# GREEN ROOF AND LOUVERS SHADING FOR SUSTAINABLE MOSQUE BUILDINGS IN RIYADH, SAUDI ARABIA

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## Abstract

The number of mosque buildings is continuously increasing with the Muslim population, which is in fast growth around the world. In particular, the demand of new mosque buildings is high in the urban areas, due to increasing urban population growth in many parts of Muslims countries, as a result of economic growth and political instabilities in some parts of the Muslims world. Mosques are becoming more overcrowded and as a result a number of researches have been conducted to address the issue of thermal comfort of mosque users. Additionally, mosque building is unique because of its intermittent operation and various users, which require a unique heating or cooling strategies. On the other hand due to environmental pressure to suppress global warming, more energy efficient and sustainable buildings design is one of the current issues in building industries. This research aims to explore the sustainable techniques for mosque buildings in different climate zones. This research assesses a number of mosques buildings in different parts of the world with different climate; and investigates the strategies employed to cool or heat these buildings depending on the climate and season. The effectiveness of the building features in relation to each climate are carefully analysed, and possibility of potential replication of these features elsewhere are examined. This paper examined two techniques, green roof and louver shading in hot arid climate. The eventual objectives are establishing a guideline for architects and mosques building designer at any climate in order to achieve sustainable mosque building. The study concludes that there is a potential saving of up to 10% in cooling loads when green roof and louvers shading are applied on simulated mosque building in Riyadh, thus achieving the environmental feasibility in addition to economic and social benefits.

## Keywords

Mosques, design, thermal performance, green roof, louver shading.

# الأسطح الخضراء وسواتر التظليل لمباني مساجد مستدامة في مدينة الرياض بالمملكة العربية السعودية

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نوع التقديم: بحث علمي

## المستخلص:

من الملاحظ عالمياً أن عدد المساجد في تزايد مستمر نظراً لتزايد تعداد المسلمين بنمو مطرد في جميع أنحاء العالم. على وجه الخصوص، الطلب على المساجد الجديدة يزداد في المناطق الحضرية بسبب زيادة النمو السكاني في أجزاء كثيرة من بلاد المسلمين، وذلك نتيجة للنمو الاقتصادي وأيضاً عدم الاستقرار السياسي في بعض الأجزاء من العالم الإسلامي. ونتيجة لإكتظاظ المساجد فقد تم إجراء عدد من البحوث لمعالجة مسألة الراحة الحرارية لمستخدمي المساجد. بالإضافة إلى ذلك، يعد مبنى المسجد فريداً من نوعه بسبب طبيعة استخدامه على فترات متقطعة من اليوم وتباين أعداد المستخدمين على الدوام وبالتالي يتطلب استراتيجيات تدفئة أو تبريد فريدة من نوعها. من ناحية أخرى وبسبب التوجهات العالمية البيئية للمساهمة بحل ظاهرة الاحتباس الحراري فإن تصميم المباني المستدامة، والتي هي أكثر كفاءة في استخدام الطاقة، هي واحدة من القضايا الراهنة والمحورية في صناعة البناء. يهدف هذا البحث إلى استكشاف التقنيات المستدامة لمباني المساجد في مناطق مناخية مختلفة عبر دراسة عدد من مباني المساجد في أنحاء مختلفة من العالم في مناخات متباينة ومن ثم تقيم الاستراتيجيات المستخدمة لتبريد أو تسخين هذه المباني اعتمادا على المناخ مع فحص إمكانية تكرارها في مكان آخري. على وجه التحديد تتناول هذه الورقة اثنين من التقنيات، السطح النباتي وتظليل النوافذ بالسواتر في المناخ الجاف الحار مثل مدينة الرياض وذلك بهدف إنشاء معايير توجيهية للمهندسين المعماريين ومصممي المساجد لتحقيق بناء مساجد مستدامة في نهاية المطاف. تخلص الدراسة في نهايتها إلى أن هناك إمكانية توفير بنسبة 10٪ من أحمال التبريد عند استخدام الاسطح الخضراء وسواتر تظليل النوافذ على مبنى مسجد في مدينة الرياض تمت محاكاته حاسوبياً وهذا مما يحقق الجدوى البيئية مع وجود منافع أخرى اقتصادية وإجتماعية.

**الكلمات الدالة:**

المساجد، التصميم، الأداء الحراري، الأسقف الخضراء، سواتر التظليل.

# 1 Introduction

The demand on the world energy market is increasing gradually and the expectations of future world energy consumption is significant which has led to strains on the depleted energy sources (Amer et al. 2015). More elaboration, The Middle East and North Africa region for example consumes a massive portion of the energy produced globally. By comparison, The Middle East countries have consumed approximately 40% more energy than Europe in 2010 whereas, Middle East countries population is only 53% of the Europe population (United Nations n.d.). Arguably, Middle East countries such as Saudi Arabia, Qatar, Kuwait and the UAE have become energy drainage, due to their extravagant energy usage. Saudi Arabia energy consumption has increased by 75.26% for the period 2000-2011. Similarly, power consumption of Qatar and United Arab Emirates (UAE) has risen sharply for the same period by 69.00% and 120.24% respectively. Figure1 shows the dramatic increase of the total energy consumption in Saudi Arabia for the period 2000 to 2012. (US Energy Information Administration 2012).

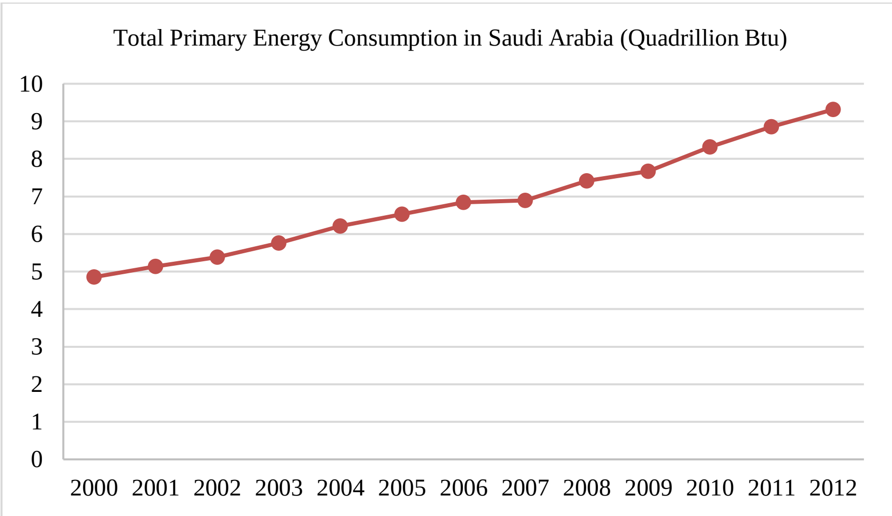



Figure 1 Total primary energy consumption in Saudi Arabia. Source: (US energy information administration 2012)

At least 40% (65% in some hot regions) of the energy consumption in buildings is used to assure user's thermal comfort by air conditioning the indoor space (Rosenlund 2000). The percentage varies based on the building type, climate zone and the microclimate of the building. Due to the harsh weather the percentage of electrical energy consumed by air conditioning is considerably higher in hot arid regions. For example, only 22% of the energy consumption is used for providing comfortable indoor temperature in buildings in UK; whereas it is 65% in Saudi Arabia(Alajlan et al. 1998). Among a range of buildings, in particular, mosque buildings in Saudi Arabia are found to be one of the highest energy consuming buildings. Figure 2 displays the energy consumption of mosque buildings in comparison to some other sectors in 2013 (Alsaeah 2013). The number of mosque building varies from country to countries, and from city to another. For example in Saudi Arabia, Riyadh city is one of the popular cities in mosques number, as there is more than 15 thousands mosques in Riyadh (MOIA 2013) and it has a harsh hot dry weather.

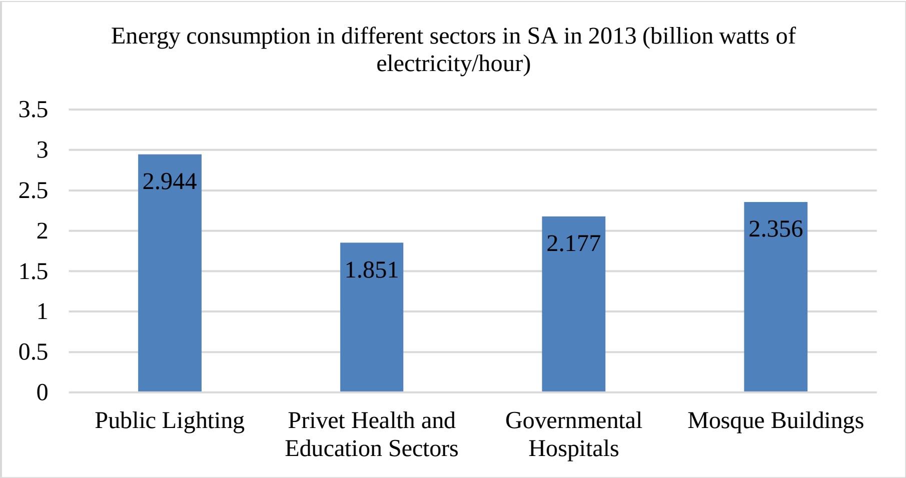



Figure 2 Mosque buildings consumed power more than hospitals in Saudi Arabia in 2013. Source: modified from (alsaeah 2013)

A mosque building is a worship place for Muslim to perform prayer and recite the holy book “the Quran”. Even though, mosques were not only for worship in the early stages of Islam, they were a socializing area, courts and administrative places in one building. Currently, mosques are used mainly for prayer and in some places for religion studies and Quran schools. Moreover, the goal of sustainability could be achieved through different ways and under many names. For instance, low energy buildings, energy efficient buildings, passive houses, sustainable buildings, green buildings and so on. All of these are about providing comfortable indoor spaces without harming the environment.

