Sustainable techniques for thermal comfort in buildings designed used by worshipers

A case of roof options for mosque buildings in hot arid climate

AASEM ALABDULLATIEF[1], SIDDIG OMER[2]

[1] PhD student, Sustainable Building Technology, Dept. of Architecture and Built Environment, Faculty of Engineering, the University of Nottingham, UK. aasem.alabdullatief@nottingham.ac.uk
[2] Associate Professor, Sustainable Building Technology, Dept. of Architecture and Built Environment, Faculty of Engineering, the University of Nottingham, UK. siddig.omer@nottingham.ac.uk

Abstract: Thermal comfort in building is a trendy that has been under investigation by many researchers. The mosque, for Muslim worshippers, is one of the most popular religious buildings. The demand of new mosques is continuously increasing due to the increasing number of Muslims population and growth in both economic and urban land escape. Recently, there have been a reasonable number of researches that have been investigating the thermal performance of mosque buildings. As a matter of fact, the location of the mosque and the climate play key roles on mosque building thermal performance. Additionally, mosque buildings are unique because of the intermittent operation pattern and the varying number of the users, which require rather controlled heating or cooling strategies. Sustainable energy techniques are keystone that ensures low energy consumption and provide better indoor environment for users of buildings. 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 explores application of sustainable technologies for mosque buildings in hot climate zone. A number of mosque buildings in different regions, time frame and climates have been studied, and application of passive techniques on these cases have been evaluated. Performance of these techniques on roofs including building insulation, shading and green roofing have been analysed taking into account the climate and building specifications. The preliminary results obtained from this research clearly indicate that, there are design correlations and guidelines to be established for the architects and mosque buildings designers under any given climate for a sustainable mosque building design. Use of these guidelines also have potential of financial saving appropriately applied in mosque buildings in hot arid climate.

Keywords: sustainable, techniques, mosque, roof, energy saving.

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's countries 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. Figure 1 shows the dramatic increase of the total energy consumption in Saudi Arabia for the period 2000 to 2012 (US Energy Information Administration, 2012).

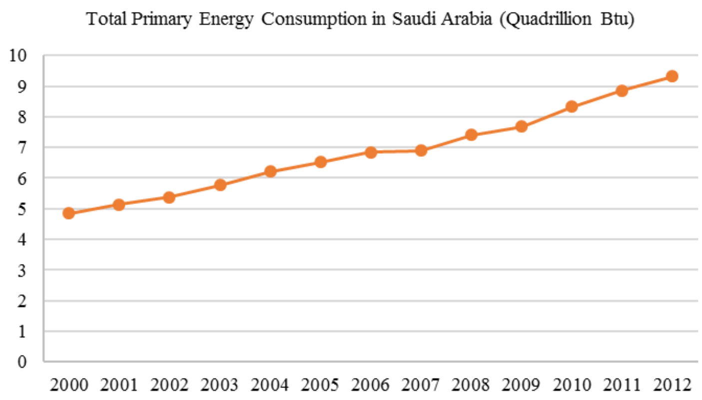

Figure 1 Total primary energy consumption in Saudi Arabia.

At least 40% (up to 65% in some extreme 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 to provide comfortable indoor temperature in buildings in UK; though 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 country, and from city to another. For example in Saudi Arabia, Riyadh city has a very large number of mosques, as there is more than 15 thousands mosques in Riyadh (MOIA 2013) and it has a harsh hot dry weather. So, studying thermal performance for mosques is very crucial.

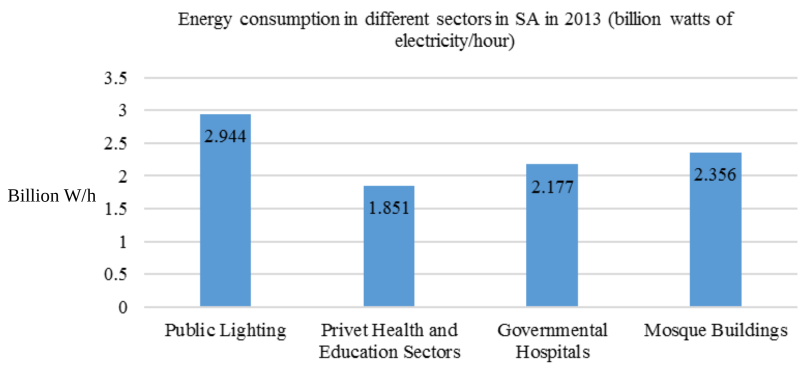

Figure 2 Mosque buildings consumed power more than hospitals in Saudi Arabia in 2013.

