Applying Passive Design Strategies to Achieve Energy Efficient Mosque in UAE
The Case of Uptown Mirdif Mosque

تطبيق استراتيجيات التصميم السلبي لتحقيق مسجد موفر للطاقة في الامارات العربية المتحدة
حالة دراسية على مسجد أبتاون مردف

by

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ABSTRACT

Energy and electricity have become a basic and necessary need that must be available in any place where the population is located, especially to use air-conditioning devices to obtain a comfortable thermal environment in hot and humid areas such as the United Arab Emirates. Burning fossil fuels to produce energy, as the percentage of carbon emissions increased, which is one of the types of greenhouse gases that lead to environmental pollution and global warming. Therefore, it was necessary to search and find solutions that help reduce energy consumption and alternative solutions to produce energy from clean sources.

Many studies have been conducted to search for solutions and strategies that contribute to reducing energy consumption. This research aims to help build sustainable mosques that consume the least possible amount of energy while maintaining a comfortable indoor thermal environment for worshipers. By clarifying and knowing some of the different passive design strategies that can be used in building mosques such as thermal insulations, glazing, shadings, green roofs and the production of clean energy using solar panels. This research helps to know the different types and possibilities for each strategy, evaluate these strategies and types, and know their efficiency in reducing the energy consumption of the building, especially in an atmosphere similar to that of the UAE, using the IES-VE simulation program.

Then a comparison was made between the strategies and their types to find out which of them are more efficient and capable of reducing building energy consumption, as the results showed that thermal insulation is the most efficient strategy than other strategies.

الملخص

أصبحت الطاقة والكهرباء حاجة أساسية وضرورية يجب توافرها في أي مكان يتواجد فيه السكان خاصة لاستخدام اجهزة التكييف للحصول على بيئة حرارية مريحة في المناطق الحارة والرطبة كالامارات العربية المتحدة، لذلك ارتفع استهلاك الطاقة مما أدى ضرورة زيادة انتاج الطاقة ولكن ذلك أدى الى حدوث اضرار للبيئة بس زيادة حرق الوقود الاحفوري لانتاج الطاقة، حيث ارتفعت نسبه انبعاثات الكربون وهي احد انواع غازات الاحتباس الحراري التي تؤدي الى تلوث البيئة وحدوث الاحتباس الحراري. لذلك كان من الضروري البحث وإيجاد حلول تساعد على تقليل استهلاك الطاقة وحلول بديلة لانتاج الطاقة من مصادر نظيفة.

تم اجراء العديد من الدراسات للبحث عن حلول واستراتيجيات تسهم في خفض استهلاك الطاقة والعمل على تطويرها. يهدف هذا البحث الى المساعدة في بناء مساجد مستدامه تستهلك اقل قدر ممكن من الطاقة مع المحافظة على بيئة حرارية داخلية مريحة للمصلين. وذلك بتوضيح و معرفة بعض من استراتيجيات التصميم السلبية المختلفة التي يمكن استخدامها في بناء المساجد كالعازل الحراري، زجاج النوافذ، انظمة التظليل، الأسقف الخضراء وإنتاج الطاقة النظيفة باستخدام الألواح الشمسية. ويساعد هذا البحث بمعرفة انواع واحتمالات مختلفة لكل استراتيجية وتقييم هذه الاستراتيجيات والانواع ومعرفة كفاءتها في خفض استهلاك الطاقة للمبنى خاصة في أجواء مشابهة لأجواء دولة الامارات وذلك باستخدام برنامج محاكاه IES-VE.

ثم تم اجراء مقارنه بين الاستراتيجيات وانواعها لمعرفة اي منها اكثر كفاءة و قابلية على خفض استهلاك طاقة المبنى, حيث أوضحت النتائج أن العازل الحراري هو الاستراتيجية الأكثر كفاءة من الاستراتيجيات الأخرى.

DEDICATION

To My Father and My Mother,

Whose encouragement, love and prays of days and night make me able to get such success

To My Husband,

For his constant encouragement, patience and support to reach my goals and achieve my dreams

And to My Sons Yousof, Elias, and Ali,

Each of whom has a special place in my heart

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CHAPTER ONE

INTRODUCTION

1 INTRODUCTION

1.1 Background

To conserve energy is one of the important challenges which the mankind is facing in this era of rapid development. Discovery and use of energy has changed the outlook of living style of human beings (Gonzalez-Pedro et al. 2014). But fossil fuels are very limited and it is believed that one day we will consume all the resources for it. The second incentive to conserve the energy is to have the sustainable environment on the planet earth. Because of the pollution that happened due to burning fossil fuels to produce energy.

The burning of fossil fuels to extract energy to run cars, trucks and engines and to fly planes and to access other luxuries of the life emits carbon such as using artificial lights and air conditioning. This emission has negative effect on the environment of planet earth. Carbon in the environment causes the solar heat of sun to stay in the atmosphere. This in turn causes the increase in temperature. Ultimately earth is getting warmer and the overall heat stored in the atmosphere is increasing, which known as global warming.

Many campaigns around the globe started to spread the awareness for conservation of energy. People came out to record the protest against the practices which are harmful for the environment. So the voices reached to decision making powers of the world. People started to realize the fact that they have to conserve energy to protect the planet. This is because from the big cluster of galaxies, only one planet in the Milky Way galaxy supports the sustainability for life. And if this planet is losing its capability to sustain life then humanity is losing its only home in this world.

A lot of new strategies have been developed to cope up with the challenge of environment pollution. Electricity production which was previously based on fossil fuels burning is now shifting towards the sources of renewable energy. Renewable energy produces are free of pollution. Solar energy, wind energy, and hydro power are some examples of renewable sources of energy. In addition to implementing some strategies that help reducing the use of energy and get a luxurious life without harming the environment. This shift is gradually increasing in industrial and domestic sector. In this thesis our concerned is only about domestic sector. Domestic sector includes household, parks, hospitals, hostels, mosques and other places of worship, schools, colleges, universities and other residential buildings. In this thesis mosques are the main area of discussion.

The mosques are the buildings where Muslims offer five times prayers. The Mosques hold a significant respect in the Muslim society. Therefore, if we want the society to have some change in it, we must have to start it from the place of spiritual importance. These spiritual places give guide people about the way of life. If we talk about the Muslim society in general, Mosques will the ideal place to start some change in the society. The thing which is implanted in their religious site will automatically come to general people life. So this idea will help us in spreading the awareness against the over consumption of energy in every sector of life. Muslims will learn that when a mosque can be used on the idea of renewable energy then why not every single home. So a gradual change will come in the society. And one day will come when all the domestic consumption will be based on the idea of energy conservation. That day will be the day when the harm of environmental pollution will start healing. And the nature will start reviving itself.

There is another parameter in which we can think about the symbolic importance of Dubai in the world, where Dubai implement every development in the world and it seeks to occupy the highest position as the best city in all sectors. His Highness Sheikh Mohammed bin Rashid launched the Dubai Urban Plan for the year 2040, to be the best city to live, provide welfare for the community and improve the quality of life by increasing green spaces, providing sustainable means of transportation, improving resource utilization efficiency, improving environmental sustainability, and preserving natural and built features, thus making Dubai the best city for life in the world (albayan 2021a). Dubai would be on the front foot and will be the key player in development of ecofriendly and energy efficient model of domestic use.

Muslim world has been facing the problem of Islamophobia in the west. The west has made the misconception that Muslims don't want to modernize their culture and the way they live. When a leading Muslim state does some innovative, particularly in the design and construction of a mosque then it will be huge lesson for the west to understand that the Muslims are progressive in nature and they know the growing demands of this era. And the contribution of the symbolic importance of mosque in the Muslim society will also enhance the Muslims' dignity in the cause of fight against environment depletion.

Decreasing the domestic demands means low consumption of energy in the cooling, aeration, ventilation and lightening of residential buildings. This will decrease the burden of National energy supply, thus the energy production from fossil fuels will reduced lowering the carbon emission. This is because of the fact that U.A.E has major production dependence on the burning of fossil fuels. Soon when the oil becomes short in supply, these sustainable models will be the only choice for the mankind and for the Governments of Gulf States. So this model is very important for a shift of energy dependence from the fossil fuels to renewable sources.

There has not been much research on mosque energy consumption and its impact on the sustainability of nature. However, it was discovered that mosques consume a large amount of energy, especially when the number of mosques increases in the world. It has become necessary to increase research and studies to reduce energy consumption by mosques, especially in areas with a hot climate, where it needs to use energy for cooling (Rezaei, Shannigrahi & Ramakrishna 2017). Budaiwi (2011 cited in Azmi & Kandar 2019) explained that consumption can be reduced by improving ceilings and walls in terms of thermal insulation, as energy consumption can be reduced by 25 percent.

A. Hussin et al. (2014 cited in Abdullah, Majid & Othman 2016) clarified that the indoor thermal environment of mosques should be suitable and comfortable for worshipers to perform their prayers and religious occasions.

Many agencies have called for improved mosque construction and the use of passive design to help obtain a suitable thermal environment for worshipers without the need to consume a lot of energy, but few studies have been conducted for this purpose. As the construction of any building without taking into account the appropriate design can lead to a rise in the internal temperature of the building, which leads to increased energy consumption to reduce heat and obtain an appropriate thermal environment. Among the passive design tools that are recommended to be used for a suitable design are suitable shade systems, improving the building envelope, building orientation, type of glass used for windows, and many more (Mushtaha 2016).

The construction of mosques is exceptional and special, as there are special characteristics of the mosque that must be taken into account when building any mosque in terms of the high ceiling, the large internal space, its intermittent work, and the difference in the number of worshipers at all times and from day to day (Alabdullatief, Omer, Elabdein, et al. 2016).

1.2 Research Aims and Objectives

Research aims and objectives include:

- The development of a mosque building for conservation of energy with maintaining the comfort of the worshippers inside the mosque, while doing their daily prayers and activities, especially during the hot summer that Dubai is known for. Firstly, a system will be developed in which we want very low consumption of energy. And at second stage a system which will be self-sufficient would be developed which will be providing electricity for all the operations in mosque.
- The aims and targets are mainly focusing on applying of passive strategies that available in the market for energy efficient masques in Dubai. By analyzing the previous literature on this topic, we will be selecting some efficient ways to conserve energy. These ways will help us to design the buildings of mosques in such a way that usage of passive strategies will be done in order to achieve a model with low consumption of energy.
- For development of sustainable model, we will be using renewable energy sources which will give electricity at very low cost. To be a reference for research and other projects in the future that are conducted on mosques in a climate similar to that of Dubai. For this purpose, a research will be done by using the simulation through IES-VE software. IES-VE simulation will tell us how much is effective our system and model with the applied strategies.

- discussing various kind of other models which are under implementation in the world, briefly. These models will provide us the comparison and will help us to evaluate the efficiency attain in our model with respect to cost and the effort we need to put in.
- Another aim is to create impact in the society by using the spiritual attachment of Muslims, we theoretically will judge how much it will effect.

1.3 Research Scope

This research is based on the analysis of data and the methods which are used as passive design techniques are those which are selected from the literature already available. Thus there comes a lot of dependency on the accuracy of already available data and research. All the analysis has been done and the simulation done by the IES software is to check the amount of savings which would have done by use of these passive techniques. These techniques are passive in nature. There effect will come at very slow pace. But this effect will have the far reaching effects with regard to the services to mankind.

The expectation from this model is such that it will affect the local as well as the international community when it is implemented in its full spirit. The techniques used in this model also have the limitations. If we talk about the use of solar panels for the electricity production for all needs of mosque, then we can say it is not as much efficient as it seems. Solar panels will reduce the consumption of electricity from the national grid but even after applying the model in its full spirit, we will still need the electricity supply. This supply will run the appliances in the evening and in the night. So we cannot avoid the other source of electricity.

This thesis is about the saving of energy and reduce energy consumption. Some strategies and techniques will be discussed and finally their evaluation will be done by the technique of simulation. Simulation will be done by the computer and software and it can be observed that the results obtained from the software are reliable.

1.4 Dissertation Layout

The dissertation divided into five chapters, and consist of the following chapters:

Chapter one: is the introduction chapter that includes background about the energy consumption, resource of energy and the impact of using energy on the environment. Then the strategies that used to reduce energy consumption, aims and objectives of the research, and research scope.

Chapter two: is the literature review chapter, which includes previous studies and researches about saving energy and literatures about the use of passive strategies and scenarios that used in this paper and the results of their use.

Chapter three: is the methodology chapter that describe the method used in the study and literature of the method and justification, and describe the case study, location of the case study and climate, in addition, the simulation steps.

Chapter four: is the analysis chapter, which display the results of the simulation and analyze it, and compare the results of each scenario and shows which scenario is the best in each strategy, then comparing the research results to the literature.

Chapter five: include the conclusion and research limitation and future recommendations.

CHAPTER TWO

LITERATURE REVIEW

2 LITERATURE REVIEW

2.1 Introduction

Environment sustainability is at stake when we consider the facts of high carbon emission, depletion of ozone layer, increase in the temperature of earth, melting of glaciers and many other events. One of the big reasons in this regard is misuse of energy. To cover the growing demands, the manufacturers have to produce electricity from every single opportunity. But they do not bother to check that either it produces more harm than good or not. For example the production of electricity from the utilization of geothermal energy comes at the cost noise, surface disturbance, thermal effect, disturbance to biological life and habitants (Schwartz et al. 2010).

Lesser the amount of energy is consumed lesser will the need for production electricity by fossil fuels. Fossil fuels burning release toxic gases, oxides of carbon and sulphur, these oxides are very toxic and are the main causes of acidic rain. Acidic rain depletes the agricultural land. Thus affecting the sustainability of mankind in the planet earth (Baselga et al. 2011)

To achieve the energy efficient model in daily consumption is ideal for every society. Every society knows that how important, save the energy and implement the techniques which are useful in reducing the consumption of energy. A lot of research has been made in this regard so that the natural resources can be used at their best and a highly efficient model (Vikhorev, Greenough & Brown 2013).

The buildings contributes significantly to carbon emissions around 40 billion of tons, and consumes about a third of the world's water and energy each year (Wang et al. 2018).

Saving the electricity conserves ecosystem for plants and wildlife, decreases the amount of acid rain, reduces the intensity of natural disasters, stops the increasing levels of seas and oceans, and avoids the abnormal weather patterns. Any form of production of the electricity from nonrenewable sources of energy causes the harms listed in the first line (Schwartz et al. 2010).

Due to warming of earth and its atmosphere, temperature of things present on the surface of the earth is increasing. Which causes the glaciers of earth which are the big bodies of snow, are melting. This melted water goes to seas by passing the natural ways. It causes the floods in the areas it passes and increases the level of sea when it reaches there. Due abnormal weather conditions, climate is disturbed which is key factor in destruction of ecosystem of wildlife (Roth et al. 2016). All this is happening due to the increased production of electricity and then misuse of it (Pace 2013).

This paper is describing the reasons to study the consumption of energy, and how to conserve the energy at domestic level, by using different passive strategies. The used strategies include insulation, glazing, external shadings, green roofing, photovoltaic (solar panels).

All the research which has been done in this regard is associated with saving of energy. The researchers have found the ways with we can save the energy. Many kind of techniques have been developed to save the energy in domestic and in industrial sector. A lot of literature has been written in order to save energy from domestic use.

2.2 Saving energy

(Morita & Ozaki 2017) emphasized the role of workers in saving the energy. It gave the way how people can reduce the consumption of energy just by simple practices. It told people how much effective it will be if a fan is turned off when it is of no use. Same is the case of LED. The article present ways of saving energy by performing simple actions of responsibility.

Different researches were done to perform the analysis of behavior of customers in dealing with the idea of saving energy in household consumption. (Dobson & Griffin 2017) shows different people's way to save the energy. They selected hundred houses which were selected from random list. They conducted survey and asked people about their behavior and achievements which they had achieved in the field of energy savings. People reacted differently; some said they don't bother to save some pennies and consume their effort to save the electricity by turning off all the appliances which are no use. Some said that they are very conscious and they think that it is global cause to save the electricity to save the energy for future generations.

As part of the Dubai Urban Plan 2040 of His Highness Sheikh Mohammed bin Rashid, which is to develop the city of Hatta in Dubai, preserve its sustainability and environment, and provide healthy residential areas for citizens. a mosque was opened in Hatta city shown in Figure 2.1, according to the specifications of green buildings, where it received the platinum rating of LEED V4. Where energy was saved by 26.5%. The mosque was built from recycled materials and solar panels were added to provide the mosque with energy. In addition to reducing 55% of water and reusing water for irrigation and cleaning purposes. And using the air purification system to improve the indoor environment and provide a healthy, sustainable environment in the indoor space (albayan 2021b).

Figure 2.1 shows the sustainable mosque built in Hatta (albayan 2021b)

2.3 Using passive design strategies in historical mosques

Mosques are religious sites and Muslims have the spiritual relations with the mosques as their religion tells them. Religious sites do have the impact on what people think about life and their way to live the life. If something is practiced from the religious site, it will change the way it will propagate in the life of general public life. An article which was based on the Buddhist Community and it was revealed that the religion and the practices under religion is based on the strong believes and same is the case with every follower of every religion. So a new idea will flourish more speedily by the impact religion than any other factor (Pace 2013). Muslims on the same pattern follow their religion and have strong affection their religious site. So the idea is saving energy or doing anything with the endorsement from the religion. This fact had been proved in the literature by many of the researcher in history and in present era (Baron 2020).

In this paper a model is to achieved in which the mosques are to build in such a way that they consume less energy. This is being done to cope with the challenge of energy crises and other harms founded in the use of excessive energy. Due to increasing cost of energy, its harms and the insecurity of energy security and the new amendments passed by the legislations are driving the people to use less amount of energy (Vikhorev, Greenough & Brown 2013).

There have been many researches about reducing energy consumption in mosques around the world, and turn them into energy efficient mosques, by applying different passive and sustainable strategies. Especially in hot regions, where there is high demand on the use of air conditioning systems, to provide comfort environment to the worshippers, while they doing their daily prayers. Al-Khalifa (2019) points out the smart solutions that used in historical mosques to become sustainable mosques, in three different regions, which are KSA, Oman, and Bahrain. Courtyard was the main feature in all mosques for many years starting from the first mosque in Islam, which was in KSA, Madinah. It helped providing cool air, especially in hot-arid regions. Based on wind velocity, the cool air reached to the interior space of the mosque through porticos that consider as a connection area between the courtyard and the prayer area as shown in Figure 2.2. Moreover, planting palms and trees around the courtyard, to provide shades and control wind velocity.

Figure 2.2 courtyard at al-Aqmar mosque (Al-Khalifa 2019)

Other historical mosques such as Qasr Al-Hokoum mosque in Najd, KSA. Used the adobe for building, which works as an insulation, and prevent heat transfer from outside the building to the interior spaces, where it helps reducing heat and provide thermal comfort for the worshipers. Historical mosques in Oman are recognized by the shape of the prayer hall, which is rectangular and directed to Qibla direction (toward KSA); with windows on the sidewalls to allow fresh air enter to the hall, and small opening on the top of the walls. In addition to high ceiling that, allow hot air rise up, escape from the small openings to the outside. In Bahrain, they used wind towers as a passive solution to provide fresh air to the interior areas such as the historical mosque Sheikh Isa Bin Ali Al-Khalifa that shown in Figure 2.3.

Figure 2.3 wind tower at Sheikh Isa Bin Ali Al-Khalifa mosque (Al-Khalifa 2019)

Azmi & Kandar (2019) specified four main factors that help for further studies and designing sustainable mosques. The first factor is the volume of the mosque and its spatial layout that helped in providing illumination for the deepest section of the mosque by using high windows. In addition to providing ventilation with the same windows by stack effect and keep the prayer hall comfortable for the worshipers while they are doing their prayers. However, after the invention of air conditioning and using electrical lighting, the needs for high ceiling and windows reduced, although many mosques now are built in the traditional style, which increase the use of electricity for lighting and air conditioning. The second factor is the fixed orientation of the prayer hall must be facing the Qiblah, and most mosques are symmetrically at the central axis with the prayer hall. In some areas, the fixed orientation causes one direction of the mosque to be exposed to the morning sun while the opposite direction to the afternoon sun. Wherefore, the envelop of the building and the roof are significant parts when designing as they control the amount of energy that enter and leave the building. Proper orientation must be considered from the early design stages as one of the passive strategies, because it controls the exposure of the prayer hall to the sun, which controls the required heating and cooling in the interior spaces. The orientation of the prayer can be remained consistent and directed to Qiblah, while change the direction of the mosque`s envelop in respect to solar geometry. The third factor is the occupancy pattern of the mosques, which is the most distinguishing feature because it`s changing pattern. Generally, regular prayers are attended by a smaller percentage of worshippers than Friday prayers. The need for lighting and air conditioning is changing based on the occupancy pattern. Since the mosque is usually empty during the day, the air conditioning is often turned on for the whole day, wasting a great deal of electricity, while some mosques turn on the air conditioning just before the prayer time, which doesn’t help in reaching the thermal comfort for worshippers because of the limited time allotted for prayers does not allow for adequate thermal control in such a large room. Different steps must be taken in mosques to ensure sufficient comfort according to number of worshippers, because the amount of worshippers differs in daily prayers from Friday prayers, as using one method will lead to severe energy consumption or an uncomfortable thermal environment inside the mosque. Separating spatial zoning help in maintain thermal comfort during prayer time and reduces energy consumption at the same time. It can be achieved by dividing the prayer area and concentrating the ventilation and thermal regulation near Qiblah wall where worshipper concentrate there especially in low occupancy during daily prayers. Dividing the prayer area can be done with many options as shown in Figure 2.4 the two options of smaller zones for low occupancy, either dividing the prayer area into smaller zone same as option 1 or adding separate small prayer hall same as option 2 for low occupancy to do the daily prayers. The fourth factor is user activity level and clothing type. The indoor environment of any building is important to ensure the occupant`s comfort. Worshippers in the mosques need a comfortable and relaxed area to do their daily prayers and concentrate in it. Thermal comfort is globally recognized scale to asses and measure the indoor environment. Air temperature, mean radiant temperature, relative humidity, air velocity, metabolic rate, and clothing insulation level of users are aspects that relate to thermal comfort. The first four affected by building form and climate condition, while the last two influenced by users. Mosques are different from other buildings, where they have consistent patterns in the previous factors, which allow designing mosques by controlling the other four factors.

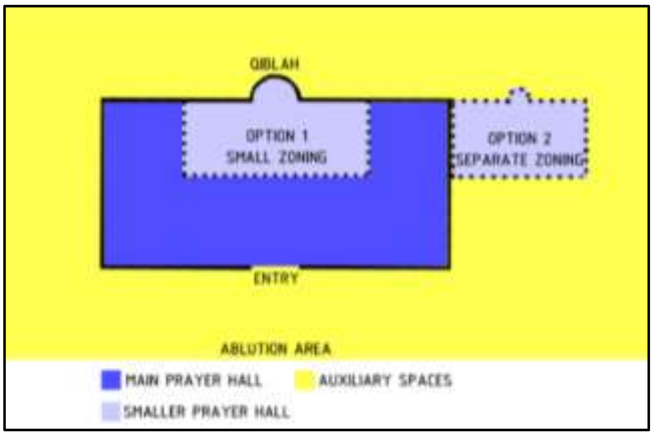


Figure 2.4 the two options of smaller zones for low occupancy (Azmi & Kandar 2019)

Sanusi et al. (2019) identify passive strategies that implemented in three mosques built in Malaysia with colonial design. As per building recommendations for hot humid climate in Malaysia, there are eight passive deign strategies that should be in the buildings. The three mosques adopted five of the eight strategies, which are open layout, cross ventilation to allow fresh air in the interior space, window to wall area should be 50% or more, the windows and opening should be placed in different placements and verandah to protect the openings. Sanusi et al. (2019) evaluated the impact of the passive design that used in the three studied mosques. They found that the verandah was the most effective strategy used. So it became the most used shading element. The large openings and large roof volume, which is the dome are effective passive strategies as well in colonial mosques in Malaysia. Where the dome act as a barrier and prevent the transmittance of solar radiation.

In 2013, the Dubai government announced that it will convert the existing large scale mosques in Dubai which number is six hundred and fifty. This was ambitious project which lead the conversion of many mosques to the system of sustainable growth. Dubai electricity and water authority announced this pilot project.

In 2014, a mosque on the green model was opened in the Dubai which would help us in the achieving the sustainable energy consumption.it is of the area of nine thousand seven hundred fifty-five square meters located near the Deira City Centre mall in Dubai. The Khalifa Al Tajer Mosque, which has the capacity of for thirty-five hundred people will be biggest mosque ever since which is following the model of low energy consumption. Another feature of this mosque is that it was built from the environment friendly materials and all the materials were recycled before using. The mosque aims to achieve LEED silver certificate, by applying the latest green technologies and standards such as thermal insulation and double-glazing (Shaaban 2014).

Director of SEWA explained that MOSQUES Have 30-40 per cent of water and electricity through the saving programs implemented by SEWA (Barakat 2012).

The mosque is a building that is exposed to the outside and is affected by all external factors such as hot and cold weathers. Therefore, improving the quality and efficiency of the building envelope is very necessary to reduce the energy consumption used for cooling in a hot climate and heating for a cold climate. The building envelope includes walls, ceilings and windows (Amatullah & Halipah 2020).

Mushtaha & Helmy (2017) applied several passive design strategies to a mosque building in the emirate of Sharjah in the United Arab Emirates, where the climate is hot and humid. Apply thermal insulation, shading systems, and a natural ventilation system to help reduce annual energy consumption, that reached 10%. By adding the hybrid cooling system, it was able to reduce annual energy consumption by 67.5%.

(Shohan & Gadi 2020) studied several buildings of different mosques in the city of Abha in Saudi Arabia, they concluded that the heat gain in the buildings is due to the inefficiency of the building envelope, which consists of the walls, roofs, windows and doors, so it is important to improve the efficiency of the building envelope by applying some of the passive strategies. In addition, the application of negative strategies will lead to the protection of the environment.

(Amr 2019) use a simulation program (design builder) to calculate the energy use of a mosque inside the Assiut University building where the climate is hot and dry. Several strategies have been implemented to reduce energy use. Including the use of thermal insulation for the walls, where the U-value was reduced from 0.986 W/m^2K to 0.263 W/m^2K. A thermal insulation was used for the roof where the U-value was reduced from 1.27 W/m^2K to 0.171 W/m^2K. The lighting used has been changed from fluorescent to LED. An external shading (horizontal louvers) with a depth of 0.5 m was used. The result was a 29 percent reduction in energy consumption, because the use of the previous strategies led to a reduction in the amount of heat gain.

2.3.1 Thermal Insulation

One of the passive techniques is to have the good quality insulation in the mosques. This will help us in keeping the indoor temperature of mosque at lowest possible level. Keeping in view the general trends of temperature in Dubai it is necessary to insulate the residential and domestic buildings so that the heat effect of summer season can be reduced.

Insulation is the key technique to develop a model for the energy efficiency in the area of domestic use. Insulation is provided to decrease the effect of high heat transmitted by the sun to earth in the summer season. The weather conditions in Dubai become very hot in the summer and we need to minimize its effect by break in the supply of heat in buildings. Insulation is the cheap method compare to high energy cost which alternatively be used in the summer season if temperature goes beyond certain limit. We will have to run multiple numbers of air conditioners to overcome the extra heat present in the buildings. So cheaper methods like the insulation of walls just have the very initial cost at the time of construction (Wang et al. 2018). And we will get long term benefits from it. This technique will be helpful in the discovery of energy efficient techniques for the design of mosques in Dubai.

(Ozel 2014) studied the impact of the position of thermal insulation on heat transmittance, the results showed that outside the wall is the best position for insulation with the optimal thickness, will gain best thermal performance.

Amatullah & Halipah (2020) used expanded polystyrene with a thickness of 25 mm, which led to a reduction in U-value from 2.41 W/m^2K to 0.87 W/m^2K, and the R-value of the insulation material was 0.73 m^2K/W, and the result was a reduction in energy consumption for cooling by 9%. The addition of 32 mm of insulation reduced U-value to 0.75 W/m^2K, increased R-value to 0.92 m^2K/W, and increased energy conservation by 5.7%.

A research was conducted on a mosque in Sharjah and used IES-VE software to run the simulation. The study applied thermal insulation material to the base case, which is polystyrene foam, to prevent heat gain and concluded that insulation material led to a very comfortable indoor environment by reducing heat gain, especially at noon time during highest outside temperature. Where at 5:00 AM, the temperature in the interior space was 4.7°C higher than outdoor temperature, while it reduced about 1.1°C after using thermal insulation and became 3.6°C (Mushtaha 2016).

Heat gain through the building envelope is the main cause of increased energy consumption in a hot climate. It leads to an increase in the use of cooling devices to obtain an appropriate and comfortable thermal environment for worshipers. But energy consumption can be greatly reduced by using heat-insulating materials in walls and ceilings, as well as shading systems with windows. Thermal insulating materials play an important role in reducing energy consumption, as they increase R-value and reduce U-value. Which leads to reducing heat gain from the outside and its conduction to the inside in hot climates. In a study conducted on a mosque in Riyadh, using thermal insulating materials helped reduce the U-value. Which reduced annual energy consumption by 10%. In another study, reducing U-value by using thermal insulation material, reduced annual energy consumption by 12% (Amatullah & Halipah 2020).

Al-Shamrani et al. (2019 cited in Amatullah & Halipah 2020) concluded in a study they conducted on a mosque in the Kingdom of Saudi Arabia, where adding 50 mm of polystyrene or polyurethane insulation to a double concrete wall with thicknesses of 100 mm and 150 mm, led to a decrease in the U-value so that it became less than 0.5 W/m^2K after it was 2.57 W/m^2K. This resulted in a reduction in energy consumption for cooling by more than 20%. By increasing the thickness of the insulator to 70 mm, the energy consumption was reduced by 25%. Despite the importance of the thermal insulation, but the choice of thickness must be appropriate, as increasing the thickness does not lead to an increase in reducing energy consumption, but on the contrary, its effect is less efficient and can affect the peak of the cooling load, as a study was conducted on a mosque building by Budaiwi (2011 cited in Amatullah & Halipah 2020) , by adding a double thermal insulator and the result was a reduction in the consumption of the general cooling load, but the peak cooling load increased due to the latent load associated with the double thermal insulation. Poor thermal insulation is the reason for the mosque's rapid temperature rise after turning off the cooling system.

Taleb (2014) used several sustainable strategies on a villa in Dubai and used bubbles of thermal insulation, with a R-value of 15.67 m^2 K/W. The results of the study were the results of using the combined strategies together, by using IES-VE simulation on the living room, which is located on the northwest side of the villa for a week in the month of August, where the climate is at the peak of the temperature rise. Analyzes showed that it was possible to reduce the cooling load by 9%, and reduce annual energy consumption by 23.6%.

Ahmed (2019) conducted a study on the use of a thermal insulator for walls and roofs on a university building in al Fayoum, Egypt. using a design builder as a computer simulation software. He used different types of heat insulator with two types of walls, single and double. and concluded that all heat insulators lead to a significant reduction in energy consumption. But, use of single wall with 70 mm polyurethane as thermal insulation was the best choice of double wall with other types of thermal insulation.

Al-Shamrani et al. (2016) examined eight types of walls for a mosque building using the Ecotec program in the city of Al-Khubar in the Kingdom of Saudi Arabia. The walls contain different types of thermal insulators, and some of them do not contain thermal insulation. Among the insulators were polyurethane, polystyrene and rock wool. The most energy consumption was in July and August due to high temperatures, which requires the use of cooling systems to obtain a comfortable thermal environment. The result showed that the most energy consumption when not using any type of thermal insulation and when adding thermal insulation helped to reduce energy consumption significantly. The large energy consumption has led to of water, air and land emissions, which led to global warming. Therefore, the use of thermal insulators reduces the environmental impact, such as polyurethane, by 33% and polystyrene by 31%.

