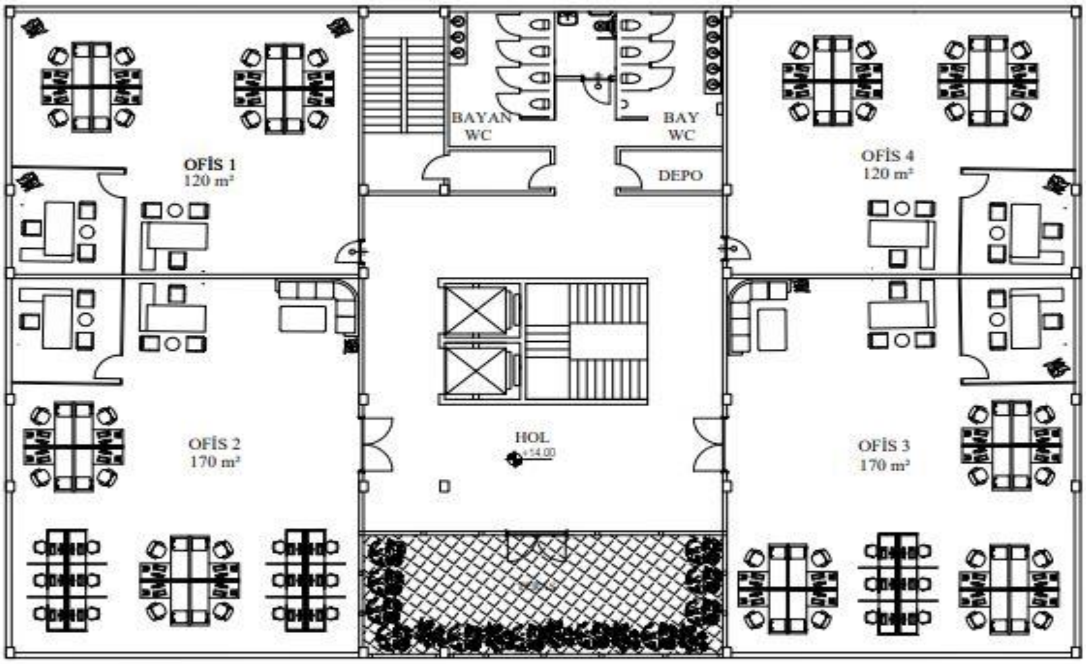
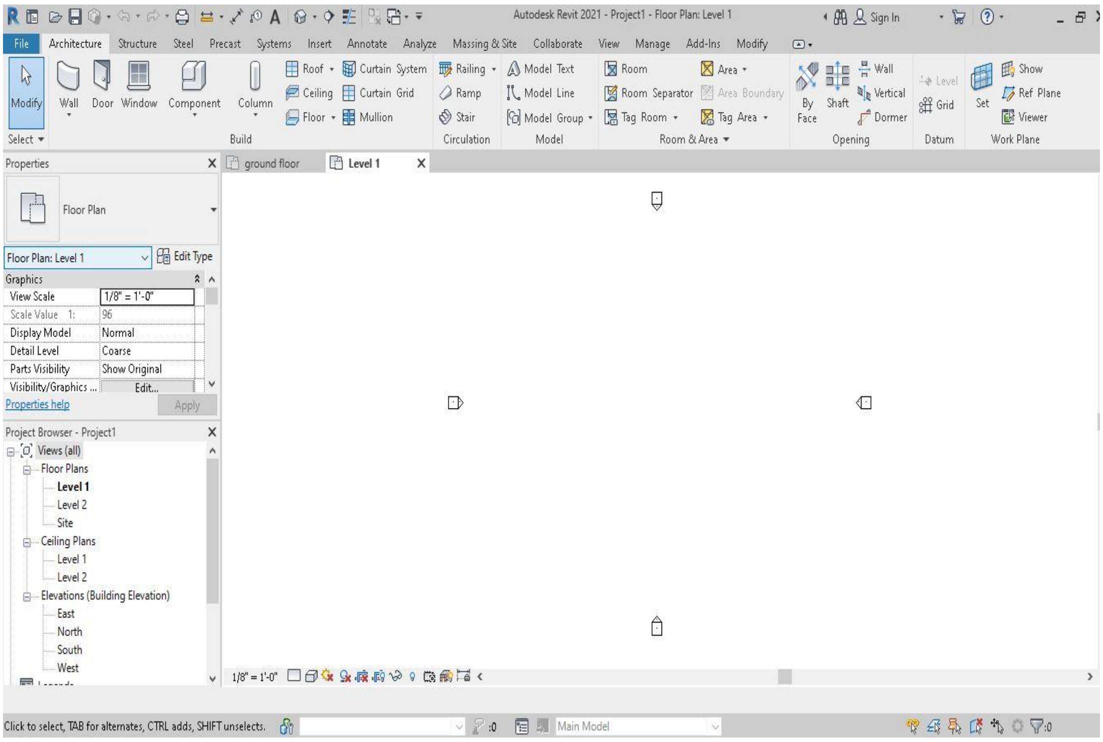


Figure 25: The fourth plan of the building (AutoCAD, 2019)

While the following figures gives a brief idea about the actual Revit software views, starting from the scratch when choosing to work on the architecture template to implement the previous AutoCAD drawings as well as the mechanical template, as shown in Figs. 26 and 27, respectively.



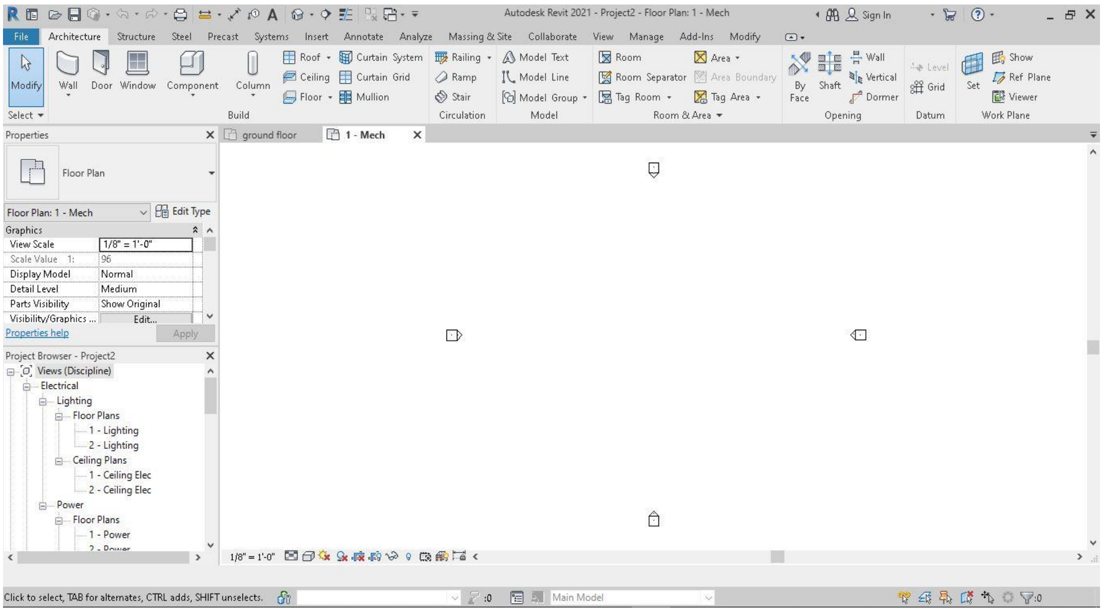
Autodesk Revit 2021 - Project1 - Floor Plan: Level 1

Floor Plan: Level 1

View Scale: 1/8" = 1'-0"
Scale Value 1: 96
Display Model: Normal
Detail Level: Coarse
Parts Visibility: Show Original

Click to select, TAB for alternates, CTRL adds, SHIFT unselects.

Figure 26: Autodesk Revit architecture template (Revit, 2021)



Autodesk Revit 2021 - Project2 - Floor Plan: 1 - Mech

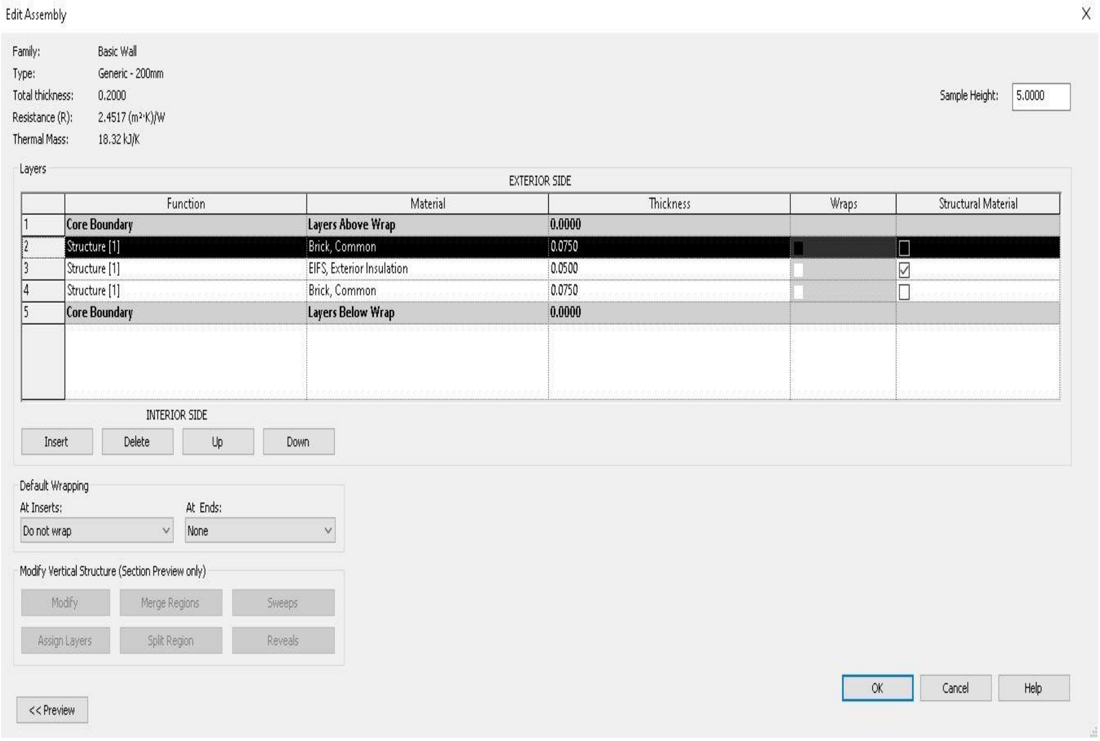
Floor Plan: 1 - Mech

View Scale: 1/8" = 1'-0"
Scale Value 1: 96
Display Model: Normal
Detail Level: Medium
Parts Visibility: Show Original

Click to select, TAB for alternates, CTRL adds, SHIFT unselects.

Figure 27: Autodesk Revit mechanical template (Revit, 2021)

In the following figures, the material selection for choosing different materials for each part and material browser are shown in Figs. 26 and 27, respectively.