1.1. Statement of the Problem

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 interns of discontinuous operation. Also, mosque buildings have unique specifications of the internal space; usually they are large and have high ceiling. Moreover, the number of users varies from day to day and from a time of the day to another which means uneven density of occupancy. All these variables should be considered while studying the thermal performance in mosque buildings.

1.2. Aim of the Research

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 sustainable design. The study assesses a number of mosque buildings in different climates, and investigates the features of these buildings to achieve sustainability. Consequently, provide a comfortable environment for worshipers and reduce the consumption of resources to obtain sustainable outcomes. The main aim of the research is to determine the most efficient sustainable features for mosque buildings in different climate, however this paper focuses on roof finishing options as means of reducing building energy load through computer simulation using a mosque building in the climate of Riyadh city as a case of hot arid climate.

2. BACKGROUND

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. Literature Review Outline

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. The researching in mosque buildings in terms of thermal performance and energy conservation is a new topic compared to other types of buildings; only within the last 20 years some researches has spotted the light into mosque buildings. Among many of the researches on mosque buildings, some of the critical issues were included, thermal comfort, thermal performance, low energy and passive strategies. There is a realistic volume of literature on sustainable mosque buildings, here are summarises of the investigations, and the key outcomes from most relative researches.

Two researchers from United Arab Emirate (Mushtaha & Helmy 2016) have studied the Impact of building forms on thermal performance and thermal comfort conditions in religious buildings in hot climates: a case study in Sharjah city (UAE). They did an analytical examination of mosques building forms, followed by testing the impact of these forms on its thermal performance and indoor thermal comfort. Passive parameters such as shading devices, thermal insulation and natural ventilation were applied in six cases, including the baseline case within each form. They came out with a conclusion of the most appropriate shape of mosque building in hot climate for the matter of heat gain and energy performance which is the octagonal shape.

Another researcher from the University of Nottingham, UK has investigated number of mosques in two different climates in Saudi Arabia and then came out with number of improvements on materials and building envelop. He has tested and suggested number of improvements for walls, roofs, floors, doors and windows (Shohan 2015). On similar side, (Al-Sanea et al., 2016) have investigated and determined the optimum insulation thickness and consequently determine the optimum R-values for walls in three different climates within the country of Saudi Arabia.

On the other hand, some researches have investigated sustainable ideas or systems within the mosque building. For example, a group of researchers from Malaysia have proposed a system that recycles used ablution-water contained by a close-loop system that to be used for 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) where they tried to raise the social value of the mosque so it doesn't remain sustainable just environmentally.

2.3. Cases Analysis

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 these 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. Tables 1 and 2 below illustrate the finalist ten cases, their features, assessment and the comparison.

Image	Location / Climate	Features	Satisfactory (Hi) 1	2	3	4	5
	Djenné, Mali (1907) Climate: Tropical	Features: Thermal Mass, local materials, courtyard, high ceiling, natural ventilation plus ceiling fans	■				
	Touba, Senegal (1963) Climate: Tropical	Features: Some local materials, shaded courtyard, water fountain, natural ventilation plus ceiling fans				■	
	Dakar, Senegal (1964) Climate: Hot Arid	Features: Local materials, courtyard with a water fountain, small size windows		■			
	London, UK (1977) Climate: Temperate	Features: Some local materials, courtyard with a vegetation, sun oriented large windows, high ceiling		■			
	Shah Alam, Malaysia (1988) Climate: Tropical	Features: Grills and coloured glazing, courtyard with a water fountain, small windows, high ceiling, landscape			■		
	Riyadh, Saudi Arabia (2003) Climate: Hot Arid	Features: expanded pray area, orientation, natural daylight		■			
	Abu Dhabi, UAE (2007) Climate: Hot Arid	Features: separate prayer hall for daily use, courtyard with water pools around the arcade, high ceiling			■		
	Istanbul, Turkey (2013) Climate: Temperate	Features: Local materials, shaded courtyard, water elements, natural ventilation, daylight, greenroof	■				
	Dubai, UAE (2014) Climate: Hot Arid	Features: LEED silver certificate, lighted partially by solar PV and for water heaters, LED lights, operation system, water recycling	■				
	Bursa , Turkey (Under construction) Climate: Temperate	Features: Designed to be a sustainable, renewable energy such as: solar panel, vertical wind turbine and water recycling					