Aldawi et al. (2014 cited in Omrany et al. 2016) conducted research on the walls of two homes in Australia, where the original wall consisted of a brick veneer, an air gap, a wooden frame with insulating foil, and plasterboard inside. The wall was modernized and built of reinforced concrete panels coated on both sides with polystyrene as a thermal insulator, and two types of glass were used for the windows, single and double glazing. Using a simulation program to measure the thermal performance of the wall, it was concluded that the new wall works better and is more efficient than the first wall, even with the use of single glass for windows, as it requires less energy for cooling during hot weather and heating during cold weather, as energy was saved by 22%, 44%. It was concluded that the reason for the good performance of the new wall was due to the use of heat insulator with thermal mass. The use of double glazing windows reduced energy consumption by 1% and 37%. The new design wall with single and double windows has better performance than traditional wall with the same type of glass.

In a study on a hospital building in Egypt, several strategies were applied to improve energy consumption, including the addition of 25mm of polyurethane as a thermal insulator to the wall and ceiling. The result was a 16.5% reduction in energy consumption by cooling systems. And reduce the total energy consumption by 7% (William et al. 2019).

Friess & Rakhshan (2017) explained that adding a thermal insulator or increasing its thickness has a significant impact on reducing the energy consumption of the building, especially in buildings where the ratio of glass to the wall is low, as the use of thermal insulation reduces heat transfer from outside to inside, especially in hot climates.

Friess & Rakhshan (2017) reviewed some studies and research on the benefit of using heat insulator in construction and the degree of its efficiency in the UAE climate. Afshari et al. (2014 cited in Friess & Rakhshan 2017) raised the thickness of the thermal insulation and added 80 mm of EPS to the wall of a 15-storey building in Abu Dhabi, and the ratio of glass to the wall was about 70 %. The addition of the thermal insulator reduced the U-value from 1.71 W/m^2K to 0.324 W/m^2K. Thermal insulation decreased the annual cooling load by 2.6%.

Friess et al. (2012 cited in Friess & Rakhshan 2017) reduced the U-value of villa`s wall located in Dubai, from 2,398 W/m^2K to 0.600 W/m^2K by adding thermal insulation to the thermal bridges, which led to a 23.3% reduction in energy consumption. Then they insulated the entire building using 50 mm of EPS, where the U-value was reduced from 2,398 W/m^2K to 0.600 W/m^2K, and the result was a 26.8% reduction in energy consumption. Then the thickness of the thermal insulation was increased from 50 mm to 160 mm, which reduced the U-value from 0.600 W/m^2K to 0.226 W/m^2K, which resulted in an increase in reducing energy consumption by 7.4%.

Radhi (2009 cited in Friess & Rakhshan 2017) added thermal insulation to the walls and roof of a villa located in al Ain. The insulation reduced U-value from 2.32 W/m^2 K to 0.3 W/m^2 K and from m 0.6 W/m^2 K to 0.2 W/m^2 K for walls and roof, respectively. Which result in reducing cooling load by 19.3%. the researcher conclude that thermal insulation and thermal mass is the most effective strategy in reducing energy consumption more than glazing and shading.

Al Masri et al. (2012 cited in Friess & Rakhshan 2017) explained in a study he conducted on a villa in Dubai that reducing the thickness of the thermal insulation from 25 cm to 15 cm leads to an increase in energy consumption by 0.6%. Increasing the thickness of the thermal insulation to 40 cm led to a reduction of energy consumption by 0.9%.

Friess & Rakhshan (2017) concluded that the thermal insulation is effective with any thickness, but increasing the thickness can lead to a decrease in the efficiency of the thermal insulation. Thermal bridges must be well insulated because if they remain without thermal insulation, it can negatively affect the efficiency of the building insulation. Thermal insulation should be placed on the outside of the wall in order to obtain a good thermal mass.

Salavatian (2019) concluded that thermal insulation and thermal mass have a different effect on buildings according to the season. Where in summer, the increase in thermal mass is beneficial in lowering the indoor temperature. But in the winter, the thermal insulation is more useful in reducing heat exchange. It is important to pay attention to the U-value of the walls of the building in a hot climate where a comfortable atmosphere during the summer is very important.

Taleb (2016), added additional insulating materials to the inner side of the external wall of the hospital building on which she researched. Despite the small increase in the wall thickness, the result was good, as the U-value was reduced to 0.365 $W/m^2 K$, which leads to a reduction in the external heat gain from 29KW to 22 KW. Thus, it reduces energy consumption.

In a study conducted on the thermal conductivity of several types of thermal insulators used in construction, it was concluded that low-density polystyrene raises the temperature of the interior space, reaching 75.93 and 72.61% for both variable thermal conductivity and constant thermal conductivity, respectively. While the UHD polystyrene emits the least amount of heat to the interior space. The low density fiberglass emits the largest amount of heat up to 85.97 KWH and 83.23 KWH for both variable thermal conductivity and constant thermal conductivity, respectively. Polyurethane and rock wool retain the most heat when they have a high density. The medium-density rock wool was the best in terms of thermal performance, as it emits the least amount of heat to the interior space, about 3% or less, while polyurethane raised the percentage of air-conditioning system use by about 15% (Khoukhi, Hassan & Abdelbaqi 2019).

2.3.2 Glazing

Second used strategy is about using the glazing in the Mosque. Windows will add to aesthetics of building. They are used in walls and connect the internal environment of the mosque with the fresh and natural environment of the outside. They do have another positive effect in which they cause the aeration, ventilation of the building. The other advantage to use the window in walls is that it allows the solar light and energy to come in the mosques which provide the sunlight in the mosques, but it can affect the energy consumption in the mosque as it raises the temperature of the place, especially in the summer season, where the climate is hot and solar energy is allowed to enter in the interior space, which leads to an increase in energy consumption for cooling to obtain a comfortable thermal environment. If we just use windows for the supply of natural light to building of mosque, then heat of sun will cause the building to get hot. Then to control heat effect and to make the building worth using we will have to use the cooling systems. This cooling system comes at the cost of very large amount of energy consumption because it gets very hot in summer in Dubai. To avoid very large consumption of energy, innovative glazing will be required (Sun et al. 2017).

In the study that took place on a hospital building in Egypt, where it was mentioned in the section of thermal insulation, several strategies were applied to improve energy efficiency, including polyurethane as a thermal insulator. The quality of the glass was also improved from single to double glazing with an air gap in between the two panes. The glazing reflect the heat by using metallic oxide covering, as this change led to a 5% reduction in energy consumption for cooling and a reduction in total energy by 2% (William et al. 2019).

Friess & Rakhshan (2017) clarified that choosing the quality of glass for windows is very important, especially in public buildings and offices, where the glazing to wall ratio is greater than its percentage in homes. The poor design of the location of the windows and the poor selection of glazing type led to the acquisition of daylight disproportionate to the need, high glare and excessive heat to the building, which increased the energy consumption required for cooling.

Afshari et al. (2012 cited in Friess & Rakhshan 2017) updated the type of glass used in the 15storey building, where 70% of the building is glazed. The study was conducted and used double glass filled with air or argon, which led to a reduction in the U-value from 2.4 W/m^2 K to 1.7 W/m^2 K and 1.47 W/m^2 K for both air-filled and Argon, respectively. The results showed a reduction in annual cooling load of up to 4.6%.

Al Masri et al. (2014 cited in Friess & Rakhshan 2017) replaced the type of vibrator used in his research on a medium-rise residential building in Dubai, where the type of glass used was single glass and the percentage of glass is 14%. Two types of vibrators were tested, the first was double-paned glass, which reduced energy consumption by 12.31%. The second type is triple-pane glass, and it helped reduce energy consumption by 2.32%.

(Amatullah & Halipah 2020) explained that using double glazing can reduce heat gain through windows, which leads to a 6% reduction in energy consumption compared to using single-glazed windows. In a study on the glass windows of a mosque in Kuwait, where the single glass was changed to double electrochromic glass, which led to a decrease in energy consumption by 9% (Al Anzi & Al-Shammer 2017). Amatullah & Halipah (2020) explained that all the studies he mentioned in his literary presentation had a small proportion of glass to the wall, so the effect of changing the quality of the glass was a little, but in fact, the proportion of glass to the wall is greater, and as a result, changing the quality of the glass has a greater impact on reducing energy consumption. It should be noted that choosing the type of glass is expensive, but its long-term effectiveness in reducing energy consumption may be worth the initial cost.

Taleb (2016), in her research on a hospital building in the UAE, used the quality of glass recommended by Ashrae (2009), where it was double glazing filled with argon gas with a U-value of 1.65 W/m^2K. Shading films have been added to windows. Where the heat gain has been reduced from 29 KW to 26 KW, and this thus reduces power consumption. The use of recommended quality glass from Ashrae resulted in better light implantation in the interior space.

(Dutta & Samanta 2018) conducted a study on a guest house in India, where the climate is tropical. They tested several types of window glass used in the market from SAINT-GOBAIN company, which are two types of single (reflectosol and EVO), and three types of double (reflectosol, EVO, NANO) as shown in Figure 2.5. they were designed using

OPTICS and LBNL WINDOWS 7 programs. Two simulation programs TRNSYS AND eQUEST were used to calculate energy consumption. It was concluded that the U-value is very important to improve the energy efficiency of the building and reduce the cooling load. Double glazing was better when using the NANO type that has a U-value of about 1.8 W/m^{2}K. The results showed that it helped reduce energy consumption by 6.39% and 5.12% in the TRNSYS and eQUEST programs, respectively.

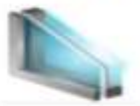
Glass name		Type	Picture	Saint Gobain specification	Optics 5 & window7 Generated Value
A.	Reflectosol (Single Glazing)	Reflectosol (11352)		U-value-5.7w/m2 K SHGC-39%	U-value-5.799w/m2 K SHGC-33.60%
B.	Evo (single glazing)	Neutrals (11406)		U-Value-3.8w/m2 K SHGC-29%	U-value-3.97w/m2 K SHGC-38.70%
C.	Reflectosol (double glazing)	Metals (11356)		U-Value-2.8w/m2 K SHGC-24%	U-Value-2.69 w/m2 K SHGC-24.40%
D.	Evo (double glazing)	Neutrals (11407)		U-Value-2.0w/m2 K SHGC-23%	U-Value-1.974w/m2 K SHGC-20.9%
E.	Nano (double glazing)	Twilight (11444)		U-Value-1.8w/m2 K SHGC-20%	U-Value-1.78w/m2 K SHGC-18.30%

Figure 2.5 shows the types of glazing used in the study (Dutta & Samanta 2018)

A study was conducted in an office in London, where a parallel transparent insulating material (PS-TIM) was added to the window glass, which led to a 15.5% reduction in energy consumption when the air conditioner was turned on during working hours only. If the air conditioner was operated continuously, the energy consumption was reduced by 33.6% (Sun et al. 2017).

The use of windows come at the next option in the saving the energy in passive techniques. Windows are installed in the walls. These windows provide many advantages to the user using them. Different researchers have used their own way of ideas about the benefits of using windows.

Ma et al. (2020), Conduct research on solar space glass in a building in China using energy plus simulation software. Several types of glass were tested as single and double glass, and several types of gases were also selected with double glass such as air, argon gas and krypton gas with different thicknesses from 3 mm to 24 mm. The results showed that the use of solar space had a significant effect in reducing energy consumption and that the use of double glass filled with air is better than single glazing. But air was less efficient than argon. Krypton gas was better than argon and air. Each gas had an optimal thickness, as air had the best efficiency at a thickness of 12 mm, argon gas was better at a thickness of 15 mm, and krypton gas had the best efficiency at a thickness of 9 mm.

Taleb & Antony (2020) used an office building in the United Arab Emirates and conducted a study on it, and explained that single glass can cause heat gain, which leads to an increase in the temperature of the interior space. Taleb & Antony (2020) used krypton gas with double glass, it was concluded that krypton can let in an amount of light equal to argon, but it prevents more heat from entering than argon, which leads to a reduction of the cooling load by 2.8%, meaning that krypton is more efficient than argon. As for the use of xenon gas, it was equal in efficiency with krypton gas, as they have the same R-value of about 0.8532 m^2 K/W.

Baek & Kim (2019) develop a triple glazing filled with CO2, and the vacuum between the layers of glass. Where the vacuum was in the inner part of the glass and the co2 gas was in the outer part as shown in Figure 2.6. The type of glass used was manufactured according to SAINT GOBAIN company specifications of clear glass. with a thickness of 3 mm, according to the conclusions of previous studies. A building was built with the simulation program Energy Plus to apply glazing to it and calculate its efficiency with the selection of Korea's climate for climate settings and the simulation for ten days during cold season. The thickness of the vacuum section was about 6.2 mm depending on the best thickness of the vacuum in triple glazing that was concluded from previous studies. As for the thickness of the section filled with co2 gas, it depended on decreasing the U-value, as it decreased as the thickness of the co2 section increased, until it reached an optimal thickness of 15 mm. So that the U-value of all the triple glass was 0.259 W/m^2K. The building's energy consumption was approximately 639.75 KWH. The type of gas used was changed from co2 to argon, then air, and then krypton. It was concluded that with the use of krypton gas, less energy is consumed than co2 gas, about 634.20 KWH. The results of using air and argon gas were close to the result of using co2 gas. Where they were 643.47 KWH and 637.50 KWH for air and argon gas, respectively.

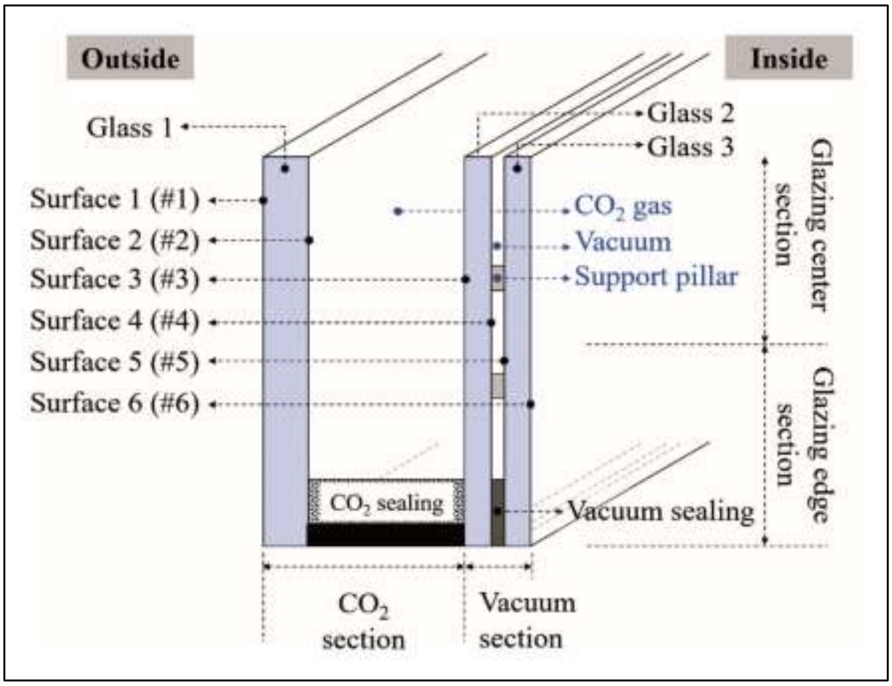


Figure 2.6 shows the developed triple glazing (Baek & Kim 2019)

2.3.3 Shading

External shadings are used to save mosque building from direct sunlight reaching in the internal territory of the mosque. Sunlight is needed for saving of energy which otherwise be used in artificial lights. But we don’t want the heat effects caused by solar radiations as these effects will make building warmer. These hot solar radiations can be avoided by the use of external shadings over the doors, windows and other openings. in addition, it can be used with the innovative glazing to increase the amount of reducing energy consumption. There are many studies conducted on shading devices, and it was concluded that shading devices have a good efficiency in reducing energy consumption (Freewan 2014). Another advantage of using the external shadings is that it provides shield against the rain water to come in the building of mosques.

Hammad et al. (2010 cited in Friess & Rakhshan 2017) used the Dynamic and static louvers as a tool to shade an office in Abu Dhabi, where glazing to wall ratio of the building is up to 60%. The result was the dynamic louvers were more effective than the static one. But both helped in reducing the annual energy consumption, where it was between 28% and 34%.

Mushtaha (2016) used several passive strategies on mosques in the city of Sharjah to provide a comfortable indoor thermal environment for worshipers, as the climate in the city of Sharjah is hot and humid. One of these strategies was the application of thermal insulation and the use of shading systems and natural ventilation. The result of the thermal insulation was explained previously in the section of thermal insulation. The application of shading systems was used to prevent direct sunlight from entering the interior space, especially during peak hours from 10.00 am until 3 pm. But the effect of shading systems was slight on reducing the temperature of the interior space by 0.1°C, but when it was added with thermal insulation and natural ventilation, the temperature of the interior space increased by 4.6°C more than the outside temperature, during the coldest time, at 5:00 am and the temperature was reduced by 2.7°C during the hottest time at 2:00 pm.

Amatullah & Halipah (2020) concluded that about 35 to 45 percent of heat acquisition which is carried out by windows can be reduced by increasing the depth of shading systems as a balcony shading. Amatullah & Halipah (2020) said that the use of shading at a mosque building in the UAE helped reduce the internal temperature more than not to use a shading system. Amatullah & Halipah (2020) mentioned in their literature review a study conducted on the use of shading, which helped reducing cooling load by 6% (Alabdullatief 2017). In another study on a mosque in Kuwait, the use of shading systems led to reducing energy consumption by 5% (Al Anzi & Al-Shammer 2017).

It was concluded that the use of shading systems can have a significant impact on reducing the energy use of any building and improving its efficiency. Increasing the depth of shading can increase its efficiency, but this depends on the building codes in each country (Liu et al. 2020). However, Taleb (2016), concluded that shading systems are not very useful and not worth using, as not using shading systems led to an increase in the temperature of the interior space by only one degree compared to its use. And the percentage of natural lighting in the back of the interior space compared to the part near the window is large when using shading devices, reaching 50%, while not using shading devices, the percentage was 30%, as she concluded from her study on a hospital building in the UAE climate.

The DAYSIM program was used to simulate a shading system shown in Figure 2.7. After adding modifications to it to help reduce energy consumption for an office room. Two types of glass were used, one of them is double glass and the other is a high performance glass designed to prevent sun loads. The U-value for both types of glass is 1.4 $W/m^2 K$. Adjustments were made to the height, width, angle and distance of the shading system from the wall. The test was conducted on two different climates, one of which is Rome, which is located in central Italy, and Trieste, which is located in northeastern Italy. The initial energy consumption reduction after optimizing the shading system was about 30% and 19% for Roma and Trieste, respectively (Manzan 2014).

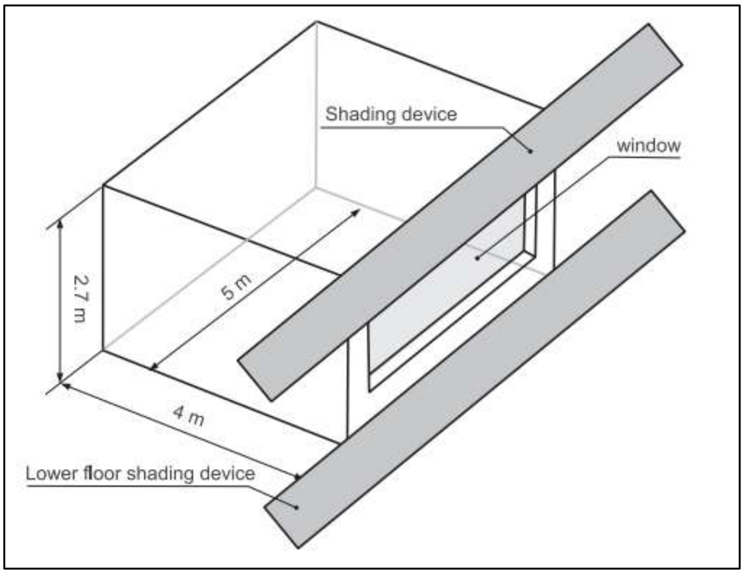


Figure 2.7 the shading used in the office (Manzan 2014)

A new shading system was used as shown in Figure 2.8 in India where the climate is warm and humid. Its efficiency and how much it helps reduce energy consumption was calculated, as it helped reduce about 4.62% of energy consumption. The shading system was used in other regions with the same warm and humid climate, in the United States of America and Vietnam, which helped reduce the cooling load by 6.34% and 3.51% for America and Vietnam, respectively. The new model of the shading system helped prevent direct sunlight from entering the interior space in the summer, while allowing it to enter in the winter as shown in Figure 2.9, in addition to that it did not prevent vision into the outer space (Ghosh & Neogi 2018).

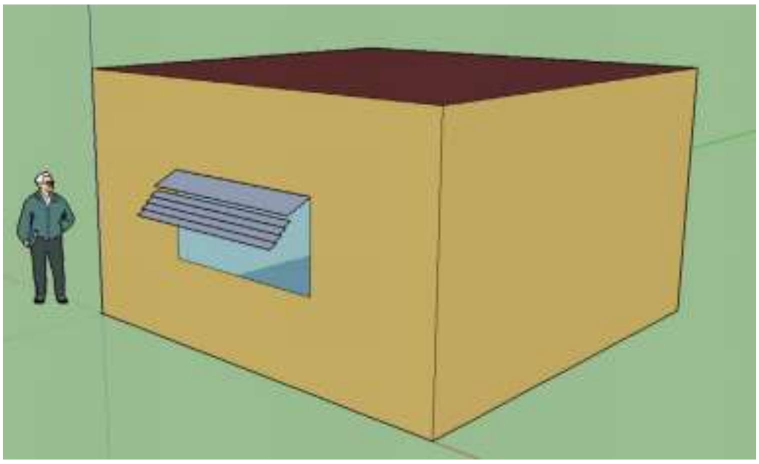


Figure 2.8 new shading design used in the simulation (Ghosh & Neogi 2018)

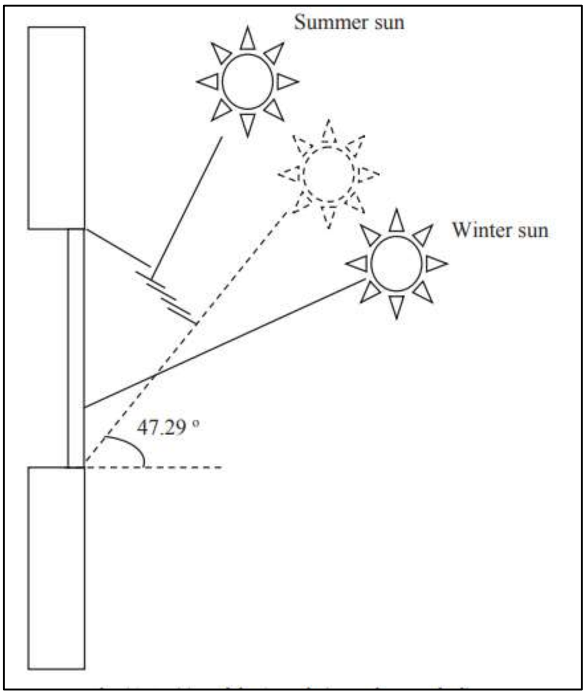


Figure 2.9 the sun`s ray fall on the new shading in summer and winter (Ghosh & Neogi 2018)

Freewan (2014) conducted a study on several shading systems on a desk in the Jordan University of Science and Technology building. Three types of shading systems were used as shown in Figure 2.10. (egg crate, vertical fins, and diagonal fins). It is clear that shading systems have a significant positive effect on reducing heat gain from outside. All species helped to reduce the temperature of the inner space with the same efficiency until one o'clock in the afternoon, but after that time the diagonal fins were more efficient than the other types, as the entry of sunlight was not heard at all. As for the other species, some sunlight was allowed to enter after 3:30 for vertical fins and after 4:30 for egg crate. Thus, the shading devices had a benefit in reducing the temperature of the interior space, which leads to a reduction in energy consumption and cooling load.

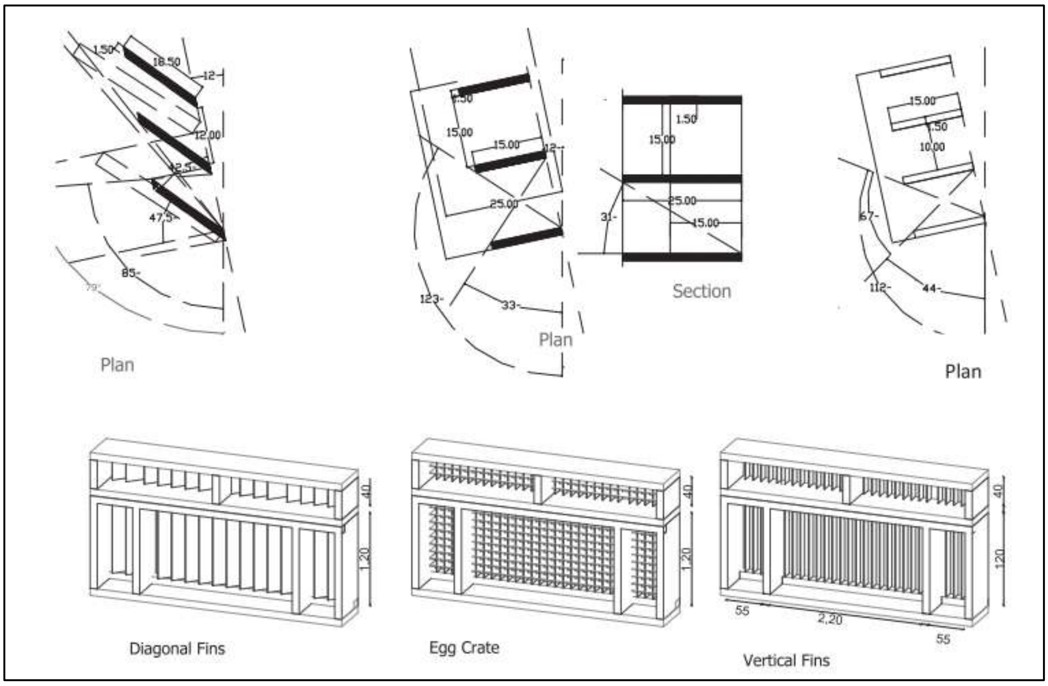


Figure 2.10 the three types of shading used in the study (Freewan 2014)

Khalid et al. (2019) conducted a study using a simulation program to calculate the effect of shading devices on a hotel building in Saudi Arabia, where the climate is hot and humid. Several types of shading devices were used, including vertical and horizontal fins, in multiple ways and directions. The result was that shading devices helped reduce energy consumption by 20.5%. While the improvement of polyurethane, the thermal insulation used in the wall and ceiling, and the use of triple glazing for windows with low e-coating helped reduce energy consumption by 5%, without using shading devices. Khalid et al. (2019) cautioned that these results may differ when using the same shading devices in other buildings, as there are several factors that can affect the decision to use shading devices and their efficiency, including the different orientation of the building, location and climate.

Next option which is being researched in the field to achieve energy efficient model is the use external shadings. These shadings come at the top of the doors and windows and other openings of the building. These are to provide a shield against the direct sunlight. Direct sunlight, if it reaches the indoor building, can increase the temperature to higher level. And this would cause uncomforted to the users using the buildings and increase energy consumption due to the need for cooling. So to avoid the sun rays reaching the indoor building, we will use the shadings at external side of the openings. This will help to reduce the inside temperature.

Several types of shading devices were used on a building cell in India, where the climate is warm and humid. The horizontal louvers reduced the energy consumption by 3.3%, and when adding the triangular fins, the efficiency increased by 0.61%. When using the vertical fins, it reduced the energy consumption by 1.83%. As for the addition of the four fins, the percentage of energy consumption reduction is 4.19%, which is a better result than the choices of other shading systems used in this research (Ghosh & Neogi 2018).

2.3.4 Green Roofing

Next technique to achieve, according to many scholar is to have green roofing on the roof of the mosque. Green roof will be consisted of plants, grass and other trees. This will act like shield on the concrete surface of the top slab of roof. It will cover the whole roof and has the many benefits to the environment.

Green roof will save the roof from solar radiations and will keep the inside temperature under control, because it will act as an insulation for the roof. Where, if green roof is not used the roof will get warmer which will make the interior space hot and large amount of energy will be consumed in reducing the temperature. For sustainable environment, the green roof will increase the supply of oxygen due to the presence of shrubs and plantings, which helps reduce air pollution. At secondary level it will increase the aesthetics level of the building of mosque. And it helps absorb rainwater, which reduces the possibility of flooding. It also acts as a sound insulator, as it reduces the transmittance of external noise into the interior space (Vijayaraghavan 2016).

(Alabdullatief et al. 2016) conducted a research on a mosque in Saudi Arabia and explained that the application of green roofs and shading systems can contribute to reducing the temperature of the interior space, as the temperature in the experiment was reduced by one degree during the summer when the cooling systems were not operating. In addition, the results showed that the addition of green roofs led to a reduction in energy consumption for cooling without the need to improve the building envelope by 4%. With the addition of shading systems, the results were better, as it increased the efficiency by 10%.

Green roofs with a thickness of 164 mm were used, consisting of metal deck, glass fiber, sand and a layer of plants, on an area of 912.34 m^2. It was concluded that lowering the u-value to 0.275 W/m^2K was effective in reducing internal heat gain by three degrees, which leads to a reduction in energy consumption. The solar energy gain was also reduced to 36.5°, after it was 39° before the use of green roofs (Taleb 2016).

Green roofs with a thickness of 10 cm were applied to a building in the city of Mashhad in Iran in the summer when the climate is hot, with an area of 350 m2. The results showed by simulation method, using the design builder program, that the green roofs reduced the cooling load by about 7.9Wh/m^2. Then 3 scenarios were performed to know how much energy consumption could be reduced. The first scenario was to cover 50% of the roofs of government buildings, the second scenario was to cover 50% of the roofs of government and private buildings in the city of Mashhad, and the third scenario was to cover all the roofs of buildings in the city, where the available space in the first, second and third scenarios is estimated to be about 7.8, 45, and 96 million square meters. The reduction in power consumption was about 61.620, 355,500, and 758,400 MWh for each scenario, respectively (Mirzababaie & Karrabi 2019).

In a study conducted in Thailand, they applied roof lawn gardens to a model and calculated its effect on reducing energy consumption used for cooling. The roof was divided into 3 sections, the first without the roof lawn gardens, the second and the third with roof lawn gardens, but with a soil thickness of 0.10 m and 0.20 m each, respectively. It was concluded that the higher the thickness of the soil, the higher the efficiency and the lower the energy consumption, as it was less by about 37.11% and 31.07 % of the energy consumption with the roof lawn gardens comparing to the roof without lawn gardens for each of the thickness of the soil 0.20 m and 0.10 m (Permpituck & Namprakai 2012).

William et al. (2016) Use a multi-layered canopy to see the efficiency of green roofs during spring and summer in Illinois. They concluded that the green roof helped reduce the temperature of the roof when compared with the temperature of the traditional roof. Green roofs act as a thermal insulator for the roof due to the presence of soil, but they need to be irrigated when there is no rain.