Edit Assembly

Family: Basic Wall
Type: Generic - 200mm
Total thickness: 0.2000
Resistance (R): 2.4517 (m²·K)/W
Thermal Mass: 18.32 kJ/K
Sample Height: 5.0000

Layers

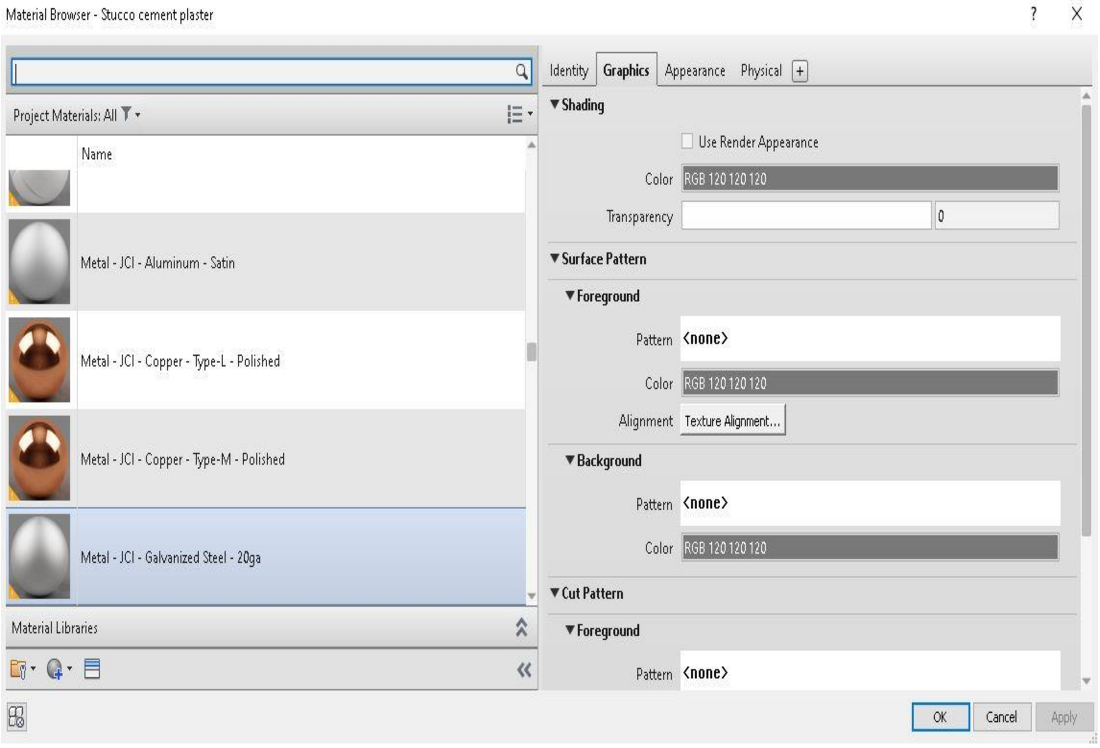
EXTERIOR SIDE

	Function	Material	Thickness	Wraps	Structural Material
1	**Core Boundary**	**Layers Above Wrap**	**0.0000**		
2	Structure [1]	Brick, Common	0.0750	☐	☐
3	Structure [1]	EIFS, Exterior Insulation	0.0500	☐	☑
4	Structure [1]	Brick, Common	0.0750	☐	☐
5	**Core Boundary**	**Layers Below Wrap**	**0.0000**		

INTERIOR SIDE

Default Wrapping
At Inserts: Do not wrap
At Ends: None

Figure 28: Edit assembly for changing the thickness and the place of each layer (Revit, 2021)


Material Browser - Stucco cement plaster

Project Materials: All

Name
Metal - JCI - Aluminum - Satin
Metal - JCI - Copper - Type-L - Polished
Metal - JCI - Copper - Type-M - Polished
Metal - JCI - Galvanized Steel - 20ga

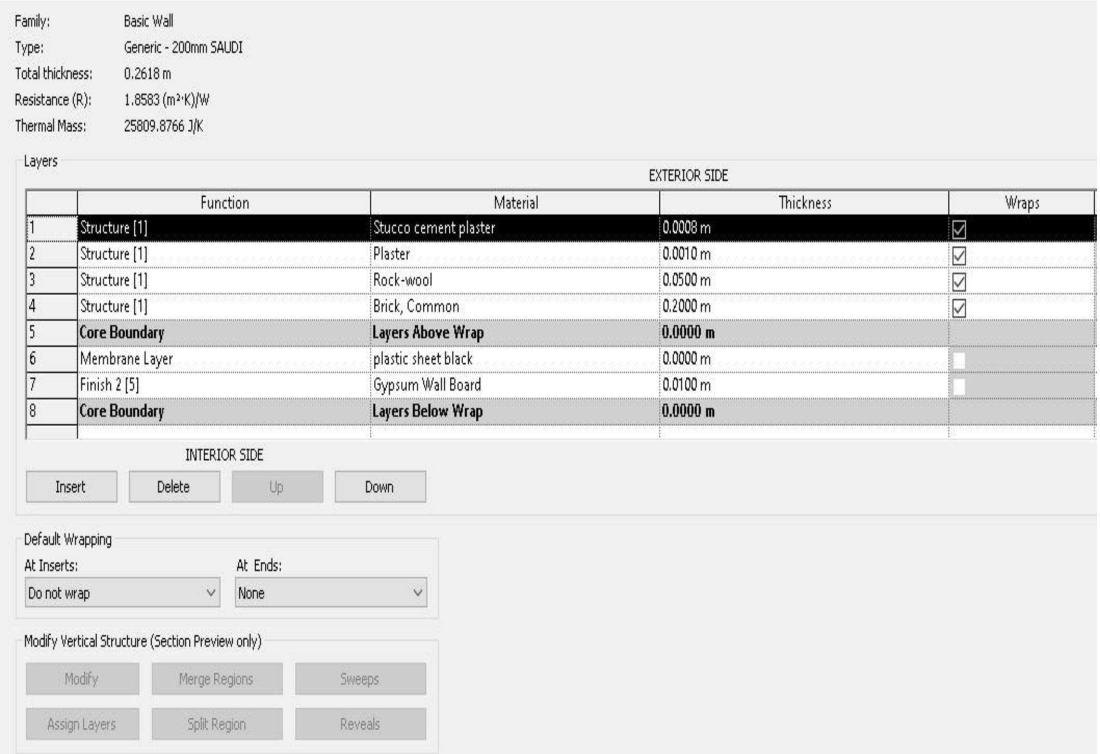
Shading
☐ Use Render Appearance
Color: RGB 120 120 120
Transparency: 0

Surface Pattern
Foreground
Pattern: <none>
Color: RGB 120 120 120
Alignment: Texture Alignment...
Background
Pattern: <none>
Color: RGB 120 120 120

Cut Pattern
Foreground
Pattern: <none>

Figure 29: Material browser for walls by choosing different material (Revit, 2021)

After choosing the wanted materials for the building walls the thickness of the material and function type is to be chosen in Fig. 30.



Family: Basic Wall
Type: Generic - 200mm SAUDI
Total thickness: 0.2618 m
Resistance (R): 1.8583 (m²·K)/W
Thermal Mass: 25809.8766 J/K

Layers

EXTERIOR SIDE

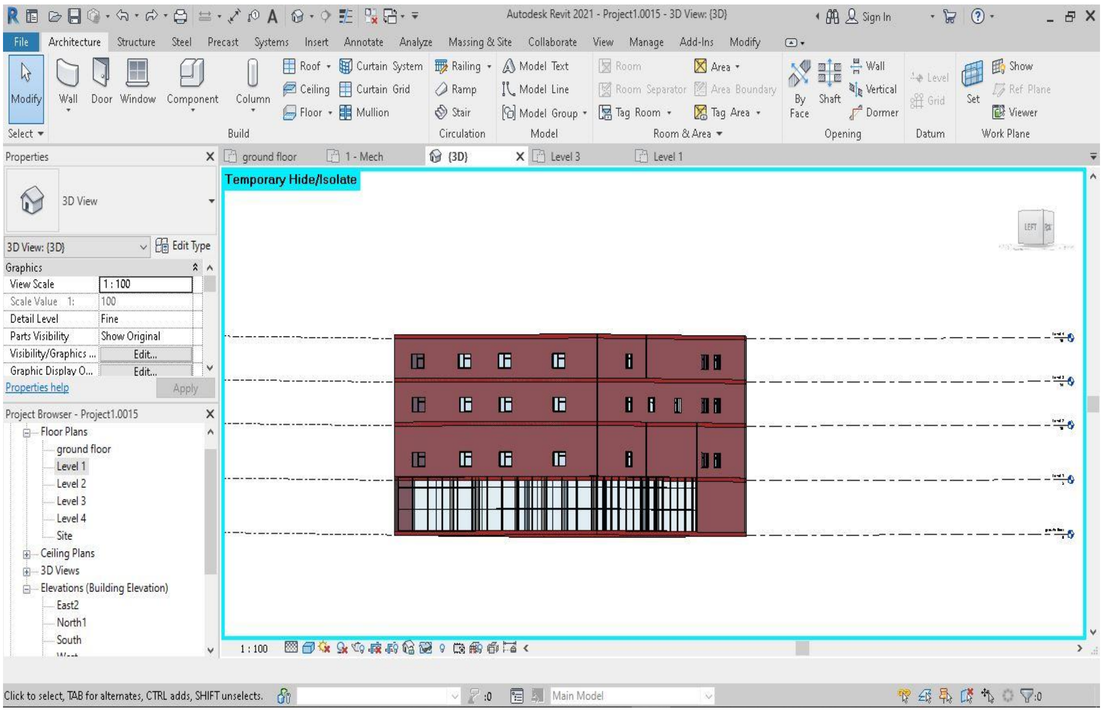
	Function	Material	Thickness	Wraps
1	Structure [1]	Stucco cement plaster	0.0008 m	☑
2	Structure [1]	Plaster	0.0010 m	☑
3	Structure [1]	Rock-wool	0.0500 m	☑
4	Structure [1]	Brick, Common	0.2000 m	☑
5	**Core Boundary**	**Layers Above Wrap**	**0.0000 m**	
6	Membrane Layer	plastic sheet black	0.0000 m	☐
7	Finish 2 [5]	Gypsum Wall Board	0.0100 m	☐
8	**Core Boundary**	**Layers Below Wrap**	**0.0000 m**	

INTERIOR SIDE

Default Wrapping
At Inserts: Do not wrap
At Ends: None

Figure 30: After choosing the wanted material & thickness (Revit, 2021)

In Figs. 31 and 32 the 3D view of the building and the architectural drawings are shown respectively.


Autodesk Revit 2021 - Project1.0015 - 3D View: {3D}

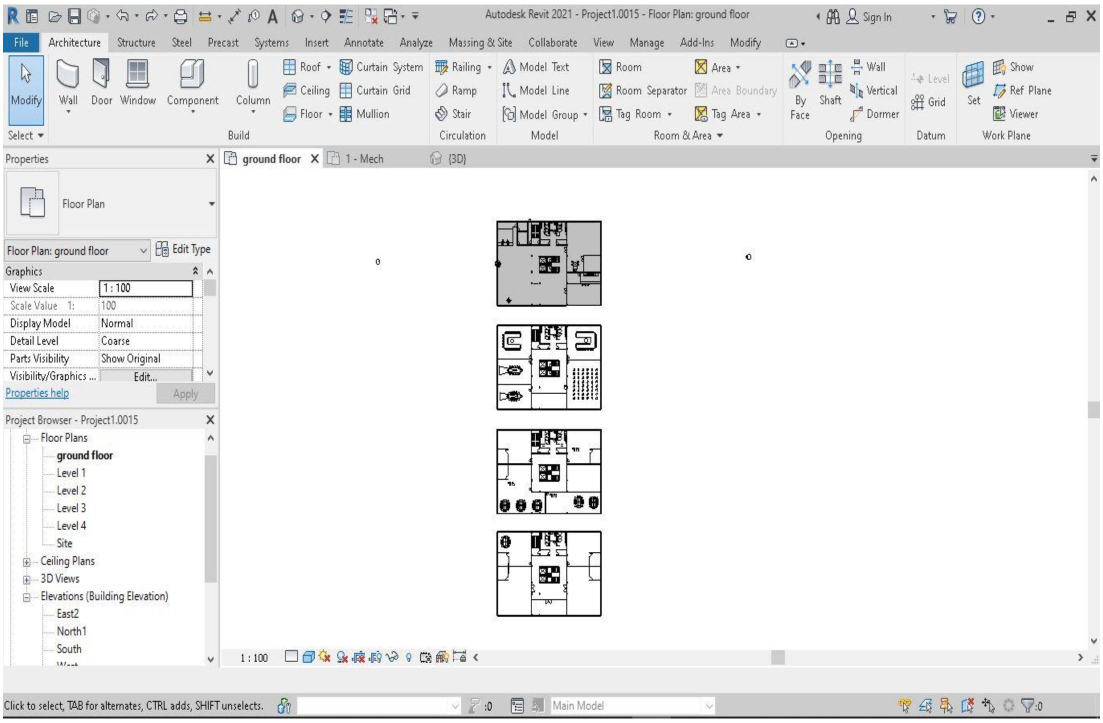
Temporary Hide/Isolate

3D View: {3D}

View Scale: 1 : 100
Scale Value 1: 100
Detail Level: Fine
Parts Visibility: Show Original

Click to select, TAB for alternates, CTRL adds, SHIFT unselects.

Figure 31: Architect virtual model of the building (Revit, 2021)


Autodesk Revit 2021 - Project1.0015 - Floor Plan: ground floor

Floor Plan: ground floor

View Scale: 1 : 100
Scale Value 1: 100
Display Model: Normal
Detail Level: Coarse
Parts Visibility: Show Original

Click to select, TAB for alternates, CTRL adds, SHIFT unselects.

Figure 32: Architect virtual model for the different levels of the building (Revit, 2021)

While the HVAC units including the implementation of the air handling unit, chiller, heater and the fan coil units and their duct and pipe connections are shown in Fig. 33.