		Lighting			HVAC			Sustainable Building Features						
	Mosque's name	Skylight	Double Glazing	Reflective 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 1 & 2: the selected 10 mosque building cases and their summarized features.

Reviewing 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.

2.4. Sustainable Buildings' Features for Hot-Dry Climate

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 58 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 - 45°C(Gut & 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.

3. THE PROPOSED BUILDING MODEL

This model was built on a real case in Riyadh, the capital city of Saudi Arabia. There is a project of a new mosque building for both daily prayers and Friday (Jumah prayer) which serves local residents in a neighbourhood on the north district of the city. The author has participated with the design team and has provided sustainable consultation to the project that made it more maintainable in the matter of energy saving and enhance its quality. Back to the ten mosques cases that were investigated, and among the many interesting features, the green roof which is only employed in Sancaklar mosque in Istanbul, Turkey (see tables 1 and 2). This mosque is located in a temperate climate and has a partial active heating but no cooling systems. The green roof was able to provide a sustainable environment solution by maintaining indoor thermal comfort all year around. This successfully working example is an inspiration to investigate the applicability of green roof for mosque buildings in different climate, which is one of the aims of this paper. This paper explores the efficiency of several alternative roof options for the hot climate of Riyadh city. (Alabdullatief et al. 2016) have studied the effect of green roof and louvers shading for a mosque in Riyadh where they found a potential saving of 10% in energy consumption could be achieved. However this paper examined other options for a different case within same climate. Figure 3 shows the initial design model and then the suggested improved model.

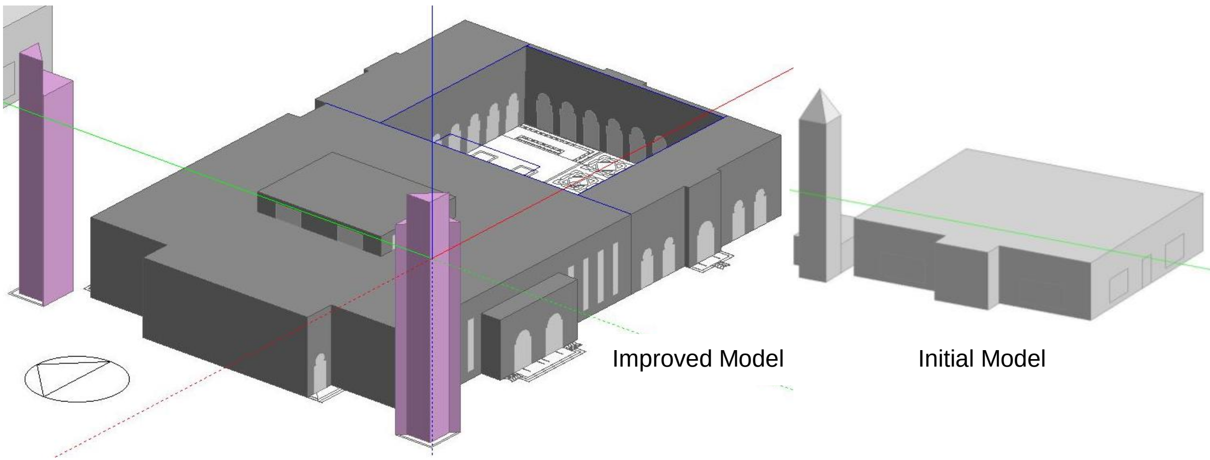

Figure 3: The initial model and the improved model design (both are same in prayer area size).