Mosque buildings are unique among other religious buildings as they are used five times a day, 365 days a year by a varying number of users each time. Therefore, designing the cooling or heating systems for mosque building is also unique to meet these varying numbers' requirements in a sustainable way. Mosque buildings are very exceptional because of their discontinuous operation way of use since they are used for prayer five times a day (early morning, afternoon, late afternoon, after sunset and night time). Also, mosque buildings have unique specifications regard the internal space; usually it’s large and has a high ceiling. Moreover, the number of users varies from day to day and from pray to another which means uneven density of occupancy. Additionally, prayer performance and nature of usage are dissimilar to users in other type of building. All these variables should be considered while studying the thermal performance in mosque buildings.

This study aims to investigate sustainable techniques for mosque buildings in order to reduce space cooling’s energy consumption and assist designers and architects to make further sustainable decisions. The study assesses a number of mosque building in different climates, and investigates the feature of these to achieve sustainability.  Figure 3 is expounding the problem statement for this study and why mosques are different than other type of buildings. The main aim is to determine the most efficient sustainable features for mosque buildings in different climate. Consequently, provide a comfortable environment for worshipers and reduce the consumption of resources to obtain sustainable outcomes. The research focuses on green roof and louvers shading as means of reducing building energy load through computer simulation using mosque building in the climate of Riyadh city as a case study.

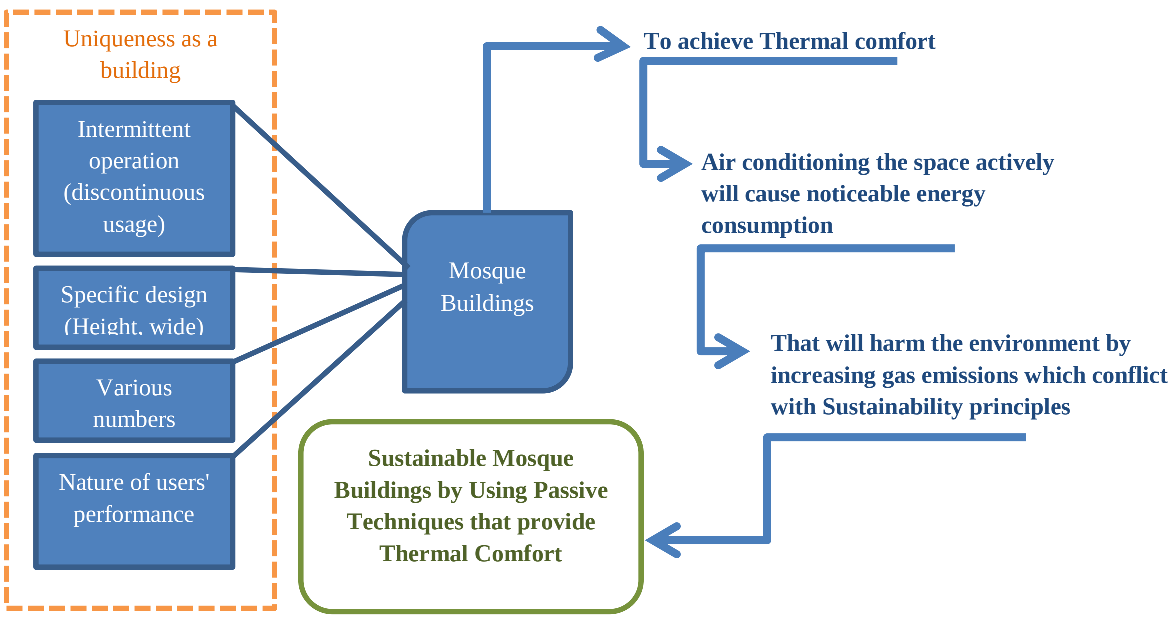



Figure 3 diagrams to elaborate the problem statement of this research project. Source: Author

## 2 Background an Review

### 2.1 Sustainability in Mosque Building

As this study is investigating mosque buildings, these types of buildings are called "Lord Houses" by Muslims or "religious buildings," thus they are considered as Islamic symbols. Many verses in the Muslim Holy book (The Qur'an) state that the Almighty Lord (Allah) commanded all human beings not to waste and treat extravagantly the resources of life, and urged us all concerning the interest and protection of the environment. Allah says in the Holy Qur'an: "*O Children of Adam take your adornment at every place of prayer. Eat and drink, and do not waste. He does not love the wasteful*" (Holy Qur'an Chapter 8, Surat Al-'Araaf, verse 31) this verse mentions the mosque with the order of avoiding waste. Therefore, it is very essential, for mosque buildings worldwide to reflect God's commands including our responsibilities towards the preservation of the resources and the environment in the first place. So if the concept of sustainability should be added as a value to all types of buildings, religions' buildings should come in the top of the list and particularly mosques due to commands of avoiding waste.

### 2.2 Previous Studies on Mosque Buildings and Energy

The researching in mosque buildings in terms of thermal performance and energy conservation is a new topic compared to other types of buildings; only in the last 20 years that some research has spotted the light into mosque building. Among many of the researches on mosque buildings, some of the critical issues included, thermal comfort, thermal performance, low energy and passive strategies. There is a large volume of literature on sustainable mosque buildings, and Figure 4 summarises some of the investigations, and the key outcomes.

A group of researchers from Malaysia have proposed a system that recycles used ablution water within a close-loop system for use toilet flushing, general washing, green roof and plants watering and flowerbed cultivation (Suratkon et al. 2014). Another group of academics and researchers have proposed a social sustainable assessment model for mosque development in Malaysia (Ahmad et al. 2012).

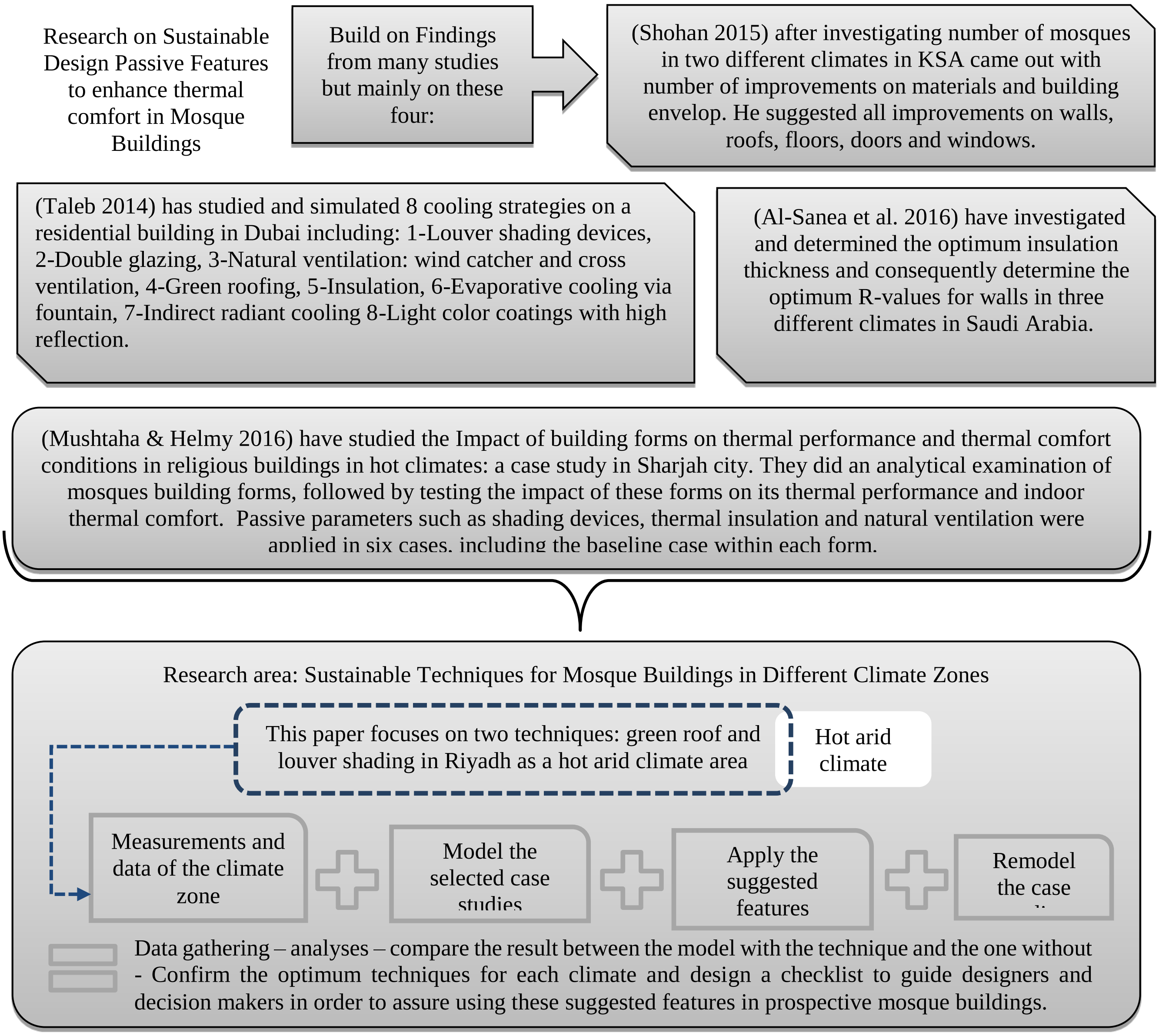



Figure 4 A simplified diagrams of the major outcomes of the key investigations on sustainable mosque buildings.