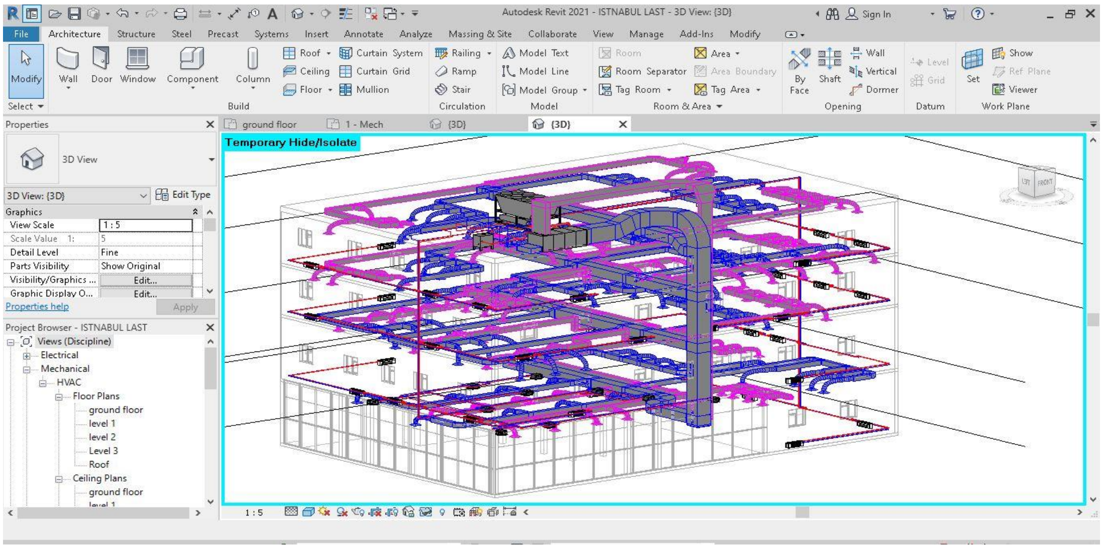


Figure 33: Mechanical virtual model for the building (Revit, 2021)

In the following section an overview of the method used in the software, and how it’s used for calculating heating and cooling loads in the software (Autodesk, 2022).

1. Radiant time series method (RTS)

The Radiant Time Series Method (RTS) is a new method for calculating design cooling load that is derived directly from the heat balance method. The radiant time series approach uses radiant time factors, or radiant time series coefficients, to convert the radiant part of hourly heat gains to hourly cooling loads. Like response factors, radiant time factors calculate the cooling load for the current hour on the basis of current and past heat gains (Fisher et al., 1997).

a. Cooling loads

In this section using RTS (ASHRAE), the four general procedures for calculating the cooling load for each component including (lights, people, walls, ceilings, windows, etc.) is as follows (Autodesk, 2022).

1. Calculate the component heat gain profile for the 24-hour design day (for conduction, first calculate conduction time delay by applying conduction time series).

2. Divide the heat gain into radiant and convective components.

3. To calculate the time delay in converting to cooling load, it applies a suitable radiant time series to the radiant portion of the heat gain.

4. To determine the cooling load for each component of the cooling load, it adds the convection parts and the delayed radiant parts of heat gain.

After calculating the hourly cooling loads for each component, the software collects those loads to determine the total hourly cooling load and selects the hour with peak load to design the air conditioning system. The software repeats this process for several months designing to determine the month in which the peak cooling occurs (Autodesk, 2022).

Heat gain through opaque outer surfaces is caused by the same solar radiation and temperature gradient elements found in heating zones. They differ primarily due to the mass and nature of the wall or roof construction, which affect the rate of conductive heat (Autodesk, 2022).

The following Fig. 34 summarizes the radiant time series method when used on Revit software for calculating the cooling load.

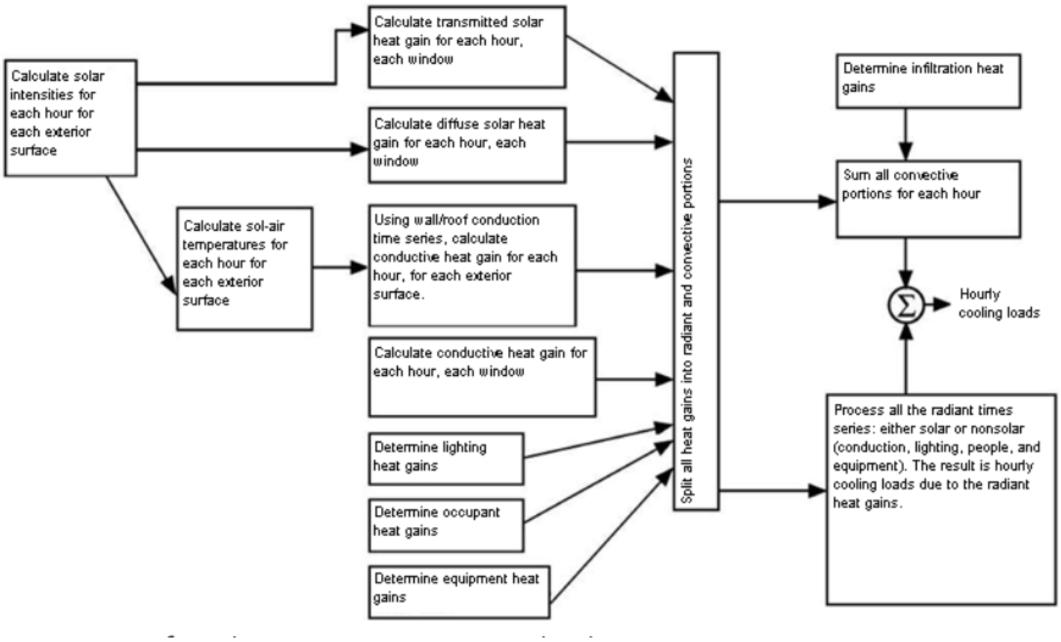


Figure 34: Overview of Radiant Time Series Method (Autodesk, 2022)

b. Heating loads

After we sum all the components of the cooling load for each space, the heating load is calculated.

To estimate the design of heating loads for commercial buildings, the same techniques will be applied but with the following exceptions (Autodesk, 2022).

1. Outside temperatures are generally lower than the temperature maintained in conditioned spaces.
2. There is no credit for solar or internal heat gains.
3. The thermal storage that effects the structure or content of the building is ignored.

After collecting all the data, the engine starts to calculate the loads.

C. Thermal insulation materials

In this section the material used on the exterior walls as thermal insulation in the project will be classified as synthetic and natural materials.

1. Synthetic materials

a. Polystyrene Expanded (XPS)

XPS thermal insulation is the most used type in the marketplace, the XPS has a good thermal conductivity value range between 0.03 – 0.04 (W/m K) (D’Alessandro et al., 2016). It’s constructed of organic cellular plastic, to manufacture expanded polystyrene insulation. Microscopic polystyrene (a byproduct of crude oil) is heated with water vapor, combined with an expansion agent as shown in Fig. 35 (Cai et al., 2017).

Figure 35: Polystyrene Expanded (XPS) insulation boards (Izocam, 2019)

b. Polystyrene extruded (EPS)

The EPS is commonly used in the market with a thermal conductivity that ranges between 0.035–0.04 (W/m K) (D’Alessandro et al., 2016). It is created by extruding a molten mixture of polystyrene and foaming agent through a pressure release nozzle as shown in Fig. 36 (Cai et al., 2017).

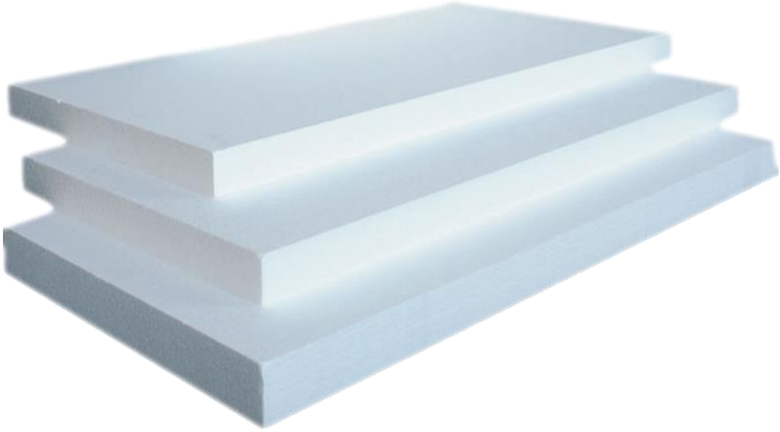


Figure 36: Polystyrene extruded (EPS) insulation boards (Plastimo, 2021)

c. Polyisocyanurate (PIR)

The PIR has the lowest thermal conductivity of all insulation types with thermal conductivity ranges between 0.018–0.028 (W/m K) (Omar et al., 2009). It is produced by the interaction of isocyanate and polyols as shown in Fig. 37 (Somarathna et al., 2018).

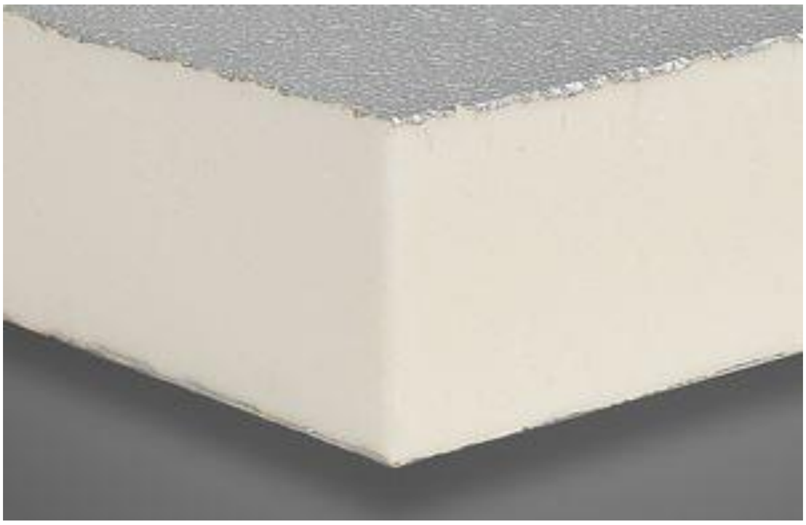


Figure 37: Polyisocyanurate (PIR) insulation board (Archiexop, 2022)

2. Natural materials

a. Wood wool

Wood wool is an effective sound-absorbing material because sound is absorbed not only by friction in the pores of the wood, but also by internal friction during elastic skeleton deformation as shown in Fig. 38 (Tsapko, 2017). Wood wool has a high thermal conductivity that equals 0.09 (W/m K) (Pfundstein et al., 2012).

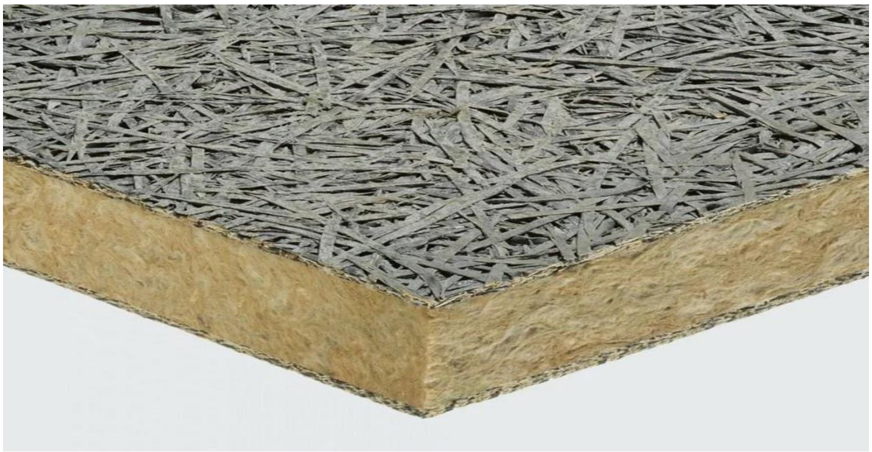


Figure 38: Wood wool insulation board (Celenit, 2021)

b. Cellulose fibers

Cellulose fiber Fig. 39 is mostly made of recycled paper fibers, cellulose is increasing in popularity due to its eco-friendly nature and favorable thermal and acoustic properties. (Papadopoulos, 2005). The thermal conductivity ranges between 0.04–0.045 (W/m K) (D’Alessandro et al., 2016).