3.1. The Suggested Improvements

The design has been through several stages, but due to some limitations of this project some suggestions were hard to apply. In addition, the size and the shape of the assigned land were hindering design team from putting some creative sustainable ideas. Figure 4 displays the plan sketch for improved model during the design process. The main suggestions were briefly as:

- Orientation: the mosque, as all mosques, has to be directed toward Mecca, however there is a possibility of manipulating the exterior façade to decrease direct heat gain from the sun.
- Shape and Form: (Mushtaha & Helmy, 2016) recommend the octagonal shape for mosque in hot climate but as the shape of the land is rectangle, the same shape has been selected with an approximate ratio 1:2. For the form, the initial design was mainly a large prayer hall and a service block separated on the north side of the mosque. In contrast at the improved model, a court yard has been applied in the opposite Qibla (Mecca) direction which is the east side. (Alhemiddi, 2003) has suggested court yard strategy for mosques in hot arid climate due to their advances in the thermal performance.
- Shading: a strip arcade has been added to west, south and east façade so the arcade provides shading and lower the direct sun gain. Also, a louver shading has been recommended on windows. Another mean for shading is the minaret, which is a tall structure represents the mosque generally, it was suggested that minaret (1or2 minarets) should be allocated on the central of south side so its shadow fall on the roof and help cooling it. Another suggestion but was not used is using the minaret as a wind catcher to cool the mosque as a means of natural ventilation. (Alfraidi et al., 2016) has investigated number of alternative designs for the porous ceramics structure that could be used in mosque's minaret for evaporative cooling purpose.
- Natural light: by following three main strategies which are: 1-tall strip windows on all sides except west façade. 2-skylight through the ceiling in the centre of the prayer hall. 3- Sun pipes at the back of the prayer hall as it has a mezzanine floor. The second and third strategies combined a ventilation system to circulate fresh air inside the building by distracting the air out.
- Doors: an important suggestion was creating double doors for the mosque which helps maintaining the cool temperature inside and help also with the insulation.
- Windows: double glazing was used in windows with a suggestion of no windows on the west (the worst in solar heat gains) wall that has been design thick to act like a thermal mass wall.
- Functional partition: as mentioned earlier the mezzanine floor is covering the third of the mosque. This third is allocated for daily prayers and once a week for Friday prayer the other two thirds are used. This zoning division contribute in a huge energy saving by controlling the occupied area.
- Roof options: there were four suggestions were given: 1-Green roof insulated 2- Insulated with white chipped stones finishing (20cm thickness) 3- Insulated roof with tiles. 4- Movable shading that covers the whole roof. After studying the options feasibility and break down their initial cost and life cycle operation cost, the second option has been selected.

Figure 4 a sketch for the improved plan design

3.2. The Model's Settings and Properties

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. The psychrometric chart for Riyadh site from Climate Consultant v4 has been used. After that, the model has been drawn in Design Builder v4.5 and then simulated using Energy Plus v8.3 computer simulation which is the built in engine for thermal analysis in Design Builder. Lastly, the results were 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. Moreover, 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 which is the case of Riyadh users. 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 percentages for each prayer for five daily prayer times as: - Fajer prayer: in early morning 4-5am with occupancy of 45% - Dhohor prayer: midday 12-1pm with occupancy of 60% - Asr prayer: late afternoon 3-4 pm and its estimated occupancy was 65% - Maghreb prayer: right after sunset 6-7pm with occupancy of 75% and the same occupancy for Isha prayer 8:30-9:30pm. To illustrate more in roof options details Table 3 presents the options with their properties, layers and u-U-Values.

Roof Options	**Uninsulated Roof**		**Insulated Roof**		**with Chipped Stones**		**with Green Roof**	
	Material/thickness (cm)		Material/thickness (cm)		Material/thickness (cm)		Material/thickness (cm)	
Layers					Stones	12	Grass	10
			Plaster	2	Soil	8	Soil	20
	Plaster	2	Waterproof	2	Waterproof	2	Waterproof	2
	Waterproof	2	Polystyrene	5	Polystyrene	5	Polystyrene	5
	Concreate	15	Concreate	15	Concreate	15	Concreate	15
U-Value (W/m2-k)	2.48		0.486		0.498		0.365	
R-Value (m2-k/W)	0.43		2		2.1		2.74	