Mahmoud et al. (2017) added green roofs to an apartment building in Saudi Arabia, where the climate is hot and humid. DESIGN BUILDER simulation software was used. Energy consumption was calculated without using green roofs and the result was about 169 KWH/m2. Then the green roofs were added in three cases as shown in Figure 2.11, and the efficiency result for each case was different. But in general, the efficiency of all cases increased with the increase in solar radiation, which helped to reduce energy consumption more as the radiation increased. The result was that green roofs helped reduce energy consumption, reaching 110 KWH/m2 when applying case 1, and reaching 126 KWH/m2 when applying case 2, it reached 128 KWH/m2 when applying case 3. Where the percentage of energy consumption reduction for case 1, 2, and 3 was 35%, 25%, and 24%, respectively.

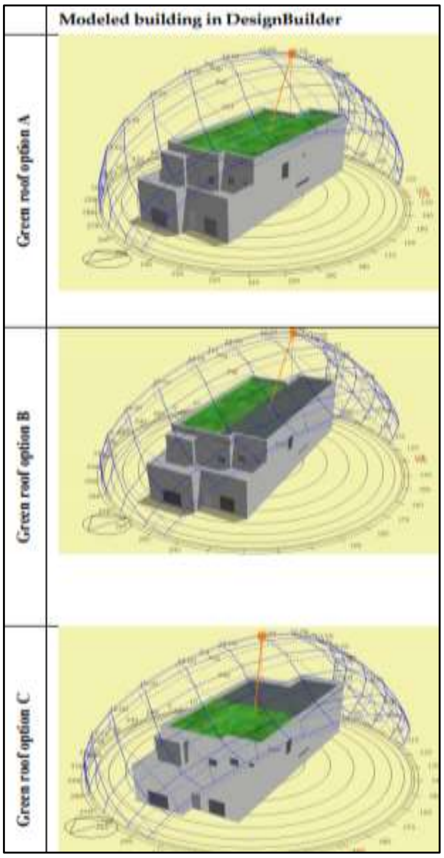


Figure 2.11 the three options of green roofing (Mahmoud et al. 2017)

Safari, Ferrão & Fournier (2019) tested 3 types of green roofs using the DESIGN BUILDER and PVSOL simulation program to calculate the technical and economic performance of the project. The three types of green roofs differ in terms of plantations, consisting of crops, grasslands and shrubs. It was concluded that when using crops, the reduction in energy consumption was about 0.1%. While reducing energy consumption for the last floor, which is closer to the roof, about 16-18 percent. Therefore, the use of green roofs in a multi-storey building is not beneficial, but it helps to reduce CO2 emissions. The best types of green roofs are those that contain high leaf reflectivity and low LAI.

By conducting a comprehensive review on green roofs, it was concluded that green roofs can reduce heat penetration by 80%. It helps reduce energy consumption by 2.2% to 16.7% (Besir & Cuce 2018).

Alabdullatief et al. (2016) concluded that adding the green roof and louvers to the mosque in which the study was conducted in Riyadh, Saudi Arabia, where the climate is hot and dry, reduced the cooling load by 10 percent. When using the green roof without louvers, it reduced the cooling load by 4%.

2.3.5 PV panels

The use of solar panels is necessary, especially in the UAE, where electricity consumption has increased by 51% in six years (Kazim 2015). So the use photovoltaic cells can help in producing the electricity for consumption at domestic and at industrial scale. This production of energy is very cheap and causes no harm to environment at large. These cells are to be installed once, and they will work for long time. Placing them at the side facing sun is very efficient and it can cover the electricity needs for the whole building. In addition to cheap production, this production can be done at the place where it is required. In this way reduces the cost of transmission as well transmission loses. So the highest level of energy efficiency is achieved by the use of solar cells in energy production at domestic level.

(Safari, Ferrão & Fournier 2019) has experimented with 3 types of green roofs with the addition of solar panels. The results of the green roofs were mentioned previously in green roofing section. Three types of solar panels were used in the study, namely CanadianSolar, Suntech, and Teina. The panels were placed on the roof of the building oriented to the south with a slope of 30 degrees. The number of solar panels is 60 panels, each panel with a power of 200 watts. Considering that the sun was available for five hours and 45 minutes, the power outputs were about 24.663 MWH, 25.037 MWH and 26,258 MWH for CanadianSolar, Suntech and Trina, respectively. The use of solar panels helped reduce CO_2 emissions, especially when used with green roofs. They had a good positive effect on reducing CO_2 emissions.

A study was conducted on 3D solar panels to analyze the temperature distribution of the solar panels under certain operating conditions. ANSYS software was used to get real results in a short time. The temperature was set at 35°C, which is the highest temperature ever recorded in Malaysia. Several solar radiations were selected for the test, which are 200, 400, 600, 800 and 1000 W/m^2. The operating temperature on solar radiation 200 W/m^2 reached to 43.19°C, which is the lowest operating temperature, as it increased with the increase in the strength of the solar radiation. It reached 75.66°C with the highest solar radiation of 1000W/m^2. The high operating temperature affects the efficiency and operation of solar panels (Series 2020).

Baitule, Sudhakar & Centre (2017) studied the usability of a solar panel power plant for an educational institution building in India. Using SAM and PVSYST programs. The results showed that the solar panels can produce 6-8 GW of energy within one year. This plant can reduce a good amount of CO_2 emissions.

Alantali, Alzarouni & Alhammadi (2020) evaluate the performance of several solar panels integrated with the building in Dubai. Cadmium telluride and monocrystalline silicon were used, oriented southward at three angles proportional to the latitude of Dubai. The 25-degree angle was the preferred angle to be used in Dubai and was the best performing angle from the 0 25-degree angle, which was the highest in terms of energy production during the year. The amount of production was almost constant and did not change much during the year. When the solar panels are placed at an angle of 90 degrees, such as those placed on the facade of buildings, they are less efficient and productive than the rest of the angles. The amount of production can change according to the angle of the sun in each season. But this angle is not affected much by the dirt, while the angle 0 degrees is greatly affected by the amount of dirt and loses its efficiency at a rate of 10.79% if it is not cleaned continuously. The monocrystalline silicon core solar panels were more efficient than the other type of cadmium telluride solar panels by 23.5% at an angle of 25 degrees, which produced 402.02 kWh/m2. 90 degree solar panels have a lower energy yield than 25 degree solar panels by about 35%. The 0-degree panels produced less energy than the 25-degree panels, by 10.6% and 12.4%.

Salameh et al. (2020) conducted a test on the energy efficiency of installing solar panels for an office building in Sharjah where the climate is hot and humid. Solar panels integrated with the facade of the building were used with windows of transparent PV type of amorphous silicon thin film. Use a simulation program to find the best orientation of the interface in order to obtain the most possible energy production and reduce the cooling load. The result led to a reduction of electrical energy by 27.69%, which Resulting in cost savings.

Dakheel, Aoul & Hassan (2018) worked to improve a school building in the UAE to obtain its ESTIDA^{M}A rating, which is a sustainability initiative to build buildings in an environmentally friendly manner. Solar panels and two cooling systems, one of which is geothermal cooling and the other by absorption cooling, were applied. The simulation was performed using TRNSYS software. Geothermal cooling helped reduce the cooling load by 5.8%. Reducing energy consumption by 2.2%. Absorption cooling helped reduce cooling load and energy consumption by 19.35% and 7.2%, respectively. Photovoltaic panels save energy by 10%. The total energy consumption savings when using the three systems was about 19.35%.

Said et al. (2021) designed a solar panel system for the home sector, to be economically, technically and environmentally evaluated. Three types of solar cells were used, monocrystalline, polycrystalline and thin film. The experiment was carried out in the UAE climate using RETScreen simulation program. It was concluded that the central grid PV system is more effective and applicable than the standalone PV system. Technically, it has a higher power factor of 2.9-4.8%. It requires a lower initial investment value of 19-27%. Polycrystalline was the best and most efficient. Monocrystalline was the least efficient in all latitudes used. The Emirate of Sharjah was the best to use solar panels in terms of the high annual solar energy available in it, while Dubai is in the last place as it receives the least amount of solar radiation. The two models used for solar panels can produce 14-15 MWH per year.

The performance of solar panels integrated into a cube building designed for testing in Dubai was tested. Two types of solar cells, Copper Indium Gallium Selenide (CIGS), and monocrystalline silicon (c-Si), were selected and integrated on the south, east and west facades of the building. The efficiency of monocrystalline silicon was more than that of CIGS, as it produced 17% more energy than CIGS from the southern side, which is optimally used to direct solar panels in Dubai, while on the east and west sides, the energy production was 15% more than CIGS. The energy production from the panels facing the south was more than from the east and west sides. But in the months with high energy consumption, where temperatures rise and dependence on cooling devices increases from

April to August, the east and west sides become more energy productive by about 40.9 percent than the south (Electricity & Authority 2020).

Said & Mehmood (2017) concluded that it is possible to use independent solar panels in the UAE climate, but the efficiency differs from one region to another. Sharjah was the best and most suitable city to use this type of solar panels in terms of its latitude. Dubai was less suitable than the rest of the cities of the United Arab Emirates. Using Maximum Power Point Tracking (MPPT) solar panels with a single axis is better than a consistent system, as it takes 33-44 percent less solar panels to produce the same amount of energy. which lead to increase the net present value by 3-4%. and enhancing internal rate of return by 5-10%. raised the value of benefit cost ratio by 1.80-3.25. the maximum power point tracking solar panels with one axis is more viable than the two axis ones, which increased net present value by 0.1-1.2%, enhance the value of internal rate of return by 1.7-4.3%. raised benefit cost ratio by 0.5-1.1.

If a solar panel of high quality is used then it will increase the amount of energy produced on daily basis. Thus system will become effective if we use solar cells of high quality and the number of cells in a system is increased (H.A Kazem, 2017).

Alhammami & An (2021) a test was conducted to calculate the amount of energy that could be produced from the use of solar panels on the roofs of houses in two residential areas in Abu Dhabi. One is Khalifa City and the other is Zayed City. the type of PV system used is polycrystalline silicon because they cost less than other types and perform and work better in hot climates, where it has high temperature coefficient. The solar panels used in every home studied can cover about 11-20% of the home's energy needs. the internal rate of return is negative for UAE nationals about -4.5% to -3.5%. while it is positive for expatriate about 9.2% to 12.0%. This makes the residents not interested in using solar panels.

Adjustments were made to a real estate building in Sharjah to help improve the efficiency of the building and reduce energy consumption due to several factors, the most important of which is cooling due to the hot and humid climate. The three directions of the building consist of glass. The direction facing the south is made of concrete, but without the use of thermal insulation. The roof of the building was improved by adding several types of thermal insulators of different thicknesses, and it was concluded that the best result could be obtained with the use of polystyrene with a thickness of about 15 cm, which contributed to reducing energy consumption by 8.43%, or about 38% of the total energy consumption reduction for the building. As for the wall, the ratio of glazing to the wall was large, about 91% on three sides and 0% on the west side. This ratio was modified and became 24% for each side of the building, then several types of thermal insulators with different thicknesses were tried, and the best result was by adding about 15cm of polyurethane, which helped reduce energy consumption compared to its consumption before modification by 4.57% or about 20% of the total energy consumption reduction of the building. The window glass is made of double glass with an air gap in the middle, with a thickness of 0.63cm. This thickness was increased to 1.27cm, which led to a reduction in energy consumption by 0.89%, which contributed to a reduction in total energy consumption by about 4%. The building contains external shading that helps reduce energy consumption by 1.99% compared to its absence, and then its depth was increased from the northwest and southeast by three meters, which helped to further reduce energy consumption by 0.19%, which equal 1% of the reduction in total energy consumption. When replacing the cooling system, it helped reduce overall energy consumption by 37%.

The effectiveness of each strategy in reducing energy consumption is illustrated in Figure 2.12 (Khoukhi, Darsaleh & Ali 2020).

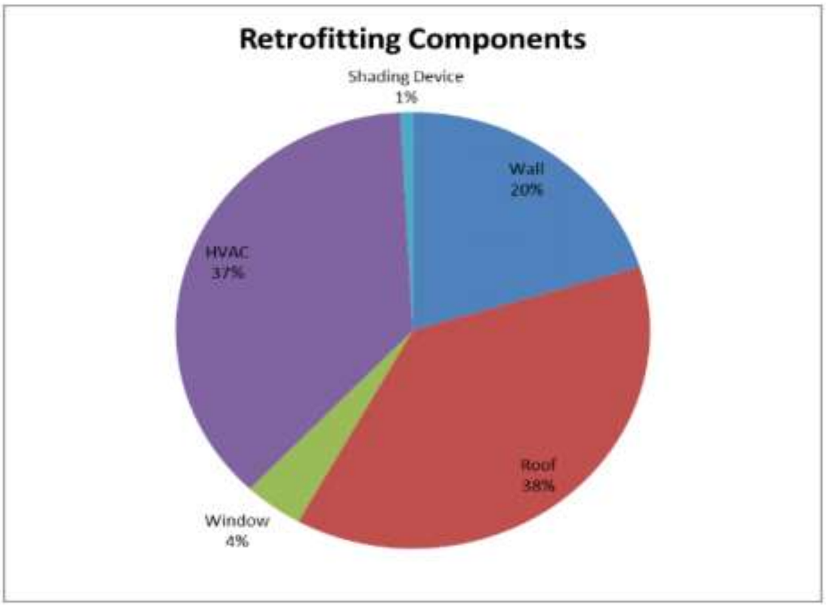


Figure 2.12 the effectiveness of each strategy in reducing total energy consumption (Khoukhi, Darsaleh & Ali 2020)

Taleb (2014 cited in Friess & Rakhshan 2017) in her research, used several strategies to reduce the energy consumption of a villa in Dubai, including changing the type of glass from a single glass to a double glass filled with 16mm argon gas. And used louver tilted 45° as a shading system. Energy consumption was reduced by 23.6%, as a result of using all strategies together.

2.4 Summary

Reducing energy consumption of any building is very important. It attracts the attention of scientists and researchers to find good solution and develop strategies that can help to obtain energy efficient buildings. The different strategies discussed, helped in reducing energy consumption of different building types. Each strategy had its own effect, as some strategies had a significant impact on reducing energy consumption, while others had a lesser effect. Although, each strategy differed in its effectiveness in each project, depending on several factors, such as location, building size, climate, orientation, etc. However, using several strategies in one project was much better than using one strategy, to get the best possible result in reducing energy consumption and achieve energy efficient building.

Table 2-1 table of state of art

Author	Title	Aim	Findings
-Amr Sayed Hassan Abdallah	Energy Audit for Low Energy Mosque in Hot Arid Climate Inside Assiut University Campus Amr	Optimizing the energy consumption in the mosque of Assiut university by improving the building and applying several techniques to reduce energy consumption	The mosque's energy performance has been improved by about 61.8 kWh/(m2.yr) compared to the original performance of 87.5 kWh/(m2.yr)
-Hasan Alhammami, -Heungjo An	Techno-economic analysis and policy implications for promoting residential rooftop solar photovoltaics in Abu Dhabi, UAE	Find out how much solar energy can be produced from the roofs of residential buildings in two cities in Abu Dhabi.	A good amount of solar energy can be produced by the rooftops used in the study. About 116.302kWh - 448,174kWh per year for the studied cities.
-Joud Al Dakheel, -Kheira Tabet Aoul, -Ahmed Hassan	Enhancing Green Building Rating of a School under the Hot Climate of UAE; Renewable Energy Application and System Integration	Improving public schools in Abu Dhabi to get a better green building rating from two to three pearls.	The possibility of getting a better rating in terms of energy, where photovoltaic energy was used and helped getting three pearls rating.

-Akshay Suhas Baitule -K. Sudhakar	Solar powered green campus: a simulation study	Make the building entirely in India dependent on solar energy	It is possible to produce about 6-8 GW of solar energy, which fills the needs of the building, especially since the working hours in the building are during the day, i.e. when the sun is present.
-Abubakar S. Mahmoud, -Muhammad Asif, -Mohammad A. Hassanain, -Mohammad O. Babsail, -Muizz O. Sanni-Anibire	Energy and Economic Evaluation of Green Roofs for Residential Buildings in Hot-Humid Climates	The impact of green roof on reducing energy consumption in a hot and humid climate	The use of green roofs effectively contributes to reducing the energy consumption of the building in a hot and humid climate, from 169 kWh/m^2 to 110 kWh/m^2 in the studied case.
-Waleed Khalid Alhuwayil, -Muhammad Abdul Mujeebu, -Ali Mohammed M. Algarny	Impact of external shading strategy on energy performance of multi-story hotel building in hot-humid climate	Studying the effect of external shading systems on building energy consumption	The findings showed that energy consumption was reduced by 20.5 percent by using shading systems
-Sanghoon Baek, -Sangchul Kim	Optimum Design and Energy Performance of Hybrid Triple Glazing System with Vacuum and Carbon Dioxide Filled Gap	Verifying the efficiency of a three-pane glazing system and knowing the U-value and the appropriate thickness for this system.	The greenhouse gas CO2 can be absorbed and used in an efficient manner, as it has the same efficiency as argon gas used in glazing systems, but is less expensive. The optimum thickness of the CO2 gap is 15 mm, the glass is 4 mm, and the vacuum gap is 6.2 mm. The system was very efficient in reducing energy consumption and usage.

-M William, -A El-Haridi, -A Hanafy, -A El-Sayed	Assessing the Energy Efficiency and Environmental impact of an Egyptian Hospital Building	Knowing the amount of energy consumption and evaluating the efficiency of reducing energy consumption using several techniques in a hospital building in Egypt.	The use of technologies helped to reduce energy, as improving the quality of the glass led to a reduction in the energy consumption of the cooling device by approximately 5%, and about 2% of the total energy consumption of the building. The use of thermal insulation reduced the total energy by 7%, and the use of LED lighting reduced the total energy by 42%. The overall energy consumption reduction after building improvement was 59%.
- Marco Manzan	Genetic optimization of external fixed shading devices	Reducing the overall energy consumption of an office room by using shading device	The use of shading devices helped reduce energy consumption between 19% and 30%, depending on the location and climate in which it is used.
- Amrita Ghosh, -Subhasis Neogi	Effect of fenestration geometrical factors on building energy consumption and performance evaluation of a new external solar shading device in warm and humid climatic condition	Knowing the efficiency of a shading device with a new design and comparing it with the efficiency of common devices in the market that used in the same climate condition	The shading device with the new design was better and more efficient than other devices, as it helped reduce energy consumption by 4.62%, which is higher than the other devices used in the study.

- Sheng Liu a, -Yu Ting Kwok, -Kevin Ka-Lun Lau, -Wanlu Ouyang, -Edward Ng	Effectiveness of passive design strategies in responding to future climate change for residential buildings in hot and humid Hong Kong	Application and testing of passive design strategies on an apartment building in Hong Kong	When several passive design strategies are used together, they can help reduce the annual cooling load by 56.7%.
- Eman Badawy Ahmed	The Effect of Thermal Insulation on Building Energy Efficiency in Northern Upper Egypt	Study of the effect of thermal insulation on improving the energy performance of a building in Egypt.	The best thermal insulation for the wall is the use of polyurethane with a thickness of 7 cm with a single wall, and for the ceiling the use of a double roof with a thermal insulation in the middle of a thickness of 20 cm.

CHAPTER THREE

METHODOLOGY

3 METHODOLGY

3.1 Introduction

To date various methods have been developed and introduced to measure the energy consumption of any building. Such as experiment, interview, survey, review of the extant literature and simulation using different software. Each methodology has its own pros and cons. The simulation method is one of the more practical ways that used measure the reduction of energy consumption of any building when applying different strategies. It gives real and prior results about the project with different strategies and scenarios before starting the construction stage or before making any change in the building (Nasaruddin et al. 2018).

The building simulation tools have grown a lot lately, because of the increasing use and demands on these tools to measure the performance of any building in terms of lighting, shading solutions and energy consumption (Loonen et al. 2021).

Polat (2009) defined the simulation method as the art and science of planning a model similar to the real life. Planning and developing a model in a simulation method, includes different variables, and the connections between them as per the goal and targets of the project.

Attia & Neuve (2010) discussed the building performance simulation tools and found that these tools easy to adapt, precise and can foresee the amount of energy consumption of the building model at all design stages. The building performance simulation tools will be the core of planning and building structures with high performance, to give an information about the effect of design choices. Attia & Neuve (2010) believe that building performance simulation tools provide a shared platform to help the coordinated effort among engineers and architects.

The methodology used in this paper and discussed in this chapter is the simulation method by using computer devices and IES-VE software, in addition to AutoCAD software.

3.2 Literature of the Methodology and Justification

As noticed from literature review, there are a lot of researches about the possibility of reducing energy consumption of any building, especially buildings that consume high energy due to the hot summer in some countries such as mosques in UAE, where there is a high demand on air conditioning to provide thermal comfort in the interior space for the worshippers, while doing their prayers. The high demand on air conditioning, cause high energy consumption.

The study in this paper is to implement different strategies and scenarios to reduce energy consumption of a mosque building. Any study about this subject needs to use a method to get the required results, and most of the studies used simulation method, to measure the energy consumption that occurred when applying different strategies, before applying those strategies in real life. So it helps getting information about the effectiveness of each strategy and calculate if it is worth the costs that it needs in order to apply it.

Different methodologies were used to investigate and study the energy consumption such as experiment, site analysis, survey and simulation. The methodology used in this paper is simulation method, by using computer devices and simulation software to get the required results.

The simulation method was used either as a basic and only method of study or as an auxiliary method as adding it to other methods such as questionnaire, test and experiment. The reliance on the simulation method increased due to obtaining real results, especially it used with other methods and obtaining similar results, so many studies have become based on the simulation method only. In addition, the simulation does not cost much, as it only needs a computer and the simulation program, which can be learned after having a few educational sessions or through some sites such as YouTube or the website of the program used, where there are educational videos.

Simulation helps to obtain real and fast results, especially if the required results are required for a full year, during all seasons of the year and at different times of the day and night. Where the research is carried out even if the study is in a place other than the place where the study is being conducted, once the climate settings for the country containing the project are loaded and the project is modeled in the program, then the simulation is carried out and the results are obtained in a short time, no matter how difficult and complex the project.

Many simulation software has been developed and used when the topic of clean energy, sustainability and energy reduction has increased. IES-VE is one of the most widely used simulation software, which chosen to do the simulation and get the required results in this study, as the simulation method is chosen as a methodology for this research paper.

The model of IES-VE software to check the performance of the system will be used. IES system will help to measure the impact of the applied strategies to building efficiency.

IES-VE helps in evaluating how much energy can be saved from every single strategy which is being implemented to reduce the energy consumption. The analysis for the reduction in energy consumption for every single component after the application of strategy is carried out. And then calculation is performed by the software to analyze the effectiveness of each strategy. At the end results are compared for each strategy and scenario.

IES-VE software was used to calculate the energy consumption of a refrigerated container and a one-day test was conducted to compare the results. The comparison result shows that both results are very close and almost similar with an error rate of approximately 0.47 kW (Budiyanto, Zhafari & Nasruddin 2019).

Budiyanto, Zhafari & Nasruddin (2019) made a comparison between IES-VE, Designbuilder and eQuest. and concluded that IES was better at importing geometry data, and the support options were available, varied and sufficient. It has a diverse and comprehensive built-in data library and an easy-to-use design system.

3.3 IES-VE software

IES software established by Dr. Don McLean in Glasgow, in 1994. depending on three essential observations. First is focusing on reducing energy consumption of the buildings to reduce CO^2 emissions. Second is that the software should include easy designing tools. Third is that the software must align the traditional buildings from lighting, load calculation, etc. with containing a single central integrated data model (Buckley 2020).

IES software helps in designing 3D models and analyze the performance of that model to increase the sustainable buildings and cities around the globe. IES-VE software provide an environment for the studied building with all details and design system to allow doing changes and enhancing in the building models to achieve the comfort level and reduce energy consumption (Hussin, Baharum & Razak 2018).

In a study which set out to determine the efficiency of IES-VE software, Science (2018) found that researchers studied the validation of IES-VE software and they concluded that it is valid to be used in researches about energy consumption of buildings.

Buckley (2020) showed the beginning and development of IES-VE software. In 2015, team IES won the best energy use results at ASHRAE first competition. The next year, IES won the CIBSE Building Performance Collaborative Partnership Award.

3.4 Case Study

3.4.1 Location

This paper focus on reducing energy consumption of uptown Mirdif mosque that shown in Figure 3.1, which located as shown in Figure 3.3 and Figure 3.4 in uptown Mirdif, Dubai, UAE. Next to uptown Mirdif park. The capacity of the mosque about 2,477 worshippers. The mosque includes two minarets with height of 45 m. and large circular dome in the middle of the roof. A praying area for ladies is available. The mosque designed in Fatimid style (Buckley 2020). It has an octagon shape, with eight sided polygons as shown in Figure 3.2. and more detail of mosque drawing shown in appendix A. The building as the base case in the simulation was constructed from cast concrete with a cavity of 60mm. and plaster layer on both sides of the wall with a thickness of 20mm for each side. the total thickness of the wall is 300mm. A double glazing with 12mm cavity between the panes filled with air used for windows.



Figure 3.1 shows uptown Mirdif mosque from inside and outside (foursquare city guide 2014)

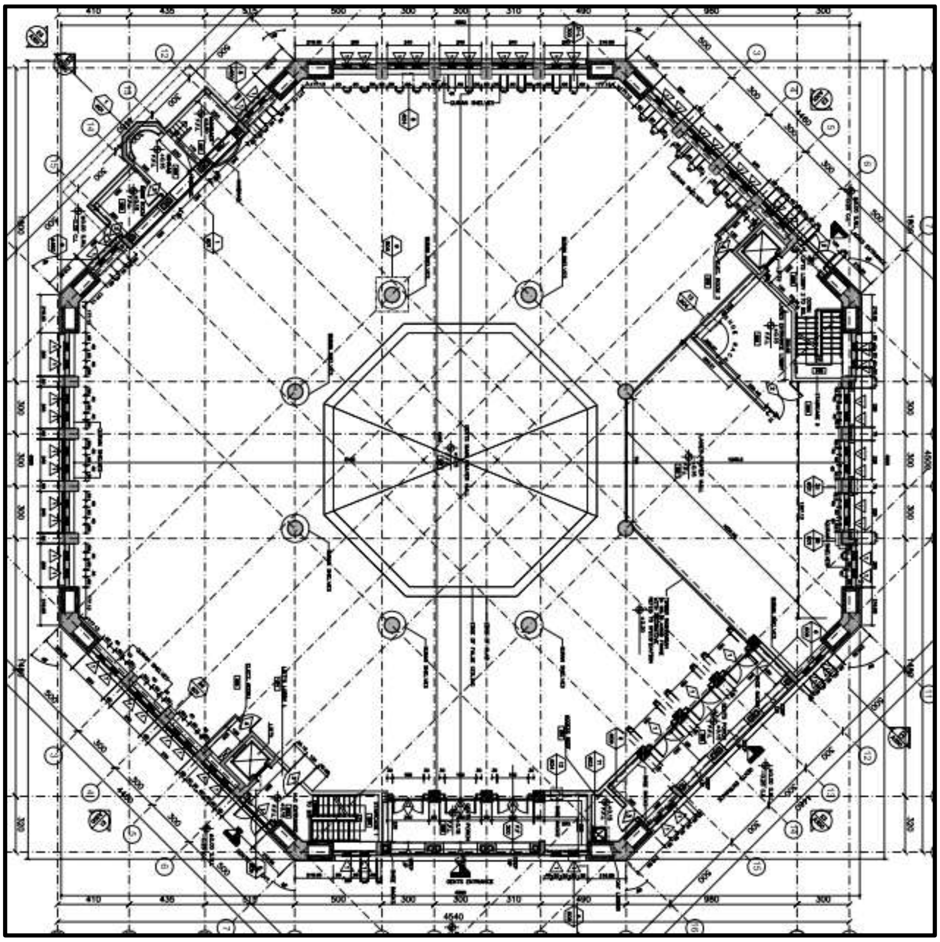


Figure 3.2 architectural floor plan of the mosque (Author 2021)

Figure 3.3 shows the location of Mirdif grand mosque in Dubai, UAE (Author2021)

Figure 3.4 the location of the mosque in uptown Mirdif (R.T. 2019)

Uptown Mirdif is a community located in Mirdif area. Which include all facilities such as schools, clinic, park and mall. As shown in Figure 3.5, there different ways to reach uptown Mirdif area, but the main way is E311 road, which known as sheikh Mohammed bin Zayed road, which connect Abu-Dhabi, Dubai and Sharjah. Then Tripoli street, then to Algeria street.

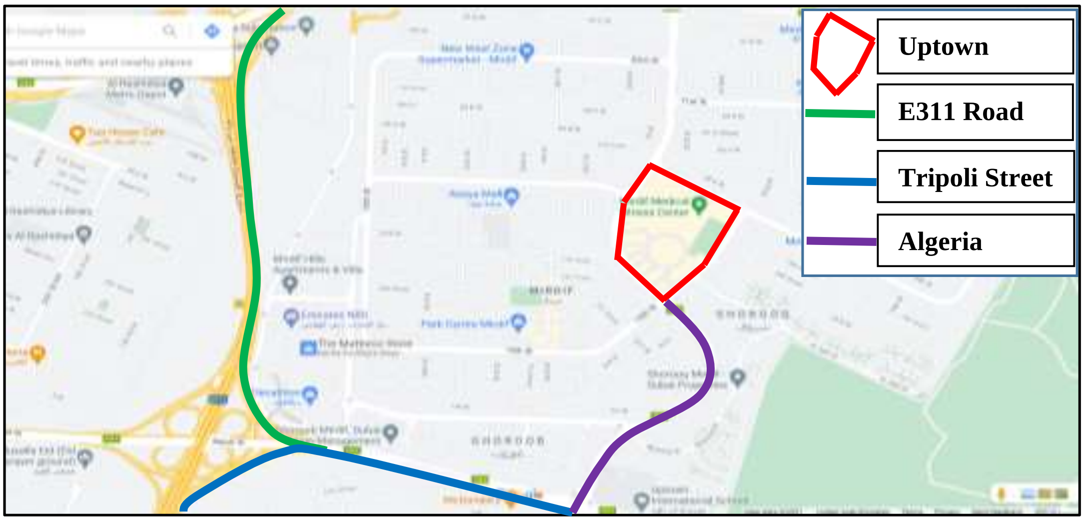


Figure 3.5 Ways and routs to reach uptown Mirdif (Author2021)

3.4.2 Climate and Weather Data

3.4.2.1 Temperature

The temperature of Dubai known as hot humid, where maximum temperature reaches up to 47°. As shown in Figure 3.6, August has the maximum temperature during the day and January is the coldest month of the year, where the temperature drop till 24° during the day and 15° at night (weather station 2021).

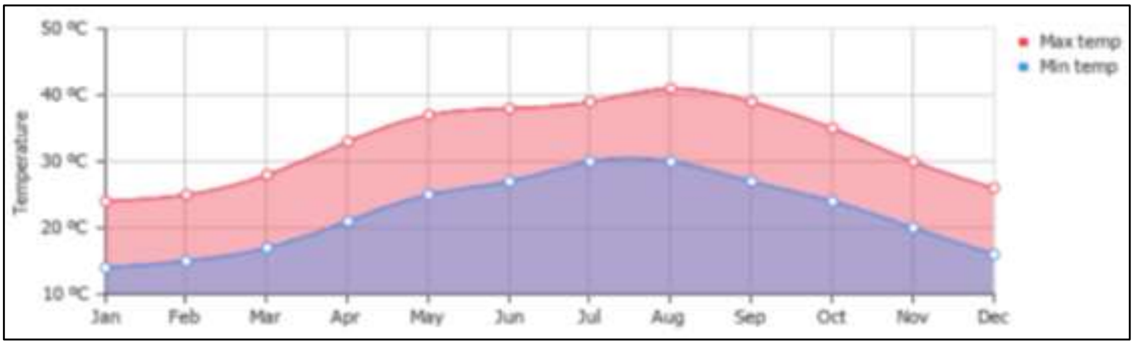


Figure 3.6 shows the minimum and maximum temperature in Dubai (weather station 2021)

As shown in Figure 3.7, The weather is mostly sunny all year round (weather station 2021). Which is what suit solar panels that need always sunny weather to be useful. July is the most sunny day of the year in Dubai (climate-data.org 2021).