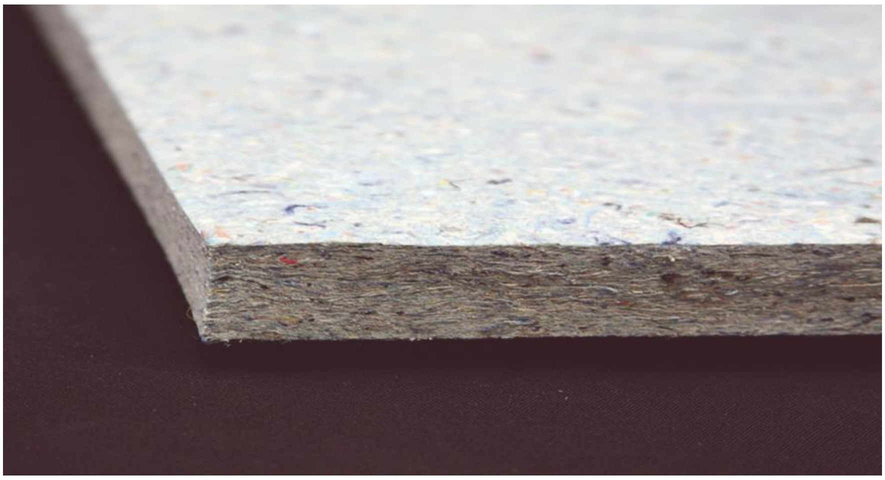


Figure 39: Cellulose thermal insulation Panels (ArchDaily, 2018)

c. Rock wool

Rock wool Fig. 40 is widely used as a heat insulating material in construction, ships, energy, industry, and other fields. Rock wool has good thermal insulation as a high-quality and effective thermal insulation material (Liu et al, 2013). Rock wool has a thermal conductivity that ranges between 0.033–0.045 (W/m K) (Abu-Jdayil., 2019).

Figure 40: Rock wool thermal insulation boards (Archiexop, 2022)

d. Glass wool

Glass wool Fig. 41 is made of made from fabric material and board products which use inorganic binders such as cement with perlite and ceramic ball (Barreira and De Freitas, 2014). The glass wool has a thermal conductivity that ranges between 0.03–0.045 (W/m K) (Abu-Jdayil., 2019).

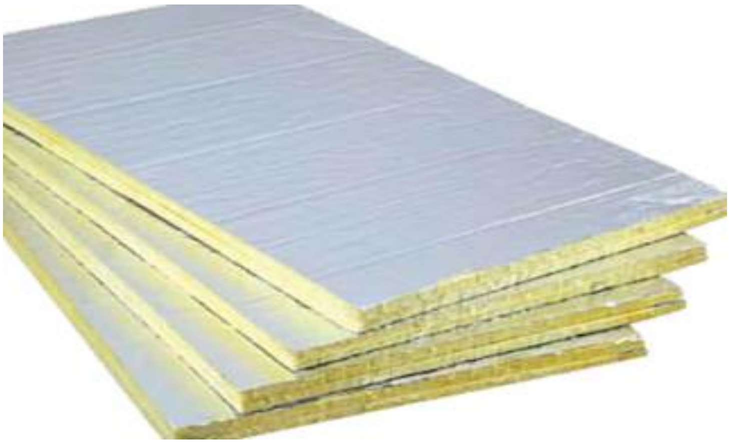


Figure 41: Glass wool thermal insulation boards (Spacemantra, 2021)

For the last two types that are shown in the figures below, each one is used in one place due to their availability in each location, the sheep wool is used in Istanbul while the date palm is used in Riyadh.

e. Sheep wool

Sheep wool Fig. 42 is one of the vital products that has proven some potential and has begun to be marketed and promoted as an alternative insulating material (Sheep wool insulation, 2013). Wool is also a renewable resource, with the average sheep (excluding hairy sheep breeds) producing between 2.3 and 3.6 kg of raw wool per year that must be mowed (removed) for the health of the animal (Stiles and Corscadden, 2011). The sheep wool has a thermal conductivity that ranges between 0.04–0.045 (W/m K) (Pfundstein et al., 2012).

Figure 42: Sheep wool thermal insulation batt (ECI, 2022)

f. Date palm

Palm trees produce large amounts of palm leaves. Each palm tree produces about 20 kg of dry leaves annually as waste. Burning waste papers is a common practice in some places, causing environmental pollution (McKendry, 2002). In addition, 11 million tons annually of agricultural waste in Saudi Arabia. Most of the waste belongs to palm trees, which, if not used properly, can cause environmental challenges. This waste is a renewable resource that can have significant economic benefits (Nassour et al, 2008; Saidik et al, 2010). The date palm Fig. 43 has thermal conductivity that ranges between 0.072–0.085 (W/m K) (Agoudjil et al., 2011).

Figure 43: Date palm thermal insulation boards (Ferrández et al., 2018)

IV. RESULTS & DISCUSSION

The usage of different types of thermal insulation should lead to reduction in energy consumption including natural thermal insulations and synthetic insulations. In this chapter, the building description, usage of the thermal insulations & its results for each location will be presented and discussed.

A. Building description & material used

At the beginning we will start by building description including

1. Building type
2. Number of people in the building
3. Area of the building
4. Levels with different heights
5. HVAC used in the building
6. Material used for, floors, walls, ceiling, and windows

The following table will include the building description for Riyadh & Istanbul, the main difference will be in the ceiling material and the upcoming exterior wall material.

Table 7: Building description

Building type	Office building
Number of people	200 persons
Area of the building	2554 m^2
Heights of the building	Ground floor – 5 m Level 1- 5 m Level 2- 4 m

	Level 3- 4 m
HVAC used in the building	Fan coil system
Location of the buildings	- Istanbul, Turkey - Riyadh, Saudi Arabia
Material used for floors (Standard) (as shown in Fig. 44)	Concrete, cast in situ – 0.1100m Plaster – 0.0050m Vinyl Composition Tile – 0.0050m
Material used for ground floor (Base) (Standard) (as shown in Fig. 45)	Site – Hardcore – 0.300m Sand – 0.012m Damp proofing – 0.00 m (Membrane layer) Concrete, cast in situ – 0.1500m Plaster – 0.0050m Vinyl Composition Tile – 0.0050m

Material used for ceiling (Istanbul) (as shown in Fig. 46)	Concrete, Cast In Situ – 0.2200 m polystyrene extruded XPS – 0.0400 m polystyrene extruded XPS – 0.0400 m Polyurethane Foam ----------- 0.0030 m Concrete, Sand/Cement Screed—0.0500 m Bitunem impregnated paper – 0.0040 m Bitunem impregnated paper – 0.0040 m Lining - Fiberglass Board – 0.0050 m Concrete, Sand/Cement Screed- 0.0300 m Gravel ----------------------------0.0200m
Material used for celing (Riyadh) (as shown in Fig. 47)	Concrete, Cast In Situ – 0.2200 m Concrete, Sand/Cement Screed- 0.0500m Bitunem impregnated paper – 0.0040 m Bitunem impregnated paper – 0.0040 m plastic sheet black- 0.00 m (Membrane Layer) polystyrene extruded XPS – 0.0400 m polystyrene extruded XPS – 0.0430 m Lining - Fiberglass Board – 0.0050 m Concrete, Sand/Cement Screed- 0.0300 m Gravel ----------------------------0.0200m
Material used for exterior walls (as	Plaster ---------------- 0.0010 m

shown in Fig. 48)	Brick, Common ------- 0.200 m Stucco cement plaster -- 0.0010 m
Material used for internal walls	Gypsum Wall Board---- 0.0130 m
Type of windows used	Metal – Aluminum – Double glazing

The following figures indicate the material used in the exterior & interior walls, floors, windows, and the different material for the ceilings for each location.

The none base floors Fig. 44 consist of concrete, plaster, and vinyl composition tiles at the top.

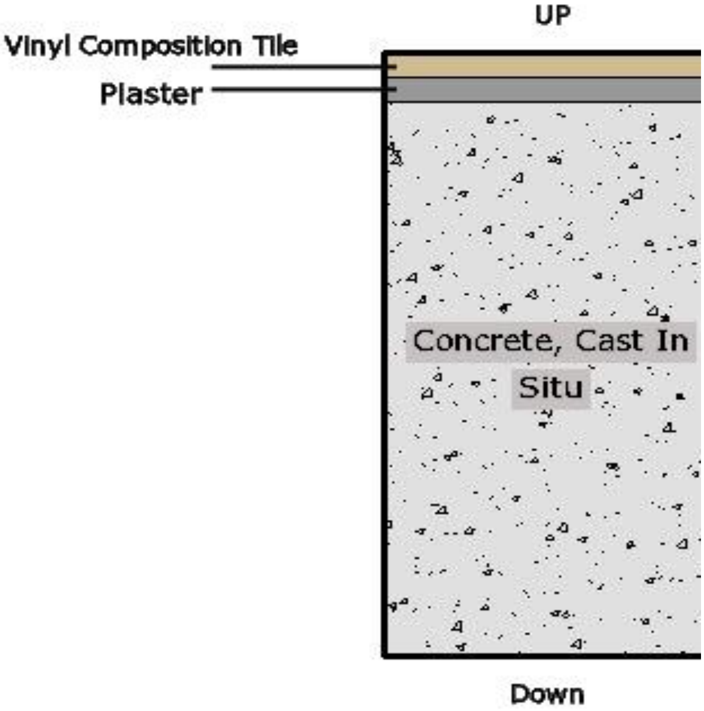


Figure 44: Floors material component (Revit, 2021)

While the ground floor (base) consists of site hardcore, two layers of concrete and vinyl composition tiles at the top, as shown in Fig. 45.

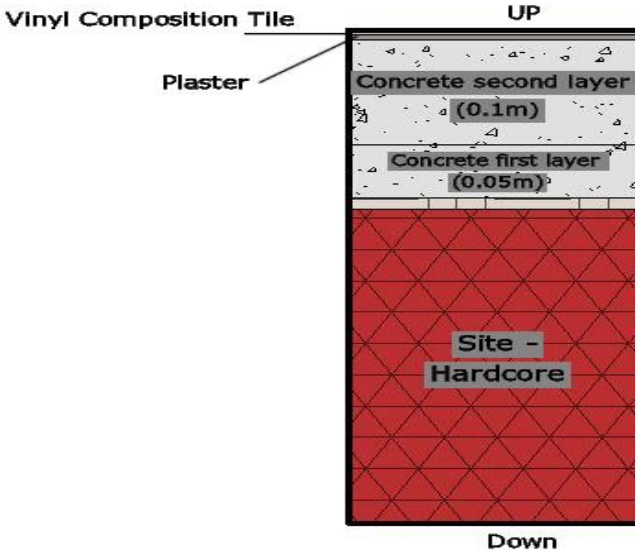


Figure 45: Ground floor base material component (Revit, 2021)

The ceiling for Istanbul Fig. 46 is made of concrete, two layers of XPS, polyurethane foam, cement screed, two layers of bitumen paper, fiberglass bord, cement screed and gravel at the top.

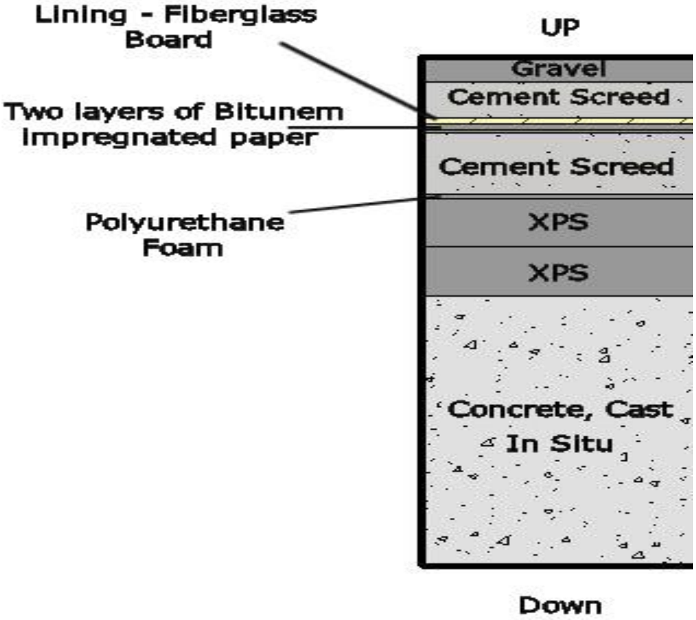


Figure 46: Istanbul ceiling material component (Revit, 2021)

While the ceiling for Riyadh Fig. 47 is same as Istanbul with a slight difference with the used thickness for each layer and the missing of polyurethane foam.