Table 3 the details properties of roof options

The green roof itself was set as semi-intensive green roof with 30cm depth that includes a 10cm grass layer on soil, filter, root barrier and waterproof layers which were arranged respectively on the top of the roof structure. On the other hand, the white shipped stones comes on layer of 20cm thickness and the white colour should act as a reflective surface. Furthermore, the insulation has been used is a 5cm layer of Extruded Polystyrene right above the concreate slap. This type of insulation is widely used in the Saudi building materials industries and it has been selected due to its availability and efficiency. Further studies might consider testing alternative insulation materials and thicknesses. Last addition in roof options was the shading which was an over hanged movable shading that covers the roof with a gap of 1m to allow air circulation between the roof and the shading layer. Correspondingly, for the envelop material matter, (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. So, for this project the suggested materials have been simplified to available materials while keeping the near u-value in range. Figure 5 below shows the model and the alternative options for roof that have been simulated in this paper.

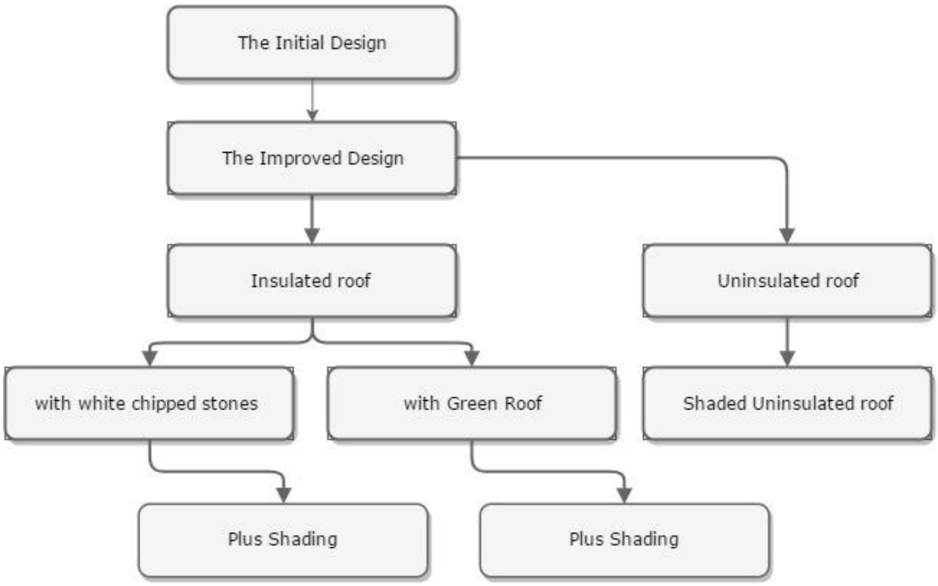

Figure 5 Diagram for the model and alternative cases for roof options

3.3. Simulation Results and Findings

Providing the required thermal comfort of any building is possible, but might cause a huge power consumption when operating an active cooling using air conditioning system. The purpose of the simulation is an attempt to investigate the building cooling load after applying different roof options while thermal comfort is fix for the indoor space. The point is to select the best option of roof that has less heat gain. Figure 6 compares the sensible cooling load between six roof options where the most saving is at the insulated green roof.