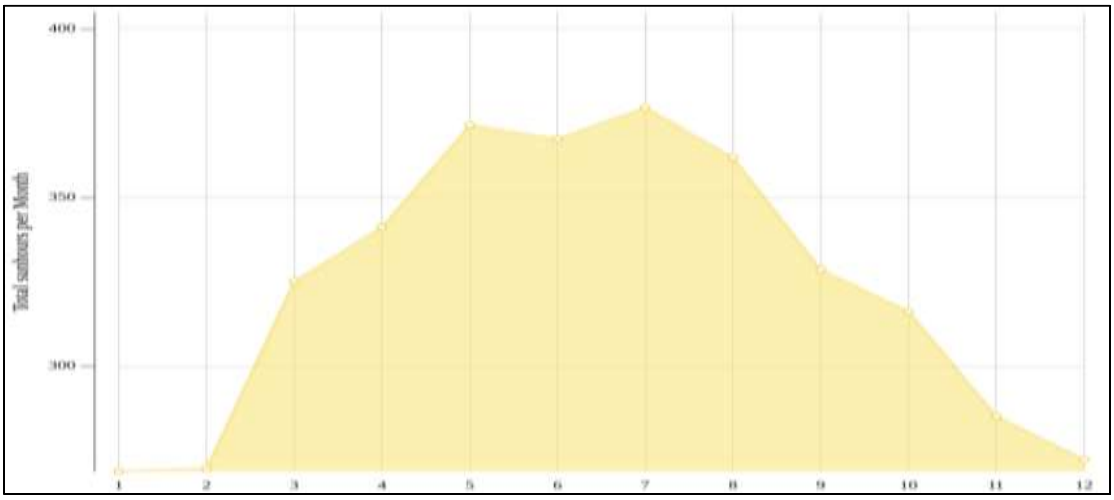


Figure 3.7 the total sunshine hours for every month during the year in Dubai (climate-data.org 2021)

3.4.2.2 Precipitation

Figure 3.8 shows the mean precipitation in every month of the year, which include rain and snow. February includes the maximum precipitation of the year, then march, January and December. Other months from April to November have either few or no precipitation, which are summer and winter seasons. Spring season doesn't face much precipitation. In Figure 3.9, shows rainy days every month in Dubai throughout the year, where march has the maximum number of days. But all months do not reach eight rainy days per month. August known as the driest month of the year, while the most wet month in Dubai is February (weather station 2021).

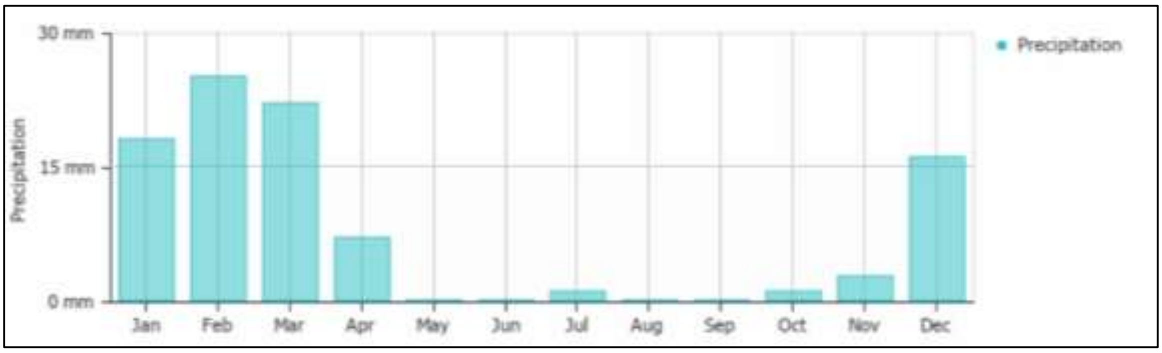


Figure 3.8 shows the mean precipitation in every month in Dubai (weather station 2021)

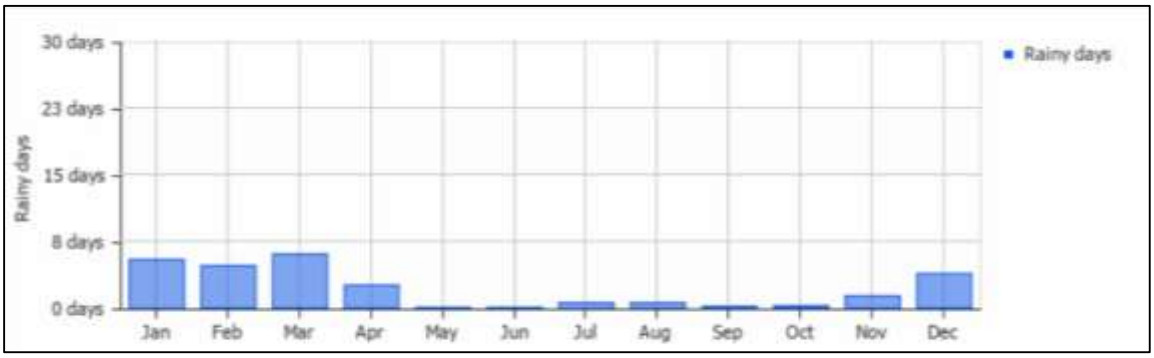


Figure 3.9 shows the rainy days each month in Dubai (weather station 2021)

3.4.2.3 Relative Humidity

The climate in Dubai known as hot humid, and the average humidity for every month of the year are shown in Figure 3.10. where the humidity range between 55% to 65%.

Figure 3.10 shows the average humidity every month in Dubai(weather station 2021)

3.4.2.4 Wind Direction

The wind direction changes each month but mostly in Dubai comes from north west direction as shown in Figure 3.11. where march has the maximum wind about 23.9 kmph for year 2020, as shown in Figure 3.12. while January has the maximum average wind about 17.3 kmph.

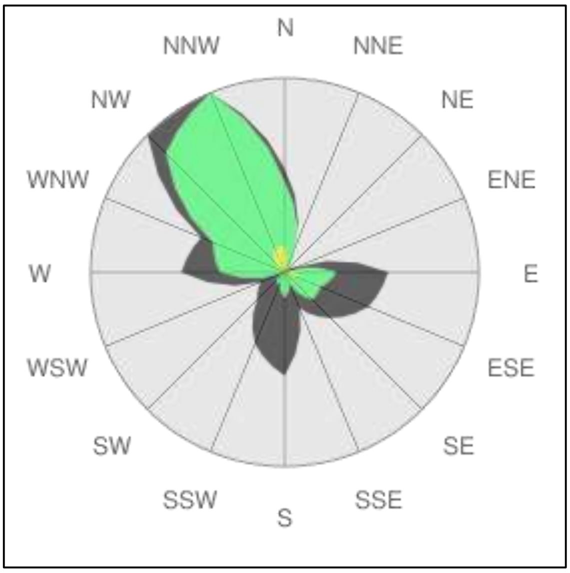


Figure 3.11 wind direction in Dubai (wind alert 2021)

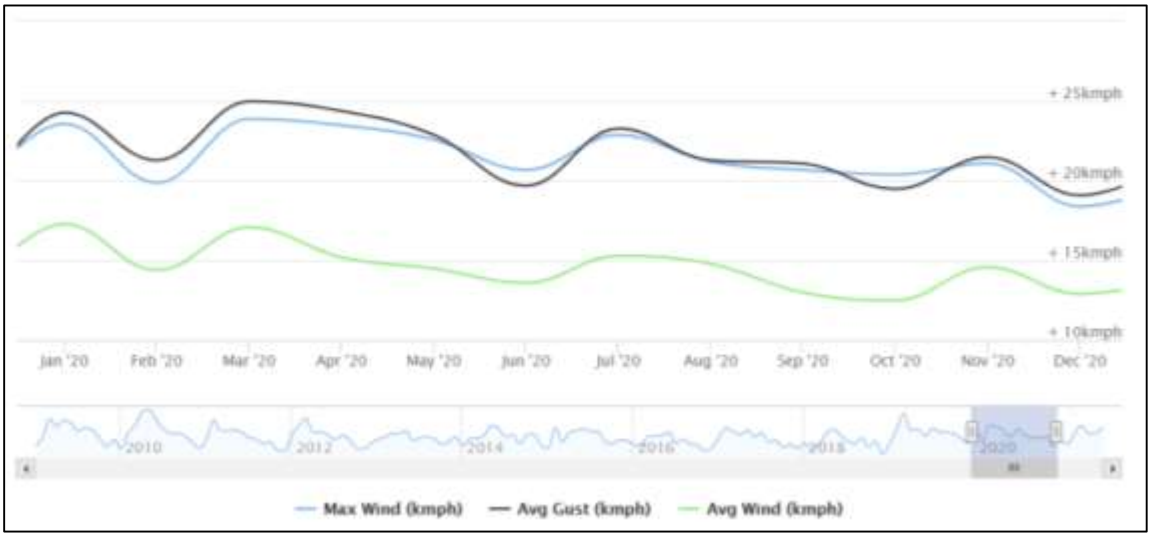


Figure 3.12 shows the MAX and Avg. wind speed and wind gust in Dubai (world weather online 2020)

3.4.3 The applied strategies and scenarios

The building material used in the simulation as the base case was very simple materials, and doesn’t meet green building`s requirements because it doesn’t include any type of insulation material which is the most important and required material in any constructed building especially in hot climates to help reducing heat transfer, which lead to reduce energy bills and provide thermal comfort environment to the occupants (Kumar et al. 2020). But the most important is choosing the suitable type to balance between the efficiency and price of the simulation material (Huang et al. 2020).

Even the glazing types used in the base case is double glazing filled with air in the cavity. Double glazing reduced energy consumption and showed well energy performance when used in hot climate (Al-dossary & Kim 2020). And glazing filled with gas such as argon doesn't gain heat same as double glazing filled with air, and it is efficient and suitable in hot humid climate (Sunanda & Budiarto 2018).

The materials used in the base case led to increase energy consumption and room cooling load to provide a thermal comfort environment for the worshippers, while doing their daily prayers and Islamic activities during some Islamic occasions. Building in hot climates consume high energy because of air conditioning, which consume about 70% of electricity provided to the buildings, especially if buildings not insulated such as many residential building in hot climates (Felimban et al. 2019).

Therefore, different strategies applied on the mosque building to reduce energy consumption. The strategies applied by using simulation method, by IES-VE software. The simulation method used because it helps applying different strategies on the same building and give results for the whole year in a short period of time, without costing a lot. Appling the strategies such as insulations and shading, on existing building is difficult and costing a lot, where they are many in number. The used strategies are five and each strategy includes four to five scenarios. So it is very expensive if we want to purchase, install and test each material separately.

The used strategies are extracted from the literature review, as they were used in previous experiments or simulations on different building types, include mosques in hot climates. The articles from which the strategies were extracted are shown in Table 3-1.

Table 3-1 shows the articles that strategies extracted from (Author2021)

The strategy	The scenario	Article	Author
Insulation	60mm Expanded Polystyrene	A comprehensive review on thermal performance and envelope thermal design of mosque buildings	-Nabeeha Amatullah Azmi -Siti Halipah Ibrahim
	70 mm polyurethane	Minimizing the Environmental Emissions Associated with Energy Consumption of Mosque Building in Saudi Arabia	- Othman Subhi Alshamrani - Mohamed Essam Ali Shaawat - Noman Ashraf
	100mm Rock wool	Minimizing the Environmental Emissions Associated with Energy Consumption of Mosque Building in Saudi Arabia	- Othman Subhi Alshamrani - Mohamed Essam Ali Shaawat - Noman Ashraf
	100mm glass wool	The Effect of Thermal Insulation on Building Energy Efficiency in Northern Upper Egypt	- Eman Badawy Ahmed
	Polystyrene	Retrofitting an Existing Office Building in the UAE Towards Achieving Low-Energy Building	- Maatouk Khoukhi - Abeer Fuad Darsaleh and Sara Ali
Glazing	Double filled with argon gas 16 mm	Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings	- Hanan M. Taleb
	Double filled with krypton gas 9 mm	Influence of sunspace on energy consumption of rural residential buildings	-Lingyong Ma -Xin Zhang -Dong Li -Müslüm Arıcı -Çagatay Yıldız -Qing Li -Shu Zhang -Wei Jiang

	Double filled with Xenon gas 12 cm	Assessing different glazing to achieve better lighting performance of office buildings in the United Arab Emirates (UAE)	-Hanan M. Taleb -Alan George Antony
	Hybrid triple glazing filled with co_2 on the exterior side and vacuum on the interior side	Optimum Design and Energy Performance of Hybrid Triple Glazing System with Vacuum and Carbon Dioxide Filled Gap	-Sanghoon Baek -Sangchul Kim
	Triple glazing filled with argon in both cavities 12 mm thickness	Parametric analysis on the heat transfer, daylight and thermal comfort for a sustainable roof window with triple glazing and external shutter	-Mingzhe Liu -Per Kvols Heiselberg -Yovko Ivanov Antonov -Frederik Søndergaard Mikkelsen
Green roofing	Cultivated peat soil 100mm	Impact of Green Roofs on Energy Demand for Cooling in Egyptian Buildings	-Ayman Ragab -Ahmed Abdelrady
	Cultivated peat soil 150mm	Impact of Green Roofs on Energy Demand for Cooling in Egyptian Buildings	-Ayman Ragab -Ahmed Abdelrady
	Cultivated peat soil 200mm	Impact of Green Roofs on Energy Demand for Cooling in Egyptian Buildings	-Ayman Ragab -Ahmed Abdelrady
	Cultivated sandy soil 150mm	Impact of Green Roofs on Energy Demand for Cooling in Egyptian Buildings	-Ayman Ragab -Ahmed Abdelrady
	Cultivated sandy soil 200mm	Impact of Green Roofs on Energy Demand for Cooling in Egyptian Buildings	-Ayman Ragab -Ahmed Abdelrady
Shading	Overhang 90°	Effect of fenestration geometrical factors on building energy consumption and performance evaluation of a new	-Amrita Ghosh -Subhasis Neogi

		external solar shading device in warm and humid climatic condition	
	Overhang 45°	Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. buildings	-Hanan M. Taleb
	Horizontal overhang with triangular fins on the two sides	Effect of fenestration geometrical factors on building energy consumption and performance evaluation of a new external solar shading device in warm and humid climatic condition	-Amrita Ghosh -Subhasis Neogi
	Mashrabia	Because it is the most shading design used in mosques	NONE
PV	Polycrystalline silicin	Standalone photovoltaic system assessment for major cities of United Arab Emirates based on simulated results	-Z. Said -Aamir Mehmood

3.5 Model setup

The model setup explaining the steps in the simulation, while using the IES-VE as follows:

- As first step, the location has been selected, which is Dubai, UAE. To help assessing the base case and the cases to which the previously mentioned strategies have been applied.
- Adding the climate of UAE, which hot and humid, to give accurate results when starting the simulation.

- The mosque building was modeled in the software by using modelling tools available in the IES-VE software, to start simulation without adding any strategy.
- The construction materials have been selected, such as walls, ceiling and glazing type.
- The selected simulation timing was for the whole year, from 1^{st} of January to 31^{st} of December and air conditioning continuously ON.
- Then the results for room cooling plant load and total energy selected from the energy category to get the chart of the results of how much reduction can be achieved with each scenario, for the whole year and for each month separately.
- The different strategies and scenarios applied to the base case, each one separately, by either adding it from the settings or model it such as shading strategy, which needed to model each shading scenario and add it to the base case.

3.6 Methodology map

The methodology map is presented in Figure 3.13, showing all the working steps, starting from planning the study to the future recommendation.

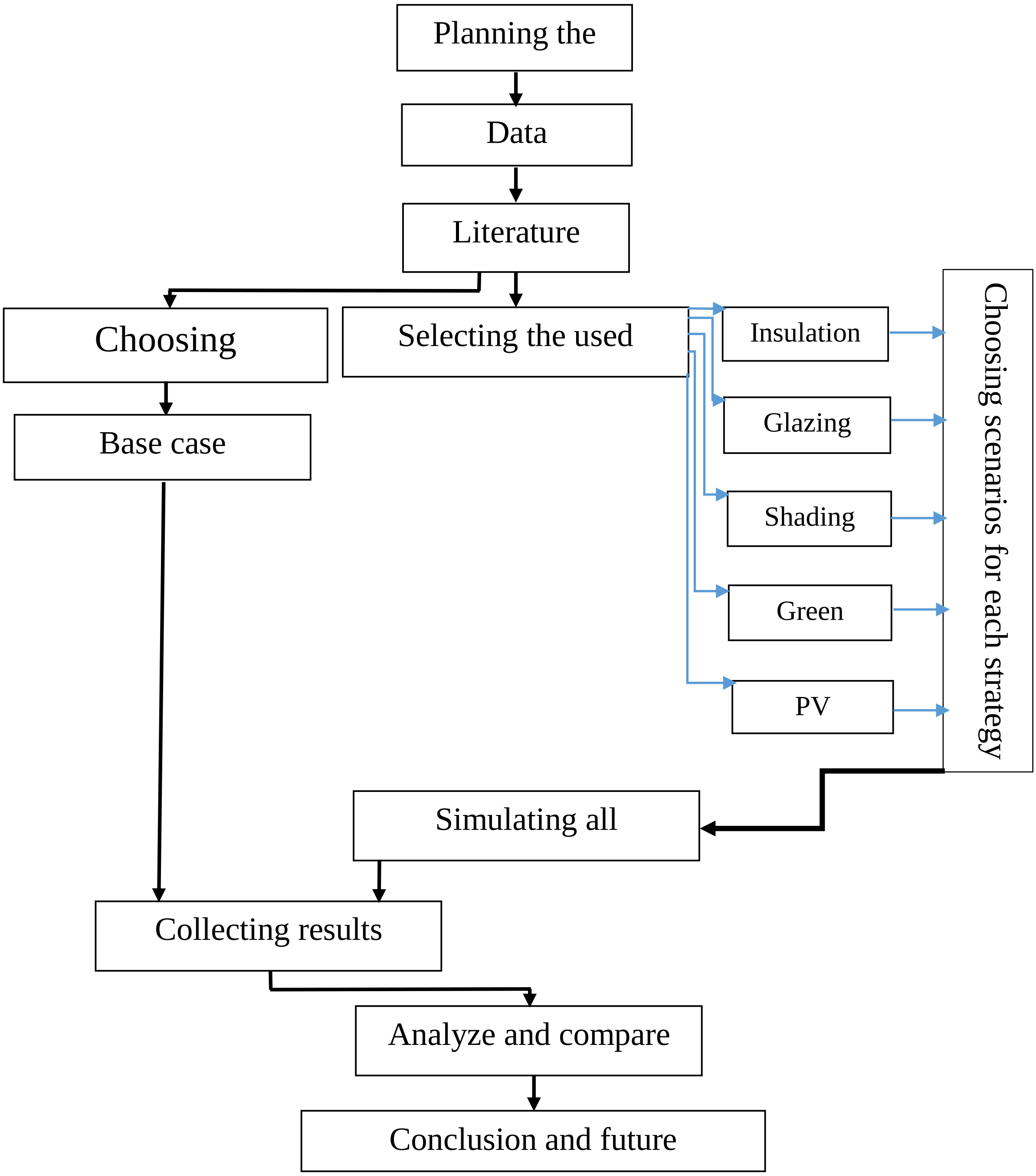


Figure 3.13 methodology map (Author2021)

3.7 Simulation steps

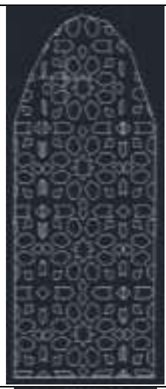
Applying the strategies and scenarios done in several stages. The first stage is the base case, which is the mosque building without applying any new strategy on it. The mosque built in the IES-VE software by using modelling tools exist in the software called ModellT. The second stage is applying each strategy and scenario separately and check the effectiveness of it. Starting with the insulation strategy, which has five scenarios. Followed by glazing strategy that include five scenarios. Then the green roofing strategy, which include five scenarios. All previous strategies done by adding them through the settings. shading strategy that needed to be drawn and modeled, has four scenarios only, because adding another type of shading doesn't make a big change, as the types used in the simulation gave similar or very close results. The third stage is adding photovoltaic to the building, which done in three steps. First step is adding PV panels to the base case on whole roof to calculate how much it can produce energy to provide the mosque. second step is combining together the best scenario from each strategy without adding PV panels. And the last step is adding PV panels with the best scenario from insulation, glazing and shading strategies only. It wasn't possible to combine PV panels and green roofing, because the building has only one roof, and it can be used for one of the two cases, either green roofs or PV panels. Each scenario has its own specification, which affects the efficiency and impact of the scenario on reducing room cooling load and total energy consumption. The specifications shown in Table 3-2 for base case, insulation, glazing and green roofing. And Table 3-3 shows the specifications of the scenarios in shading strategy.

Table 3-2 shown the specifications of each scenario used in the simulation (Author2021)

The strategy	The scenario	U-value	R-value
Base case	Concrete cast with 60mm cavity	1.3462 W/m^{2}K	0.5729 m^{2}K/W
Insulation	60mm Expanded polystyrene	0.2974 W/m^{2}K	2.1071 m^{2}K/W
	70mm Polyurethane	0.2974 W/m^{2}K	3.1929 m^{2}K/W
	100mm Rockwool	0.2567 W/m^{2}K	3.7262 m^{2}K/W
	100mm Glass wool	0.3265 W/m^{2}K	2.8929 m^{2}K/W
	150mm Polystyrene	0.1798 W/m^{2}K	5.3929 m^{2}K/W
Glazing	Double with 16mm Argon	1.4643 W/m^{2}K	0.9092 m^{2}K/W
	Double with 9mm Krypton	1.37 W/m^{2}K	1.00 m^{2}K/W
	Double with 12mm Xenon	1.2856 W/m^{2}K	1.1095 m^{2}K/W
	Triple with CO^2 and vacuum	0.9161 W/m^{2}K	2.0376 m^{2}K/W
	Triple with Argon	1.37 W/m^{2}K	1.00 m^{2}K/W
Green roofing	100mm Cultivated peat soil	0.4350 W/m^{2}K	1.6752 m^{2}K/W
	150mm Cultivated peat soil	0.4046 W/m^{2}K	1.6752 m^{2}K/W
	200mm Cultivated peat soil	0.3782 W/m^{2}K	1.6752 m^{2}K/W
	150mm Cultivated sandy soil	0.4907 W/m^{2}K	1.6752 m^{2}K/W
	200mm Cultivated sandy soil	0.4841 W/m^{2}K	1.6752 m^{2}K/W

Table 3-3 shows the specifications of shading strategy (Author2021)

Shading	Overhang	90°	Depth 0.5 m
	Overhang	45°	Depth 0.5 m
	Overhang with triangular fins	90°	Depth 0.5 m

	Mashrabia		Window area $85m^2$	Glazing area $32m^2$
			Window area $40m^2$	Glazing area $16m^2$
			Window area $54m^2$	Glazing area $26m^2$

One type of PV panel was used in this study, which is polycrystalline silicon. because this type has high temperature coefficient, so it was preferable in different studies done in hot climates. Sendy (2020 cited in Alhammami & An 2021) explained the benefits of polycrystalline silicon panels and mentioned that the these types of PV panels perform better in hot climates. (Said & Mehmood 2017) explained that these panels are more suitable for UAE than other types. is the most efficient and best to use in areas with hot climate, where the weather degree reaches 47° during the hot summer. The size used of PV panels was 1.94 m^2 with 25° tilted angle towards south direction.

CHAPTER FOUR

ANALYSIS

4 ANALYSIS

4.1 Introduction

In this chapter, the mosque will be simulated by using IES-VE software to investigate the impact of each strategy and scenario on reducing the mosque`s energy consumption. The reduction will be in the annual cooling plant load and total energy.

As a beginning, the base case of the building will be simulated without any type of simulation, shading, green roofing, and PV panels, and with normal single glass type. Then applying the different strategies separately and each strategy with different scenarios. At the end applying PV panels on the base case then with the most efficient scenario from each strategy.

4.2 Results

The results from the simulation that shown in Figure 4.1 to Figure 4.43, present and compare the amount of energy consumed by the mosque in the base case and with all strategies and scenarios. Comparing the results as follow.

1. Base case, which is the first stage of simulation, when the building with normal single glass and without insulation, shading, green roofing, and PV in Figure 4.1.
2. The second stage when applying different strategies, each strategy includes five to four scenarios.
3. The third stage is adding photovoltaic strategy to the building. First step is adding PV panels to the base case on whole roof to calculate how much it can produce energy to provide the mosque in Figure 4.34. second step is combining together the best scenario from each strategy without adding PV panels. And the last step

is adding PV panels with the best scenario from insulation, glazing and shading strategies only.

4.2.1 First Stage: Base Case

The total energy consumption for base case is 130.6677 MWH as shown in Figure 4.1, and room cooling plant load is 261.3354 MWH. The building blocks is concrete sandwich with 60mm cavity. The total thickness is 300mm, and U-value is 1.3462 W/m²K, which is very high, and that is mean the wall has high thermal transmittance, which cause increasing the cooling load of the building. The R-value is 0.5729 m^2K/W, which means the wall has low resistance to heat flow.

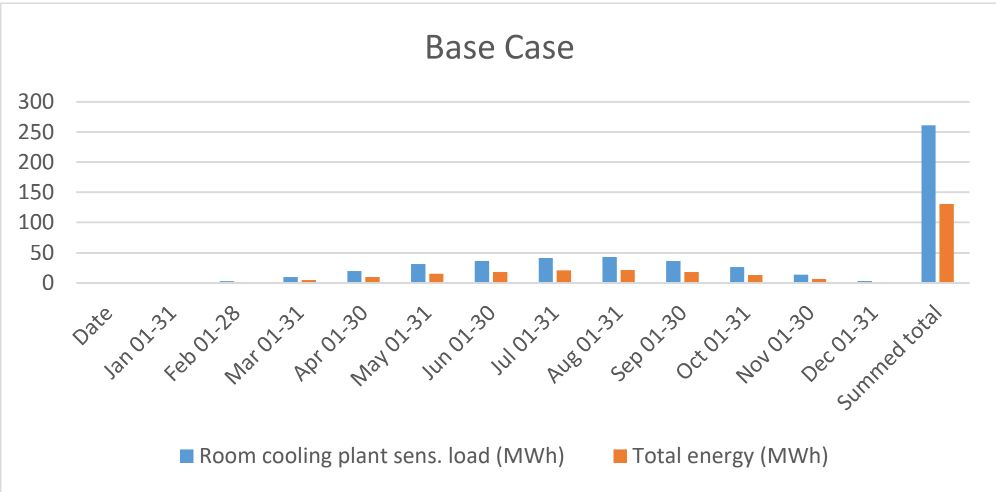


Figure 4.1 base case results (Author2021)

4.2.2 Second Stage: Applying the different strategies

4.2.2.1 Insulation Strategy

4.2.2.1.1 Expanded polystyrene scenario

Insulation is very important in the buildings, as it has high impact on reducing energy consumption. In Figure 4.2 expanded polystyrene insulation results, the cooling load is

165.9243MWH, and total energy consumption is 82.9622MWH, which mean reduction about 36.51%. Although the thickness of the wall remained the same and the cavity too, but it filled with the expanded polystyrene insulation, which reduced the U-value of the wall and became 0.4391 W/m²K, and increased the R-value to 2.1071 m^2K/W.

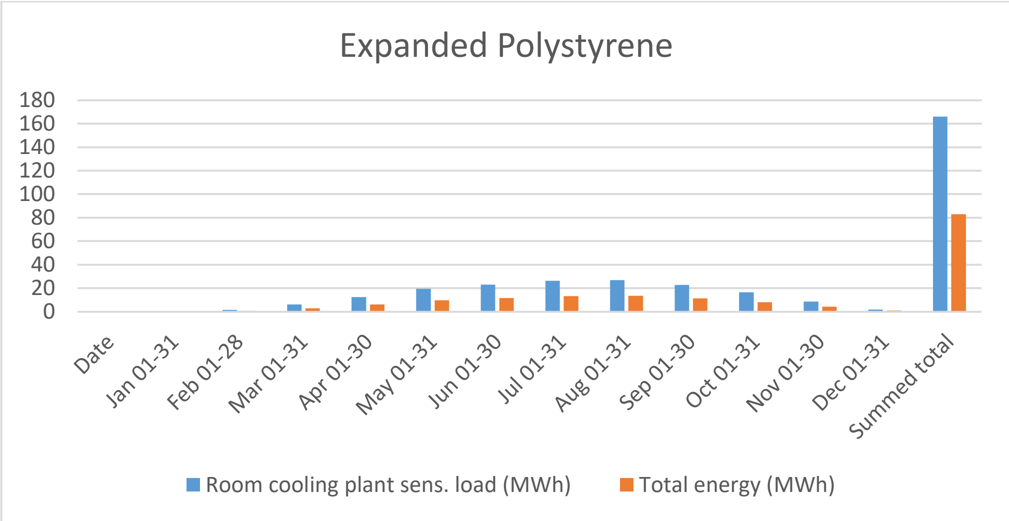


Figure 4.2 expanded polystyrene insulation results (Author2021)

4.2.2.1.2 Polyurethane scenario

By adding polyurethane insulation as shown in Figure 4.3, the cooling load reduced until 150.7319MWH and total energy until 75.366MWH. The thickness of the wall increased by 10mm because the thickness of the insulation increased and became 70mm, which reduced the U-value more than when using expanded polystyrene and became 0.2974 W/m²K. In addition, increased the R-value of 3.1929 m^2K/W. Using polyurethane is more efficient than using expanded polystyrene as shown in Figure 4.4, when just increasing the thickness by 10mm. moreover, the density increased from 25 kg/m^3 for expanded polystyrene to 30 kg/m^3 for polyurethane as shown in Table 4-1.