Source: Author

### 2.3 Causes of Irrational Use of Electricity in Mosques Buildings

Mosque buildings are considered as the most frequently temporally used buildings compared to other public buildings (Alsaeah 2013), and for this reason they are adequately investigated in terms of their energy performance. Many mosque buildings are built based on the traditional Islamic architectural design, which in some occasions are well designed based on the climate. In many other cases this was not the case, as architects just copy and paste these cultural design. The causes of power wastage in mosque building could be due to the following points. First, mosque buildings are usually designed and built using donations, as well their operational coat are covered by local donations or through ministries of religions affairs, as it is the case in many Islamic countries. As a result, the comfort of the mosque user was the most important issue when, so heavily air-conditioning systems and exaggerated lighting are employed. As most part of the equipment are also provided on donation resources the HVAC system is not normally one of the important issues. Thirdly, paying no attention to the number of users at any specific time and seasons, results in use of the same energy systems for varying numbers of mosque users. Most are normally full during

Friday prayers, and the number declines in dawn and other periods of the week. Therefore the energy use per a user is very intensive in most occasions. In order to rationalise the energy consumption, Mosque buildings have to be designed in a flexible way to allow expanding upon need (Umran 2009). Fourth, there is a disregard to use of rationalized solutions in building; such as use of building materials of poor thermo-physical properties. Fifth, low prices of air conditioning devices compared to the monthly operation cost. Sixth, there is a lack of awareness of the impact of mosque buildings on the energy bill and the environment at all stages of the building process starting from the donors, the architect, constructers, users and the government authorities in religions affaire departments, based on the understanding that these are Lord houses, and so the cost and the environmental impact are not relevant, as all these owe rewards from the Lord. Therefore, it was necessary to pause and reflect on how mosque building are designed and operated, in order to highlight the pros and cons of mosque buildings features in relation to energy use and the resulting environmental impact that they cause (Rosenlund 2000).

# 3 Mosque Buildings Features

## 3.1 Comparison of Mosques Buildings in Different Regions

In order to correlate mosque buildings features with the climate for the sustainability point of view, a number of mosque buildings have been selected randomly around the world, and these are then filtered to ten buildings with unique features related to the climate zone. An extended analysis has been carried out to investigate theses and assess the sustainable features that have been employed in these building with regards to the climate zone. The purpose is to assess the relevant of the feature to the climate zone. Each case has been investigated and presented in a specific order.

A brief of the mosque's sustainable features including the architectural and geometrical arrangement are highlighted. Analysis is made of the heating, ventilating and air conditioning functions and lighting systems. Finally, the mosque facilities and serves are noted, highlighting their sustainability. The following tables 1 and 2 summarise the selected mosque, their features and facilities.

| | | | | | Weather | | | |
|---|---|---|---|---|---|---|---|---|
| | Mosque's name | Location | Year of built | Notes on sustainable features | Climate zone | Classification | Average Temperatures (weatherbase) | Average Humidity |
| 1 | **Great Mosque of Djenné** | Djenné, Mali | 1907 | 1- Assuring Security by building it on a 3 m high platform. 2- Using local materials of mud bricks, palm wood and mud plaster. 3- It has a courtyard. 4- Very good insulated muddy walls that is up to 1m thickness. 5- Basic but effective solutions for natural lighting (diffuse light) and ventilating. | Tropical | Tropical Savanna | Annual: 29°C Highest : 45°C Lowest : 6°C | Morning:62% Evening:35% |
| 2 | **The Great Mosque of Touba** | Touba, Senegal | 1963 | 1- Using some local materials for textures but it is a concrete building as a structure. 2- It has a courtyard mostly shaded and a water fountain in the centre. 3- It depends on the natural ventilation plus ceiling fans. | Tropical | Mid-Latitude Steppe and Desert | Annual: 28°C Highest : 35°C Lowest :20°C | Morning:56% Evening:32% |
| 3 | **Great Mosque of Dakar** | Dakar, Senegal | 1964 | 1- Using local materials from Moroccan style since it's partly funded by Moroccan prince. 2- It has a courtyard with a water fountains. 3- The mosque small windows to limit heat gain from the sun. | Hot Arid | Mid-Latitude Steppe Humid and Desert | Annual: 24°C Highest : 38°C Lowest : 11°C | Morning:85% Evening:65% |
| 4 | **London Central Mosque** | London, UK | 1977 | 1- Even if the main material for the mosque is concrete, the designer used some natural materials such as: Derbyshire spar aggregate on wall's decoration and copper on the dome. 2- High monumental ceiling that help in ventilation. 3- Good use of daylight from skylight, vents at the base of the dome and the large windows in two parallel walls. | Temperate | Marine West Coast | Annual: 10°C Highest : 35°C Lowest :-13°C | Morning:91% Evening:68% |
| 5 | **Sultan Salahuddin Abdul Aziz Mosque** | Shah Alam, Malaysia | 1988 | 1- It provides windows glasses solution of grills and coloured glaze. 2- The site overlooks the Garden of Islamic Arts which gave a unique surrounding and offered a clean and desirable environment. 3- It has a courtyard with a water fountains. 3- The mosque has small windows to limit heat gain from the sun. | Tropical | Rainforest | Annual: 27°C Highest : 39°C Lowest :16°C | Morning:96% Evening:70% |
| 6 | **Masjid Alabbas** | Riyadh, Saudi Arabia | 2003 | 1- The concept behind this mosque is saving energy by using expanded pray area in 3 halls to be used as needed. 2- This solution decrease maintenance cost as well. 3- Skylights have been used to get natural daylight. | Hot Arid | Subtropical and Desert | Annual: 26°C Highest : 47°C Lowest :-1°C | Morning:36% Evening:19% |
| 7 | **The Shaikh Zayed Grand Mosque** | Abu Dhabi, UAE | 2007 | 1- water pools around the arcade of the building. 2- It unites the cultural diversity of Islamic world by its complex design from different Islamic styles. 3- It has a separate prayer hall for daily use; the whole mosque is used weekly for Jumaa pray on Friday and for two Eid prayers. | Hot Arid | Subtropical Desert/ Costal Humid | Annual: 27°C Highest : 47°C Lowest :5°C | Morning:75% Evening:43% |
| 8 | **Sancaklar Mosque** | Istanbul, Turkey | 2013 | 1- The mosque highly respected the site and it harmonies with the location. 2- Using natural stone from local sources. 3- Using water elements. 4- Using natural daylight and skylight perfectly. | Temperate | Mediterranean | Annual:14°C Highest : 37°C Lowest :-8°C | Morning:82% Evening:61% |
| 9 | **Khalifa Altajer** | Dubai, UAE | 2014 | 1- This mosque got accepted from USGBC and awarded the silver certificate. 2- The first sustainable mosque in Islamic world. 3- All external lights are powered by solar PV. 4- Other solar panels to heat water for ablution and imam house (no electrical heater). 5- All lights inside and outside are LED lights. 6- It uses a Light operation system during prayer times on need base. 7- Water reusing system from ablution to flush toilets and gardening. 8- Insulated materials for building and double glazing windows. | Hot Arid | Subtropical Desert/ Costal Humid | Annual: 27°C Highest : 48°C Lowest :7°C | Morning:71% Evening:49% |
| 10 | **Nilüfer Trade Centre Mosque** | Bursa , Turkey | Under construction | 1- This mosque has been designed to be a sustainable mosque. It featured some great ideas in using renewable energy such as: solar panel, vertical wind turbine and reusing grey water from rain and after ablution. | Temperate | Mediterranean | Annual: 14°C Highest : 41°C Lowest : -15°C | Morning:86% Evening:57% |

Table 1 the comparison of mosque buildings in different regions. Source: Author

| | | Lighting | | | HVAC | | | Sustainable Building Features | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mosque's name | Skylight | Double Glazing | Reflictive film | Electrical fans | Mechanical air conditioning Heat | Mechanical air conditioning Cool | Courtyard | Photovoltic | light color coating | Shading | Green Roofing | Evaporative cooling | Thermal Mass |
| 1 | Great Mosque of Djenné | ■ | | | ■ | | | ■ | | ■ | | | | ■ |
| 2 | The Great Mosque of Touba | | | | ■ | | | ■ | | ■ | ■ | | ■ | ■ |
| 3 | Great Mosque of Dakar | ■ | ■ | | ■ | | ■ | ■ | | ■ | ■ | | ■ | ■ |
| 4 | London Central Mosque | ■ | ■ | | ■ | ■ | | ■ | | | | | | ■ |
| 5 | Sultan Salahuddin Abdul Aziz Mosque | ■ | ■ | | ■ | | ■ | ■ | | ■ | ■ | | ■ | |
| 6 | Masjid Alabbas | ■ | ■ | ■ | | | ■ | | | ■ | ■ | | | ■ |
| 7 | The Shaikh Zayed Grand Mosque | ■ | ■ | ■ | | | ■ | ■ | | ■ | ■ | | ■ | ■ |
| 8 | Sancaklar Mosque | ■ | ■ | | | ■ | ■ | ■ | | | ■ | ■ | ■ | ■ |
| 9 | Khalifa Altajer | | ■ | ■ | | | ■ | | ■ | ■ | ■ | | | ■ |
| 10 | Nilüfer Trade Centre Mosque | ■ | ■ | | | | | | ■ | ■ | | | ■ | |