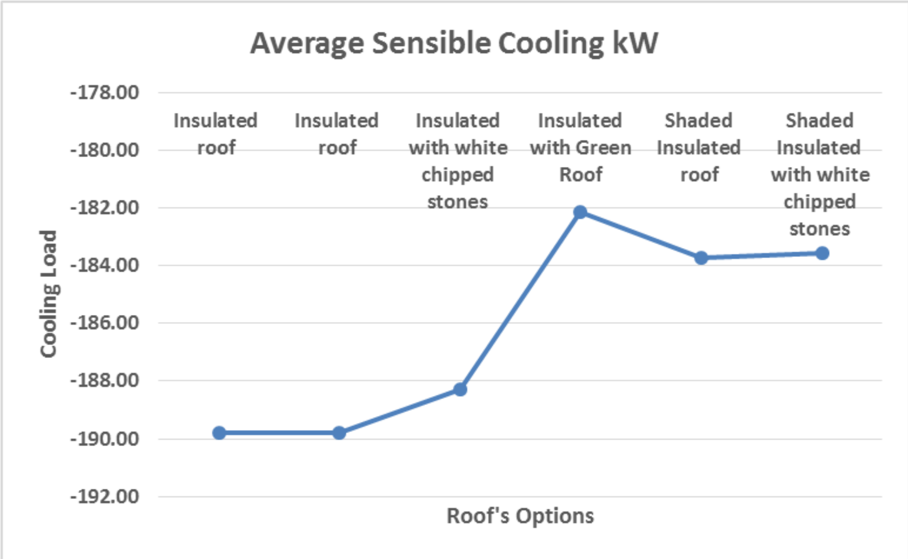

Figure 6 Average sensible cooling load for roof options

Likewise, results show that generally a reduction of about 7% from cooling load could be achieved by applying the white shipped stones and 8% when green roof is applied on a case of mosque building in Riyadh. Additionally, extra saving is achievable when shading is applied to roof surface. Figure 7 shows a possible reduction of the cooling load in the hottest day (summer day) of the year i.e.; 15th of July according to Weather and Climate Consultant. The chart represents the alternative roof options and their cooling load.

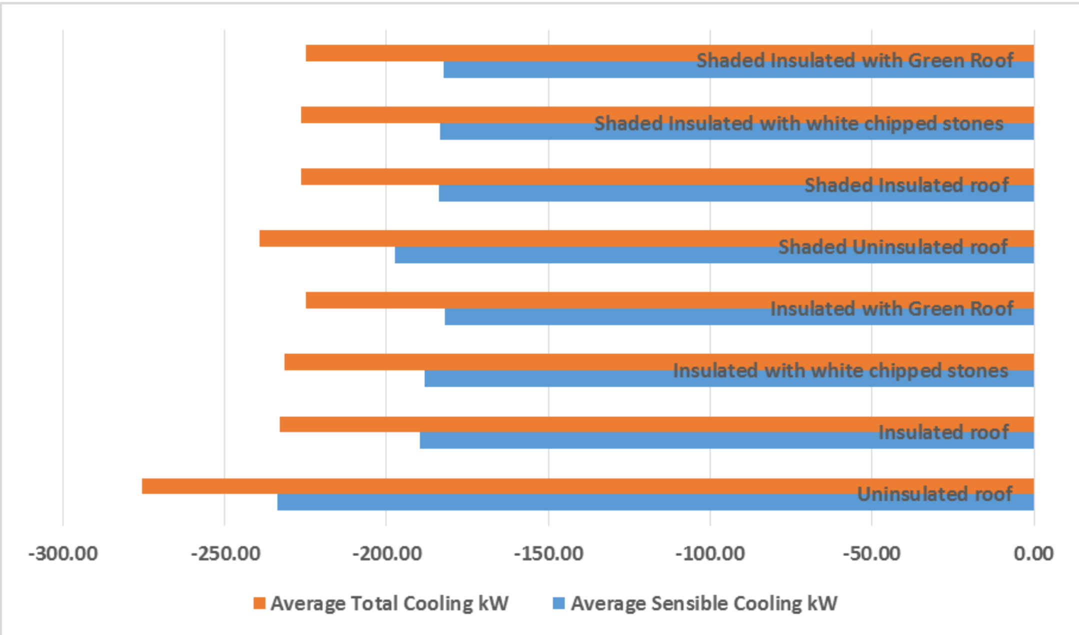

Figure 7 Cooling load in summer day for all options

4. CONCLUSIONS

In line with the growing population of Muslims a demand for new mosque buildings all around the world is growing. The increasing claim of sustainable buildings generally due to global warming is becoming a significant issue as well. This paper is part of current research about sustainable mosque buildings design by addressing the sustainable features for each specific climate zone, thus, achieving thermal comfort for worshipers and maintaining natural resources are the ultimate goals.

In this research, a number of mosque buildings have been investigated to obtain the most relevant sustainable features. At this end, the linking between the features and the climate zones has been considered. This paper focused on the roof options for mosque building which is very unique due to its type of operation. There are many alternative strategies for roof, and in the case of hot dry climate, four main options with their combinations have been investigated. the techniques tested included the insulated roof, green roof, white chipped stones finishing and the applicability of movable shading layer on top of the roof. The results show a promising saving in cooling load for the selected climate, in particular by using insulated roof with green surface among others.

5. REFERENCES

Ahmad, M.H. et al., 2012. A Social Sustainable Assessment Model for Mosque Development in Malaysia.