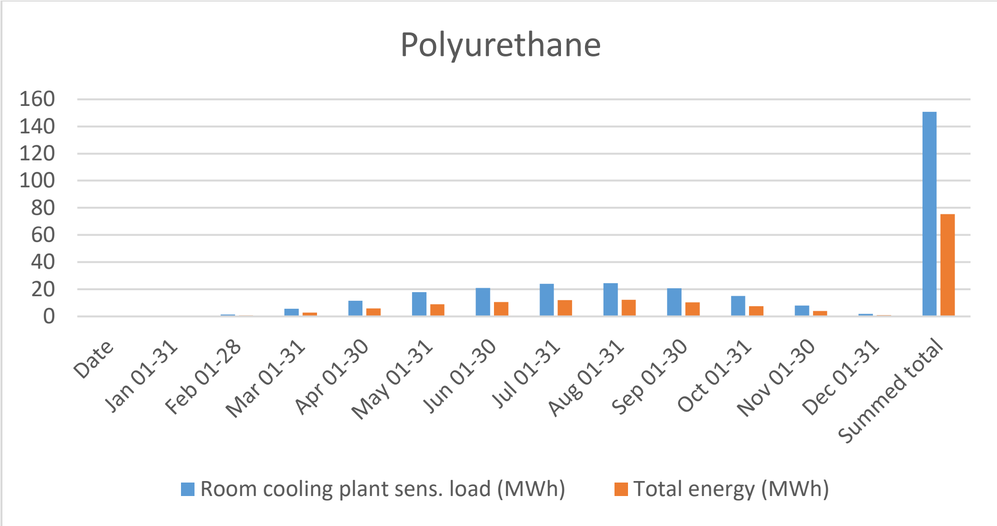


Figure 4.3 polyurethane insulation results (Author2021)

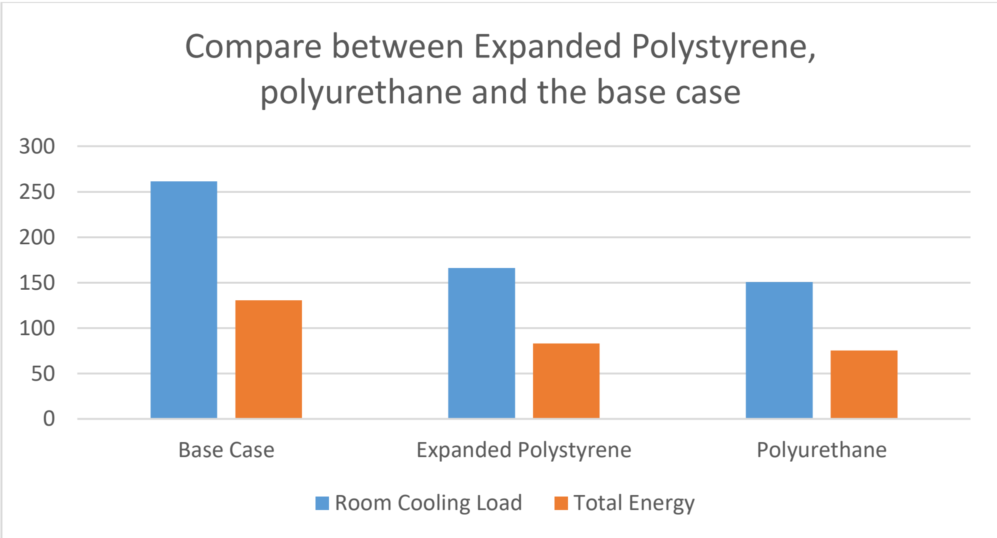


Figure 4.4 comparing the base case, expanded polystyrene and polyurethane (Author2021)

4.2.2.1.3 Rock wool scenario

Using Rock wool insulation was more efficient than using expanded polystyrene and polyurethane as shown in Figure 4.5. It reduced cooling load and total energy consumption by 44.00% as shown in Figure 4.6. The thickness of the simulated rock wool insulation was 100mm, and density about 75 kg/m^3, which are more than the previous two types. Although increasing the thickness caused reduction in thermal transmittance and increment in the ability of the wall to resist heat flow. It causes an increment in wall thickness, which became 340mm. They U-value and R-value became 0.2507 W/m²K and 3.7262 m^{2}K/W, respectively.

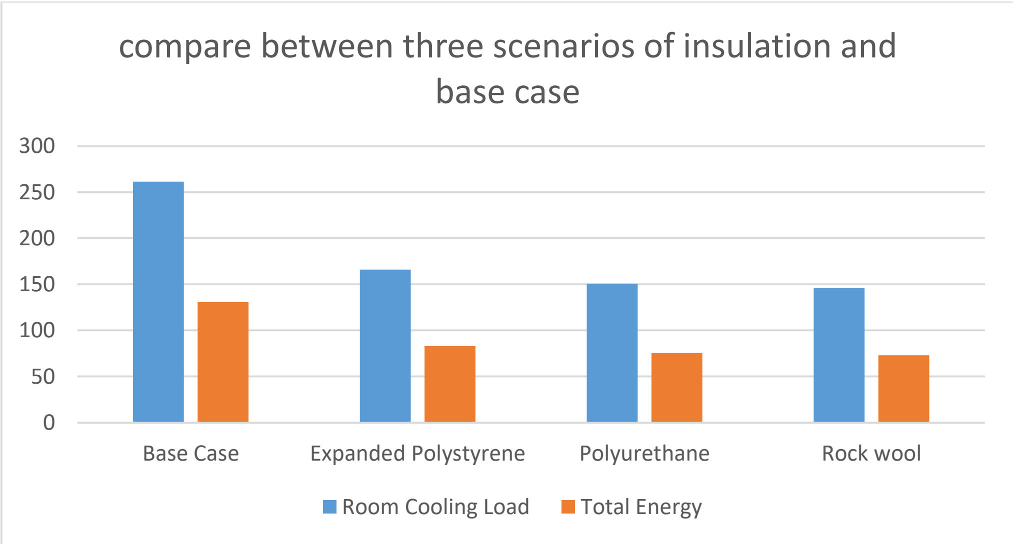


Figure 4.5 compare between expanded polystyrene, polyurethane, rock wool and base case (Author2021)

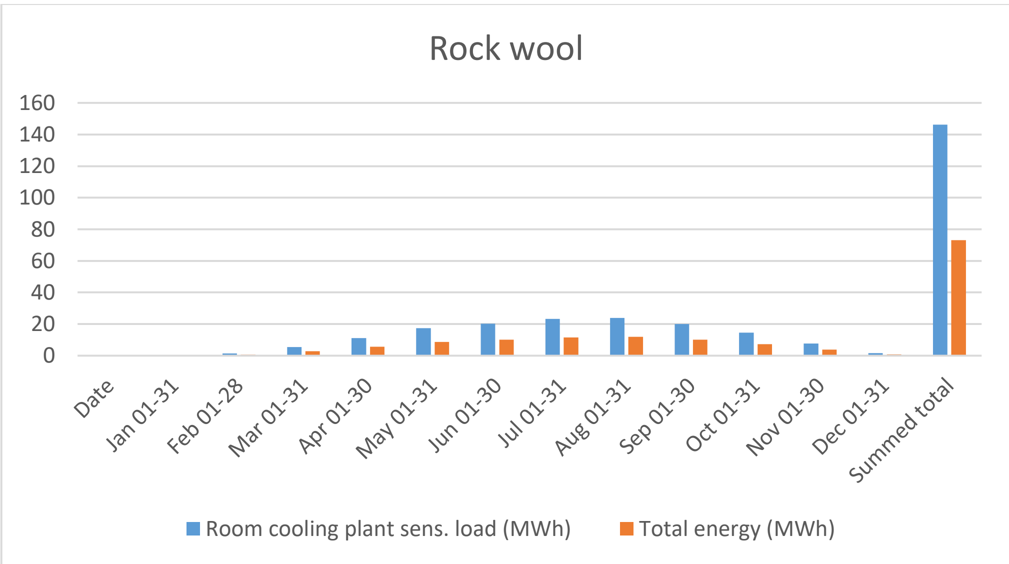


Figure 4.6 rock wool insulation results (Author2021)

4.2.2.1.4 Glass wool scenario

By using glass wool insulation, the room-cooling load and total energy reached 153.8534 MWH and 76.9267 MWH, respectively as shown in Figure 4.7. The reduction percentage was 41.13%, which is higher than the expanded polystyrene insulation, but less than polyurethane and rock wool insulations as shown in Figure 4.8. Where the U-value was higher and R-value was less, they were 0.3265 W/m²K, and 2.8929 m^2K/W for each, respectively as presented in Table 4-2. Although it has higher thickness than polyurethane and same as rock wool of 100 mm, and higher density of 200 kg/m^3 as shown in Table 4-1.

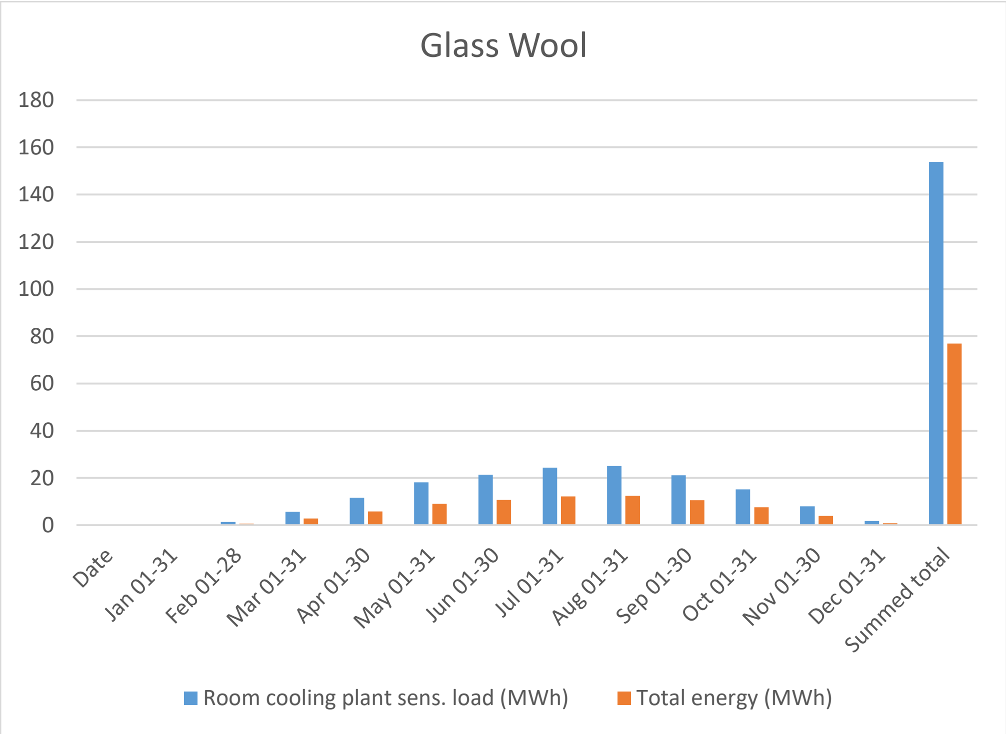


Figure 4.7 glass wool insulation results (Author2021)

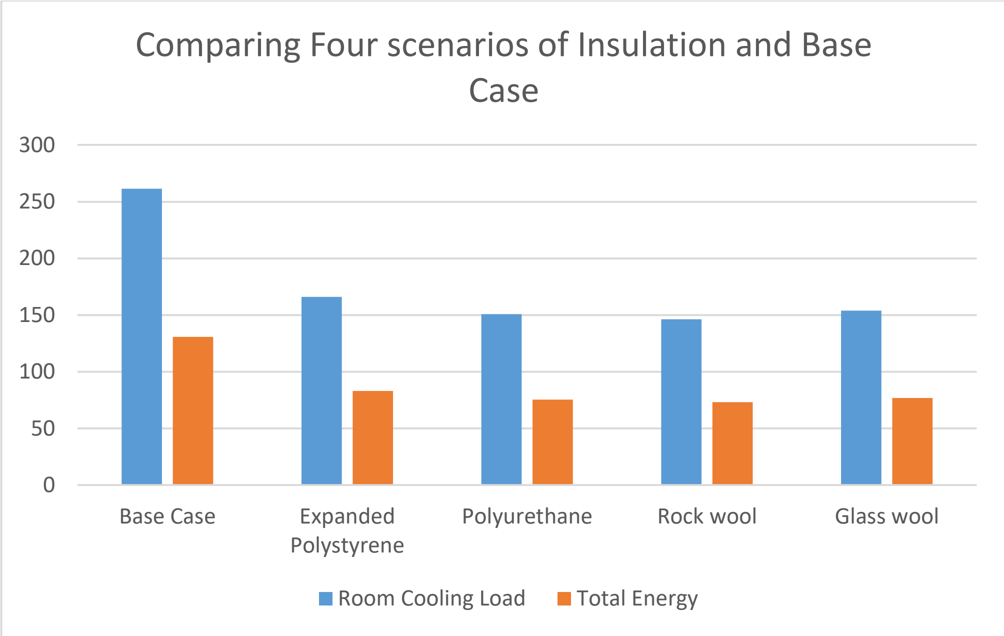


Figure 4.8 comparing expanded polystyrene, polyurethane, rock wool, glass wool and base case (Author2021)

4.2.2.1.5 Polystyrene scenario

The last simulated insulation type was polystyrene, with a greater thickness than other types, where it was 150 mm. but the density is less, reached 25 kg/m^3, which is same density as expanded polystyrene as shown in Table 4-1. Despite this, it was the most efficient type as presented in Figure 4.9. Where it has the lowest U-value and highest R-value as presented in Table 4-2. They are 0.1798 W/m^2K and 5.3929 m^2K/W for each, respectively. The room cooling load and total energy reduced until 138.0538 MWH and 69.0269 MWH, respectively as shown in Figure 4.10. Comparing to the base case, the reduction about 47.17% as shown in Table 4-3.

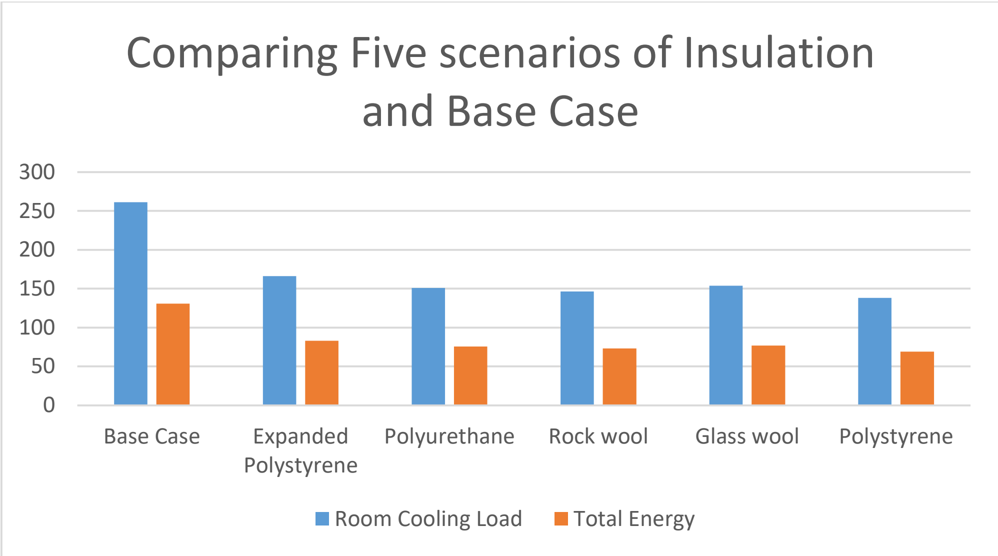


Figure 4.9 comparing expanded polystyrene, polyurethane, rock wool, glass wool, polystyrene and base case (Author2021)

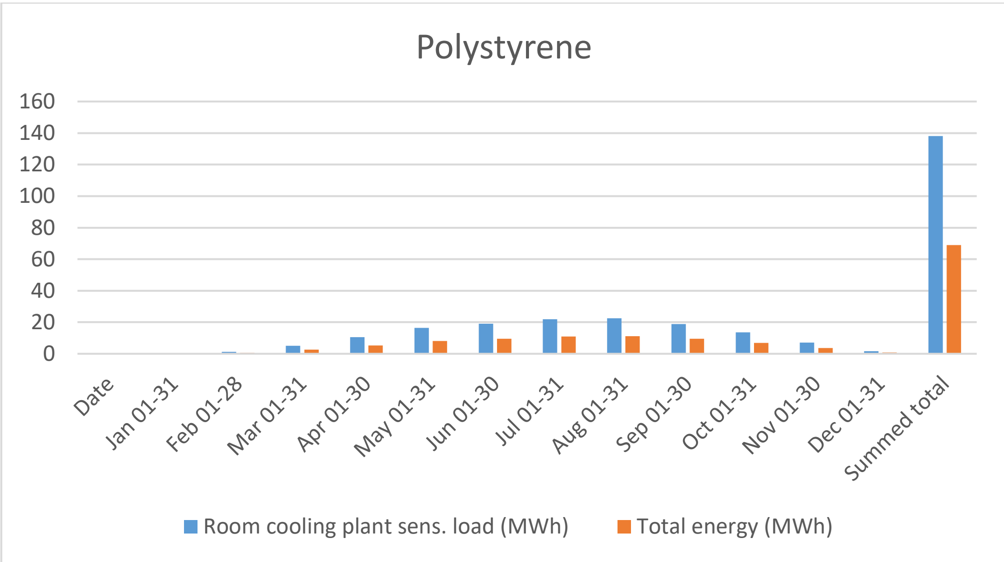


Figure 4.10 polystyrene insulation results (Author2021)

Table 4-1 the different types of insulation with their thickness and density (Author2021)

Type of Insulation	Thickness in mm	Density in kg/m^3
Expanded polystyrene	60 mm	25 kg/m^3
Polyurethane	70 mm	30 kg/m^3
Rock wool	100 mm	75 kg/m^3
Glass wool	100 mm	200 kg/m^3
polystyrene	150 mm	25 kg/m^3

Table 4-2 the different types of insulation with their U-value and R-value (Author2021)

Type of Insulation	U-value	R-value
Expanded polystyrene	0.4391 W/m²K	2.1071 m^2K/W
Polyurethane	0.2974 W/m²K	3.1929 m^2K/W
Rock wool	0.2567 W/m²K	3.7262 m^2K/W
Glass wool	0.3265 W/m²K	2.8929 m^2K/W
polystyrene	0.1798 W/m²K	5.3929 m^2K/W

Table 4-3 reduction percentage for each type of insulation (Author2021)

Type of Insulation	Reduction percentage
Expanded polystyrene	36.51%
Polyurethane	42.32%
Rock wool	44.00%
Glass wool	41.13%
polystyrene	47.17%

4.2.2.2 Glazing Strategy

The glazing of any building can effect on the energy consumption of that building. Some glazing are double panes, and some are triple panes with cavity in between that can be filled with gas, air or vacuumed. Five types of glazing simulated in this paper found in different literatures.

4.2.2.2.1 Double-glazing with 16 mm argon gas scenario

The first simulated type is double-glazing with 16 mm cavity filled with argon gas. The thickness of each pane is 6 mm. the net U-value and R-value of the window as presented in Table 4-4, are 1.4636 W/m²K and 0.9092 m^2K/W. When using the double-glazing with 16 mm argon gas with the base case, the reduction was about 0.70%. Where room cooling load reduced until 259.509 MWH, and total energy reduced until 129.7545 MWH as presented in Figure 4.11.

4.2.2.2.2 Double-glazing with 9 mm krypton scenario

While the second type of glazing was double-glazing with 9 mm krypton gas. Reduced the room cooling load and total energy by 0.83%. Where room cooling load and total energy reduced until 259.1424 MWH and 129.5712 MWH, respectively as shown in Figure 4.12. The using of krypton type is more efficient as presented in Figure 4.13, because it reduced the U-value and increased the R-value as shown in Table 4-4.

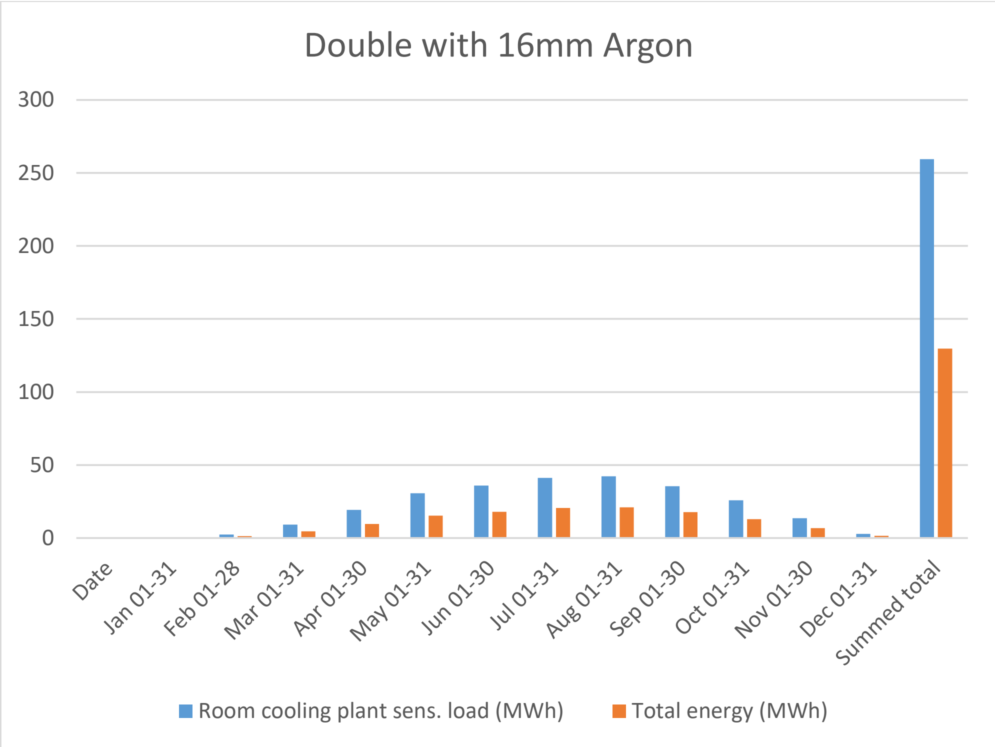


Figure 4.11 double-glazing with argon results (Author2021)

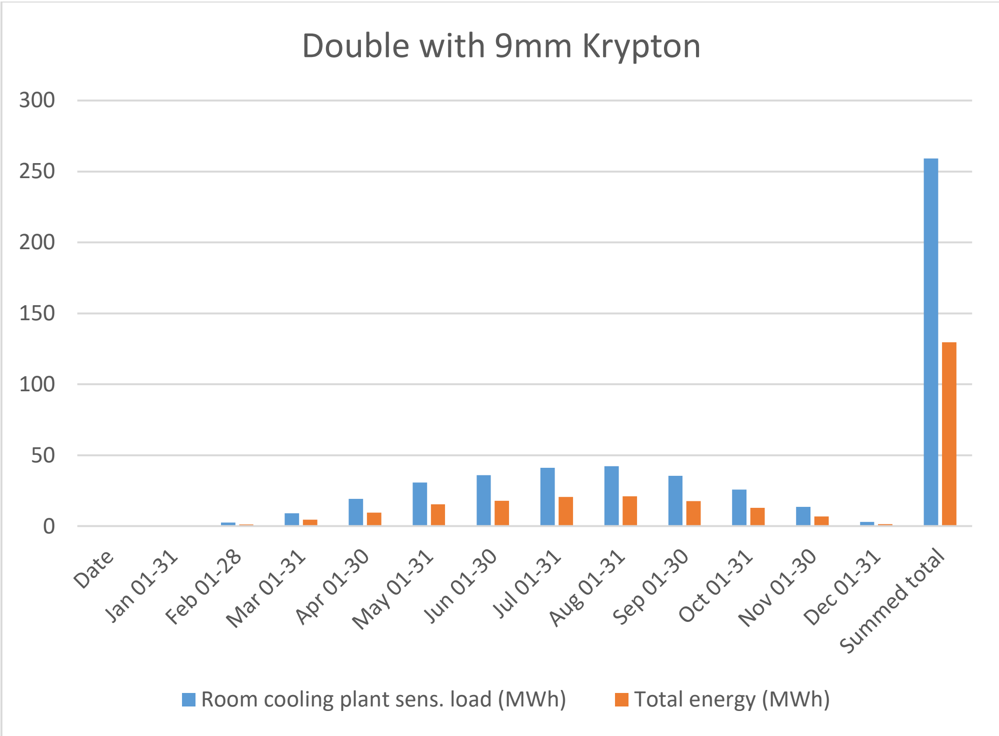


Figure 4.12 double-glazing with krypton results (Author2021)

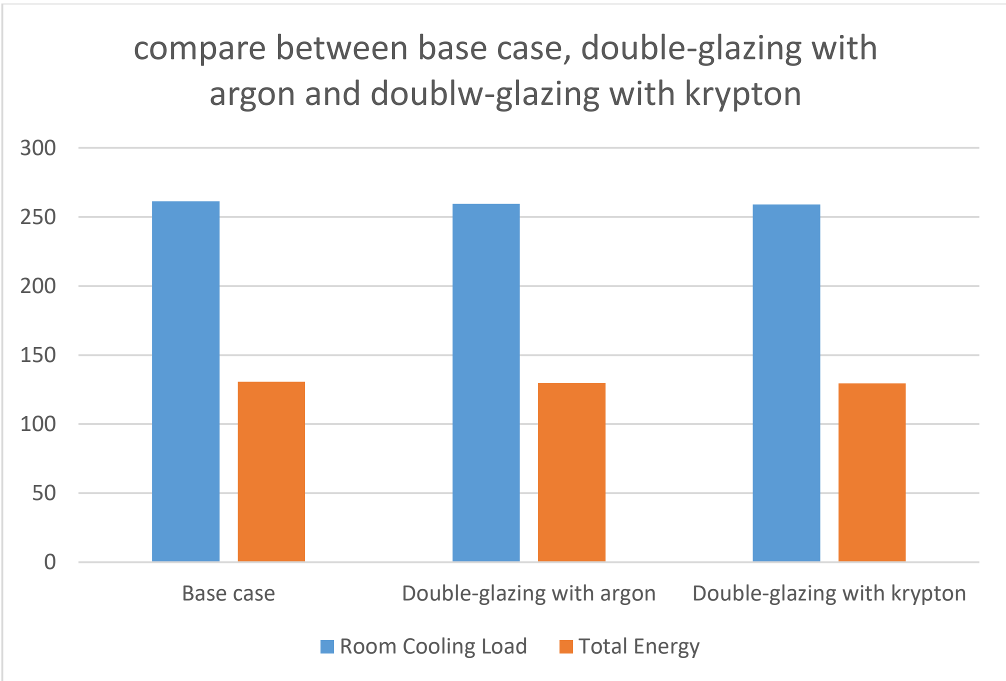


Figure 4.13 compare between base case, double-glazing with argon and double-glazing with krypton (Author2021)

Table 4-4 the U-value and R-value for different glazing types (Author2021)

Type of Glazing	U-value	R-value
Double-glazing with argon	1.46 W/m^2K	0.90 m^2K/W
Double-glazing with krypton	1.37 W/m^2K	1.00 m^2K/W
Double-glazing with xenon	1.28 W/m^2K	1.10 m^2K/W
Triple glazing with CO^2 and vacuum	0.91 W/m^2K	2.03 m^2K/W
Triple glazing with argon	1.37 W/m^2K	1.00 m^2K/W

4.2.2.2.3 Double-glazing with 12 mm xenon scenario

Using double-glazing with 12 mm xenon was more efficient than the two previous types, because it reduced the U-value and increased the R-value as presented in Table 4-4. The used glass panes remained the same in the whole scenarios at thickness of 6 mm. As shown in Figure 4.14, the Double-glazing with xenon reduced the room cooling load to 257.9001 MWH, and total energy to 128.9501 MWH. The difference between the reductions from using the three types of double-glazing was very low, but the most efficient type was when using 12 mm xenon as shown in Figure 4.15. The thickness of the cavity between the two panes was changing, but it did not affect the efficiency, where cavity for krypton gas is 9 mm, but it was more efficient than the double-glazing with 16 mm cavity filled with argon gas. Likewise, the glazing with 12 mm xenon gas was more efficient than glazing with 16 mm argon gas. The more efficient glazing type has less U-value and higher-value as presented in Table 4-4.

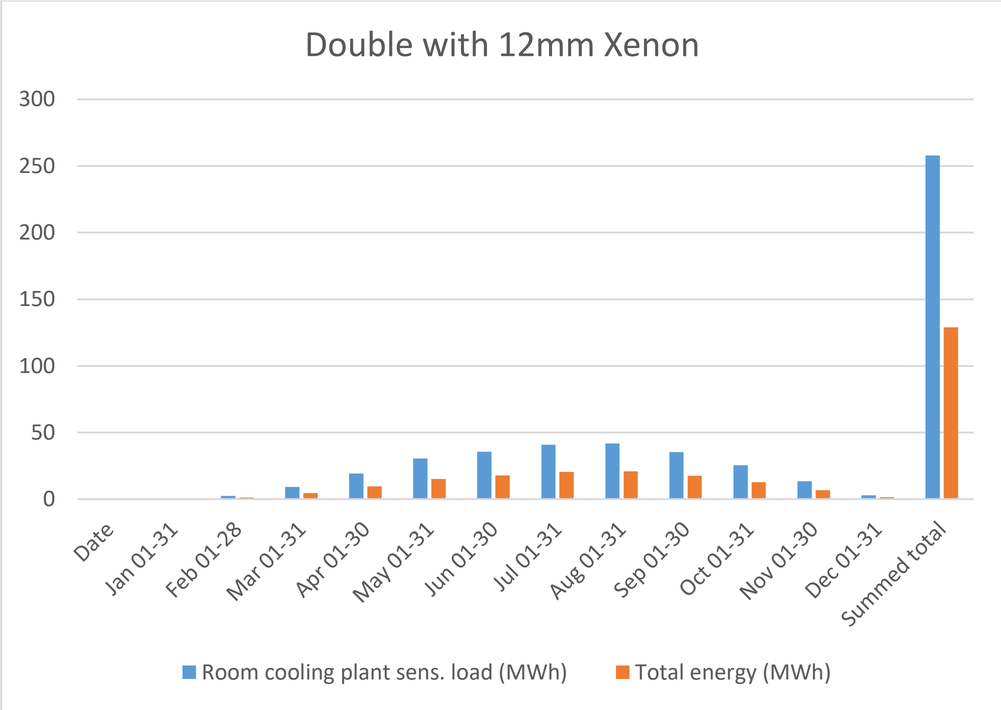


Figure 4.14 double-glazing with xenon results (Author2021)

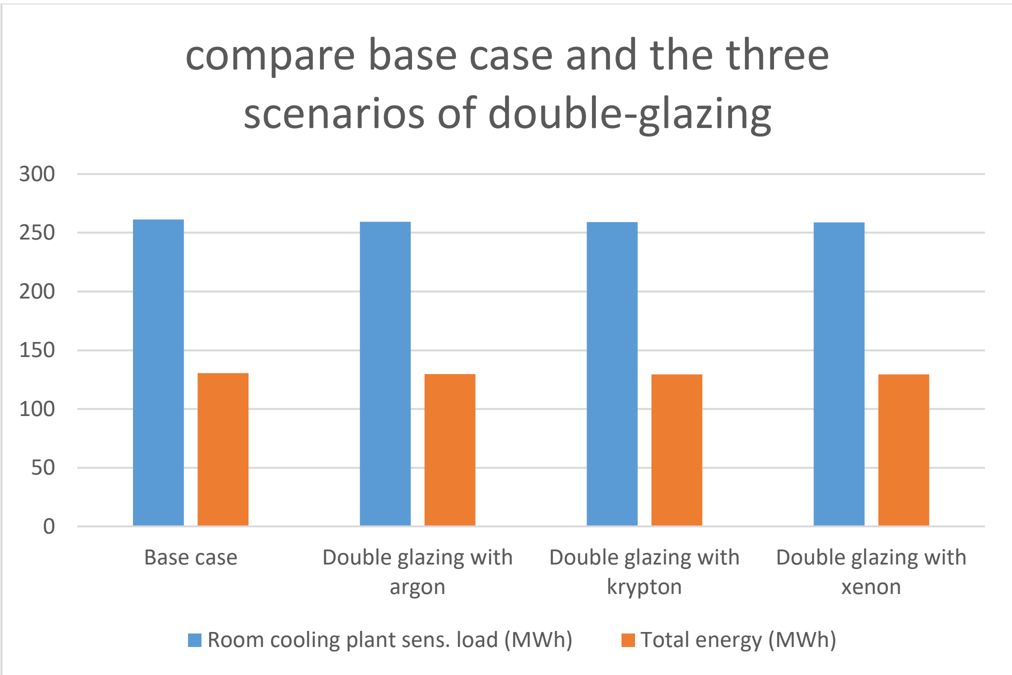


Figure 4.15 compare base case and three types of double-glazing (Author2021)

Table 4-5 the cavity thickness and percent of reduction for each double-glazing type (Author2021)

Type of Glazing	Cavity Thickness	Percent of reduction
Double-glazing with argon	16 mm	0.70%
Double-glazing with krypton	9 mm	0.84%
Double-glazing with xenon	12 mm	0.96%

4.2.2.2.4 Triple glazing with CO^2 and vacuum scenario

Increase the panes of the glazing can help in reducing energy consumption of the building but it can have the same effect as double-glazing, depending on the type gas used between the panes. When simulating triple glazing with CO^2 in the cavity between the outer pane and the middle pane and vacuum in the second cavity between the middle and inner panes, the results showed that this type of glazing have the best impact as shown in Figure 4.16. It was 1.31% as shown in Table 4-6. When using triple glazing with CO^2 and vacuum as shown in Figure 4.17, the room cooling load and total energy were 257.9001 MWH and 128.9501 MWH, respectively.