Table 2 the analysis of mosques features. Source: Author

## 3.2 Mosque Building Climate Zones Classification

Following critical analysis of the selected ten case studies, the features that enhanced their sustainability are summarised. The objective here is to demonstrate the ability of these features to sustain the building operation in particular its accessibility, energy consumption for both lighting and cooling/heating and ventilation under the relevant climate. Pacheco et al. (2012) mentioned that even there are many factors affecting climate based building design; the most important are energy-efficient design methods. A building design based on energy-saving criteria reduces economic costs throughout the useful life of the building, and this compensates for the greater initial investment. Since there are also less $CO_2$ emissions into the atmosphere throughout the building's life cycle, this benefits the society through ecological and environmental sustainability (Pacheco et al. 2012). Likewise, suitable heating and cooling designs are paramount in energy efficient building designs (Omer 2008). On account of this, and among many features, those which will be considered here are: shape & orientation of the building with respect to solar geometry and wind flow, building envelops materials, shading and green roof. Most of these features and parameters are determining the building energy requirements (Bektas Ekici & Aksoy 2011), and should be carefully considered when designing a mosque building under any given climate or region. The climate zones could vary considerably, however in this study the main three zones that are widely recognised in related previous case studies will be considered and include: Tropical, Hot Arid, and Temperate climate. These classifications have been recognised and used in many other resources like (Gut, P., & Ackerknecht 1993; Rosenlund 2000). The climatic conditions are sensitive and may vary even within the same country, so general outlines is sufficient to understand how buildings performance are effected by a given climate. Climate dictates what passive design strategies are most suitable for a given building site. There are many parameters that contribute to the climate definition like temperature, altitude, humidity, solar position, precipitation, topography and wind; but for practical reasons, this paper focuses on most effective factors that play a key role in building features and indoor comfort.

Review of the ten cases of mosque buildings from various climates and investigation of the climate design features, have led to the understanding of the relationship between each climate and the potential passive cooling/heating and ventilation features. Further search has been carried out on the building standards and green building codes in a number of countries, which has recognised building regulations and building codes. The top sources, in addition to recently published papers, were from the United Nation documentations, USA, United Kingdom and Australia. Some of these countries such as USA and Australia has the capacity of involving almost all climate zones in their codes due to the size of these countries, covering a range of climate zones. The following diagram in figure 5 illustrates the links between climate zones and the most relevant passive features.

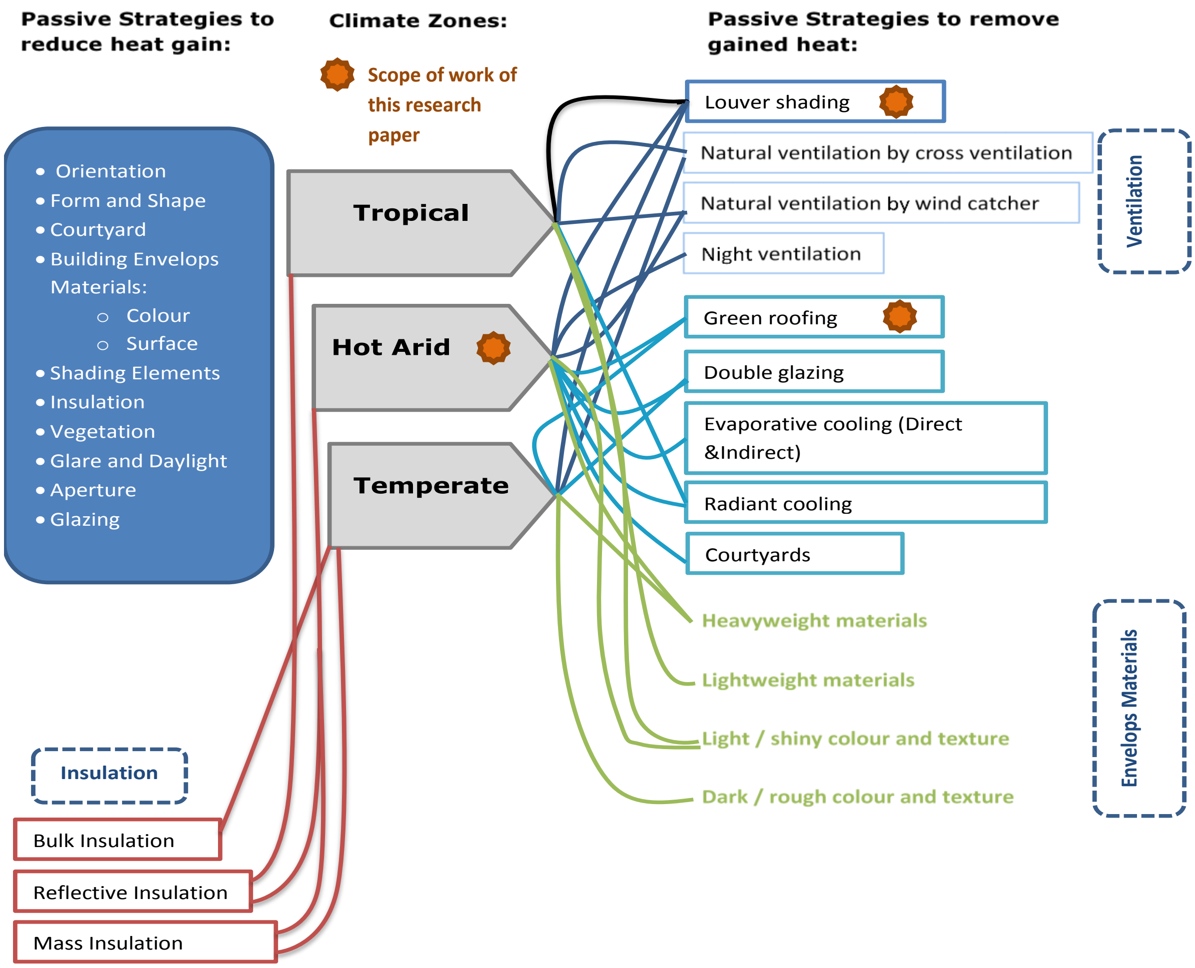



Figure 5 Correlation of Mosque buildings' features with climate. Source: Author

## 3.3 Discussion of Sustainable Buildings' Features for Different Climate Zone

Across the history, people built and host themselves in enclosures that have strong consideration to the local climate (Olgyay 1982). The buildings in most cases have some special features to overcome the harsh weather conditions, for example compact well insulated and airtight form in cold climate versus a wider form associated with courtyards, heavy construction materials, shading devices and small windows in hot climate (Mofidi 2007; Liu et al. 2006). Hot and dry climatic zones generally occur at latitude between 15 degrees to 30 degrees on both the hemispheres. Maximum day time summer temperature goes as high as 48 degree centigrade and relative humidity as low as 20 %. This type of climate is experienced in areas far from sea coasts and do not receive heavy rainfall. Thus, the humidity is very low. In this climate air flow is paramount to ventilate the enclosure. Similarly, the hot humid climate has same feature of the hot-dry climate except for the level of humidity. The temperature range is relatively high at around 30 - 35°C(Gut, P., & Ackerknecht 1993) and is fairly even during the day and throughout the year. Winds are light or even non-existent for longer times because of slight temperature differences; however, heavy precipitation and storms happen commonly. The indoor temperature can barely be kept much underneath the open air temperature but with an effective design the indoor temperature can abstain from surpassing the outside temperature and internal surfaces can remain generally cool. Accomplishing comfort conditions can be obtained by largely a legitimate ventilation.

The followings are some of the features that are key and should be carefully considered for building design for most of the climate zones.

### 3.3.1 Shape & Orientation:

The shape of the building plays a key role in the area of external surfaces which consequently determines its energy balance and hence the cooling or heating energy demands. As a general rule, the square and rectangular shapes with 1:2 percentages of wide and depth are most suitable choices. Use of courtyards is a means of meeting this requirements for hot climate (Olgyay 1982). A number of studies have shown that courtyards can offer the greatest energy efficiency assistances in hot arid climate (Aldawoud 2008; Almhafdy et al. 2013), owing to the extra external surface area that they offer as means of heating removing mechanism.

Building orientation can provide reductions to cooling loads through minimising solar penetration through windows, minimising or increasing solar income through walls and roofs based on the climate. Choosing an appropriate orientation relative to wind rose or wind direction can also help to maximise cross ventilation which mostly suits building in hot arid areas (St. Clair 2009).

It is generally agreed that a southern orientation is optimal for gaining heat in the winter and for controlling solar radiation in the summer. As a general rule, the longest wall sections should be oriented towards the south especially if the shape is not a cube which is the most efficient shape in general (Mingfang 2002) (Olgyay 1982).

