Comparison of Energy Efficiency Strategies for Mosques in the United Arab Emirates

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ABSTRACT

As public buildings that are typically financed by charities, mosques are commonly designed, built, and operated using very limited resources. Hence, failure to design energy efficient mosques either affects occupants' thermal comfort or re-orients the limited resources from other important activities to achieve that comfort. This paper documents part of an on-going study to determine the best allocation of limited financial resources to reach the most feasible energy saving in mosques in the United Arab Emirates. At this stage of the study, energy modeling is used to compare the impact of using various energy efficiency strategies on the cooling load. The results show the importance of controlling infiltration. They also show the value of insulating the walls and roof. However, a significant reduction in cooling load is achieved by splitting the mosque into two zones of operation. A similar result is demonstrated by using fans along with the air conditioning set at a higher temperature.

INTRODUCTION

Mosques are a unique building type from an energy analysis point of view. Muslims pray five times a day using a schedule that is linked to sun positions in the sky. Hence, prayer times vary throughout the year. While most people pray these five prayers in places other than mosques, Friday noon prayers are obligatory for males to be performed in a mosque. Hence, mosques are mainly sized to accommodate a very large number of occupants for just one hour or so per week. The rest of the week typically has significantly lower occupancy. In addition to this weekly peak of use, there is an annual peak that occurs throughout the month of Ramadan; a month in the Islamic calendar where fasting is obligatory and a night time prayer in mosques is popular. This Islamic calendar is a lunar-based one. Hence, every year in this calendar is about eleven days shorter than the solar-based Gregorian calendar. Consequently, Ramadan - with its peak usage of about 2 hours daily - is scheduled throughout all the climatic seasons of the year.

From an energy consumption point of view, the challenge of a mosque design is to economically achieve human thermal comfort throughout the day - when very few people use the mosque - while considering the daily, weekly, and annual peak

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times. This challenge is particularly important for the harsh hot environment such as that of the United Arab Emirates (UAE) in the Arabian Peninsula. Due to the luxurious lifestyle in the country, there is the expectation of having an ideal and comfortable indoor thermal condition all year long. Yet, the designer should consider that mosques financially run as charity based buildings. Hence, they need to be constructed and operated with a low budget. Unfortunately, this low budget typically means fewer resources dedicated by mosque designers to investigate the strategies to lower their energy consumption.

It is also important to consider that there are indirect values to investigating how to lower energy consumption in mosques. Due to their central location and visibility in the community - which is the case in most cities with large Muslim populations - mosques are perfect catalysts to promote energy conservation in buildings throughout the society (Mokhtar, 2011a). Additionally, mosques are perfect shelters in cases of disasters. Designing them with low energy consumption can significantly enhance such a potential role (Mokhtar, 2011b).

This paper is part of a study in progress to investigate the impact of using different strategies for energy saving in mosques. Each investigated strategy has its cost implications and energy saving potential. The study ultimately aims to investigate which strategy (or combination of strategies) can potentially provide more energy saving in relation to the amount of money spent. At this stage of the study, this paper shows a comparison for the impact of using different strategies on the cooling load without considering the cost implications. It also investigates the impact of considering the month of Ramadan and its movement throughout the year on assessing the cooling load of a mosque.

The paper starts with describing the used methodology. It then shows the results of investigating the different energy saving strategies. Finally, it presents the conclusion of these investigations as a step towards the continuation of the study.

METHODOLOGY

Comparing energy saving using different design strategies starts with establishing a baseline. This baseline enables the estimation of the potential energy saving of each strategy, hence enabling the comparison. The American Society for Heating Refrigeration and Air Conditioning Engineers (ASHRAE) standard 90.1-2013 describes one of the commonly used baselines (ASHRAE, 2013). This baseline is used by several sustainability assessment tools such as LEED (2014) and Estidama (2014). Because the objective of this study is neither to gain any certification points nor to compare with similar buildings around the world, but rather to investigate the energy saving potential of different design strategies, the study establishes another baseline. This baseline uses very basic construction systems for a model mosque. Using such systems is considered the case where no energy saving design strategy is in use. For example, external walls are constructed with one layer of regular masonry covered with stucco without any insulation. Similarly, the roof is made of reinforced concrete with simple water proofing and 2 cm of cement tiles. Used windows have single-pane 6 mm clear glass. The thermal conductance of the main building elements used for the baseline is summarized in table 1.