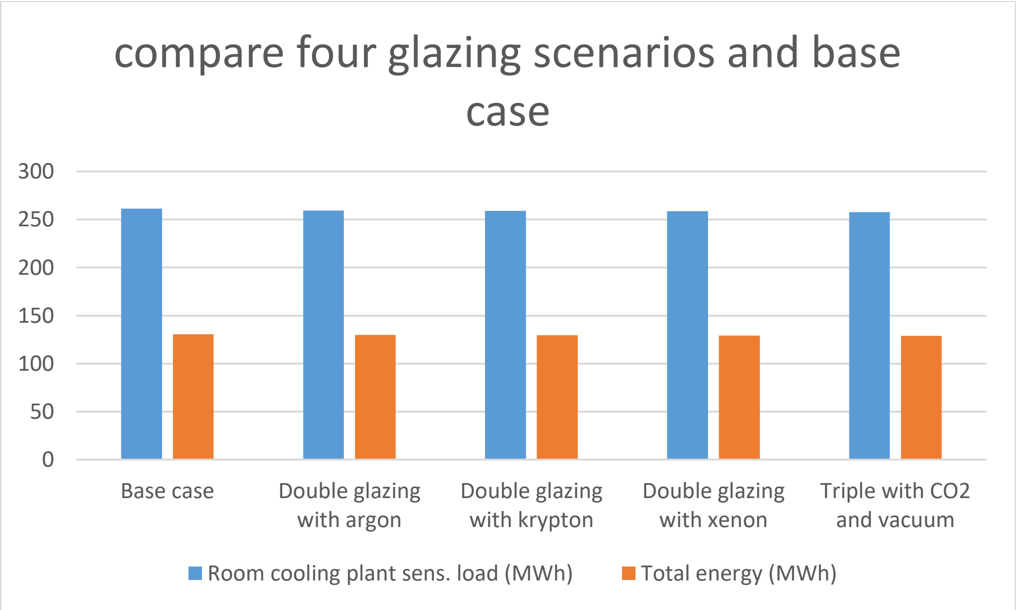


Figure 4.16 compare four glazing types and base case (Author2021)

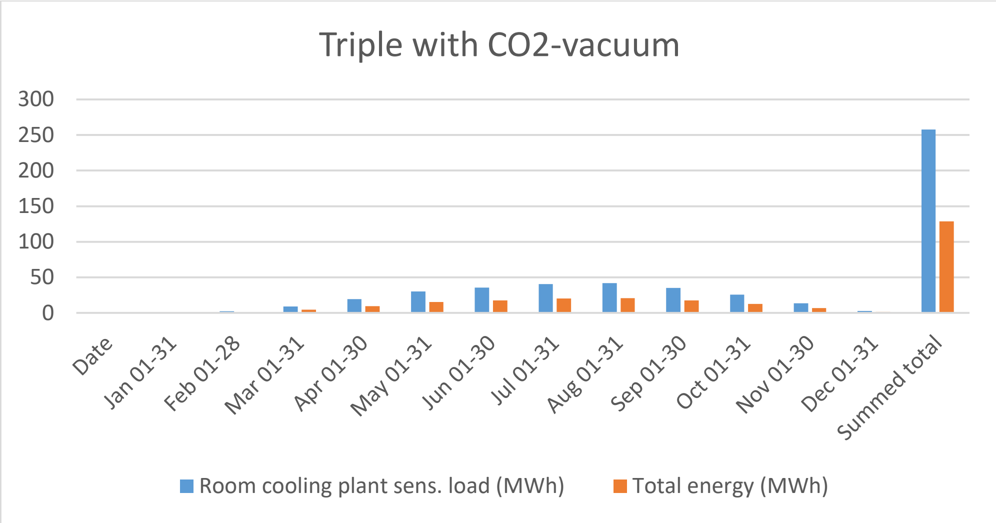


Figure 4.17 triple with CO2-vacuum results (Author2021)

4.2.2.2.5 Triple glazing with argon gas scenario

When using triple glazing with argon gas in between, the reduction reduced comparing with the previous type of triple glazing, although the thickness remained the same. However, the cavity filled with argon gas instead of CO^2 and vacuum, which cause to increase the U-value and reduce the R-value as shown in Table 4-4. The room cooling load and total energy when using triple glazing with argon as shown in Figure 4.18 were 259.1403 MWH and 129.5701 MWH, respectively.

Table 4-6 the cavity thickness and percent of reduction for all simulated glazing type (Author2021)

Type of Glazing	Cavity Thickness	Percent of reduction
Double-glazing with argon	16 mm	0.70%
Double-glazing with krypton	9 mm	0.84%
Double-glazing with xenon	12 mm	0.96%
Triple with CO^2 and vacuum	12 mm	1.31%
Triple with argon	12 mm	0.84%

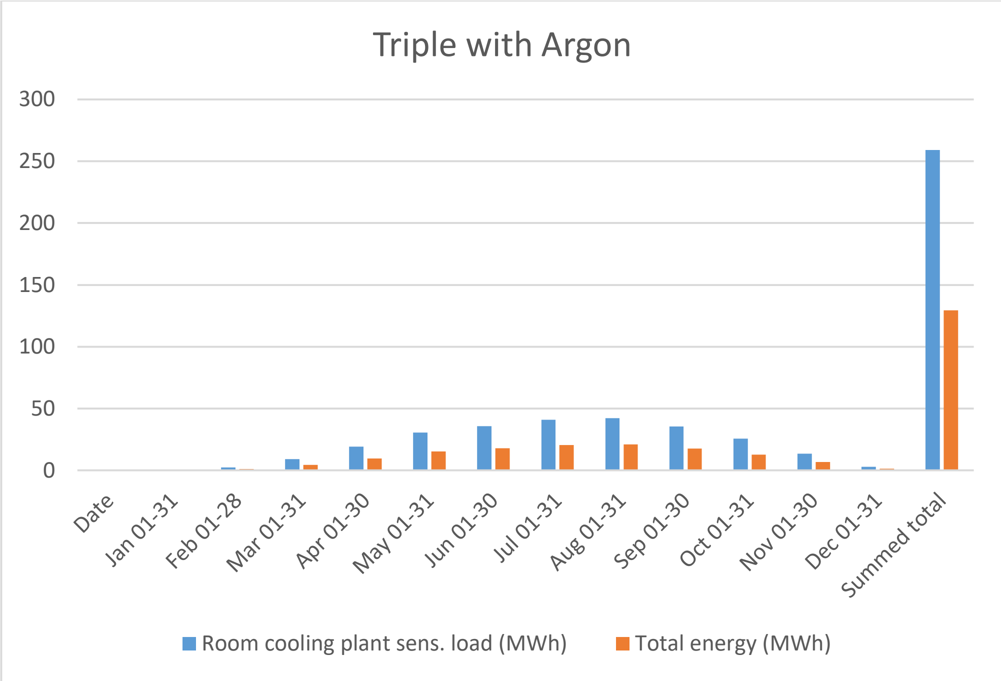


Figure 4.18 triple with argon results (Author2021)

As can be shown from Figure 4.19, the triple glazing filled with argon gas in the cavities has the same impact on reducing energy consumption as double-glazing with krypton. Because the net U-value and R-value were the same for both, so the reduction was same for both types, it was 0.84%. By comparing the results of the all types of glazing as shown in Figure 4.19, the difference is very low between the effectiveness of each glazing type. The maximum reduction was 1.31% when using triple glazing with CO2 in the cavity between the outer pane and the middle pane and vacuum in the second cavity between the middle and inner panes. where the U-value was 0.9161 W/m²K and R-value was 2.0376 m2K/W, respectively. The least reduction in glazing scenarios and the other strategies was 0.70% when using double-glazing with argon gas, because it has the highest U-value about 1.4643 W/m²K, and the lowest R-value about 0.9092 m^{2}K/W.

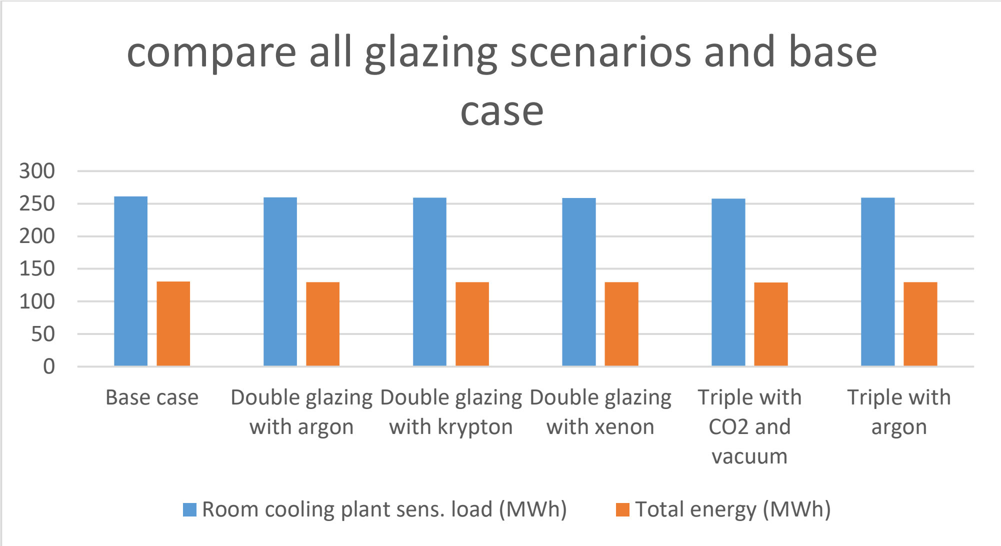


Figure 4.19 compare base case and all glazing scenarios (Author2021)

All types of glazing have the same conductivity value which is 1.06 W/mK as shown in Table 4-12. but the differences in U-value and R-value impact the effectiveness of each glazing type.

4.2.2.3 Green Roofing Strategy

4.2.2.3.1 Cultivated peat soil 100 mm scenario

The green roofing can help in reducing energy consumption, where it can work as an additional insulation layer to the building. Five types of green roofing simulated in this paper and it was effective in reducing energy consumption of the mosque. All simulated soils were cultivated, but it differs is soil thickness and type. The first type simulated was cultivated peat soil with 100 mm thickness. It reduced the consumption by 4.47%. Where room cooling load and total energy showed in Figure 4.20, 249.5563 MWH and 124.8327 MWH, respectively. The U-value reduced comparing to the base case U-value. It reduced until 0.4350 W/m²K, and R-value increased, where it reached 1.6752 m^2K/W.

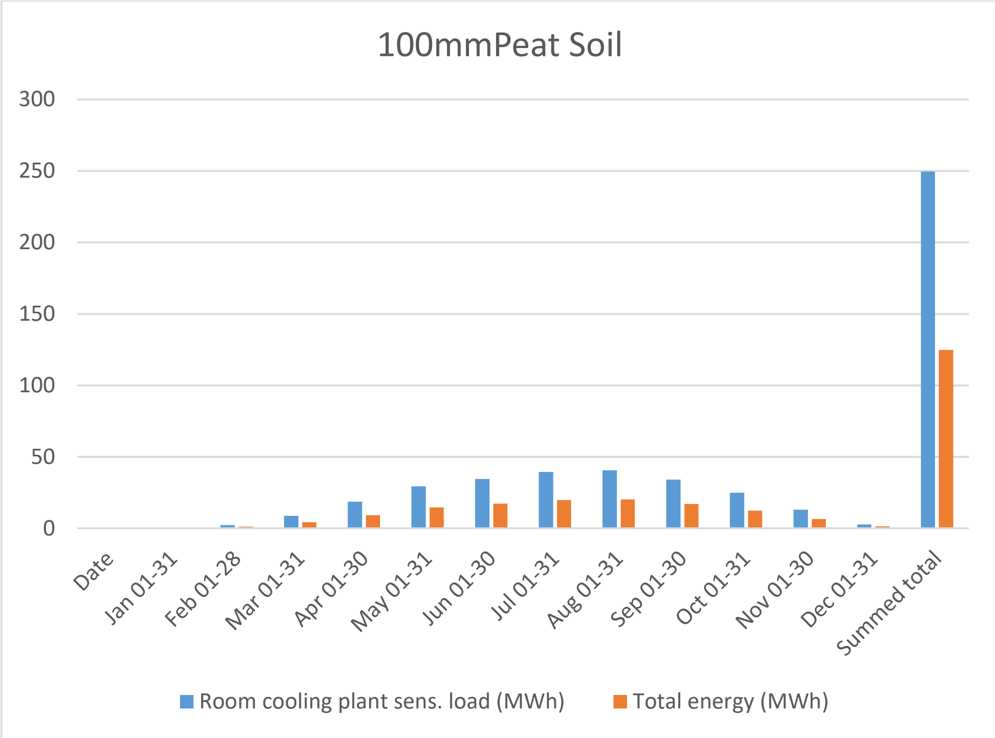


Figure 4.20 peat soil 100mm results (Author2021)

4.2.2.3.2 Cultivated peat soil 150 mm scenario

By increasing the soil thickness from 100 mm to 150 mm, the reduction percentage increased. It became 6.00% as shown in t. Where room cooling load and total energy reduced. Figure 4.21 shows room cooling load was 245.6537 MWH and total energy consumption was 122.8269 MWH. When the soil thickness increased, the U-value reduced and the R-value stayed the same for all soil types as shown in Table 4-7.

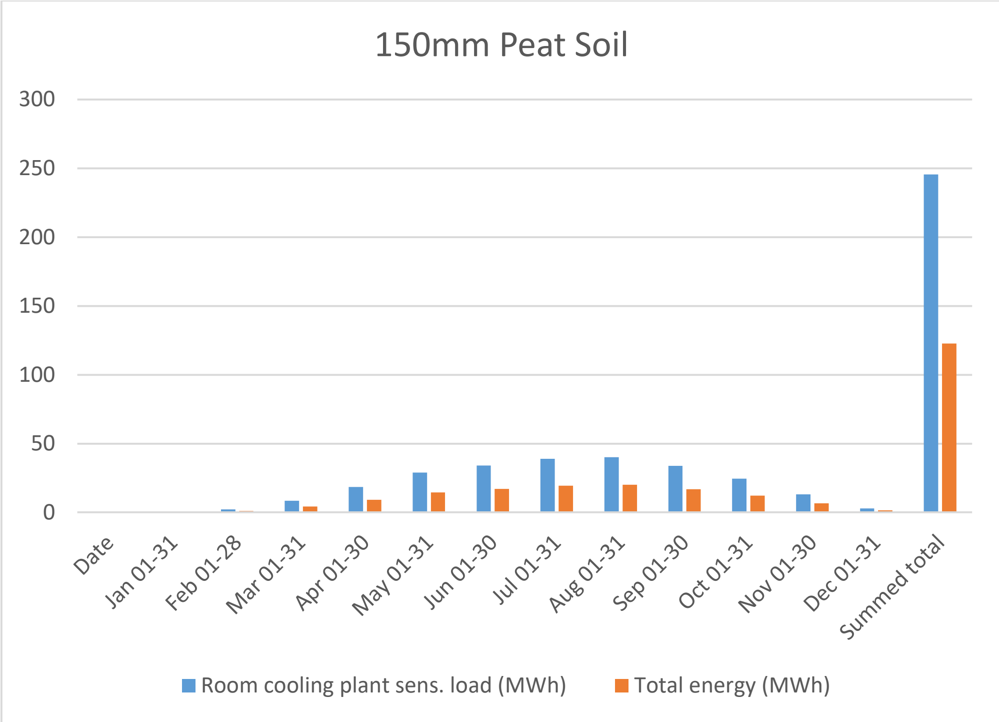


Figure 4.21 peat soil 150mm results (Author2021)

Table 4-7 the U-value and R-value for green roofing (Author2021)

Type of Green Roofing	U-value	R-value
Base Case	1.3462 W/m²K	0.5729 m²K/W
Cultivated peat soil 100 mm	0.4350 W/m²K	1.6752 m²K/W
Cultivated peat soil 150 mm	0.4046 W/m²K	1.6752 m²K/W
Cultivated peat soil 200 mm	0.3782 W/m²K	1.6752 m²K/W
Cultivated sandy soil 150 mm	0.4907 W/m²K	1.6752 m²K/W
Cultivated sandy soil 200 mm	0.4841 W/m²K	1.6752 m²K/W

4.2.2.3.3 Cultivated peat soil 200 mm scenario

Increasing the soil thickness to 200 mm, reduced the U-value and increased the efficiency of the soil until 7.29%. Where the room cooling load reduced as shown in Figure 4.22, until 242.2747 MWH and total energy consumption reduced until 121.1374 MWH.

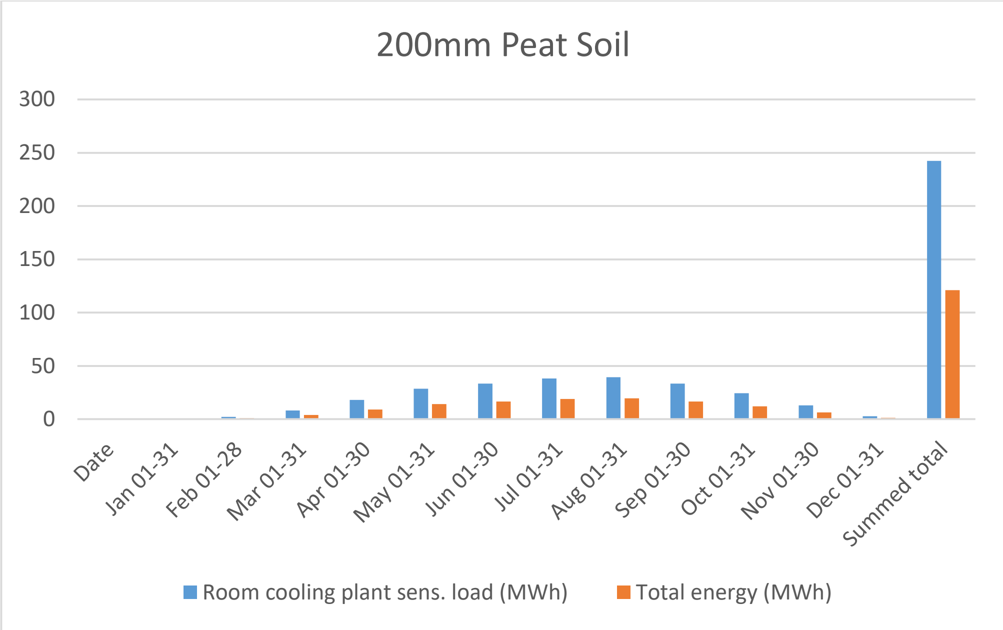


Figure 4.22 peat soil 200mm results (Author2021)

The results showed that increasing the soil thickness increased the efficiency of the green roofing. Because it reduced the heat transfer coefficient value. Nevertheless, the resistance to heat flow stayed the same and did not change with the increasing of soil thickness as shown in Table 4-7.

4.2.2.3.4 Cultivated sandy soil 150 mm scenario

Changing the soil type can also affect the effectiveness. The second type of soil was cultivated sandy soil with thickness of 150 mm. it helps reducing room cooling load and total energy by 1.56%. As shown in Figure 4.24, they were 257.2517 MWH and 128.6259 MWH, respectively.

4.2.2.3.5 Cultivated sandy soil 200 mm scenario

From the results, the sandy soil was less efficient than peat soil. Therefore, the thickness of sandy soil increased to get more effectiveness. With 200 mm sandy soil, the reduction percentage increased and became 1.81%. The room cooling load and total energy reduced. They were 265.6181 MWH and 128.3091 MWH, respectively as presented in Figure 4.24.

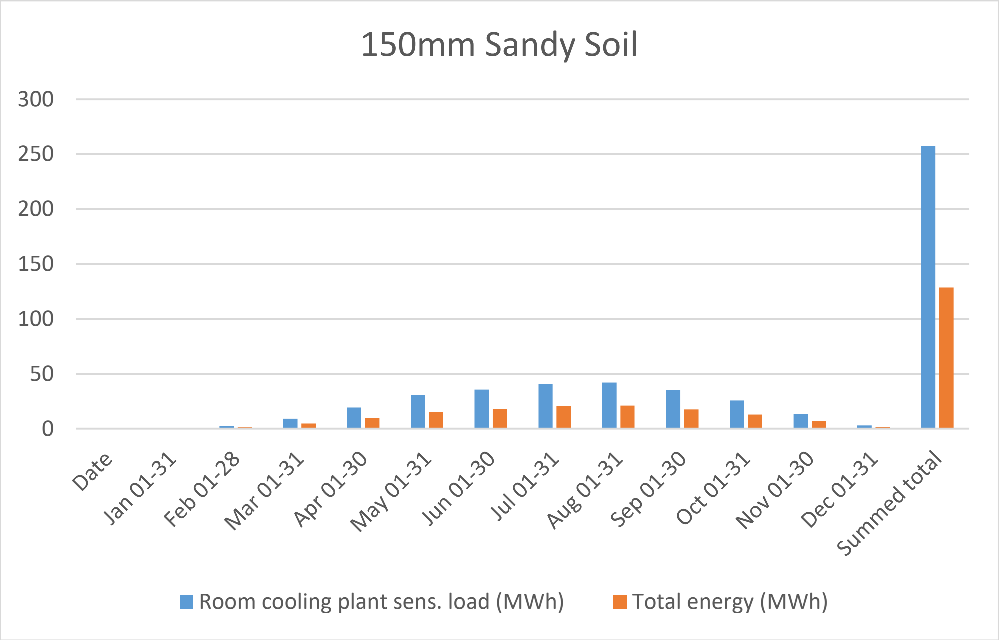


Figure 4.23 sandy soil 150mm results (Author2021)

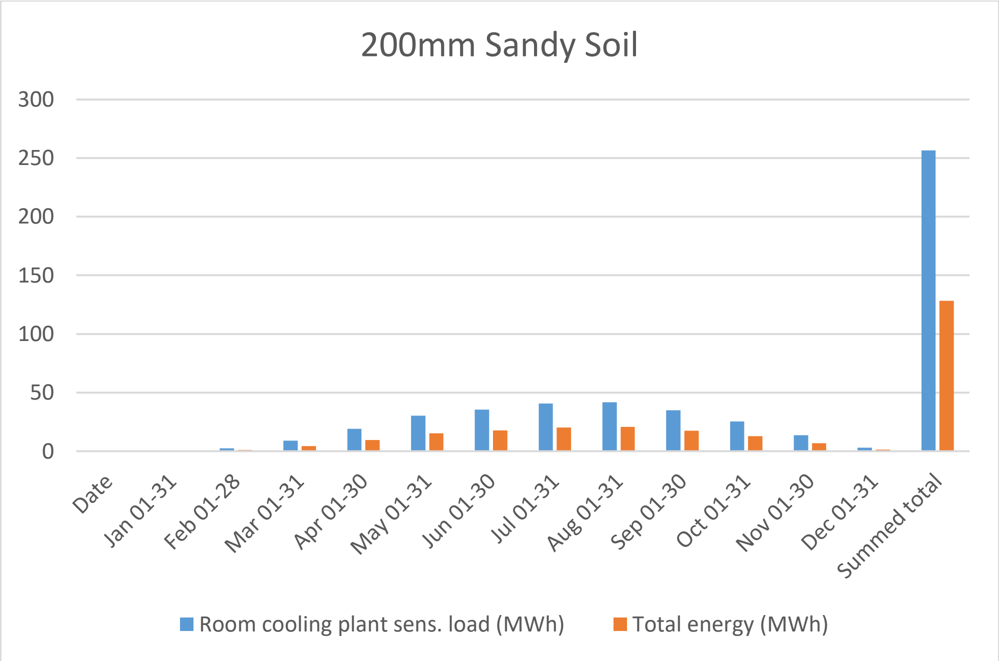


Figure 4.24 sandy soil 200mm results (Author2021)

The green roofing reduction was varying from 1.56% to 7.29% as shown Figure 4.25, and that related to the type and thickness of soil, which caused in changing the U-value, but kept the R-value the same, which is 1.6752 m^2K/W. The peat soil reduced energy consumption more than sandy soil, even when the thickness of the peat soil less than the sandy soil as shown in Figure 4.25, the 100mm peat soil is more efficient than the 200mm sandy soil. Because the U-value for peat soil less than sandy soil`s U-value, as well as the conductivity for peat soil less than sandy soil`s conductivity. The higher reduction has the lower U-value as shown in Table 4-8. However, with any type of soil, increasing the thickness can help in increasing the effectiveness of the green roofing. The layers of green roofing are the same in whole scenarios, except the top cultivated soil layer was changing. The other layers below the cultivated soil from to bottom were gravel, bitumen layers, membrane, expanded polystyrene, membrane, screed, and reinforced concrete. Each layer has its own thickness, density and conductivity, which help in reducing heat transfer and therefore energy consumption.

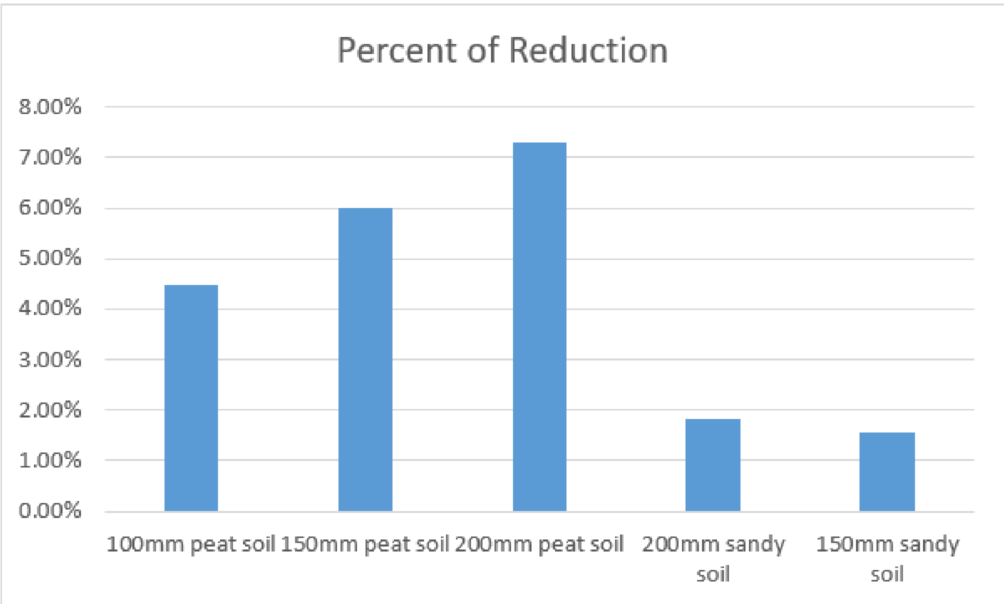


Figure 4.25 green roofing scenarios (Author2021)

Table 4-8 the U-value and reduction percentage of each soil type and thickness (Author2021)

Type of soil	Reduction percentage	U-value
Peat soil 100mm	4.47%	0.4350 W/m²K
Peat soil 150mm	6.00%	0.4046 W/m²K
Peat soil 200mm	7.29%	0.3782 W/m²K
Sandy soil 150mm	1.56%	0.4907 W/m²K
Sandy soil 200mm	1.81%	0.4841 W/m²K

4.2.2.4 Shading Strategy

Use the shading with any opening can help in reducing the energy consumption of any building. By providing shades, it prevents direct sunrays from entering the interior space; therefore, can reduce the temperature inside the building.

4.2.2.4.1 Overhang scenario

The overhang shading fixed on the top of each windows at 90° with depth of 0.5 m. it reduced room cooling load and total energy as shown in Figure 4.26, by 1.21%. They were 258.1808 MWH and 129.0904 MWH, respectively.

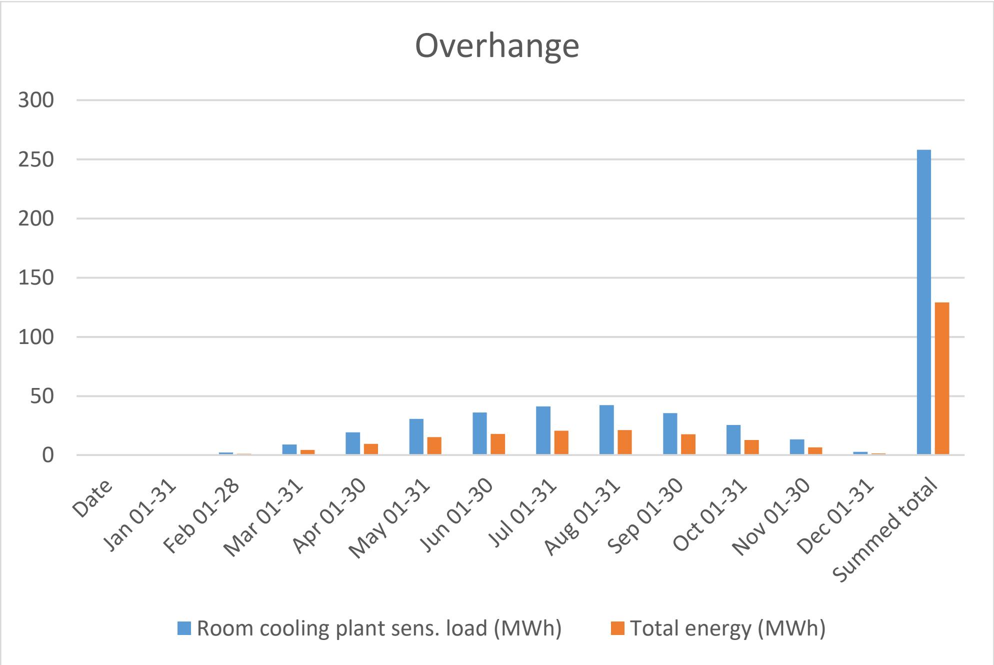


Figure 4.26 overhang shading results (Author2021)

4.2.2.4.2 Overhang with triangular fins scenario

The same previous scenario but adding triangular fins on the both side of each window. As shown in Figure 4.27. The room cooling plant reduced to be 258.1808 MWH and total energy 129.0904 MWH. Which means the same results as overhang only scenario as shown in Figure 4.28. Adding triangular fins will be useless and costly, and it might prevent the penetration natural light to the interior space.