For any architect, the problem for orientating the mosque building is its requirement to be toward Qibla (the direction to Mecca where holy mosque is located and all mosques around the world has to be directed towards Qibla). Still, there is a possible change in orientation of the whole building but not the prayer hall as the eighth case – Masjid Alabbas in Riyadh, KSA (case number 6 in table 1and 2). Most design or architect tend to orient the whole building based on the direction of "Qibla", though this not necessary, as prayers row could be adjusted, while the building domain could be appropriately oriented make use of the climate zone key factor. For example in hot climate, to reduce solar penetration in the afternoon, the glazing on the west facade should be minimise, and the building may be oriented along east-west direction for minimum solar heat gain by the building envelope (Ahsan & Tekniska 2009). In cold climate, the emphasise is to enhance solar heat gain, and the building should be orientated with larger glazing facing south, east and west.

### 3.3.2 Building Envelops Materials:

The building exterior materials play a major role in the overall energy performance of any building, controlling heat transfer, solar radiation and airflow and moisture penetration. All these have impact on the building energy requirement. A study conducted by Al-Sanea et al.(2016) has concluded that, the optimum R-values of buildings walls for Riyadh city, which is classified as hot and dry, are in the 2 to 2.9 m2.K/W. The most suitable colour for external surfaces is a light colour for roofs and walls in order to reflect heat.

The comfort of people inside the buildings depends largely on the thermal properties of the outer and inner walls and the roof. Although not very much investigation or considered in many mosque building, the internal thermal storage capacity otherwise known as “thermal mass" is one of the most important elements of sustainable building features, as this helps to decrease the diurnal temperature variations and also may be employed to utilise the night ventilation potential by “storing the cool of the night for use during the day time. There are a range of material which could be considered based on the climate characters (Gut, P., & Ackerknecht 1993).

### 3.3.3 Blinds and Shading:

As a general rule for extremely sunny areas, it is indorsed to avoid overuse of glazing in buildings and both low U-value glazing and double glaze are essential in all cases. The Australian government selected the passive shading for north-facing windows in their sustainable housing guide (Reardon 2013). On the other hand, the opposite is selected for the northern hemisphere.

Figure 5 shows some example types of shading arrangements, which have been studied by varies researchers. The use of adjustable shading devices is recommended to allow variable solar access in different seasons based on the climate variation. The type and arrangement of the shading elements may vary depending on the climate zone, however, it was widely suggested to have vertical shading elements for northern and southern facades in southern and northern hemisphere respectively, where the horizontal ones are suggested or western and eastern (St. Clair 2009). Also, these shading devices are recommended to be operable since they are most effective in hot and arid climates where they can reduce solar heat gain through windows by 85%- 90%, while still permitting day-lighting (Givoni 1998).

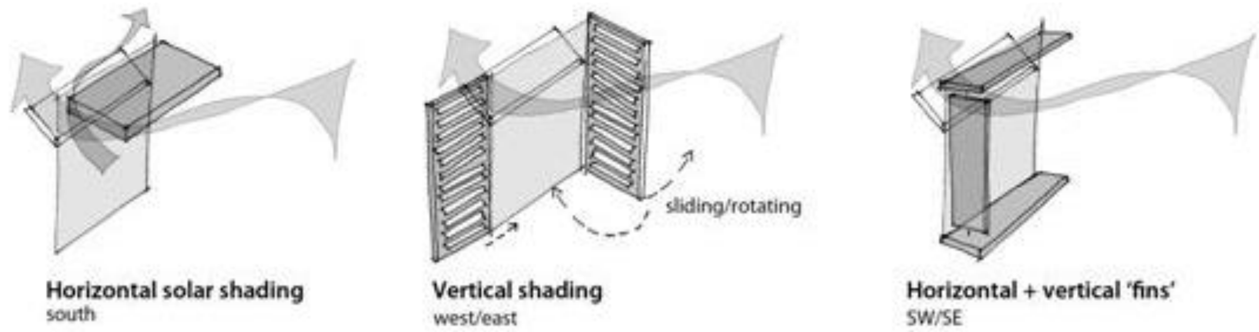



Figure 6 shows different types of shading devices, the middle one is the movable louvers. Source:(R J McGregor 2013)

### 3.3.4 Other Sustainable Systems:

A range of sustainable techniques including passive techniques for temperature and inside humidity control were employed for long time and in many parts of the world in ancient times, and with the widespread use of electrical energy, these methods gradually became obsolete (SANJAY & Chand 2008). A passive system refers to any technical solutions or design features implemented to reduce the temperature of buildings without the need mechanical device or minimum power consumption. Taleb (2014) has performed a study in hot arid climate, Dubai city as a case, testing eight passive cooling strategies. It has found that the total annual energy consumption of a residential building may be reduced by up to 23.6% when the building uses passive cooling strategies (Taleb 2014).

### 3.3.5 Green Roofs

In this paper, same strategy has been assessed following Taleb (2014) investigation. The green cover on outer walls and roof has many advantages: It protects the walls against driving rain and the wind velocity on the surface is reduced. Also, green cover result in eliminated glare and offers visual aesthetic value. In particular, green roof system has many advantages that worth considering not only for environmental reason but also economically and for aesthetically purposes. Green roof system has many advantages that worth considering not only for environmental purposes, but also economically and aesthetically reasons. For the environment, green roof helps lowering gas emissions, improving air quality, water management and heat gain reduction. Aesthetically, it provides open spaces, visual value, acoustic absorption and vegetables production. On the other hand, green roof aids in increasing life for the roof, insulating building and energy efficiency (Aziz & Ismail 2011). Table 3 explains the motive of this paper by using green roof for mosque buildings.

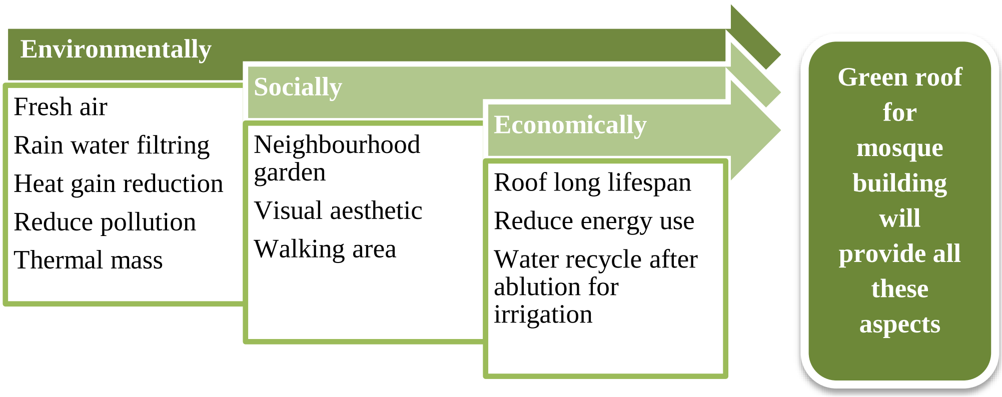



Table 3 the motive of using green roof for mosque buildings. Source: Author

The green roof is a building's top surface which could be flat or pitched, that is either planted completely or partially. It could be planted with eatable or non-eatable vegetation on a growing medium, soil as an example. The main objective of any green roof is to enhance building's thermal performance through two ways: decrease direct heat gain from the sun and reducing energy consumption. These two ways are providing thermal mass and insulation functions to the building by its green roof. Figure 7 shows the basic layers of green roof system, also green roof is known by living roof, planted roof and vegetated rooftop (Sailor 2008). There are many types of green roofs around the world and because of the on-growing industry there is new invention from time to another in green roof field. However, the main three types are extensive, semi-extensive and intensive which are compared in table 4.

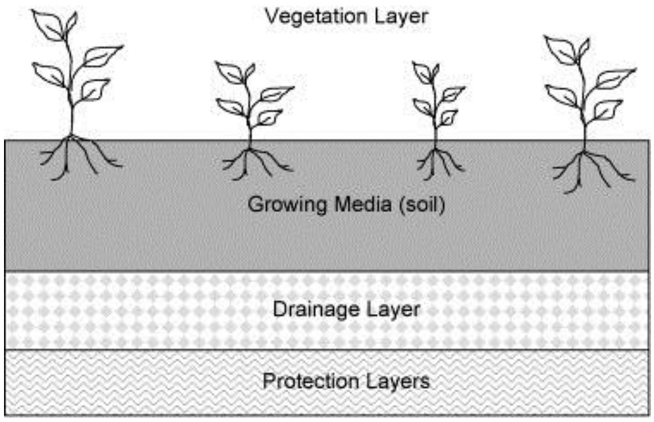



Figure 7 the basic layers of green roof. Source: (Sailor 2008)

| Characteristics | Extensive | Semi-intensive | Intensive |
|---|---|---|---|
| Depth of material | 150 mm or less | Above and below 150 mm | More than 150 mm |
| Accessibility | Often inaccessible | May be partially accessible | Usually accessible |
| Fully saturated weight | Low (70–170 kg/m$^2$) | Varies (170–290 kg/m$^2$) | High (290–970 kg/m$^2$) |
| Plant diversity | Low | Greater | Greatest |
| Plant communities | Moss-sedum-herbs and grasses | Grass-herbs and shrubs | Lawn or perennials, shrubs and trees |
| Use | Ecological protection layer | Designed green roof | Park-like garden |
| Cost | Low | Varies | Highest |
| Maintenance | Minimal | Varies | Highest |

Table 4 comparison table of major types of green roofs and their characteristics. Source: (Hui 2011)

### 3.4 The Proposed Building Model

Among the many interesting features, the green roof which is only employed in Sancaklar mosque in Istanbul, Turkey (see table 2). This mosque is located in a temperate climate and has neither active heating nor cooling systems. The green roof was able to provide a sustainable environment by maintain indoor thermal comfort all year round. This successfully working example is an inspiration to investigate the applicability of green roof for mosque buildings in different climate, which is the aim of this paper.