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Table 1. Conductance of the main elements used in the baseline

Element	U - Value	Element	U - Value
External Walls	2.8 W/m^2.˚K	Windows Glass (SGHC = 0.8)	6.4 W/m^2.˚K
Roof	1.7 W/m^2.˚K		
Slab-on-grade	1.35 W/m^2.˚K	Doors	1.7 W/m^2.˚K

In addition to the construction system, the baseline requires an architectural design. The study uses a standard mosque design that is used with minor variations in many residential zones in the UAE (see Figure 1). The mosque is roughly 2400 m^2 of a single open prayer space with a central open dome. The direction of Mecca – which controls the building orientation – is very close to the west direction, which is the case for all mosques in the UAE.

Figure 1. Photo of the mosque used for the study

The mosque is centrally air conditioned and the temperature is set to 22˚C. For modeling purposes, the air conditioning is assumed operable starting 15 minutes before the Dawn (first) prayer and continues to operate till 15 minutes after the Night (fifth and last) prayer. In reality, this schedule depends on the person responsible for operating the mosque but it is possible to program the system for these times. Because of the change in prayer times throughout the year, three different schedules of occupancy and the related HVAC operations are defined for the purpose of modeling. These schedules represent summer, winter, and both fall and spring activities. As the modeled mosque is a representative for mosques serving residential areas, it is assumed that Dawn prayers fill 5% of the mosque occupancy capacity, Noon and Afternoon prayers fill 10%, and Sunset and Night prayers fill 20% (see Figure 2). Only Friday Noon prayers and Ramadan Night prayers fill 100% of the mosque occupancy capacity (see Figure 3). As figure 2 shows, it is assumed that occupants start to gradually fill the mosque for 15 minutes before each prayer time, stay for 15 minutes for the prayer, and gradually leave during a period of 15 minutes

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after the prayer. The rest of the time, the mosque is assumed vacant. Exceptions are for Friday Noon prayers and Ramadan Night prayers where these times are extended as shown in Figure 3. Occupancy rates are also increased in all prayers in Ramadan to reflect typical users' behavior in that month. This data is anecdotal and is based on the author's numerous observations for such patterns of use.

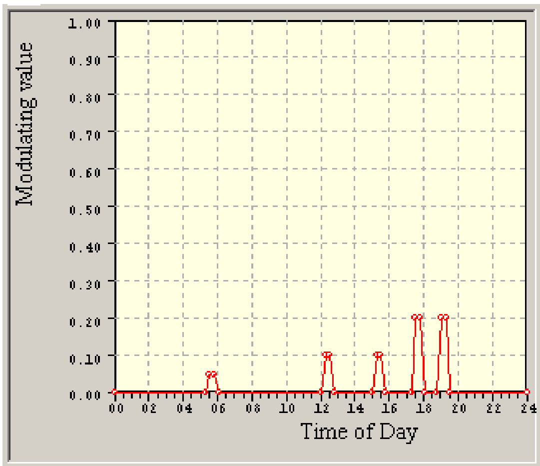

Figure 2. Pattern of occupancy relative to mosque capacity on a normal day (in December)