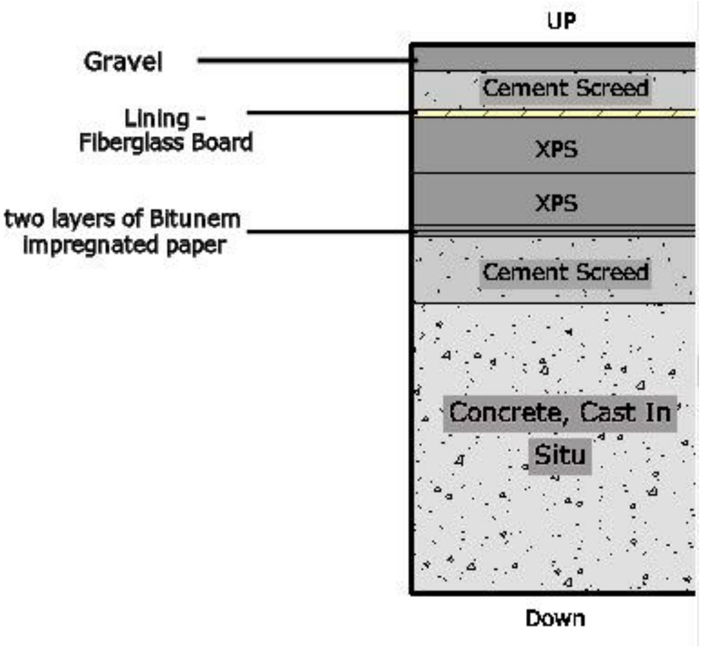


Figure 47: Riyadh ceiling material component (Revit, 2021)

While here we have the stander exterior wall when no thermal insulation is used Fig. 48, consisting of plaster from the inside then brick in the middle and cement plaster at the outside of the wall

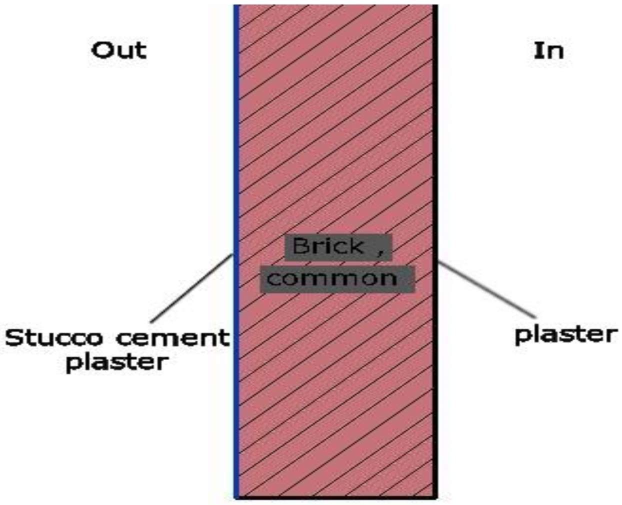


Figure 48: Exterior walls component material (Revit, 2021)

The upcoming thermal insulations are used in the exterior walls as shown in figure 49 with the change of insulation material only.

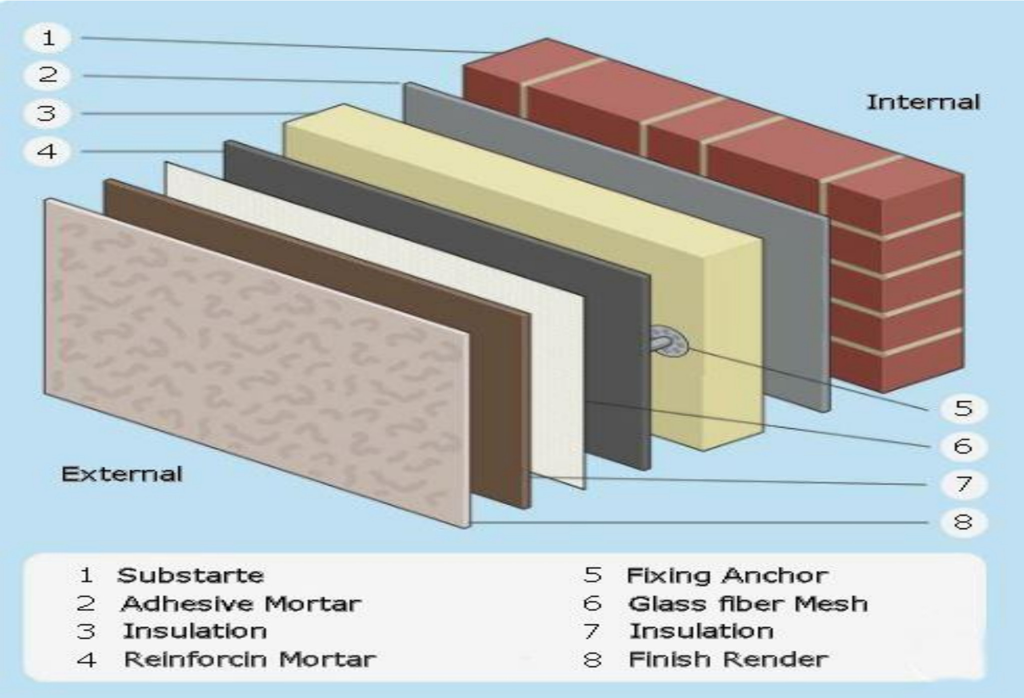


Figure 49: External wall insulation material (TGG, 2018)

In this part of the study and after we saw the building description and the material used in building for both case studies we will start to implement the different types of thermal insulation for external walls for each case and see how it would affect the overall energy consumption and the drop change that will happen in cooling and heating load, then at the end of the implementation we will have a general comparison & discussion between all the types that had been used.

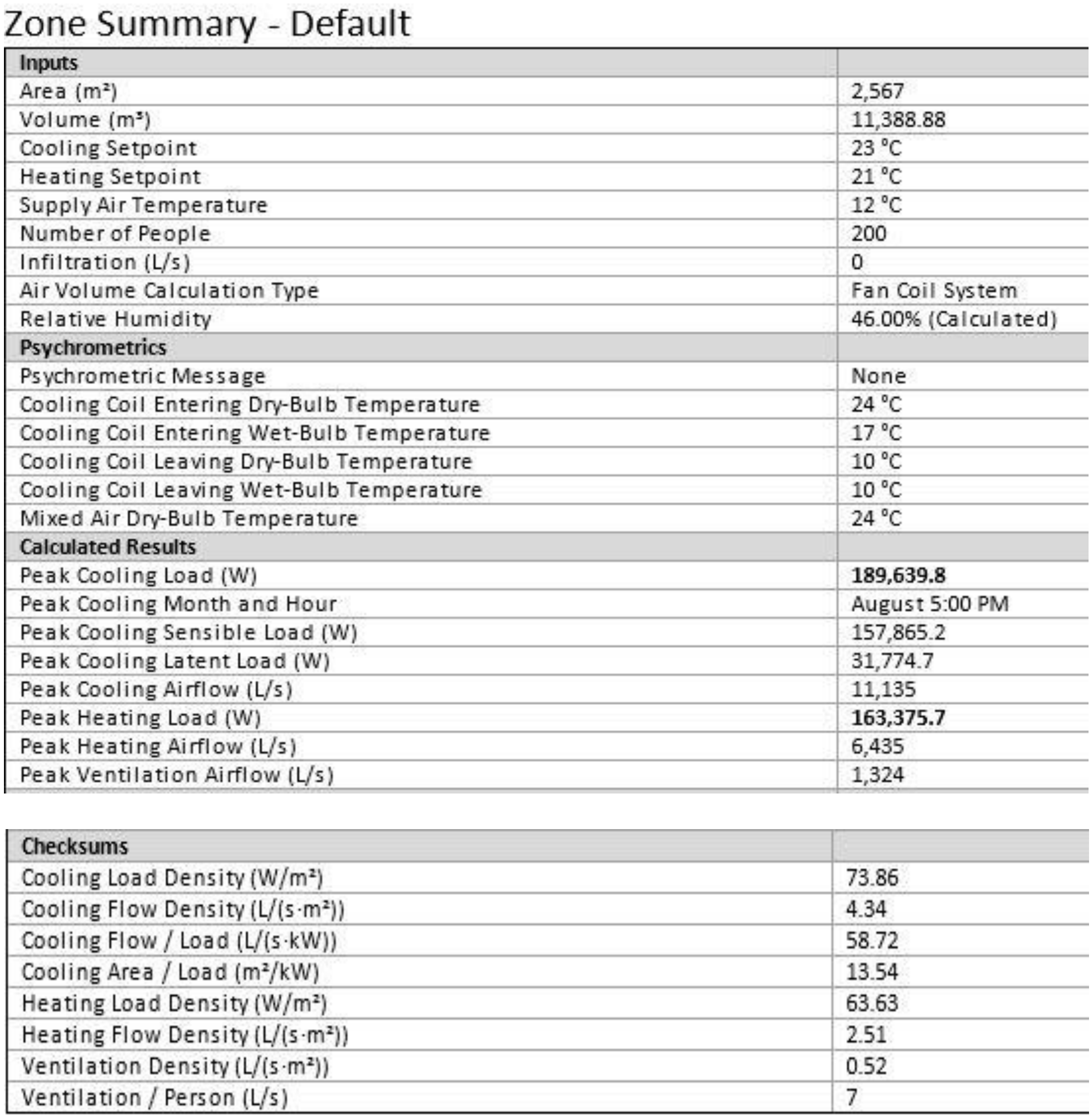
B. Case study 1 (Istanbul)

The case study 1 indicates the results and the information that been found in Istanbul – Turkey by using Revit software to calculate the heating and cooling loads starting with the no addition of insulations for the exterior walls.

The zone summary (Table 8) shows all the inputs and the calculated results for Istanbul.

- No thermal insulation is used (standard) as shown in Table 8.

Table 8: Zone summary with no thermal insulation addition Istanbul



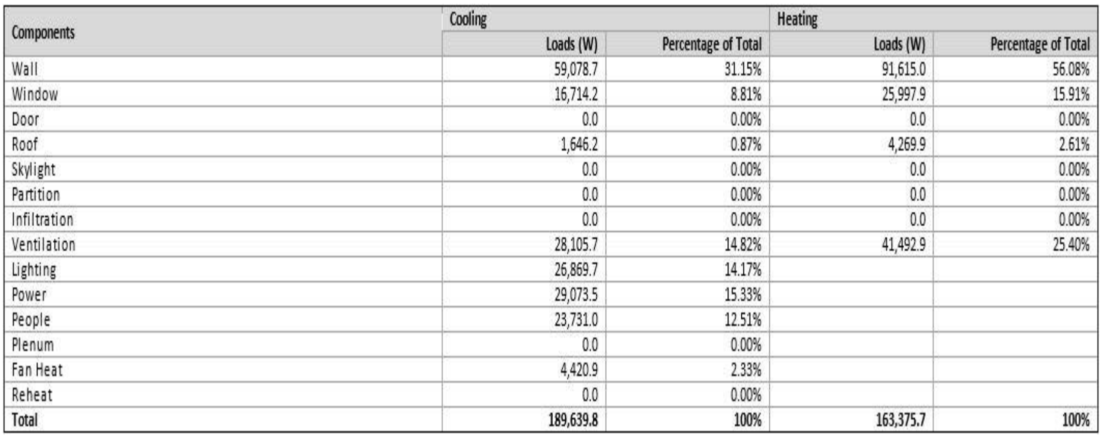
Zone Summary - Default

Inputs	
Area (m²)	2,567
Volume (m³)	11,388.88
Cooling Setpoint	23 °C
Heating Setpoint	21 °C
Supply Air Temperature	12 °C
Number of People	200
Infiltration (L/s)	0
Air Volume Calculation Type	Fan Coil System
Relative Humidity	46.00% (Calculated)
Psychrometrics	
Psychrometric Message	None
Cooling Coil Entering Dry-Bulb Temperature	24 °C
Cooling Coil Entering Wet-Bulb Temperature	17 °C
Cooling Coil Leaving Dry-Bulb Temperature	10 °C
Cooling Coil Leaving Wet-Bulb Temperature	10 °C
Mixed Air Dry-Bulb Temperature	24 °C
Calculated Results	
Peak Cooling Load (W)	**189,639.8**
Peak Cooling Month and Hour	August 5:00 PM
Peak Cooling Sensible Load (W)	157,865.2
Peak Cooling Latent Load (W)	31,774.7
Peak Cooling Airflow (L/s)	11,135
Peak Heating Load (W)	**163,375.7**
Peak Heating Airflow (L/s)	6,435
Peak Ventilation Airflow (L/s)	1,324

Checksums	
Cooling Load Density (W/m²)	73.86
Cooling Flow Density (L/(s·m²))	4.34
Cooling Flow / Load (L/(s·kW))	58.72
Cooling Area / Load (m²/kW)	13.54
Heating Load Density (W/m²)	63.63
Heating Flow Density (L/(s·m²))	2.51
Ventilation Density (L/(s·m²))	0.52
Ventilation / Person (L/s)	7

In the previous Table we can see that the cooling & heating load with no thermal insulation for Istanbul are 189,639.8 W, and 163,375.7 W respectively.