In order to obtain a more valid results, a real case has been chosen to simulate the applicability of the green roof. Shohan (2015) had selected some cases in Riyadh city to investigate the thermal comfort for mosque buildings and then he has selected one case to apply the suggested improvements on building’s envelop which are the building fabric. These improvements will be referred to as (Ref.1). The building is Prince Sultan mosque in Almoroj district in northern part of Riyadh city where he used both methods: field studies and TAS (Thermal Analysis Simulation from (EDSL) Environmental Design Solutions Limited) simulation to gain the required data. This mosque has in addition to services zone, a main prayer hall of 480 $m^2$ (Shohan 2015) which is the main space for this study. Figure 8, 9 and 10 show the mosque in 3D model in Design Builder and in real from Google Earth and some photos show the building elevation.

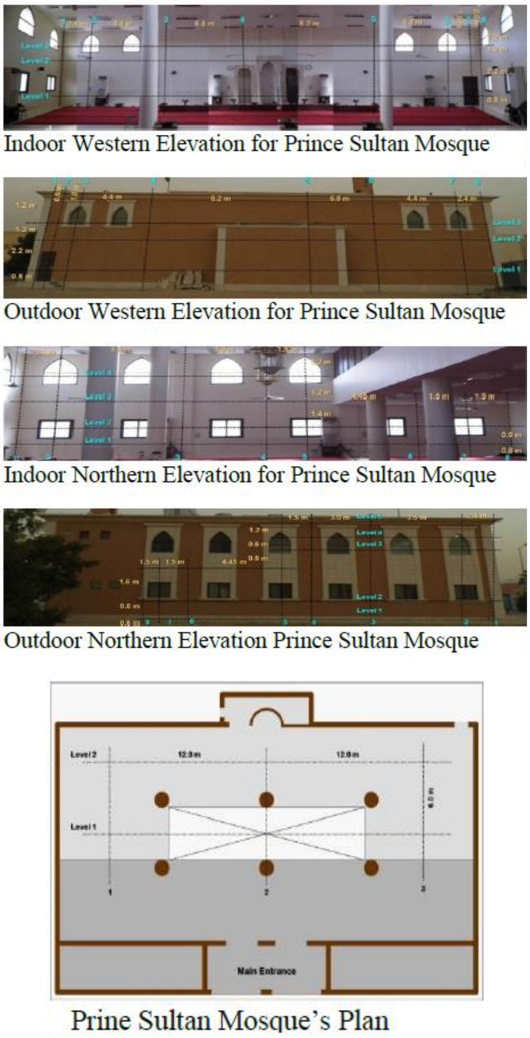



Figure 10 the selected case mosque. Source: (Shohan 2015)

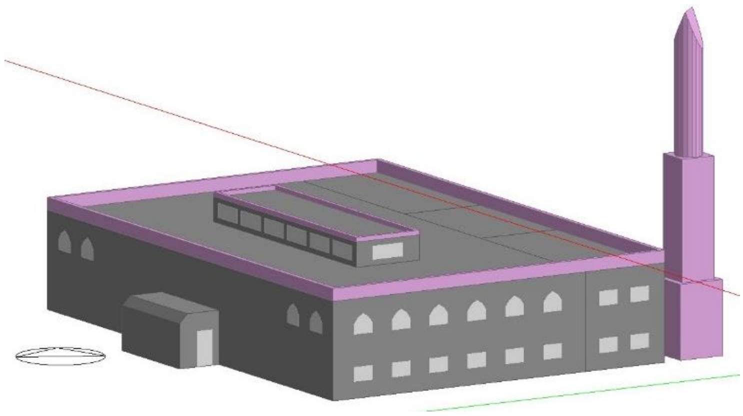


Figure 8 the 3D model of the mosque for energy study. Source: Authors

Figure 9 Prince Sultan mosque. Source: Google Earth

### 3.4.1 Mosque Building Model's Setting:

The building configuration setting for Riyadh city was developed in a Design Builder software and has been used in conjunction with data from Climate Consultant v4, a software that analyse the weather data for a given site based on the climate. Figure 11 shows the psychrometric chart for Riyadh site from Climate Consultant v4. The model has been drawn in Design Builder v4.5 and then simulated using Energy Plus v8.3 computer simulation. The results are analysed and compared. The model setting for the building template and specifications was selected based on ASHRAE Standard 90.1 and 62.1 (Stanke 2006) where the selected building type was Public Assembly Spaces - Place of religious worship. Clothing set for winter was at 1.25 clo and for summer was 0.75 clo according to a study carried out by Al-ajmi (Al-ajmi 2010) which took into account the Arabic style of clothing. Regarding the occupancy density, from observation it varies from day to day and from prayer time to another in most mosque buildings. In this model it was assumed as shown in Figure 12 below as percentages for each prayer for five daily prayer times.

The green roof itself was set as semi-intensive green roof with 30cm depth and includes a 10cm grass layer on soil, filter, root barrier and waterproof layers that arranged respectively on the top of the roof structure. On the other hand, the shading louvers are assumed to be made of aluminium material with 6mm thickness of 5 blades in 15° angle. Each blade is 20cm in depth and with a width similar to that of the relevant window i.e.; 120cm.

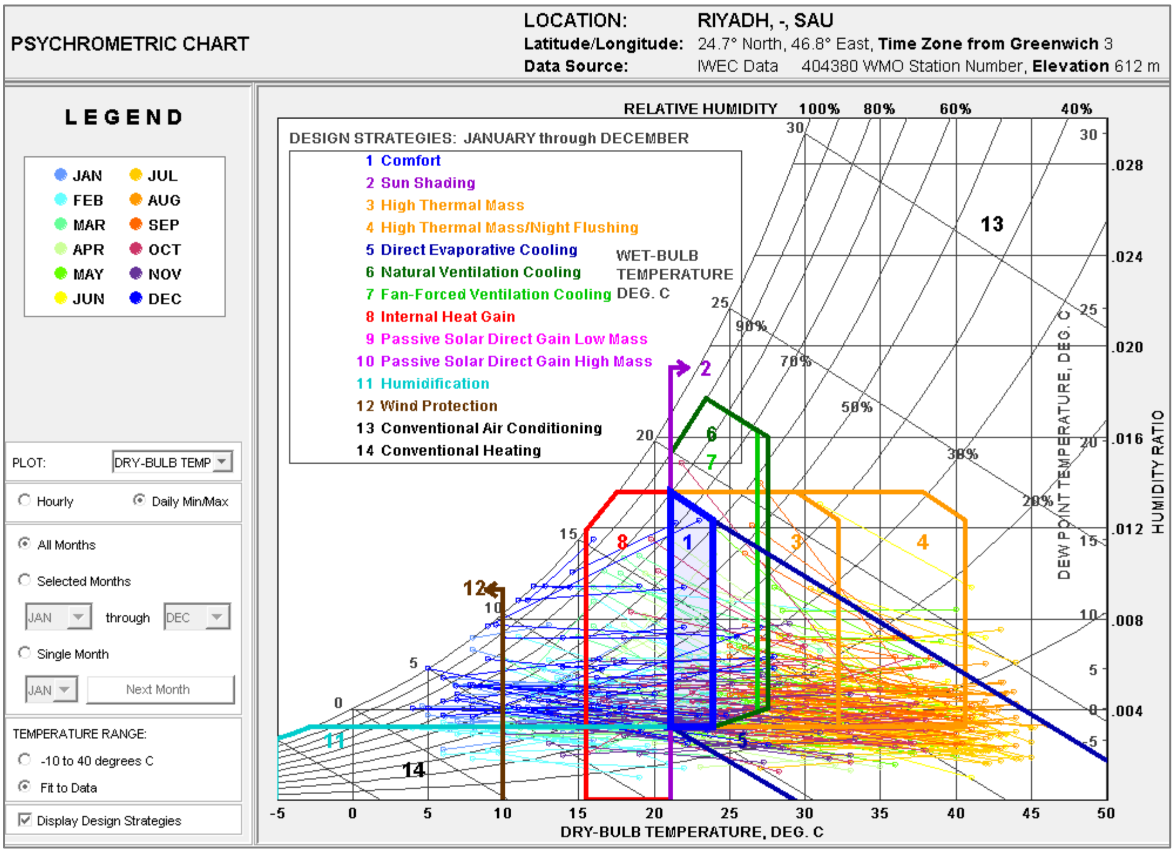



Figure 11 Psychrometric chart for Riyadh from Climate Consultant. Source: modified from Climate Consultant