Al-ajmi, F.F., 2010. Thermal comfort in air-conditioned mosques in the dry desert climate. *Building and Environment*, 45(11), pp.2407–2413.

Al-Sanea, S.A. et al., 2016. Optimum R-values of building walls under different climatic conditions in the Kingdom of Saudi Arabia. *Applied Thermal Engineering*, 96, pp.92–106. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1359431115013186.

Alabdullatief, A. et al., 2016. GREEN ROOF AND LOUVERS SHADING FOR SUSTAINABLE MOSQUE BUILDINGS IN RIYADH, SAUDI ARABIA. In *Proceedings of The First International Conference on Mosque Architecture I December 2016*. Nottingham, p. 129.

Alajlan, S. a., Smiai, M.S. & Elani, U. a., 1998. Effective tools toward electrical energy conservation in Saudi Arabia. *Energy Conversion and Management*, 39(13), pp.1337–1349.

Alfraidi, S. et al., 2016. COOL MINARET: A FUNCTIONAL ELEMENT OF PASSIVE COOLING FOR MOSQUES IN HOT-ARID CLIMATES. In *Proceedings of The First International Conference on Mosque Architecture I December 2016*. p. 155.

Alhemiddi N. A., 2003. Strategies to Reduce the Electricity Energy Consumption in Mosque Buildings: An Analysis Study for Riyadh Mosque Buildings and Arrahmaniyah Mosque in Sakaka City in Saudi Arabia. *King Saud University Journal, Architecture and Planning Department*. Available at: http://faculty.ksu.edu.sa/3702/Documents/RE SH/Res-90-1.pdf [Accessed June 13, 2016].

Alsaeah, T., 2013. Energy consumption in Mosques in Saudi Arabia. *Aleqtsadia*. Available at: http://www.aleqt.com/2014/09/17/article_887629.html.

Amer, O., Boukhanouf, R. & Ibrahim, H.G., 2015. A Review of Evaporative Cooling Technologies. *Interantional Journal of Environmental Science and Development*, 6(2), pp.111–117.

Gut, P., & Ackerknecht, D., 1993. Climate Responsive Buildings: Appropriate buiding construction in tropical and subtropical regions. , p.324. Available at: http://collections.infocollections.org/ukedu/en/d/Jsk02ce/.

Liu, Y. et al., 2006. Passive Design of Traditional Buildings in the Hot and Arid Regions in Northwest China. , (September), pp.6–8.

Mofidi, S.M., 2007. Passive architectural cooling principles for arid climates. In *2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century*. pp. 674–677.

MOIA, 2013. Statistics of Ministry of Islamic Affairs. Available at: http://www.moia.gov.sa/Eng/Menu/Pages/Statistics.aspx.

Mushtaha, E. & Helmy, O., 2016. Impact of building forms on thermal performance and thermal comfort conditions in religious buildings in hot climates: a case study in Sharjah city. *International Journal of Sustainable Energy*, pp.1–19. Available at: http://www.tandfonline.com/doi/abs/10.1080/14786451.2015.1127234?journalCode=gsol20 [Accessed April 28, 2016].

Olgyay, V., 1982. *Design With Climate, Bioclimatic Approach to Architectural Regionalism*, New Jersey: Princeton University Press, New Jersey.

Rosenlund, H., 2000. Climatic Design of Buildings using Passive Techniques. Available at: http://www.heatinghelp.com/files/articles/721/29.pdf.

Shohan, A.A.A., 2015. Thermal Comfort and Energy Demand of Small and Large Mosque Buildings in Saudi Arabia. , p.99.

Stanke, D., 2006. Standard 62.1-2004: System operation: Dynamic reset options. *ASHRAE Journal*, 48(12).

Suratkon, A., Chan, C.M. & Ab Rahman, T.S.T., 2014. SmartWUDHU': Recycling Ablution Water for Sustainable Living in Malaysia. *Journal of Sustainable Development*, 7(6), pp.150–157. Available at: http://www.ccsenet.org/journal/index.php/jsd/article/view/42489.

United Nations, World Population Prospects: The 2012 Revision.

US Energy Information Administration, 2012. International Energy Statistics. Available at: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=44&pid=44&aid=2&cid=regions&syid=2000&eyid=2012&unit=QBTU.