Table 9: Cooling & heating load in Watts when no thermal insulation is used, Istanbul



Components	Cooling		Heating	
	Loads (W)	Percentage of Total	Loads (W)	Percentage of Total
Wall	59,078.7	31.15%	91,615.0	56.08%
Window	16,714.2	8.81%	25,997.9	15.91%
Door	0.0	0.00%	0.0	0.00%
Roof	1,646.2	0.87%	4,269.9	2.61%
Skylight	0.0	0.00%	0.0	0.00%
Partition	0.0	0.00%	0.0	0.00%
Infiltration	0.0	0.00%	0.0	0.00%
Ventilation	28,105.7	14.82%	41,492.9	25.40%
Lighting	26,869.7	14.17%		
Power	29,073.5	15.33%		
People	23,731.0	12.51%		
Plenum	0.0	0.00%		
Fan Heat	4,420.9	2.33%		
Reheat	0.0	0.00%		
Total	189,639.8	100%	163,375.7	100%

As we can see from Table 9 that walls has the biggest share for effecting on the total consumption of cooling load with (31.15%), (59,078.7 W). and the heating load with (56.08%), (91,615 W).

By looking at Fig. 50 we can see the difference in cooling load using different thermal insulation materials while different thicknesses had been used, for instance, the energy drop for sheep wool was higher than the EPS with 50 kW and 49 kW respectively for all the thicknesses, and that shows us how the natural insulation had outworked the synthetic type.

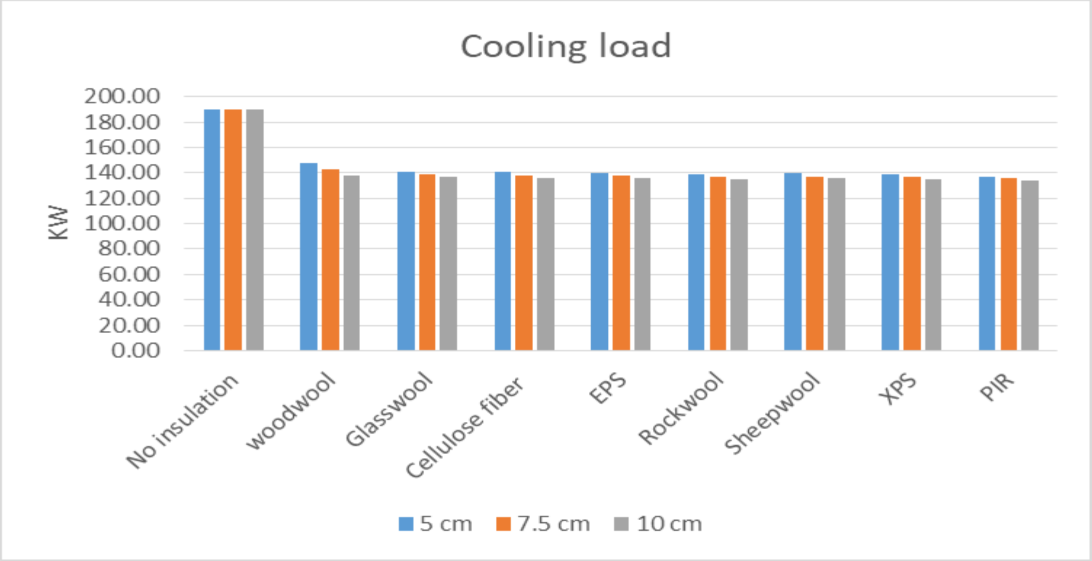


Figure 50: Different results using different thickness in cm for each insulation material for finding the cooling load.

While if we look at Fig. 51, we can see the difference in heating load using different thermal insulation materials while different thicknesses had been used, for instance, the Rockwool and the sheep wool was higher than the EPS with 50 kW and 49 kW respectively for all thicknesses, and that shows us how the natural insulations had outworked one of the well-known synthetic types.

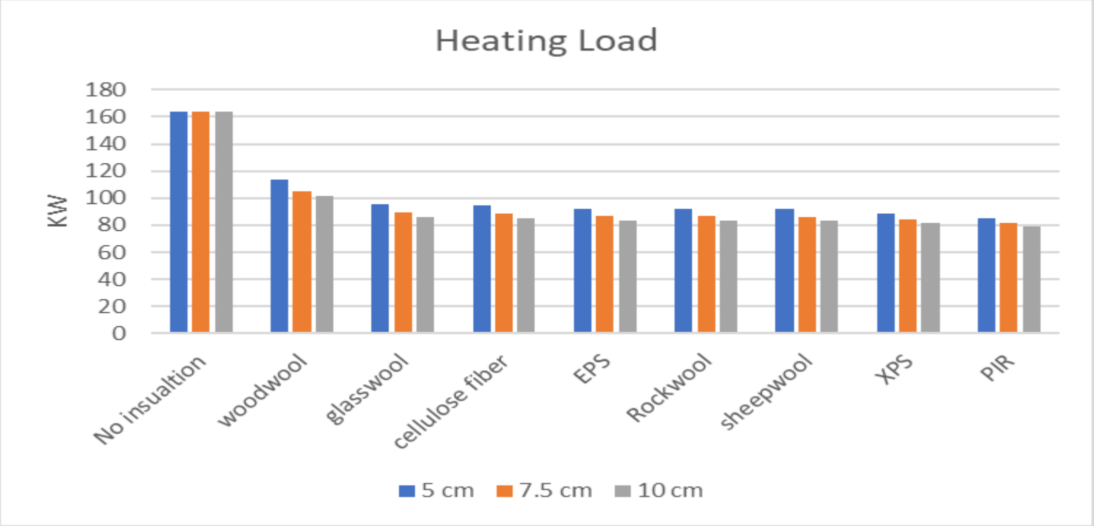


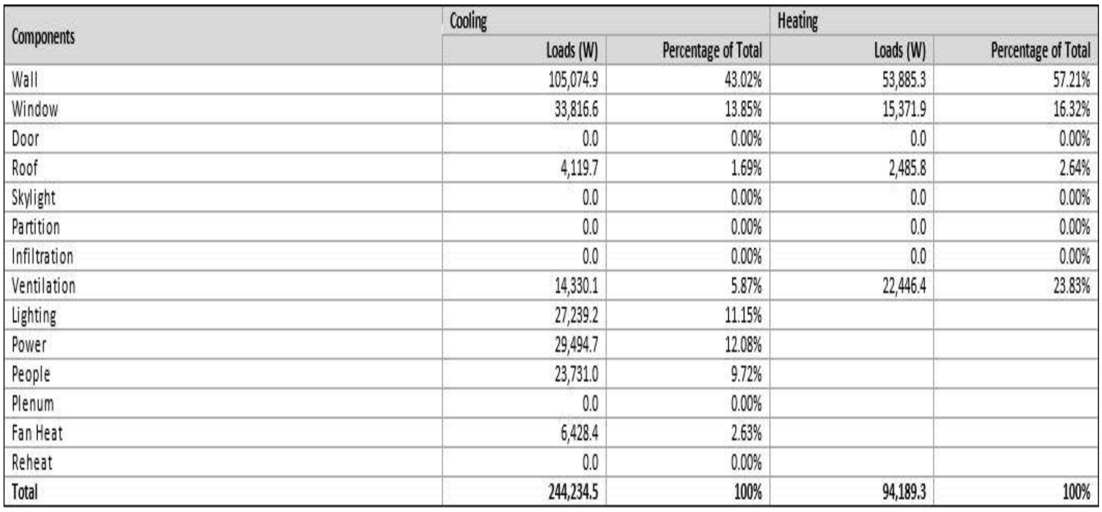
Figure 51: Different results using different thickness in cm for each insulation material for finding the heating load.

C. Case study 2 (Riyadh)

The case study 2 indicates the results and the information that been found in Riyadh – Saudi Arabia by using Revit software to calculate the heating and cooling loads starting with the no addition of insulations for the exterior walls.

- ❖ No thermal insulation is used (standard).

Table 10: Cooling & heating load in Watts when no thermal insulation is used, Riyadh



Components	Cooling		Heating	
	Loads (W)	Percentage of Total	Loads (W)	Percentage of Total
Wall	105,074.9	43.02%	53,885.3	57.21%
Window	33,816.6	13.85%	15,371.9	16.32%
Door	0.0	0.00%	0.0	0.00%
Roof	4,119.7	1.69%	2,485.8	2.64%
Skylight	0.0	0.00%	0.0	0.00%
Partition	0.0	0.00%	0.0	0.00%
Infiltration	0.0	0.00%	0.0	0.00%
Ventilation	14,330.1	5.87%	22,446.4	23.83%
Lighting	27,239.2	11.15%		
Power	29,494.7	12.08%		
People	23,731.0	9.72%		
Plenum	0.0	0.00%		
Fan Heat	6,428.4	2.63%		
Reheat	0.0	0.00%		
Total	**244,234.5**	**100%**	**94,189.3**	**100%**

As we can see from Table 10 that the cooling load for Riyadh is more than Istanbul, and that because the weather and temperature change during the year. As we can see the percentage of walls is 43.02% for cooling load while 57.21% for heating load.

By looking at Fig. 52 we can see the difference in cooling load using different thermal insulation materials while different thicknesses were used, for instance, the energy drop for Date palm was lower than all the synthetic types with 79 kW while the EPS with 88 kW for 5 cm thickness.

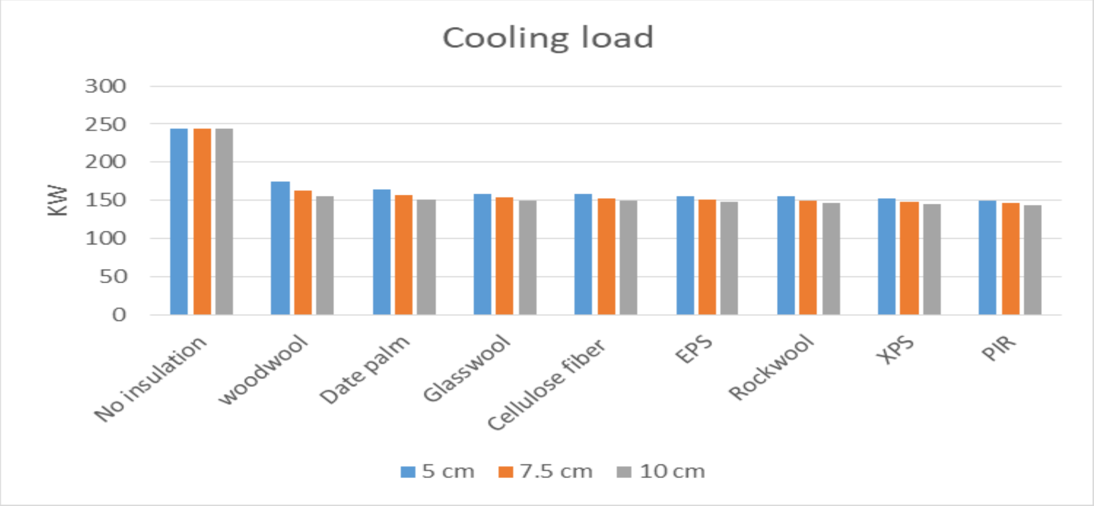


Figure 52: Different results using different thickness in cm for each insulation material for finding the cooling load

By looking at Fig. 53, we can see the difference in heating load using different thermal insulation materials while different thicknesses were used, for instance, the energy drop for Date palm was also lower than all the synthetic types with 34 kW while the EPS with 41 kW for 5 cm thickness.