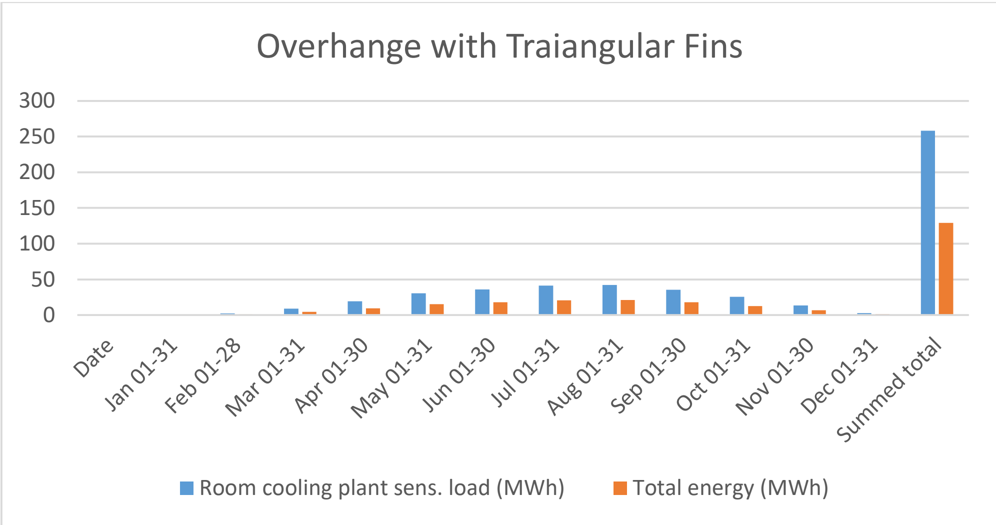


Figure 4.27 overhang shading with triangular fins results (Author2021)

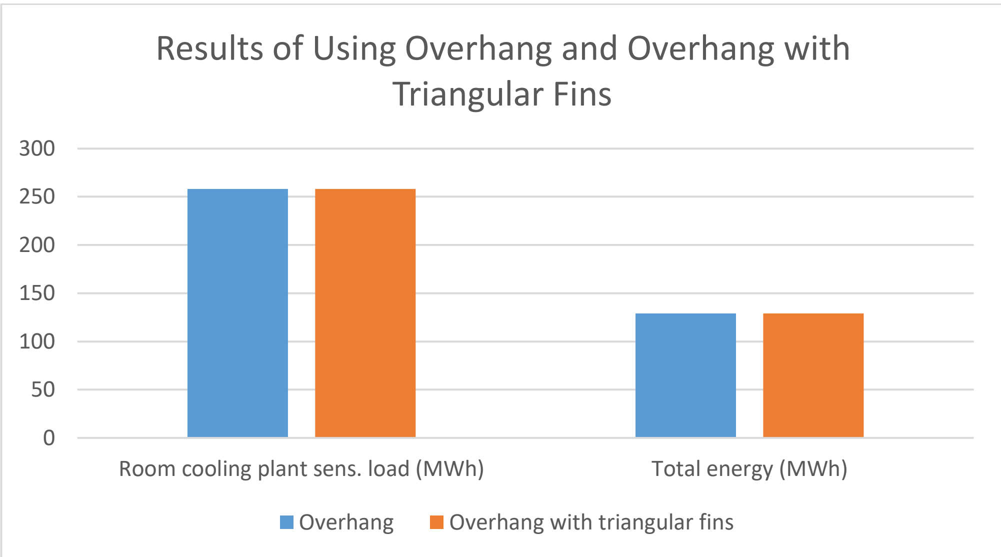


Figure 4.28 Overhang and overhang wit triangular fins results (Author2021)

4.2.2.4.3 Overhang 45° scenario

Changing the angle of overhang can reduce energy consumption, but not effective as overhang 90°. The room cooling load and total energy as shown in Figure 4.29 are 258.7444 MWH and 129.3722 MWH, respectively.

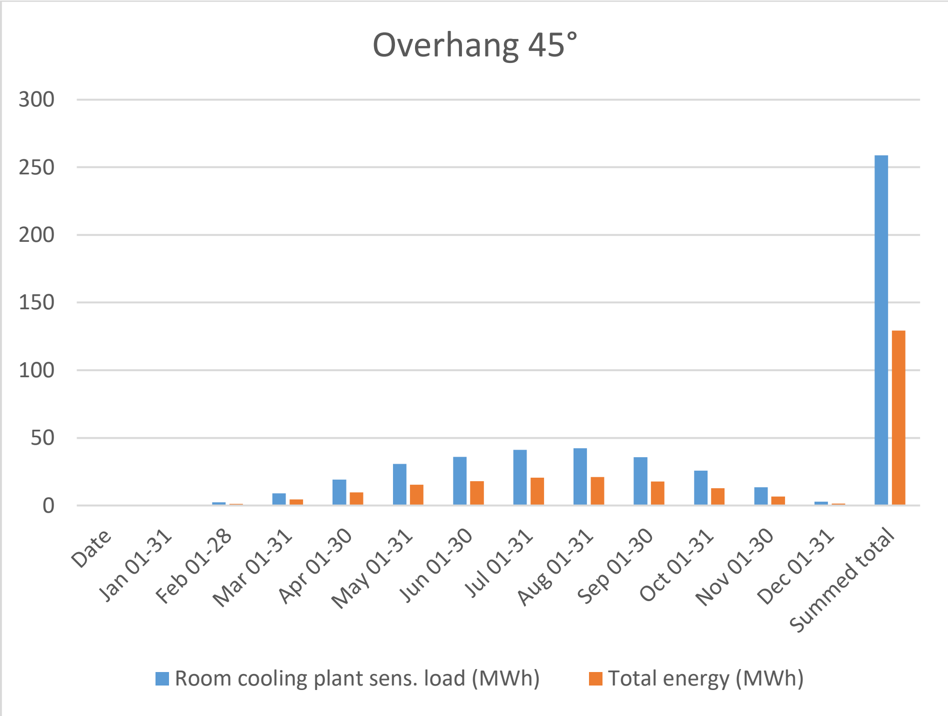
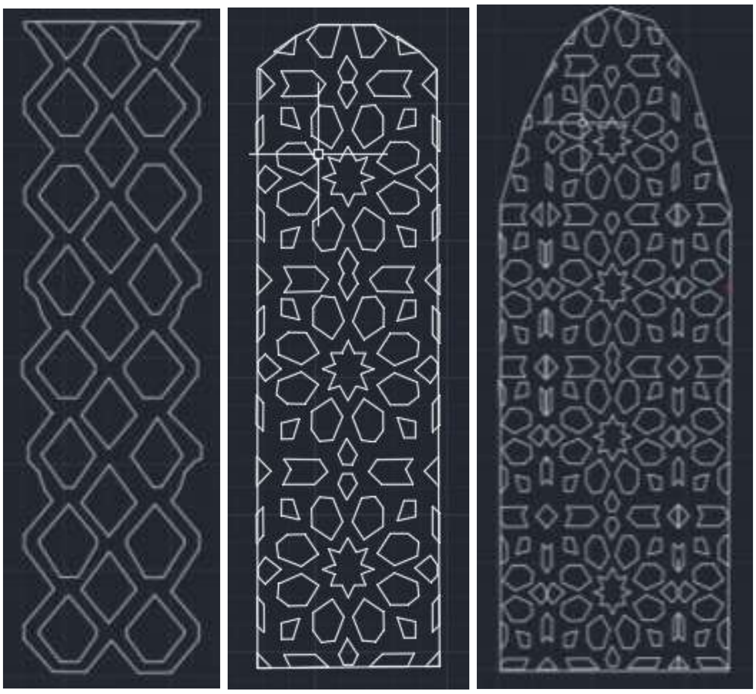


Figure 4.29 overhang shading 45° results (Author2021)

4.2.2.4.4 Mashrabia scenario

Mashrabia provide shading, it is the most suitable design with the mosques, aesthetically, and related to Islamic patterns and history. It used in the past for different building types such as house to provide shading and privacy to the interior space. Three designs of Mashrabia used in the simulation as shown in Figure 4.30 (a,b,c). the design of Figure 4.30 a, used with the windows in the first floor, where the window total area 54 m^2, and glazing area 26 m^2, which is the area of glazing after applying the shading. The design of

Figure 4.30 b, used with the windows in the second floor, where the window total area 40 m^2, and glazing area 16 m^2, which is the area of glazing after applying the shading. The design of Figure 4.30 c, used with the windows in the dome, where the window total area 85 m^2, and glazing area 32 m^2, which is the area of glazing after applying the shading. The reduction from using the mashrabia shading shown in Figure 4.31. The room cooling plant and total energy were 258.3328 MWH and 129.1660 MWH, respectively.



(a) (b) (c)

Figure 4.30 shows the three Mashrabia design used in the building (Author2021)

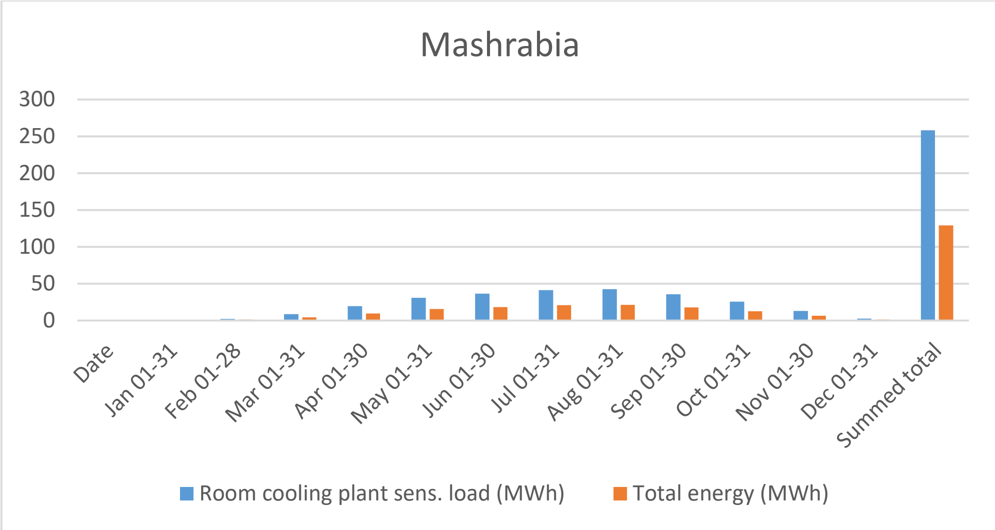


Figure 4.31 mashrabia shading results (Author2021)

The reduction percentage from using mashrabia shading was 1.15%, which is less effective than overhang shading. As shown in Figure 4.32, the most effective shading was overhang and overhang with triangular fins, then mashrabia in the second place. The least effective was overhang with tilt angle 45°.

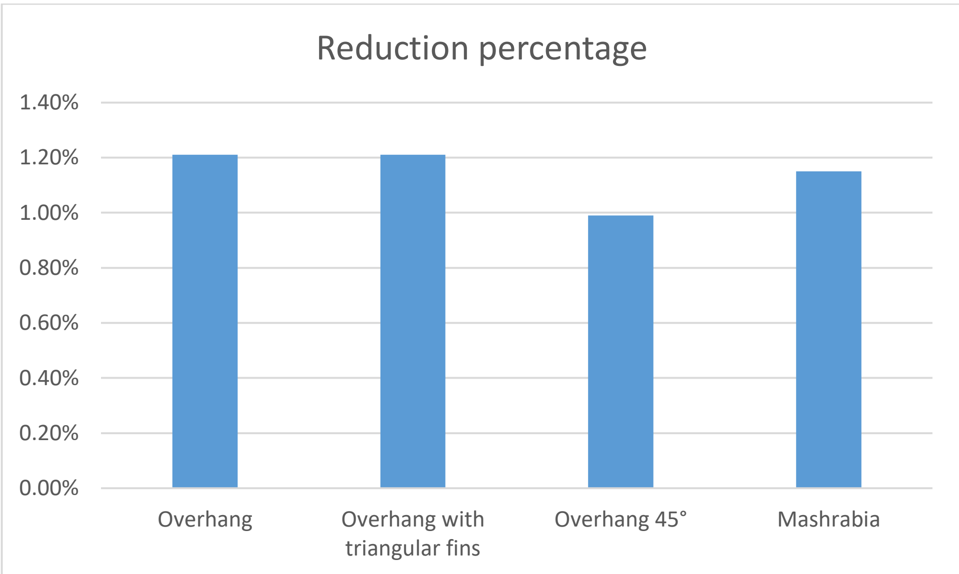


Figure 4.32 reduction percentage from each shading scenario (Author2021)

4.2.3 Third stage: Photovoltaic Strategy

4.2.3.1 Applying PV to the base case

After applying different strategies and scenarios. PV panels system applied on the base case, on the rooftop. The types of PV panels used in the simulation were polycrystalline silicon, which is the favorable in UAE because it has high temperature coefficient that helps withstand high temperatures such as the temperature in UAE, where it can reach in summer till 47°. Based on experiment done in UAE by Waqarullah Kazim (Kazim 2015), and by using shams Dubai calculator (DEWA 2021), the slope of PV panels was fixed for the whole year at 25°, which is the most suitable angle in UAE, and directed toward south direction as shown in Figure 4.33. The size of each panel used was the same size of panels used in experiment done by Waqarullah Kazim, which is about 1.94m^2 (Kazim 2015).

Figure 4.33 DEWA calculation for the best angel and direction for PV panels (DEWA 2021)

The PV panel’s simulation was first done on the base case, and the results as presented in Figure 4.34, showed that each 100 m^2 produce 28 MWH. As the base case results, the total energy consumption is 130 MWH, so it requires about 465 m^2 of panels to be enough for the mosque. However, apply PV with the best scenario of each strategy can be done with insulation, shading and glazing scenarios only. Green roofing cannot be applied with the PV panels, because the roof can be used either for green roofing or for PVs. There are two option, the first is combining the whole strategies together without PV panels and calculate how much reduction can be achieved. The second option is applying PV panels with glazing, shading and insulation strategies only.

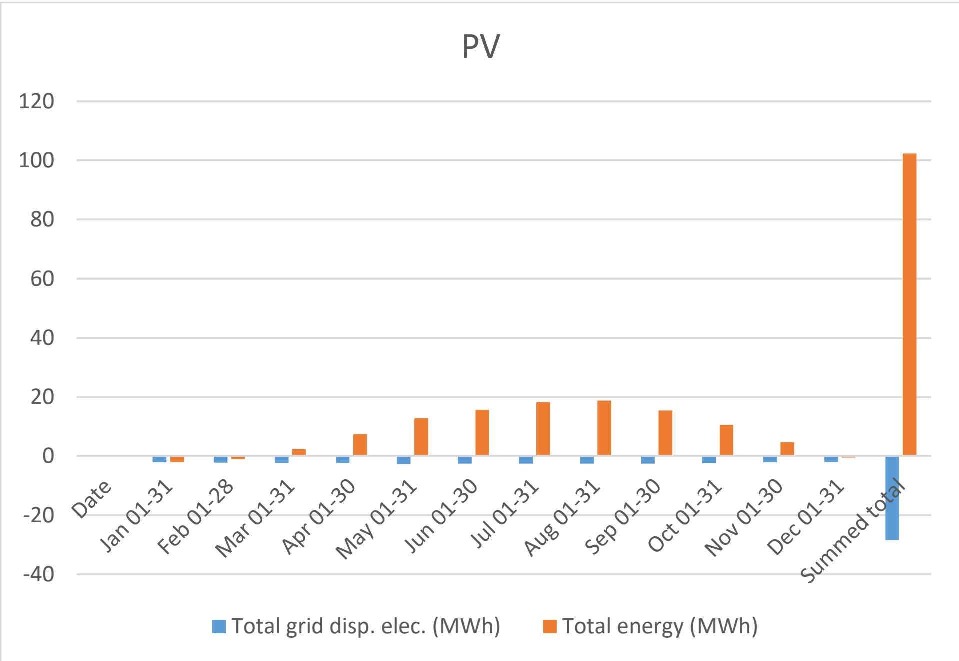


Figure 4.34 adding PV panels to the base case (Author 2021)

The negative results in Figure 4.34 shows that the PV panels produce extra energy than required, which can be used for other purposes that need energy.

4.2.3.2 Combining together the best scenario from each strategy without PV panels

By combining the best scenario from each strategy, which are polystyrene insulation, triple glazing filled with CO^2 in the first cavity and vacuum in the second cavity, overhang shading 90° and green roofing with 200 mm cultivated peat soil. The total reduction of total energy consumption reached 57.35%. room cooling plant load reduced till 111.457 MWH, and total energy 55.7285 MWH.

There are two best scenarios of shadings, which are overhang 90° and overhang with triangular fins. But the best chosen shading is overhang 90° without fins, because adding the fins will not effect on reducing the energy consumption, but it might increase the cost of shading because of the materials and fixing that required for the fins.

4.2.3.3 Adding PV panels with best scenario of glazing, insulation and shading

By adding PV panels, the green roofing should be removed because the roof can be used either for PV panels or for green roofing. The best scenario of glazing, insulation and shading are the same scenarios that used in combining together the best scenario from each strategy without PV panels. The reduction was about 49.66%, where room cooling plant and total energy reached 131.5468 MWH and 65.7734 MWH, respectively. Adding PV panels will generate about 28.4 MWH with every 100 m^2, increasing the area till 200 m^2 will generate about 56.8 MWH. And therefore, the mosque will consume about 8.9 MWH as total energy. The total roof area is 1550 m^2, without the dome area. If the roof filled with PV panels will generate extra electricity that can be used for other functions.

In Figure 4.35 and Figure 4.36, show the reduction in the annual room cooling plant load and total energy respectively, when using the different strategies and scenarios and the variations between them. In Figure 4.37 presents the percentage in reducing the annual cooling plant load and total energy. The most effective strategy in reducing the energy was the insulation, where its conductivity is 0.16 W/mK, which is lower than the conductivity of the other strategies. In addition, it has the lowest thermal transmittance that known as the U-value and highest R-value, which is the ability of material to resist heat flow. The base case U-value was 1.3462 W/m²K for normal concrete wall sandwich with 60mm air cavity in between. But when using insulations, the maximum reduction was about 47.17% when using polystyrene insulation with thickness of 150 mm and U-value of 0.1798 W/m²K and R-value of 5.3923 m^2K/W, while the lowest reduction was about 36.51% by using 60 mm of expanded polystyrene with U-value of 0.4391 W/m²K and R-value of 2.1071 m^2K/W. The other simulated types of insulations were also effective in similar percentages about 44.00%, 42.23% and 41.13% when using rock wool, polyurethane and glass wool respectively. Increasing the thickness of the insulation can increase its effectiveness. However, some types such as glass wool have higher thickness and density than polyurethane but it less efficient than it is. On the other hand, the least effective strategy was the glazing, because it has the highest U-value and the lowest R-value. Its conductivity is 1.0600 W/mK. The conductivity of glazing is higher than insulation strategy, so it has higher heat transfer which cause to reduce the efficiency. The maximum reduction was 1.31% when using triple glazing with CO^2 in the cavity between the outer pane and the middle pane and vacuum in the second cavity between the middle and inner panes. The least reduction in glazing scenarios and the other strategies was 0.70% when using double-glazing with argon gas, because it has the highest U-value about 1.4643 W/m²K, and the lowest R-value about 0.9092 m^2K/W. The other glazing types reduced energy consumption about 0.84% when using both double-glazing with 9mm krypton gas and triple glazing with argon gas as shown in Figure 4.38. Because both scenarios have similar U-value R-value about 1.37 W/m²K and 1.00 m^2K/W respectively. When comparing insulation and glazing strategies in Figure 4.39. there are big difference between their effectiveness, due to the high variation between their U-value and R-value as shown in Table 4-9.

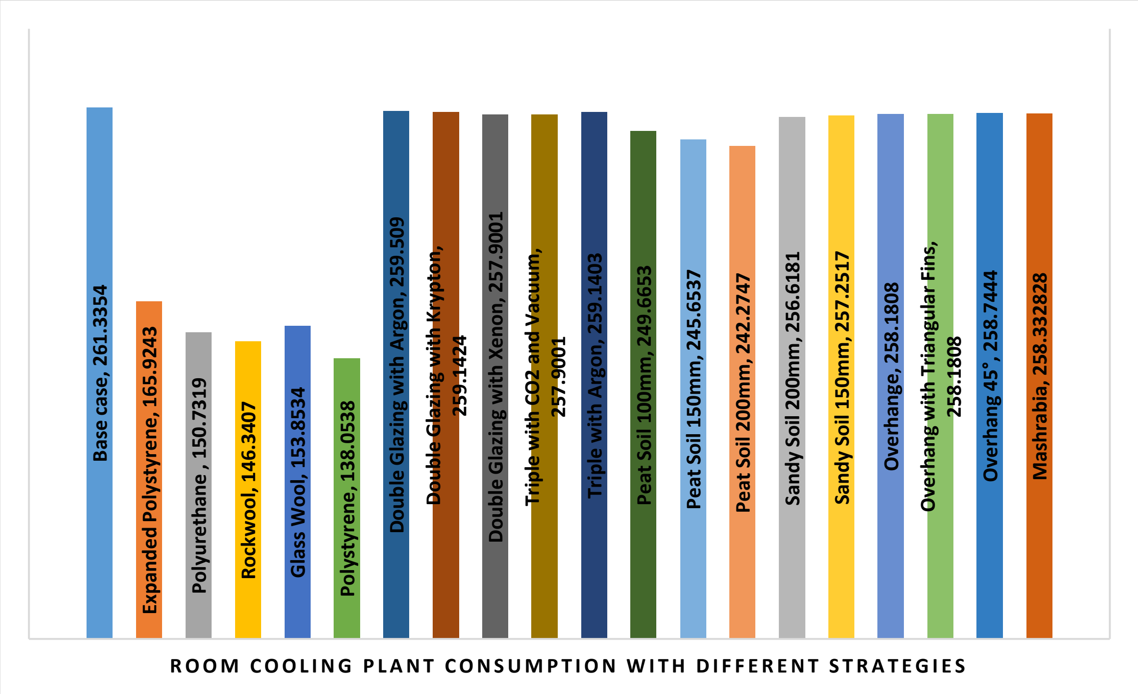


Figure 4.35 shows room cooling plant load with using different strategies (Author 2021)

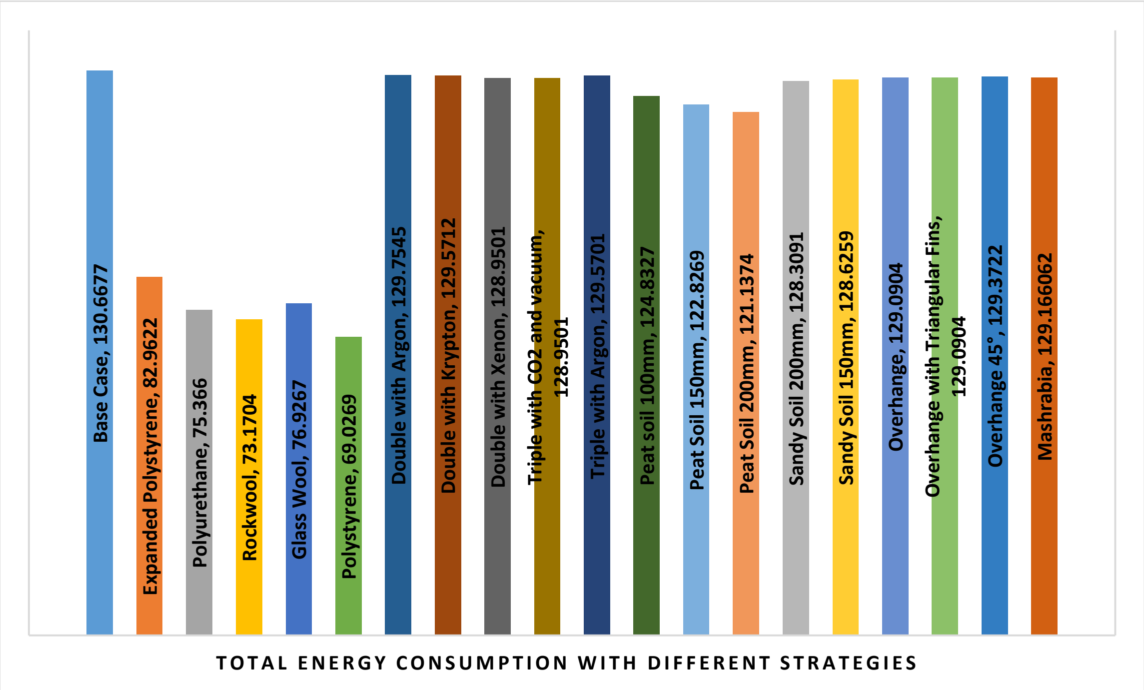


Figure 4.36 shows Total energy consumption with using different strategies (Author2021)

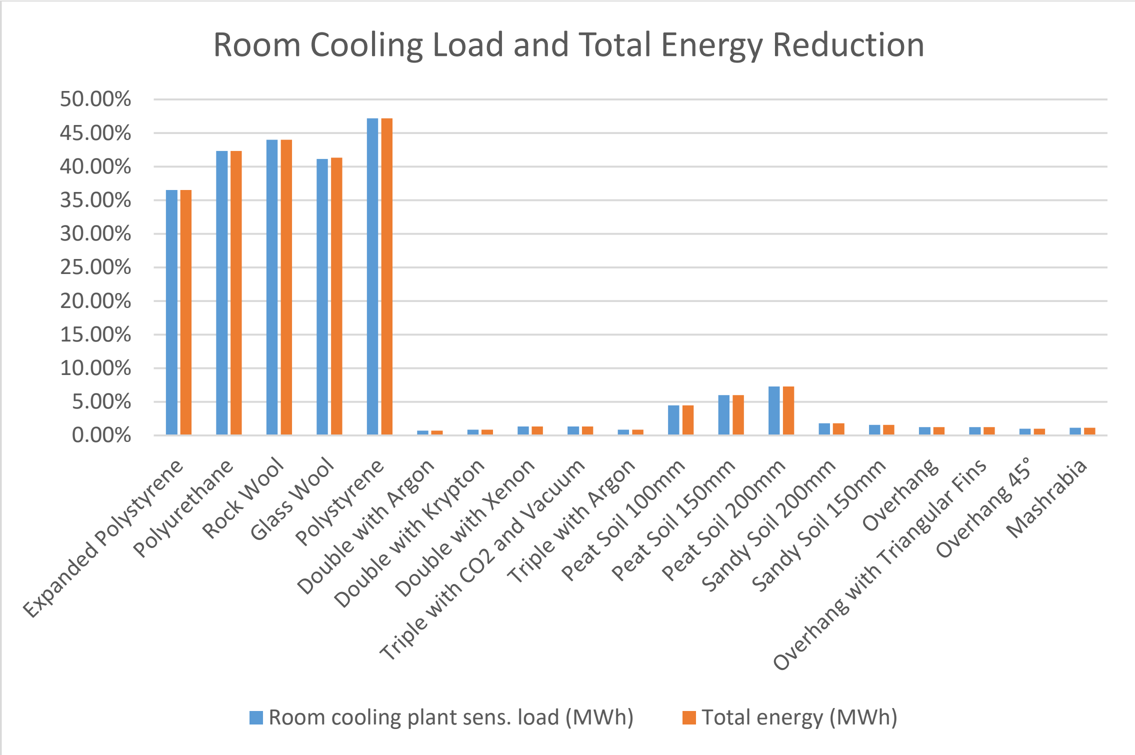


Figure 4.37 shows room cooling load and total energy reduction for different strategies (Author2021)

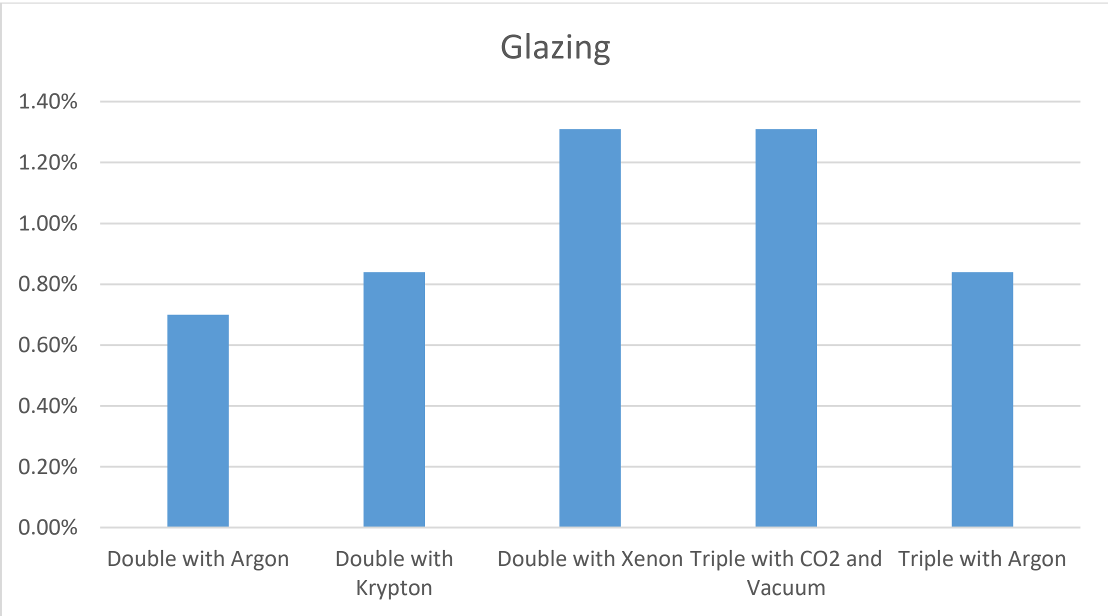


Figure 4.38 shows the reduction in total energy when using different scenarios from glazing strategy (Author2021)

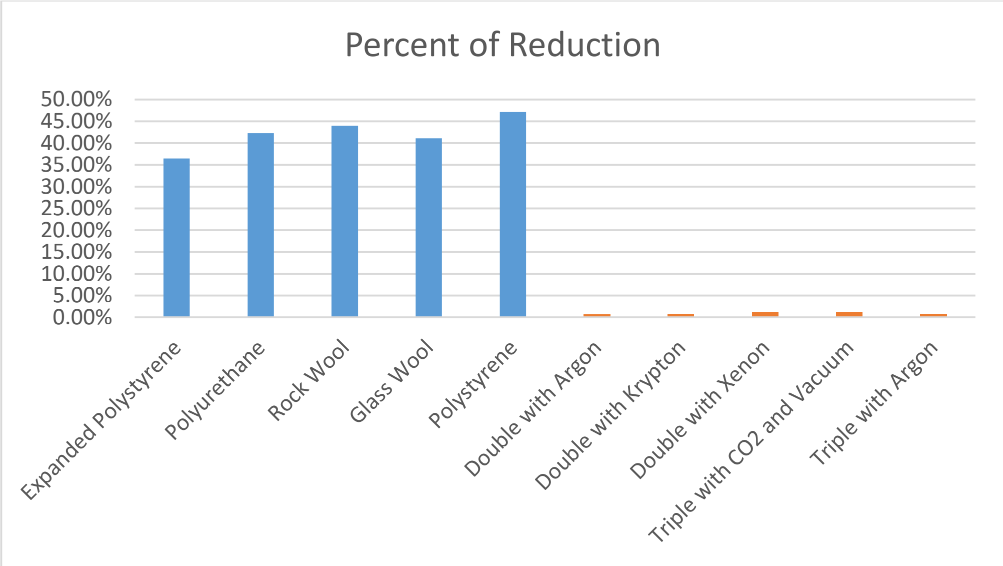


Figure 4.39 compare between insulation and glazing (Author2021)

Table 4-9 compare U-value and R-value for insulation and glazing strategy (Author2021)

Types of Insulation and Glazing	U-value	R-value
Expanded polystyrene	0.4391 W/m²K	2.1071 m²K/W
Polyurethane	0.2974 W/m²K	3.1929 m²K/W
Rock wool	0.2567 W/m²K	3.7262 m²K/W
Glass wool	0.3265 W/m²K	2.8929 m²K/W
polystyrene	0.1798 W/m²K	5.3929 m²K/W
Double-glazing with 16 mm argon	1.4643 W/m²K	0.9092 m²K/W
Double-glazing with 9 mm krypton	1.37 W/m²K	1.0049 m²K/W
Double-glazing with 12 mm xenon	1.2856 W/m²K	1.1095 m²K/W
Triple with CO^2 and vacuum	0.9161 W/m²K	2.0376 m²K/W
Triple with argon	1.37 W/m²K	1.0012 m²K/W

The shadings strategy includes four scenarios. The scenarios and design of shadings used shown in Figure 4.40. The best scenario is less efficient than the best scenarios in the glazing strategy, while the less effective scenario in the shading strategy is more efficient than other scenarios in the glazing strategy as shown in Figure 4.41. The most efficient scenarios in the shading strategy were overhang with 90° and overhang with triangular fins with reduction percentage of 1.21%, then mashrabia comes in the second place with reduction about 1.15%, and the least reduction was 0.99% for overhang tilted 45°. The shading strategy included only four scenarios because the simulation results were very close to each other, and as a mosque, not all shading types can be used with it from the aesthetic side, so even if simulation will be done for different types of shadings, it will not be used when building a real mosque.