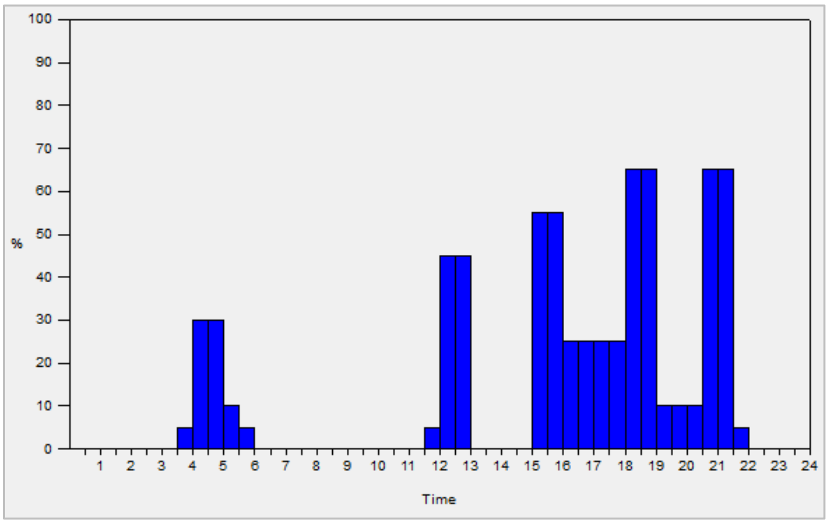
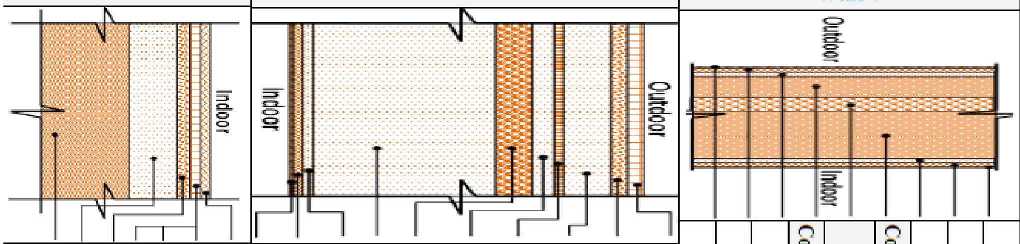



Figure 12 Average daily occupancy for each prayer time. Source: Author

### 3.4.2 Materials Properties:

(Shohan 2015) has examined a number of alternatives for building materials for selected case envelops, following actual measurements and energy simulation using TAS software. He came up with an arrangement for a number of materials for Riyadh climate to assure higher insulation in walls, roof and floor that provide the most suitable annual thermal comfort. Figure 13 below explains in detail each element of the materials and its description.




| Envelope type | Description of materials | Thickness (cm) | Conductivity (W/m. °C) | Specific heat (J/kg. °C) | Density (kg/m³) | Solar reflectance External | Solar reflectance Internal | Emissivity External | Emissivity Internal | U-Value (W/m².°C) |
|---|---|---|---|---|---|---|---|---|---|---|
| Floor-1 | Clean sands for filling the ground spaces under the concrete layer | 20 | 0.81 | 837 | 1800 | 0.18 | 0.18 | 0.91 | 0.91 | 1.409 |
| | Lightweight concrete floor slab | 8 | 1.35 | 1000 | 2000 | 0.30 | 0.30 | 0.90 | 0.90 | |
| | Cement mortar | 2.5 | 0.94 | 1000 | 1750 | 0.30 | 03.0 | 0.90 | 0.90 | |
| | Marble | 2.5 | 2.40 | 840 | 2600 | 0.55 | 0.55 | 0.95 | 0.95 | |
| | Ceramic, or | 0.8 | 1.30 | 1000 | 2300 | 0.30 | 0.30 | 0.90 | 0.90 | |
| | Terrazzo tiles, or | 2.5 | 1.75 | 850 | 2400 | 0.35 | 0.35 | 0.90 | 0.90 | |
| | Carpet and layer of rubber pad | 2 | 0.06 | 1382 | 288 | 0.30 | 0.30 | 0.90 | 0.90 | |
| Roof-10 | Internal paint layer | 0.2 | 999.9 | 0.001 | 0.001 | 0.64 | 0.64 | 0.92 | 0.92 | 0.251 |
| | Internal cement render | 2.5 | 0.50 | 769 | 1300 | 0.60 | 0.60 | 0.90 | 0.90 | |
| | Cement plaster | 2.5 | 0.42 | 837 | 1200 | 0.60 | 0.60 | 0.90 | 0.90 | |
| | Lightweight (L.W.) concrete of Portland cement 500kg/m | 30 | 0.53 | 837 | 1281 | 0.35 | 0.35 | 0.90 | 0.90 | |
| | Foamed polyurethane insulation | 5 | 0.026 | 1260 | 30 | 0.40 | 0.40 | 0.90 | 0.90 | |
| | Lightweight (L.W.) concrete of Portland cement 500kg/m | 3 | 0.53 | 837 | 1281 | 0.35 | 0.35 | 0.90 | 0.90 | |
| | Bitumen polyester 180/m2 for waterproofing | 0.4 | 0.50 | 1000 | 1700 | 0.26 | 0.26 | 0.91 | 0.91 | |
| | Gradient foamed lightweight (L.W.) concrete of Portland cement 500kg/m | 5-7 | 0.53 | 837 | 1281 | 0.35 | 0.35 | 0.90 | 0.90 | |
| | Cement mortar | 2.5 | 0.94 | 1000 | 1750 | 0.30 | 03.0 | 0.90 | 0.90 | |
| | Terrazzo tiles | 2.5 | 1.75 | 850 | 2400 | 0.35 | 0.35 | 0.90 | 0.90 | |
| Wall-7 | External paint layer | 0.2 | 999.9 | 0.001 | 0.001 | 0.64 | 0.64 | 0.92 | 0.92 | 0.393 |
| | External cement render | 1.5 | 0.57 | 1000 | 1300 | 0.30 | 0.30 | 0.90 | 0.90 | |
| | Cement plaster | 1.5 | 0.42 | 837 | 1200 | 0.60 | 0.60 | 0.90 | 0.90 | |
| | Concrete block (solid grouted) | 10 | 1.315 | 913 | 1842 | 0.35 | 0.35 | 0.90 | 0.90 | |
| | Foamed polyurethane insulation | 5 | 0.026 | 1260 | 30 | 0.40 | 0.40 | 0.90 | 0.90 | |
| | Concrete block (solid grouted) | 20 | 1.315 | 913 | 1842 | 0.35 | 0.35 | 0.90 | 0.90 | |
| | Cement plaster | 1.5 | 0.42 | 837 | 1200 | 0.60 | 0.60 | 0.90 | 0.90 | |
| | Internal cement render | 1.5 | 0.50 | 769 | 1300 | 0.60 | 0.60 | 0.90 | 0.90 | |
| | Internal paint layer | 0.2 | 999.9 | 0.001 | 0.001 | 0.64 | 0.64 | 0.92 | 0.92 | |

Figure 13 the arrangement material for Riyadh with description. Source: (Shohan 2015)

### 3.4.3 Assessment Procedure:

After obtaining the dimensions of the real case mosque, the building materials specifications have been drawn. Then all the settings and weather configuration are set as mentioned above. Four different scenarios were established; the first scenario is the base case which is the current condition of the mosque building where model specifications were entered based on the actual building materials specifications. The second scenario involves the same base case integrated with a green roof. The third scenario is the base case scenario with an addition of basic louver shading elements on all windows. The fourth scenario involves scenario 2 and 3 integrated with the improvement suggested by Ref.1(Shohan 2015) which includes improvement of the building envelop and the addition of louver shadings. Figure 14 shows the rendered model with Riyadh sun-path with and without the green roof. Moreover, to acquire accurate result the minaret was built as a component block so it doesn't affect the thermal performance of the mosque.

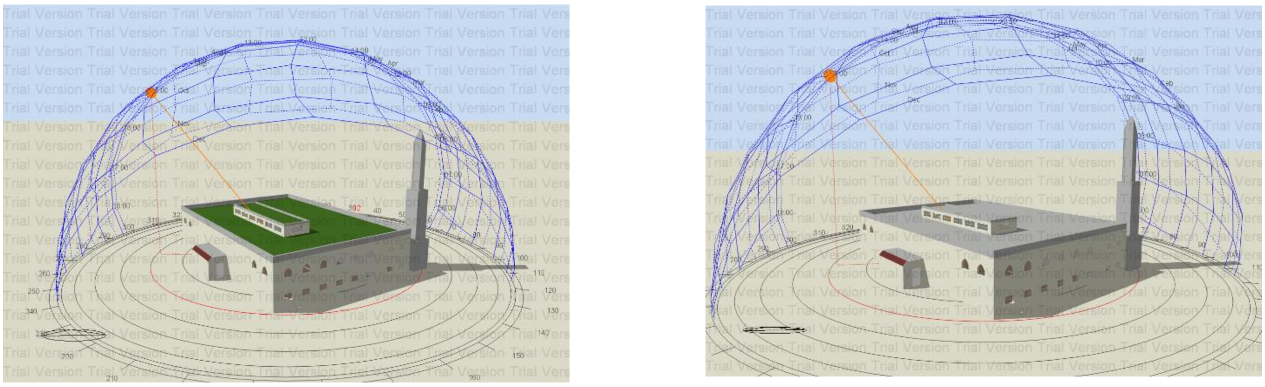


Figure 14 the model showing the sun path, left is with green roof and without it on right. Source: Author

### 3.4.4 Simulation Results and Findings:

Provision of the required thermal comfort of any building is possible, but might cause a huge power consumption when operating an active cooling system using air conditioning system. The purpose of the simulation is an attempt to investigate the annual building cooling load for the different scenarios where thermal comfort is fix for the indoor space. Results show that generally a reduction in indoor air temperature could be achieved by applying both green roof and louver shading. Figure 15 shows a possible reduction by an average of one degree in the hottest day (summer day) of the year i.e.; 21$^{st}$ of July according to Weather and Climate Consultant. This simulation was run while no active air conditioning was operated.