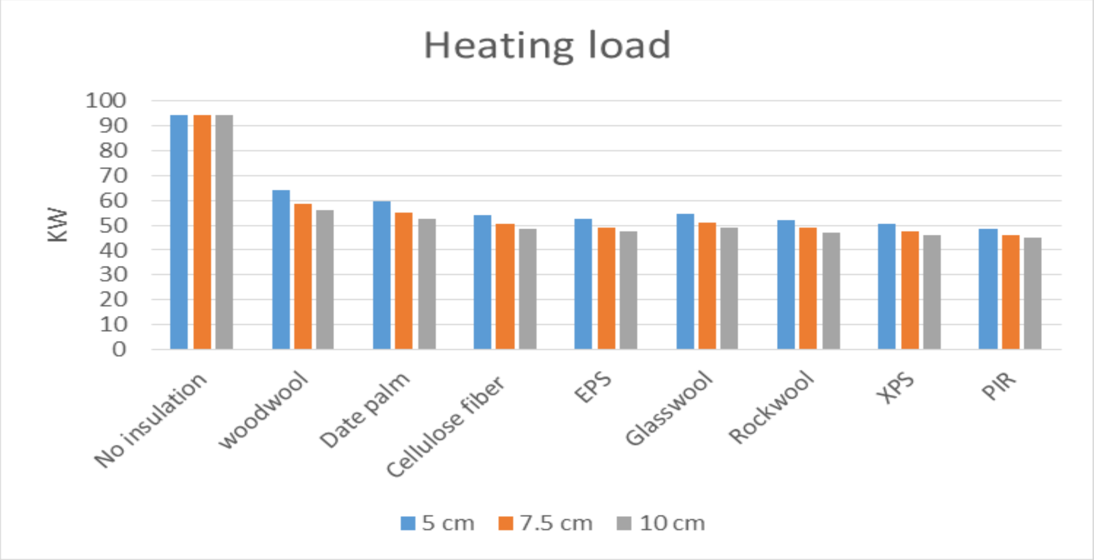


Figure 53: Different results using different thickness in cm for each insulation material for finding the heating load

D. Discussion and results

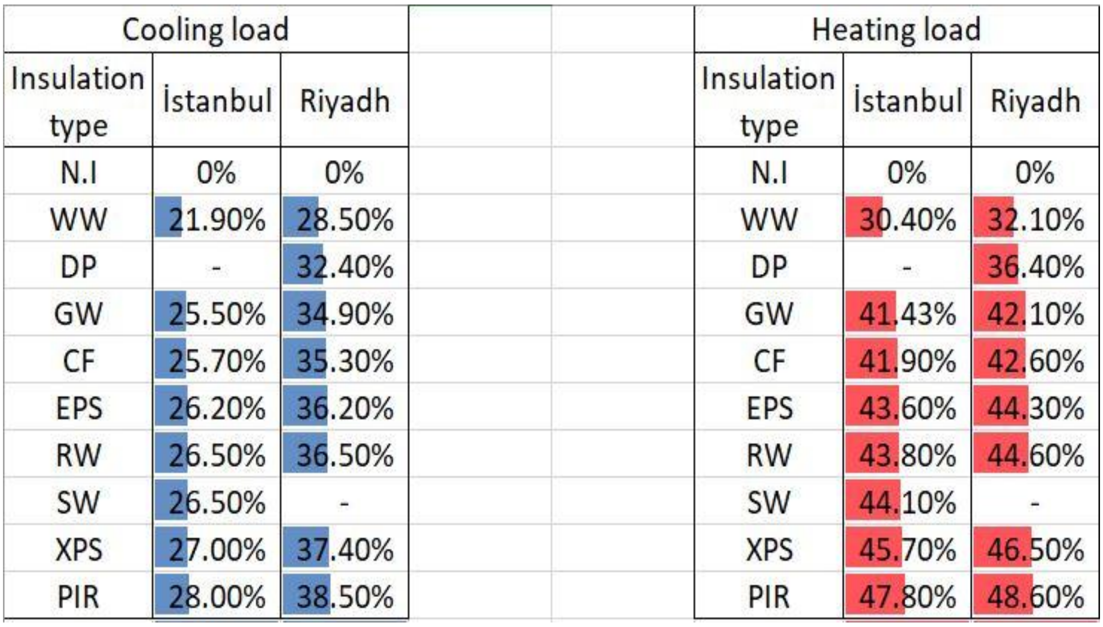
It was noticed that the energy consumption that refers to the cooling load is higher in Riyadh than Istanbul with 244 kW and 186 kw respectively, on the other hand, the heating load is higher in Istanbul than Riyadh with 160 kW and 93 kW respectively, and that goes back to the difference of climatic conditions in each location and the need of cooling for Riyadh all around the year.

In the upcoming figures a comparison between thermal insulation materials and their total cooling and heating load reduction using different thicknesses.

❖ Using 5 cm thickness

The following Table 11 shows a summary for all the thermal insulation types for both locations that indicates the energy drop that happens from no insulation to using different types of insulation.

Table 11: Reduction in energy for cooling and heating load using 5 cm thickness



Cooling load			Heating load		
Insulation type	İstanbul	Riyadh	Insulation type	İstanbul	Riyadh
N.I	0%	0%	N.I	0%	0%
WW	21.90%	28.50%	WW	30.40%	32.10%
DP	-	32.40%	DP	-	36.40%
GW	25.50%	34.90%	GW	41.43%	42.10%
CF	25.70%	35.30%	CF	41.90%	42.60%
EPS	26.20%	36.20%	EPS	43.60%	44.30%
RW	26.50%	36.50%	RW	43.80%	44.60%
SW	26.50%	-	SW	44.10%	-
XPS	27.00%	37.40%	XPS	45.70%	46.50%
PIR	28.00%	38.50%	PIR	47.80%	48.60%

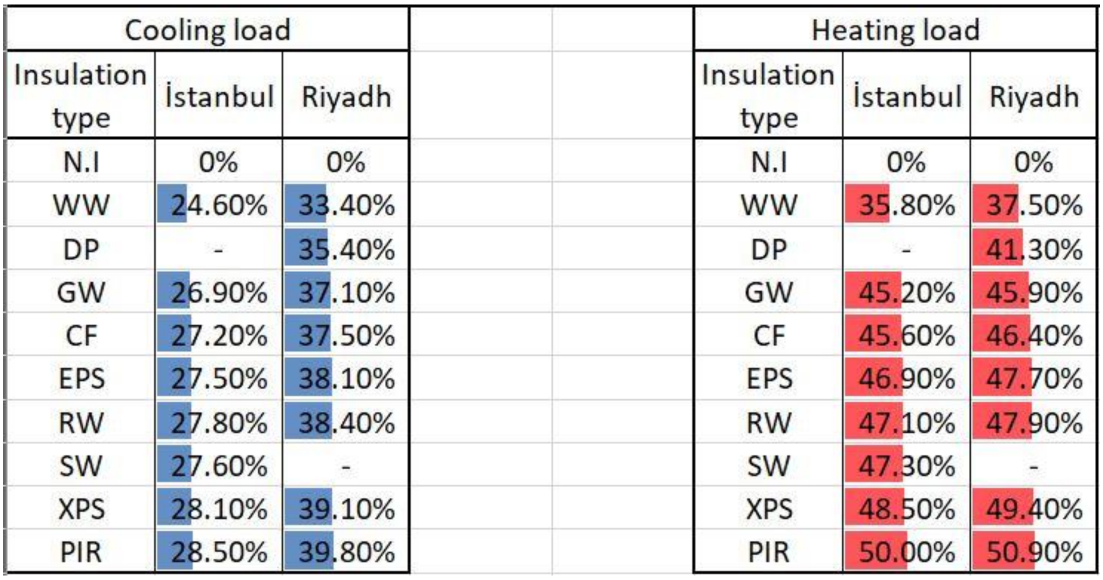
c. N.I: No insulation, WW: wood wool, DP: Date palm, CF: Cellulose fiber, EPS: Expanded Polystyrene, GW: glass wool, RW: Rockwool, SW: sheep wool, PIR: Polyisocyanurate.

By looking at Table 11 we can see from that the energy drop percentage that refers to cooling load is different for both locations since the need of cooling in Riyadh is almost all the year, while for Istanbul is needed only in specific months, while that was not the case in terms of heating, and that because the high moist weather that Istanbul have while almost in Riyadh the moisture percentages reach to zero.

That high moist weather has a big role in increasing the thermal conductivity of a material, that increase in thermal conductivity will lead to lower energy savings by time.

❖ Using 7.5 cm thickness

Table 12: Reduction in energy for cooling and heating load using 7.5 cm thickness



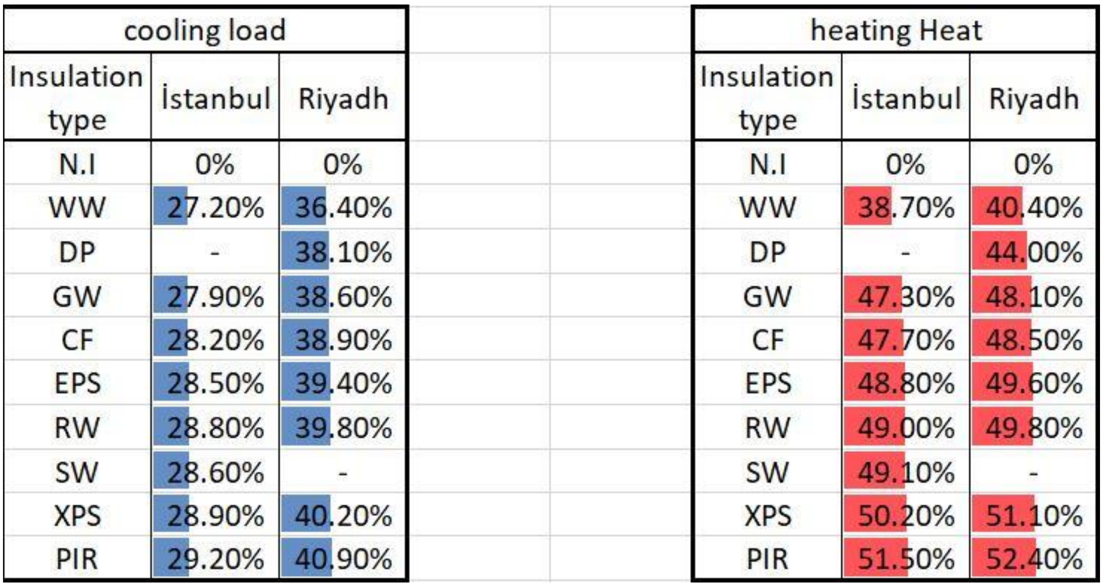
Cooling load		
Insulation type	İstanbul	Riyadh
N.I	0%	0%
WW	24.60%	33.40%
DP	-	35.40%
GW	26.90%	37.10%
CF	27.20%	37.50%
EPS	27.50%	38.10%
RW	27.80%	38.40%
SW	27.60%	-
XPS	28.10%	39.10%
PIR	28.50%	39.80%

Heating load		
Insulation type	İstanbul	Riyadh
N.I	0%	0%
WW	35.80%	37.50%
DP	-	41.30%
GW	45.20%	45.90%
CF	45.60%	46.40%
EPS	46.90%	47.70%
RW	47.10%	47.90%
SW	47.30%	-
XPS	48.50%	49.40%
PIR	50.00%	50.90%

d. N.I: No insulation, WW: wood wool, DP: Date palm, CF: Cellulose fiber, EPS: Expanded Polystyrene, GW: glass wool, RW: Rockwool, SW: sheep wool, PIR: Polyisocyanurate.

❖ **Using 10 cm thickness**

Table 13: Reduction in energy for cooling and heating load using 10 cm thickness



cooling load		
Insulation type	İstanbul	Riyadh
N.I	0%	0%
WW	27.20%	36.40%
DP	-	38.10%
GW	27.90%	38.60%
CF	28.20%	38.90%
EPS	28.50%	39.40%
RW	28.80%	39.80%
SW	28.60%	-
XPS	28.90%	40.20%
PIR	29.20%	40.90%

heating Heat		
Insulation type	İstanbul	Riyadh
N.I	0%	0%
WW	38.70%	40.40%
DP	-	44.00%
GW	47.30%	48.10%
CF	47.70%	48.50%
EPS	48.80%	49.60%
RW	49.00%	49.80%
SW	49.10%	-
XPS	50.20%	51.10%
PIR	51.50%	52.40%

e. N.I: No insulation, WW: wood wool, DP: Date palm, CF: Cellulose fiber, EPS: Expanded Polystyrene, GW: glass wool, RW: Rockwool, SW: sheep wool, PIR: Polyisocyanurate.

By looking at Table 11 & 12, we noticed that the energy drops between the 5 and the 7 cm insulation thicknesses ranges between 7 to 8 kW energy drop, but if look at table 12 & 13 the drop between the 7.5 and the 10 cm insulation thicknesses we can see that the energy savings ranges between 2 to 4 kW, so it doesn’t mean that having a thicker thermal insulation will lead to more energy savings, and that’s why companies are generally producing thermal insulations with 5 cm thickness.

And by looking at the previous tables we can notice that the natural insulation types had reaches a level of savings that almost the same as the synthetic types, for instance looking at Table 11 we can see that the sheep wool that were used in Istanbul for cooling had saved almost 50 kW of energy and that saving can be comparable to one of the most used commercial insulation the XPS with a 51 kW of energy saving.

We also noticed that the highest reduction in both cities when PIR insulation was used, and that because of the low thermal conductivity of 0.020 $\mathrm{W/(m.K)}$, while the lowest was the wood wool, owing to its good ability to conduct heat.