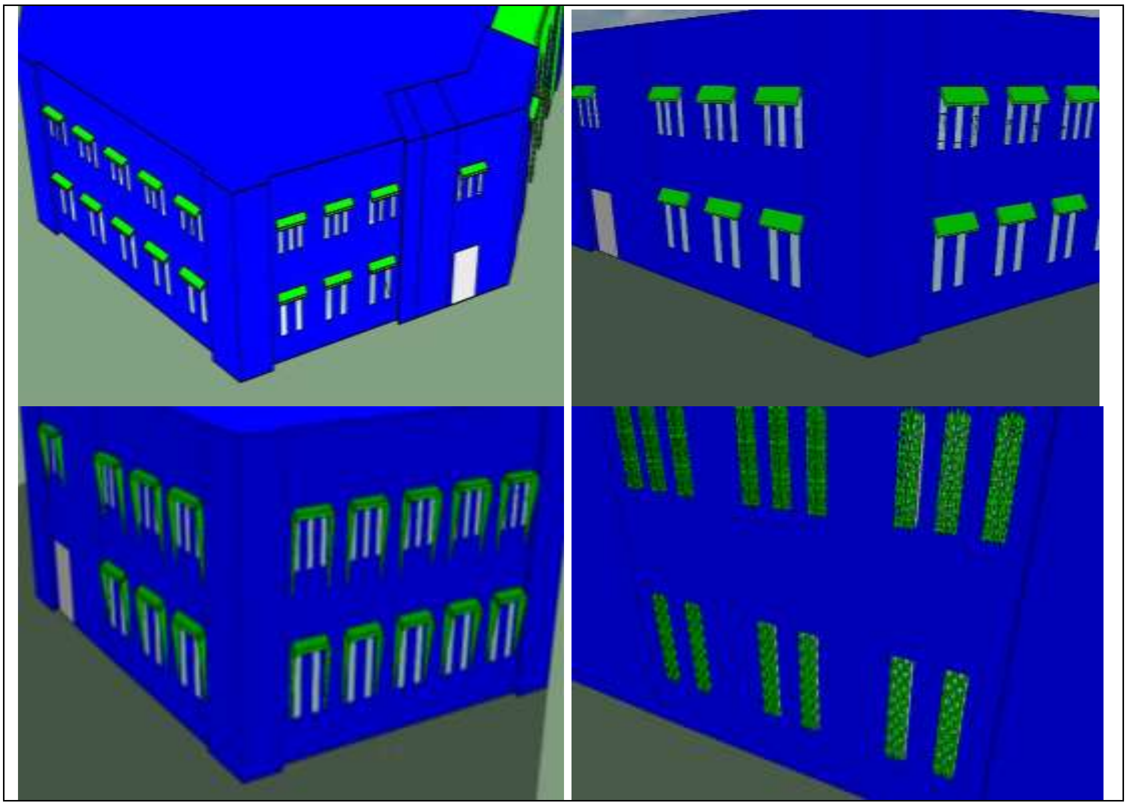


Figure 4.40 the different shadings design used in simulation (Author2021)

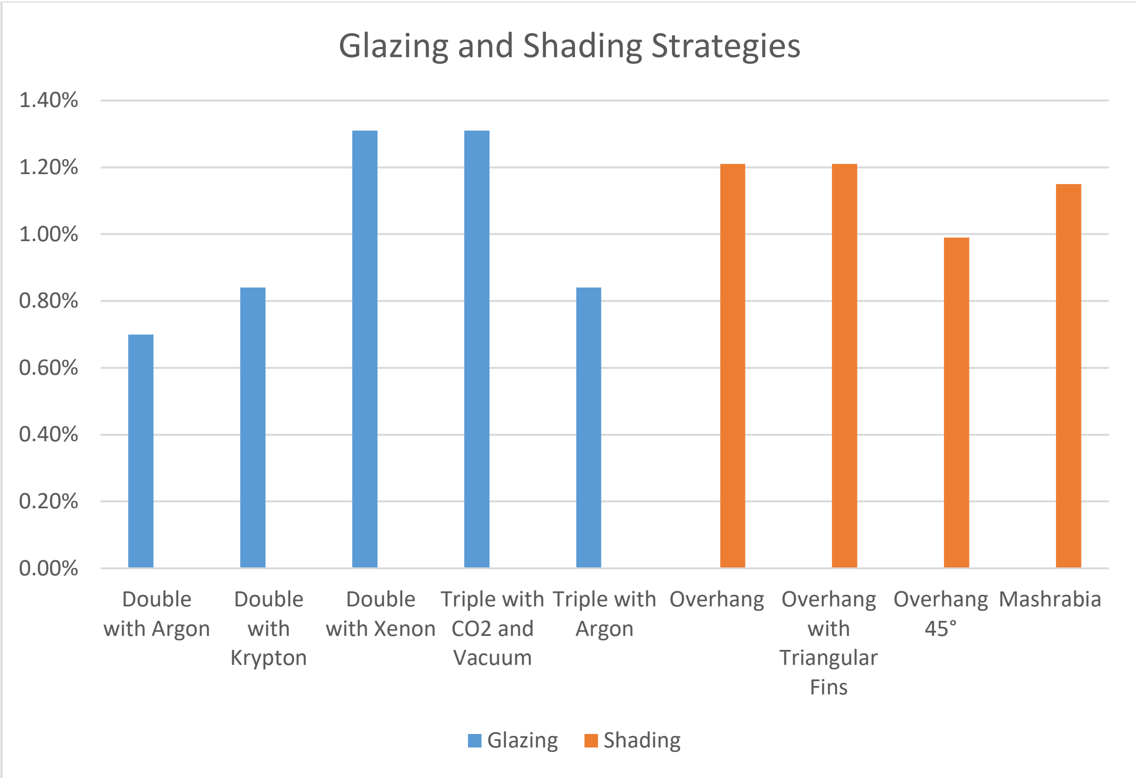


Figure 4.41 the difference between glazing and shading strategies efficiency (Author2021)

The green roofing results was better than glazing and shading strategies as shown in Figure 4.42. The green roofing have better U-value and R-value than the glazing strategy have as shown in Table 4-10. but it is not good as insulation results as shown Figure 4.43. Where the U-value and R-value of the insulation are much better than green roofing have as presented in Table 4-11. Therefore, the insulation is the best strategy used in this paper.

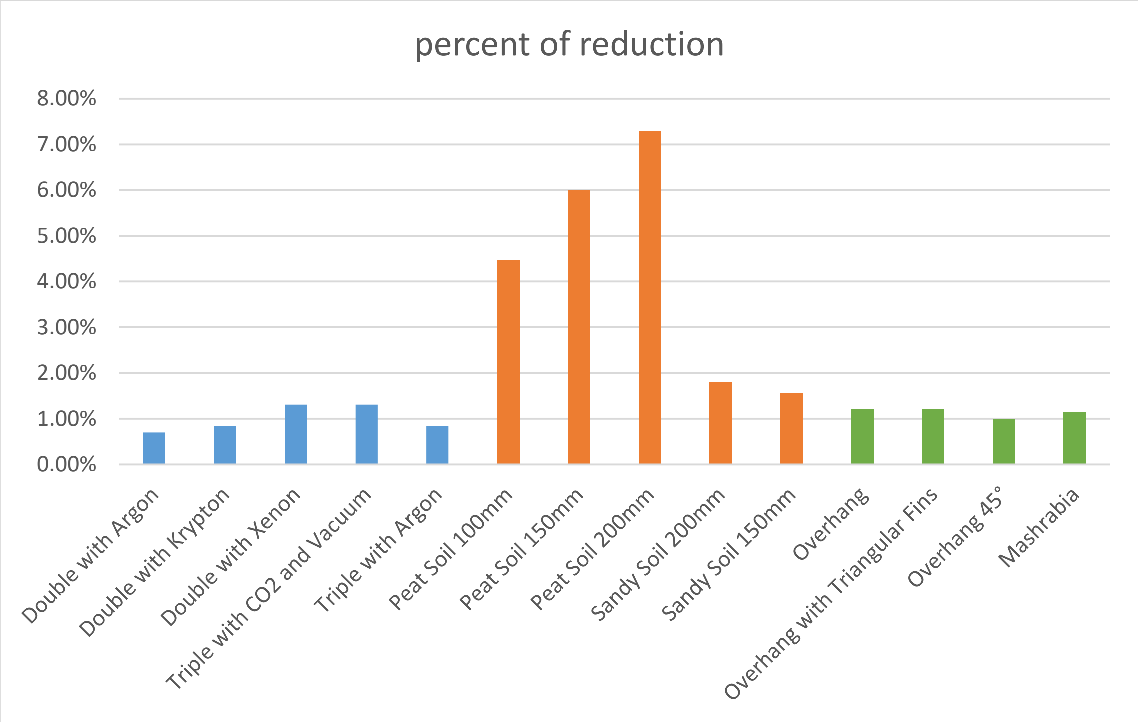


Figure 4.42 compare between glazing, green roofing and shading strategies (Author2021)

Table 4-10 the U-value and R-value for green roofing and glazing strategies (Author2021)

Types of Green Roofing and Glazing	U-value	R-value
Cultivated peat soil 100 mm	0.4350 W/m²K	1.6752 m²K/W
Cultivated peat soil 150 mm	0.4046 W/m²K	1.6752 m²K/W
Cultivated peat soil 200 mm	0.3782 W/m²K	1.6752 m²K/W
Cultivated sandy soil 150 mm	0.4907 W/m²K	1.6752 m²K/W
Cultivated sandy soil 200 mm	0.4841 W/m²K	1.6752 m²K/W
Double-glazing with 16 mm argon	1.4643 W/m²K	0.9092 m²K/W
Double-glazing with 9 mm krypton	1.37 W/m²K	1.0049 m²K/W
Double-glazing with 12 mm xenon	1.2856 W/m²K	1.1095 m²K/W
Triple with CO^2 and vacuum	0.9161 W/m²K	2.0376 m²K/W
Triple with argon	1.37 W/m²K	1.0012 m²K/W

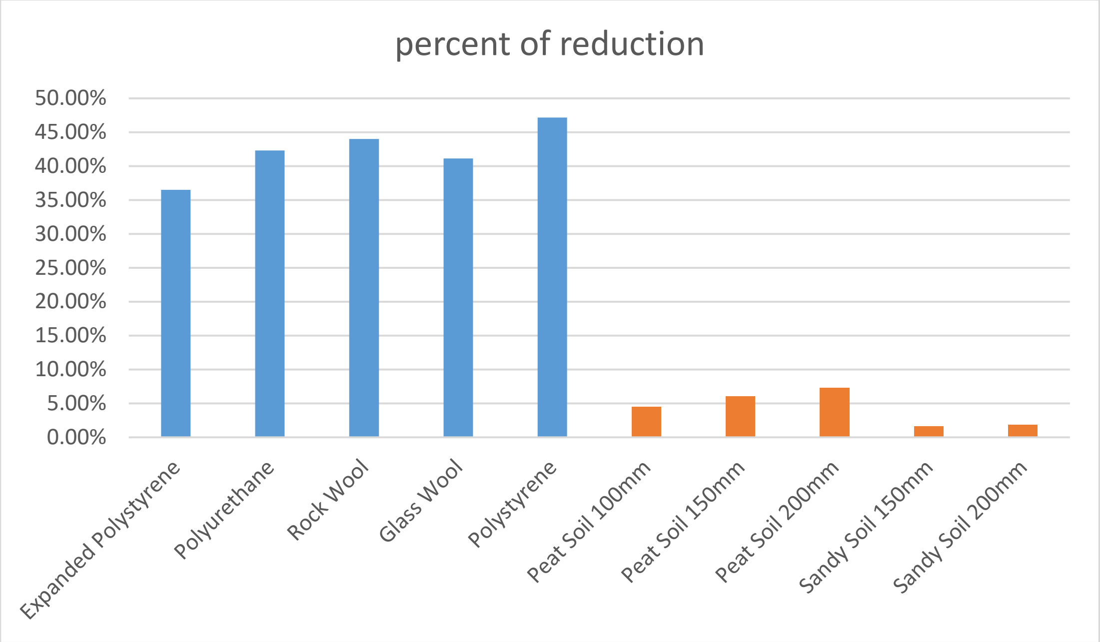


Figure 4.43 compare between insulation and green roofing strategies (Author2021)

Table 4-11 the U-value and R-value for green roofing and insulation strategies (Author2021)

Types of Green Roofing and Glazing	U-value	R-value
Cultivated peat soil 100 mm	0.4350 W/m²K	1.6752 m²K/W
Cultivated peat soil 150 mm	0.4046 W/m²K	1.6752 m²K/W
Cultivated peat soil 200 mm	0.3782 W/m²K	1.6752 m²K/W
Cultivated sandy soil 150 mm	0.4907 W/m²K	1.6752 m²K/W
Cultivated sandy soil 200 mm	0.4841 W/m²K	1.6752 m²K/W
Expanded polystyrene	0.4391 W/m²K	2.1071 m²K/W
Polyurethane	0.2974 W/m²K	3.1929 m²K/W
Rock wool	0.2567 W/m²K	3.7262 m²K/W
Glass wool	0.3265 W/m²K	2.8929 m²K/W
polystyrene	0.1798 W/m²K	5.3929 m²K/W

The conductivity for each strategy was differ as shown in Table 4-12, which caused changing the amount of energy consumption. The conductivity of the green roofing differs, and each type has different conductivity. The cultivated peat soil`s conductivity was 0.29 W/mK, while the cultivated sandy soil was 1.79 W/mK. The thickness of the soil did not affect conductivity but the soil`s moisture did, where the moisture of the cultivated peat soil is 133%, while for cultivated sandy soil is 12.5%.

Table 4-12 conductivity for each strategy (Author2021)

Strategy	Conductivity
Insulation	0.16 W/mK
Glazing	1.06 W/mK
Green roofing	0.29/mK, 1.79 W/mK

4.3 Relating the research results to results from the literature

By reviewing the literary research and research on the same topic, we find that the insulation strategy has the biggest influence in reducing energy consumption in mosques reached until 10%, and reducing the U-value reduced the heat gain by 20%. (Amatullah & Halipah 2020). The energy consumption reduction reached up to 22% with using insulation, and increasing the thickness of insulation, reduced energy consumption and the most efficient insulation type was polyurethane (Ahmed 2019). In this paper, the best type was polystyrene insulation because the thickness for polystyrene was more than the thickness for polyurethane, where it was 150mm and 70mm for polystyrene and polyurethane, respectively. Ma et al. (2020) proved that when using krypton gas with double glazing is better than argon gas and air, which similar to this paper results, and the thickness of gas layer improve the effectiveness of glazing type. The triple glazing with CO^2 and vacuum showed better performance than different types of glazing (William et al. 2019), which is the same result in this paper. It was more efficient than other glazing types. Using different shading types reduced energy consumption of the building, however using overhang type and overhang with triangular fins have almost the same effect on reducing the energy consumption, which is similar to the result found by Ghosh & Neogi (2018), where the building consume almost same amount of energy about 1009 MJ/m^2 and 1002 MJ/m^2, for overhang and overhang with triangular fins, respectively. The reduction percentage were 3.0% for overhang, and 3.61 for overhang with triangular fins. In this study, the tilted overhang reduced energy consumption by 0.99%, which is less than the overhang, but as a study done by Taleb (2014), the tilted overhang block the solar heat in addition to provide lighting to the interior space. The green roofing strategy has a great impact on reducing cooling load and total energy as shown in Figure 4.25. The tilted angel for PV panels were 25°, which was calculated in shams Dubai calculator (DEWA 2021). Kazim (2015) also used 25° as tilted angle for PV panels that he used in his experiment, as it is the optimal angle in UAE. Alantali, Alzarouni & Alhammadi (2020) evaluate three common angle, which are 90°, 25°, and 0° for BIPV and BAPV in Dubai. The PV panels used is polycrystalline silicon, because it is more preferred type to be used in hot weathers (Said & Mehmood 2017), where they have higher temperature coefficient (Alhammami & An 2020).

4.4 Summary

The insulation strategy is the most effective strategy, where it provides the maximum reduction. While glazing the least effective one. The most effective scenario with insulation strategy was by using polystyrene insulation, which reduced about 47.17% from room cooling load and total energy. While The least effective scenario was by using polyurethane, where the reduction reached 32%. The maximum reduction with glazing strategy was by applying triple glazing window with CO^2 in the first cavity from the outside and vacuum in the second cavity, which reduced about 1.31% from room cooling load and total energy. While The minimum reduction was about 0.70% by using double glazing with 16 mm argon.

The results of shading strategy were close to those of glazing, with a slight difference, which gives preference to shading strategy.

Green roofing strategy had better results than glazing and shading strategies. But it doesn't reach the efficiency of thermal insulation, as there is a big difference between them. The use of green roofs with peat soil with the largest possible thickness of about 200 mm, led to the best result as it helped reduce room cooling load and total energy consumption by 7.29%. While using sandy soil with 150 mm thickness was the least effective studied type of soils in green roofing. It reduced energy consumption by 1.56%.

Using polycrystalline silicon that is the most suitable type of PVs, which can tolerate the high temperature in UAE, as a clean source to generate electricity for the mosque, which helped generating 28 MWH for every 100 m^2, and the roof area is 1550 m^2, so the mosque can be self-sufficient during daytime.

CHAPTER FIVE

CONCLUSION

5 CONCLUSION

5.1 Summary

This article is all about the using passive strategies to save the energy in mosques for long term purposes. These passive strategies give us the way to look forward for future to have some sustainable changes in the system and the approach with we live and consume the resources of nature in an efficient way. To create little impacts will be beneficial when all the construction design follows the suit.

The main purpose is to provide a thermal comfort environment for the worshipper inside the mosque, but consuming the least amount of energy. And providing the energy needed for lighting, cooling and other purposes by using clean energy sources such as PVs.

In the first part of the study, some studies and literature review on energy reduction in mosques or other domestic buildings using passive strategies. presenting the results of the previous studies and the efficiency ratio of each strategy in each study, where the location and climate might differ. Using simulation method to conduct the study, where it is the most method used for such studies. Where it can save time and give results for the whole year in a short period of time, in addition, it doesn’t cost much, where it requires a computer device and simulation software. IES-VE software used for simulation in this study. Starting simulating the base case, then applying the strategies and scenarios that were selected from the literature review. Each strategy and scenario applied separately. After collecting the results, the best scenario from each strategy was selected then combining them together in one scenario and run the simulation to get the maximum reduction that can achieved. At the end, applying the most used PV panels in UAE with the other strategies without using the green roofing strategy and calculating how much a mosque can be self-sufficient. Then the results were analyzed, discussed and compared, and the results were concluded which scenario is better from each strategy, and then a simulation was conducted using the best scenario from each strategy to find out the maximum possible reduction in energy consumption by using all strategies together. The case study is a mosque located in Dubai, UAE. where the weather is hot and humid. The base case was without insulation, green roofing, shading and PV, and windows are double glazing with air in the cavity. Five different strategies applied on the base case, which are insulation, glazing, shading, green roofing and PV. Each strategy has different scenarios, which have been used in previous studies and articles.

The results conclude that the insulation strategy is the most effective strategy, where it provides the maximum reduction. And the most effective scenario was by using polystyrene insulation, which reduced about 47.17% from room cooling load and total energy.

The maximum reduction with glazing strategy was by applying triple glazing window with CO^2 in the first cavity from the outside and vacuum in the second cavity, which reduced about 1.31% from room cooling load and total energy.

The use of green roofs with peat soil with the largest possible thickness of about 200 mm, led to the best result as it helped reduce room cooling load and total energy consumption by 7.29%.

Overhang shading was the best scenario in reducing room cooling load and total energy consumption by 1.21%.

The minimum reduction was with glazing strategy, by using double glazing with 16 mm argon. The least effective scenario with insulation by using polyurethane, where the reduction reached 32%. Using sandy soil with 150 mm thickness was the least effective studied type of soils in green roofing. It reduced energy consumption by 1.56%. using overhang shading with tilt angel of 45°, reduced total energy consumption by 0.99%, which is the least effective scenario in shading strategy.

Using polycrystalline silicon that is the most suitable type of PVs, which can tolerate the high temperature in UAE, as a clean source to generate electricity for the mosque, which helped generating 28 MWH for every 100 m^2, and the roof area is 1550 m^2, so the mosque can be self-sufficient during daytime.

The results were related to literature and most of them were similar or close the results in other studies. The difference is caused by the change of different factors such as location, climate, and building orientation.

5.2 research Contributions

To conserve the energy, mankind has to find ways to conserve and to less use the energy, so that our future generations could also have this blessing of nature. We will have to implement these strategies to save our energy. A lot of efforts have been made in this regard to search for some strategies to conserve energy.

This research can contribute to building mosques with low energy consumption, by following the strategies used in this research. It can also benefit by following the same strategies and scenarios, whether it is thermal insulation, glazing, shading systems, green roofs and solar panels, in the construction of buildings other than mosques, such as residential buildings and offices, to be buildings with high efficiency and low energy consumption. It is also can help from knowing the efficiency of several types of thermal insulators, glazing, shading systems and green roofs with different thicknesses. For future researchers to have a reference and a basis for their research to develop these strategies and make them more efficient. And can give an information on how these strategies will act in their projects, especially if they have the same climate of Dubai, hot and humid.

5.3 Research limitations and future recommendation

The previous research was limited to five strategies used only, but there are several other strategies that can be tried, such as ventilation in the winter and improving the lighting inside the mosque, whether natural or artificial lighting.

There are several other types of each strategy that is not used in this research, it must be tested and more research conducted on it, as it may be more efficient than the types used in this research and more suitable for the climate of the Emirate of Dubai.

The study was carried out in a hot and humid climate, and the results were a result of the climate, location and degree of inclination of the sun in this region. The results may differ in another place with a climate different from that of Dubai.

Another aspect is that the effect of these strategies are very low. In other words, they need to be applied on most of the buildings to register the difference in consumption at national level. So, the campaigns of awareness will cause the many people to come up and ready to make the change and help conserve energy and strive for a better future.

It was not possible to conduct a visit to the study site, as the study was conducted during the period of the Covid-19 pandemic. All places of worship were closed, and even after they were opened, the opening was limited to prayer time only and to men only for a period of several months.

Modeling shading devices in IES-VE such as Mashrabia was very difficult and slowed down the program and the calculations took a lot of time to complete. In addition, the program stopped for several times due to the great pressure that occurred.

Some studies should be conducted to calculate the cost of the strategies used in this study and compare it with their efficiency in reducing energy consumption to see if they are worth the cost imposed or not.

Suggesting conducting studies on the use of the strategies and scenarios used in this study in other buildings such as residential and office buildings with different size and area, and different glass to wall ratios.

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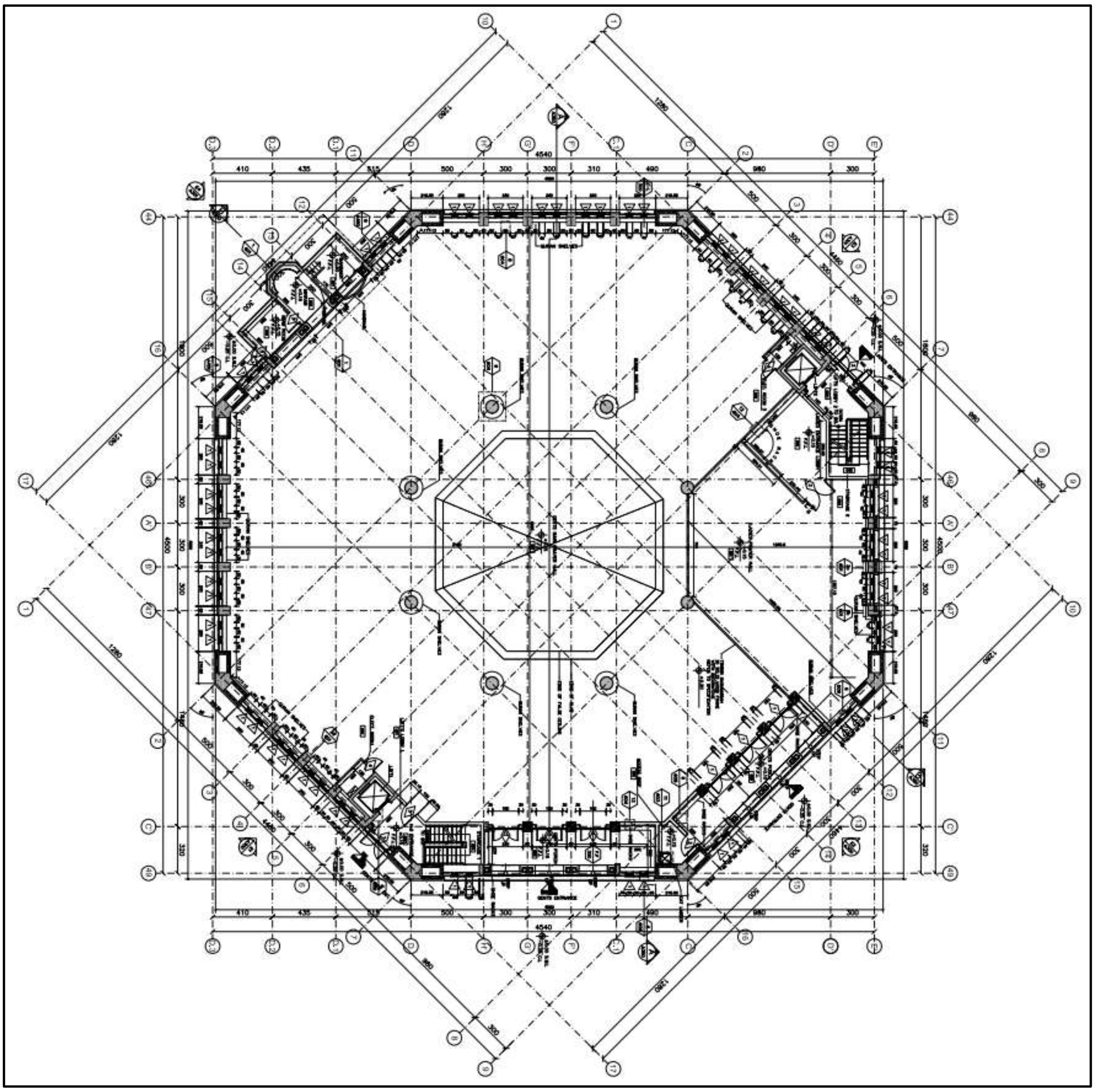
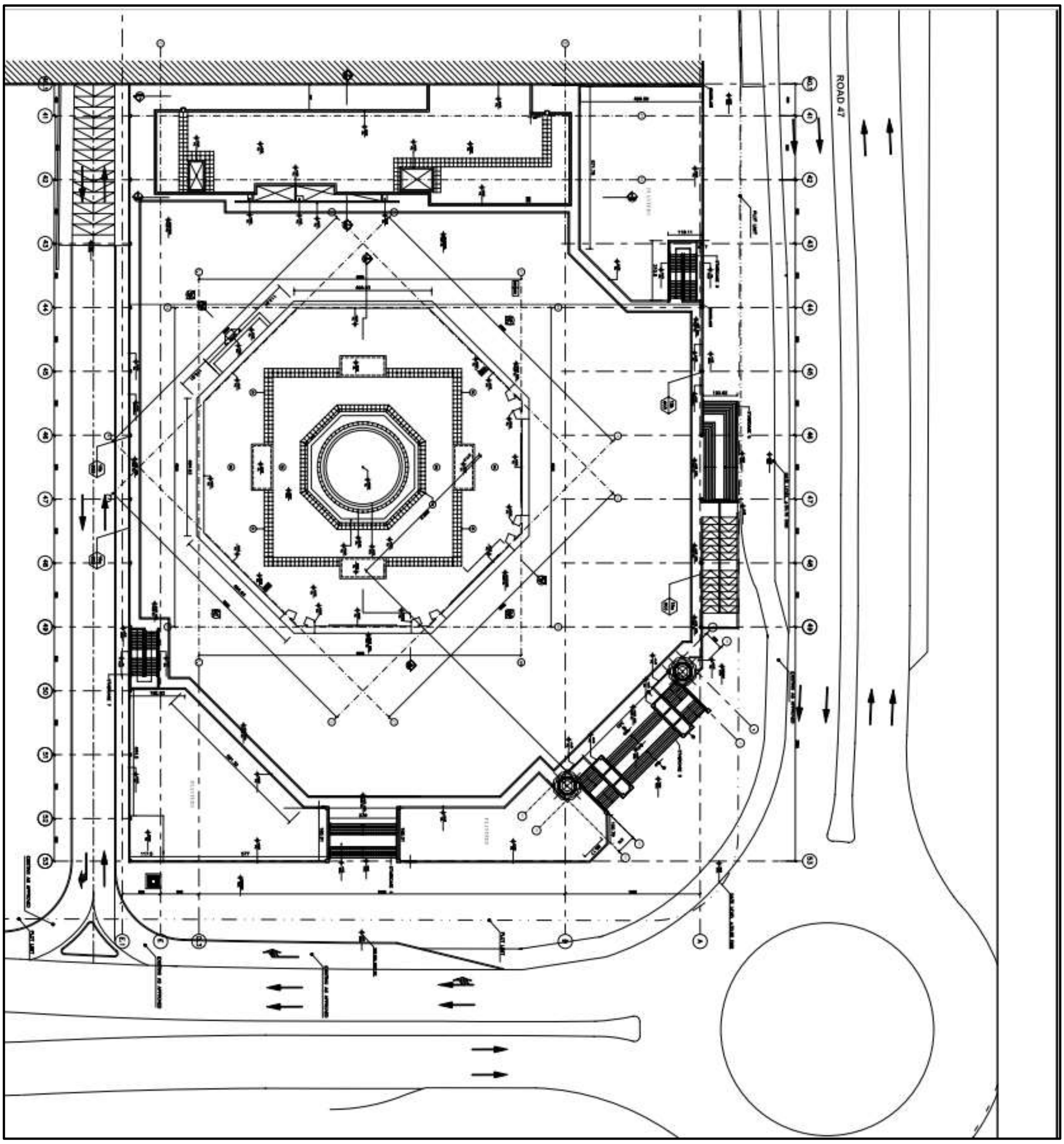
APPENDIX A

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