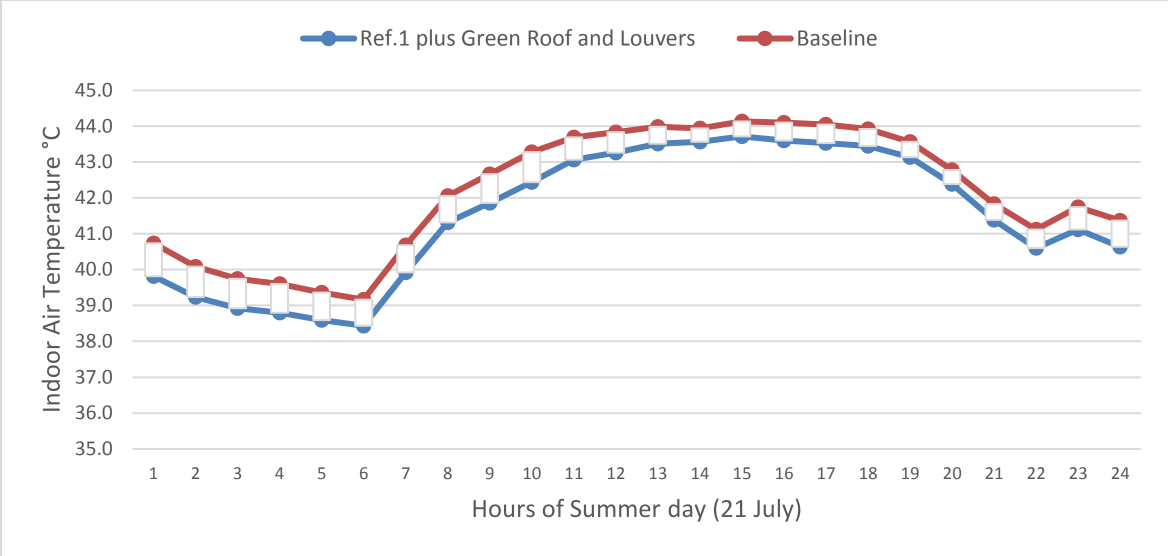



Figure 15 Reduction in Air Temperature of summer day (21st of July). Source: Author

Equally important, is how the cooling load responds to the applications of the proposed technologies and the potential energy saving of the mosque building. Figure 16 shows the monthly variation in summer months for the cooling load of the mosque building under the three scenarios, the base case, base case plus green roof, and base case, plus green roof combined with improvement of thermal insulation of the building fabric. The results show that there is a promising reduction in the cooling load when a green roof is applied to the mosque building without introducing any improvement to the building fabric. Of course there are a further improvements when both the green roof and shading louvers are applied. Because the effectiveness of the blind varies with the sun geometry, the benefits of the shading louvers also vary with the months, as shown in Figure 16. The green chart show the cooling load, when all improvement to the building design are included i.e.; improved fabric, green roof and shading louvers. Moreover, an annual saving by 4% of cooling load could be achieved in mosque building in Riyadh by using the green roof, however, this percentage could be raised up to 10% if shading louvers were added to windows while keeping the green roof. Figure 17 below shows annual cooling load.

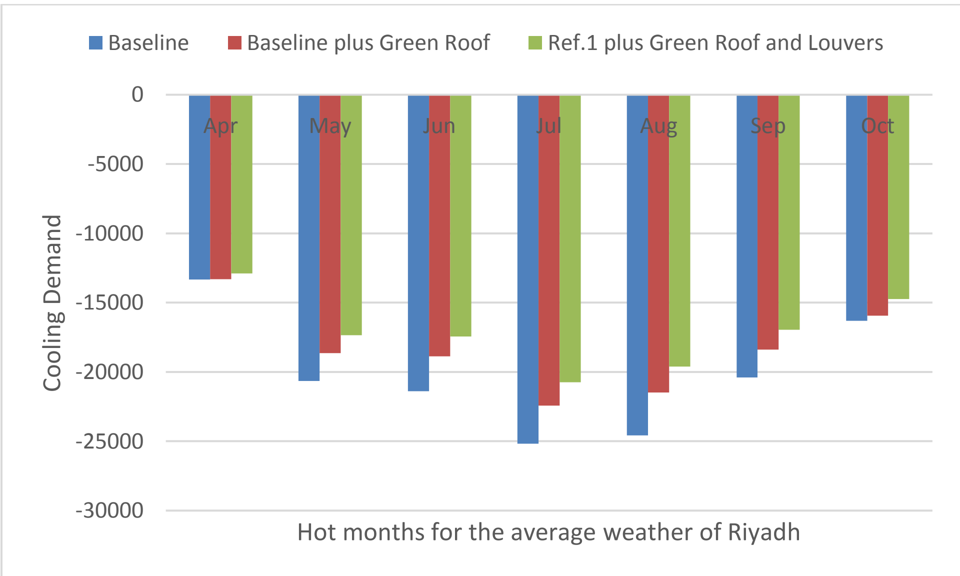



Figure 16 Monthly cooling demand reduction when apply both green roof and louvers shading particularly in not-cold months of Riyadh. Source: Author

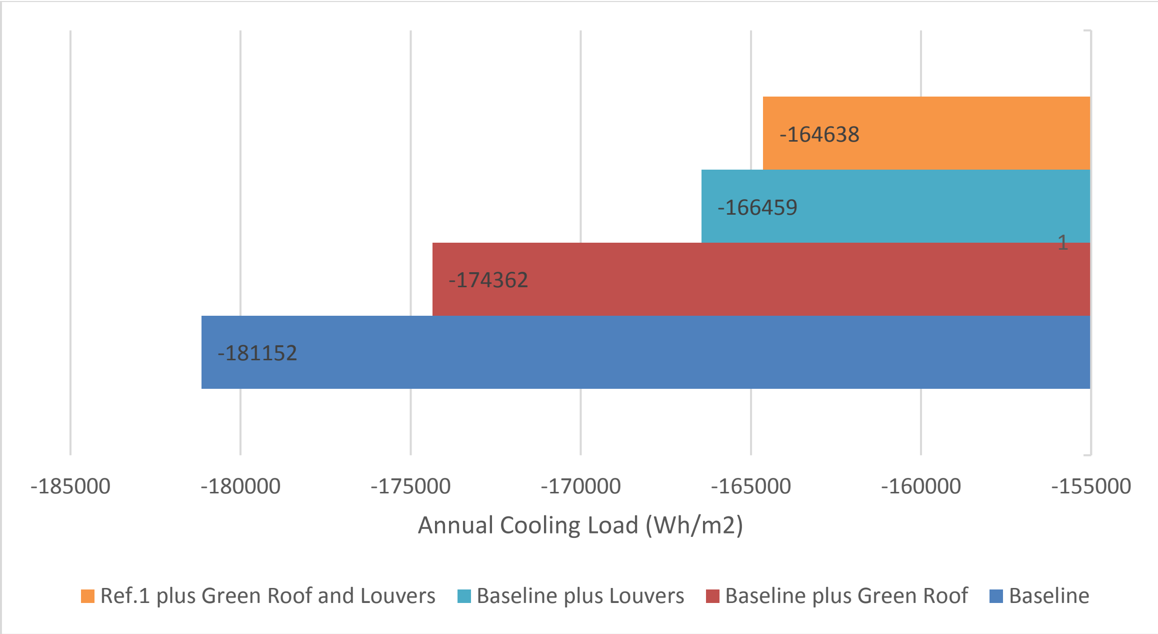



Figure 17 Annual cooling load per square meter could be reduce by 10%. Source: Author

## 4 Conclusions

With the increasing number of Muslims and the on-going demand of new mosque buildings, it is important to give attention to the thermal performance of mosque buildings and use appropriate sustainable technologies based on the climate zone.

This paper is part of an ongoing research that aims to determine the most appropriate sustainable features for sustainable mosque buildings in different climate. Consequently, provide a comfortable environment for worshipers and reduce the consumption of resources. A number of mosque building are explored to acknowledge there sustainable features, and classify these according to the climate zone. The purpose is to draw attention to these technologies when considering mosque building in any climate.

The investigation found that most of the research work on mosque building focused only on the building fabric and envelop without suggestion of applying appropriate sustainable techniques and technologies to enhance building performance and its energy consumption/provision. This research aims to fill this gab by considering the most appropriate sustainable techniques for mosque buildings in different climate zones. Application of green roof and shading devices in hot - arid climate are examined alongside the fabric improvement, and the results illustrated that the potential of these techniques in improving the building performance and reducing building energy consumption. Further investigations are required to relate these techniques and other potential sustainable technologies to particular climate zone.

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