1. Payback period calculation

In this part the prices and the payback periods for all the insulation materials will be presented expect the sheep wool and the date palm, and that because there is no actual price for these types in the marketplace.

In the following section the prices for 1 m^2 with 5 cm thickness of thermal insulation in Turkish lira will be presented.

Polystyrene Expanded (XPS) = 95.4 TL/m^2

Polystyrene extruded (EPS) = 106.3 TL/m^2

Polyisocyanurate (PIR) = 125.8 TL/m^2

Rock wool (RW) = 134.2 TL/m^2 for 150 kg/m^3

Wood wool (WW) = 131.25 TL/m^2

While glass wool is available for 10 cm thickness with a price as follows

Glass wool with (GW) = 41.6 TL/m^2

Now the total prices for thermal insulation for the whole area of the walls will be presented.

XPS = 1983 m^2* 95 TL/m^2 = 188,355 TL = 10,349 $

EPS = 1983 m^2 * 106.3 TL/m^2 = 196,442 TL = 10,793 $

PIR = 1983 m^2 * 125.8 TL/m^2 = 249,480 TL = 13,707 $

RW = 1983 m^2 * 134.2 TL/m^2 = 248,001 TL = 13,626 $

WW = 1983 m^2 * 131.25 TL/m^2 = 242,550 TL = 13,326 $

GW = 1983 m^2 * 41.6 TL/m^2 = 76,876 TL = 4,224 $

While in this section the total calculation of the payback period for Istanbul will be presented.

Starting with the electricity price for commercial use for Istanbul.

1 KWh = 0.053$ = 0.053 $\$/KWh$

In this section the daily & yearly electricity consumption with no insulation used will be presented

189 KWh/day * 0.053 $\$/KWh$ = 10 $\$/day$ (Cooling)

163 KWh/day * 0.053 $\$/KWh$ = 8.64 $\$/day$ (Heating)

130 working days per half year (10$ * 130 days = 1300 $\$/halfyear$) (cooling)

130 working days per half year (8.64$ * 130 days = 1123 $\$/halfyear$) (heating)

Total energy consumption = 2423 $\$/year$

✓ The rest of the calculations are in Appendix A.

In this part the daily & yearly energy consumed & saved with the payback period for one thermal insulation material will be presented.

- **Polystyrene Expanded (XPS)**

138 KWh/day * 0.053 $\$/KWh$ = 7.3 $\$/day$ (cooling)

88.62 KWh/day * 0.053 $\$/KWh$ = 4.69 $\$/day$ (heating)

7.3 $\$/day$ * 130 days = 949 $\$/half\ year$

4.69 $\$/day$ * 130 days = 609.7 $\$/half\ year$

Total energy consumption = 1558 $\$/year$

Total energy saved = 2423 $\$/year$ – 1558 $\$/year$ = 865 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{10{,}349\ \$}{865\$}$ = 11 years

Table 14: Payback period in years for 5 cm thickness using different materials

Material type	GW	XPS	EPS	WW	RW	PIR
Payback period (Istanbul)	5	11	13	19	16	15
Payback period (Riyadh)	4	9	10	16	12	12

- WW: wood wool, DP: Date palm, CF: Cellulose fiber, EPS: Expanded Polystyrene, GW: glass wool, RW: Rockwool, SW: sheep wool, PIR: Polyisocyanurate

As we can see from table 14, that glass wool has the lowest payback period, and that goes back to the low price for 1 m^2 of glass wool plus the energy savings that the glass wool provides. While the heights payback period was the wood wool, and that because of the high price and the high thermal conductivity that the wood wool has.

While if we look at overall effectiveness, we can see that XPS, and GW are the most rational insulation to be chosen due to their short payback periods, their energy savings level and their availability in both locations.

V. CONCLUSION

In conclusion, two different geographic sites with two different climate variables had been used to model the project. Even though the thermal insulation used in both buildings was the same, the reduction in energy use was variable depending on the location. To increase the energy efficiency of both buildings, a range of materials was tested. We discovered that employing some natural insulation materials made of sheep wool will produce similar results to synthetic materials for reducing energy usage. For instance, while comparing sheep wool to XPS for Riyadh, we can observe a greater reduction in cooling load than in Istanbul.

While in Riyadh, the date palm is one of the least efficient in terms of energy savings, compared to the ones utilized in Istanbul, since no actual costs for sheep wool or the date palm could be determined, there was no way to compare the two commercial varieties.

We also found that the energy drops between 5 and 7.5 cm insulation thicknesses ranged from 7 to 8 kW. On the other hand, the energy reduction that ranges between 7.5 and 10 cm insulation thicknesses was found to be 2 to 4 kW.

As a result, having a thicker thermal insulation does not mean that it will save more energy, which is why companies usually produce 5 cm thickness insulation.

In further studies, we could also focus on not only the thermal insulation material but also on the brick type using volcanic brick, this type of brick is already in use in Saudi Arabia specially in the Hijaz area due to its volcanic zone. Windows also can improve overall savings by changing their size and type and choosing better HVAC systems so we could make the building more efficient.

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APPENDIX

APPENDIX A: Payback period calculations

APPENDIX A

- **Polystyrene extruded (EPS)**

139.9 KWh/day * 0.053 $\$/KWh$ = 7.4 $\$/day$

92.145 KWh/day * 0.053 $\$/KWh$ = 4.88 $\$/day$

7.3 $\$/day$ * 130 days = 962 $\$/half\ year$

4.88 $\$/day$ * 130 days = 634.4 $\$/half\ year$

Total energy consumption = 1595 $\$/year$

Total energy saved = 2423 $\$/year$ – 1558 $\$/year$ = 828 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{10{,}793\ \$}{828\$}$ = 13 years

- **Polyisocyanurate (PIR)**

136.5 KWh/day * 0.053 $\$/KWh$ = 7.23 $\$/day$

85 KWh/day * 0.053 $\$/KWh$ = 4.505 $\$/day$

7.23 $\$/day$ * 130 days = 939.9 $\$/half\ year$

4.505 $\$/day$ * 130 days = 585.65 $\$/half\ year$

Total energy consumption = 1595 $\$/year$

Total energy saved = 2423 $\$/year$ – 1525.5 $\$/year$ = 897 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{13{,}707\ \$}{897\ \$}$ = 15 years

- **Rock wool**

138.4 KWh/day * 0.053 $\$/KWh$ = 7.33 $\$/day$

91.8 KWh/day * 0.053 $\$/KWh$ = 4.86 $\$/day$

7.33 $\$/day$ * 130 days = 952.9 $\$/half\ year$

4.86 $\$/day$ * 130 days = 631.8 $\$/half\ year$

Total energy consumption = 1584.7 $\$/year$

Total energy saved = 2423 $\$/year$ – 1584.7 $\$/year$ = 838 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{13{,}626\ \$}{838\ \$}$ = 16 years

- **Wood wool**

148 KWh/day * 0.053 $\$/KWh$ = 7.84 $\$/day$

113.7 KWh/day * 0.053 $\$/KWh$ = 6 $\$/day$

7.33 $\$/day$ * 130 days = 952.9 $\$/half\ year$

6 $\$/day$ * 130 days = 780 $\$/half\ year$

Total energy consumption = 1732.9 $\$/year$

Total energy saved = 2423 $\$/year$ – 1732.9 $\$/year$ = 690 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{13{,}326\ \$}{690\ \$}$ = 19 years

- **Glass wool**

141 KWh/day * 0.053 $\$/KWh$ = 7.48 $\$/day$

95.6 KWh/day * 0.053 $\$/KWh$ = 5 $\$/day$

7.48 $\$/day$ * 130 days = 972.4 $\$/half\ year$

5 $\$/day$ * 130 days = 650 $\$/half\ year$

Total energy consumption = 1622.4 $\$/year$

Total energy saved = 2423 $\$/year$ – 1622.4 $\$/year$ = 800 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{4224\ \$}{800\ \$}$ = 5 years

In this section the total calculation of payback period for Riyadh will be presented.

Starting with the electricity price for commercial use for Riyadh

The 1 KWh = 0.063 $ = 0.063 $/ KWh

Daily & yearly electricity consumption with no insulation used

244 KWh/day * 0.063 $\$/KWh$ = 15.3 $\$/day$

94 KWh/day 0.063 $\$/KWh$ = 5.9 $\$/day$

130 working days per half year (15.3$ * 130 D = 1989 $\$/halfyear$) (cooling)

130 working days per half year (5.9$ * 130 D = 767 $\$/halfyear$) (heating)

Total energy consumption = 2756 $\$/year$

- **Polystyrene Expanded (XPS)**

152.8 KWh/day * 0.063 $\$/KWh$ = 9.5 $\$/day$ (cooling)

50.4 KWh/day * 0.063 $\$/KWh$ = 3.1 $\$/day$ (heating)

9.5 $\$/day * 130$ days = 1235 $\$/half\ year$

3.1 $\$/day * 130$ days = 403 $\$/half\ year$

Total energy consumption = 1638 $\$/year$

Total energy saved = 2756 $\$/year$ – 1638 $\$/year$ = 1118 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{10{,}349\ \$}{1118\ \$}$ = 9 years

- **Polystyrene extruded (EPS)**

155.8 KWh/day * 0.063 $\$/KWh$ = 9.8 $\$/day$ (cooling)

51.3 KWh/day * 0.063 $\$/KWh$ = 3.2 $\$/day$ (heating)

9.8 $\$/day * 130$ days = 1274 $\$/half\ year$

3.2 $\$/day * 130$ days = 420 $\$/half\ year$

Total energy consumption = 1694 $\$/year$

Total energy saved = 2756 $\$/year$ – 1694 $\$/year$ = 1062 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{10{,}793\ \$}{1062\ \$}$ = 10 years

- **Polyisocyanurate (PIR)**

150.2 KWh/day * 0.063 $\$/KWh$ = 9.4 $\$/day$ (cooling)

48.4 KWh/day * 0.063 $\$/KWh$ = 3.0 $\$/day$ (heating)

9.4 $\$/day$ * 130 days = 1229 $\$/half\ year$

3.0 $\$/day$ * 130 days = 390 $\$/half\ year$

Total energy consumption = 1619 $\$/year$

Total energy saved = 2756 $\$/year$ – 1619 $\$/year$ = 1137 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{13{,}707\ \$}{1137\ \$}$ = 12 years

- **Rock wool**

155 KWh/day * 0.063 $\$/KWh$ = 9.7 $\$/day$ (cooling)

50.3 KWh/day * 0.063 $\$/KWh$ = 3.1 $\$/day$ (heating)

9.7 $\$/day$ * 130 days = 1270 $\$/half\ year$

3.1 $\$/day$ * 130 days = 403 $\$/half\ year$

Total energy consumption = 1673 $\$/year$

Total energy saved = 2756 $\$/year$ – 1673 $\$/year$ = 1083 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{13{,}626\ \$}{1083\ \$}$ = 12 years

- **Wood wool**

174.6 KWh/day * 0.063 $\$/KWh$ = 10.9 $\$/day$ (cooling)

63.9 KWh/day * 0.063 $\$/KWh$ = 4 $\$/day$ (heating)

10.9 $\$/day$ * 130 days = 1417 $\$/half\ year$

4 $\$/day$ * 130 days = 524 $\$/half\ year$

Total energy consumption = 1941 $\$/year$

Total energy saved = 2756 $\$/year$ – 1941 $\$/year$ = 815 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{13{,}326\ \$}{815\ \$}$ = 16 years

- **Glass wool**

158.9 KWh/day * 0.063 $\$/KWh$ = 10 $\$/day$ (cooling)

54.5 KWh/day * 0.063 $\$/KWh$ = 3.4 $\$/day$ (heating)

9.7 $\$/day$ * 130 days = 1300 $\$/half\ year$

3.4 $\$/day$ * 130 days = 442 $\$/half\ year$

Total energy consumption = 1742 $\$/year$

Total energy saved = 2756 $\$/year$ – 1742 $\$/year$ = 1014 $\$/year$

Then payback = $\frac{total\ payment\ in\ \$}{energy\ saved\ per\ year\ in\ \$} = \frac{4224\ \$}{1014\ \$}$ = 4 years

RESUME

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- Master in Mechanical Engineering at Istanbul Aydin University. 2020-2022
- Bachelor of Engineering in Mechanical Engineering at Eastern Mediterranean University Famagusta- North Cyprus. 2016- 2020

SKILLS AND INTEREST:

- Programming Language: Java
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- Revit for desiging HVAC system, heating & cooling loads
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Air craft maintaninace engineer at Royal Jordanian air ways Amman – Jordan, including

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