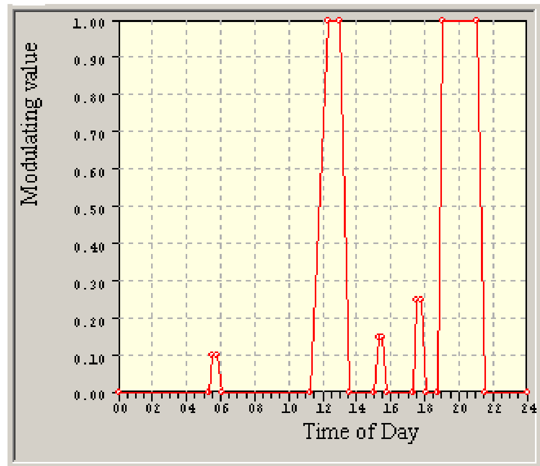

Figure 3. Pattern of occupancy relative to mosque capacity on a Friday during Ramadan (in December)

The study focuses on investigating strategies that are related to architectural design and architectural details. It also focuses on a region that is dominated by cooling load. Therefore, comparing the strategies is made by comparing the impact of each strategy on the conditioned space cooling load (both sensible and latent). Such impact is measured as the percentage of reducing the cooling load relative to the baseline cooling load. Using the cooling load rather than total energy consumption removes the impact of irrelevant factors to the investigation such as the performance of the different components of the mechanical system.

The investigation is performed using an energy modeling software that is based on and tested through ASHRAE standards (IESVE, 2014). The software is approved for energy modeling by LEED and is commonly used by professionals (LEED 2014).

INVESTIGATION RESULTS

1. Change in thermal insulation of the wall

The studied mosque has an external walls area of 2750 m^2. Table 2 demonstrates the impact of adding an insulating material to reduce the U-value of the external walls from that of the baseline. It also shows the corresponding reduction in the cooling load relative to that estimated for the baseline.

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The table identifies the impact of using (ASHRAE baseline) as well as the standard external walls commonly used in mosques in the UAE. The results show that there is an important impact to adding thermal insulation. However, doubling the thermal resistance (reducing the U-value from 0.42 to 0.2 and then to 0.1) has a diminishing impact on the cooling load reduction.

Table 2. Impact on the cooling load due to change in the U-value of the walls

External walls U-value	% Reduction in cooling load
2.8 (Baseline)	0.00%
1.4	8.27%
0.53 (ASHRAE)	13.99%
0.42 (Current Design)	15.24%
0.2	16.85%
0.1	17.00%

2. Change in the thermal insulation of the roof and the slab-on-grade

The mosque has a roof area of 2400 m^2 and the same area for the slab-on-grade. Table 3 demonstrates the results of changing the thermal insulation for each of these elements separately.

Table 3 Impact on the cooling load due to changes in the U-value of the roof and the slab-on-grade

Roof U-value	% Reduction in cooling load	Slab-on-grade U-value	% Reduction in cooling load
1.7 (Baseline)	0.00%	1.63 (ASHRAE)	-0.67%
0.8	6.18%	1.3 (Baseline) & (Current Design)	0.00%
0.57 (Current Design)	7.83%	0.6	1.36%
0.37 (ASHRAE)	9.36%	0.3	1.97%
0.2	10.80%	0.1	2.36%
0.1	11.51%		

3. Change in glass

There is about 220 m^2 of glass on the external walls (8% of the walls' area). Two energy saving strategies are used for the glass. The first is to increase the number of glass panes but with the same 6 mm clear glass. The second is to reduce the solar heat gain coefficient (SHGC) of the glass but for a single pane of glass. The results show that using either of these strategies separately has a minor impact on reducing the cooling load. However, SHGC has a bit more impact. This is expected considering that the weather in the UAE dominantly has a clear sky.

Table 4. Impact on the cooling load due to change in glass

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Number of 6mm clear glass panes	% Reduction in cooling load	Change in single glass SHGC	% Reduction in cooling load
Single Glass (Baseline)	0.00%	0.8 (Baseline)	0.00%
Double Glass with air space	1.51%	0.4	2.24%
Triple Glass with air space	2.09%	0.2	3.38%

4. Change in shading

The baseline uses no shading device on the external windows. The study investigated the use of lattice gypsum work that is used in many mosques as a shading device to prevent direct solar penetration. This is modelled in the software through manipulating the transmittance and reflectance of the glass to have zero SHGC. This results in a reduction of 4.5% in the cooling load.

5. Change in building tightness (infiltration rate)

One important challenge in energy modeling is determining the value that represents the tightness of the envelope. To overcome this challenge, the following process is used.

Younes et al 2011 with reference to ASHRAE, Dickerhoff et al. (1982), and Harrje and Born (1982) showed that infiltration air leakage through cracks of doors and windows in residential buildings represents an average of 15% of the total leakage. Therefore, if the study can estimate the leakage through doors and windows, it can roughly estimate that of the whole building.

The modeling software used in the study can estimate the infiltration through door and window cracks based on site wind data. To make such estimations, non-weather-stripped windows with a crack flow coefficient of 1.1 ($l\ s^{-1}\ m^{-1}\ Pa^{-0.6}$) and non-weather-stripped doors with a crack flow coefficient of 1.4 ($l\ s^{-1}\ m^{-1}\ Pa^{-0.6}$) are used to represent the doors and windows of the baseline. These coefficients are recommended by the software used based on AIVC (1994).

While assigning 0 Air Change per Hour (ACH) for the envelope and the above data for door and window cracks, the cooling load from these cracks is estimated by the software and divided by 0.15 to estimate the total contribution of infiltration to the cooling load. This contribution is found to be equivalent to a value of 0.33 ACH through the envelope including the doors and windows. This value is close to the ASHRAE reference value of 0.4 ACH. To allow the controlling of the leakage through doors and windows separately, a value of 0.289 ACH is used in the model to represent leakage from all the envelope components except doors and windows.

For the baseline, it is also assumed that the windows are continuously closed while the doors are continuously open at 20% of their area during prayer times only. This is to accommodate the fact that entering – and later exiting – users open and close the doors very frequently during that time (see Figure 2 and Figure 3).

Table 5 shows that using weather stripping for the doors (Crack Flow Coefficient = 0.082 $l\ s^{-1}\ m^{-1}\ Pa^{-0.6}$) and for the windows (Crack Flow Coefficient = 0.079 $l\ s^{-1}\ m^{-1}\ Pa^{-0.6}$) – which are the values recommended by the software used based

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on AIVC (1992) – reduces the cooling load by about 3%. However, using tight construction with ACH = 0.05 and weather stripping can result in an important 20% reduction in the cooling load.

Investigating the use of two layers of (non-weather-stripped) doors and windows - to reduce the impact of wind pressure on the leakage from them - reveals a reasonable reduction of 7.76% in the cooling load.

Table 5. Impact on the cooling load due to change in infiltration

Infiltration control strategy	% Reduction in cooling load
No weather strip on doors and windows and ACH 0.29 for the rest of the envelope (Baseline) & (Current Design)	0.00%
Weather strip on doors and windows and ACH 0.29 for the rest of the envelope	2.92%
Weather strip on doors and windows and ACH 0.20 for the rest of the envelope	9.01%
Weather strip on doors and windows and ACH 0.10 for the rest of the envelope	16.08%
Weather strip on doors and windows and ACH 0.05 for the rest of the envelope	19.87%
Using double doors and double windows and ACH 0.29 for the rest of the envelope	7.76%

6. Increase the thermostat set temperature for the air conditioning and add fans

This strategy depends on manipulating both air temperature and air speed as two of the factors impacting human thermal comfort. In this investigation, the thermostat is set to 28°C rather than 22°C for the baseline. The cooling load based on this new temperature is calculated. To achieve thermal comfort at this temperature, ceiling fans are installed to increase air speed. One ceiling fan covers 10 m^2 of the mosque area. The energy consumption for the fans is calculated with the assumption that only half the fans function for an average of 15 hours daily except for Friday prayer and Ramadan night prayers where all fans function.

In order to assess the impact of this strategy, the cooling loads of the baseline and that of this strategy are converted to energy consumption by dividing by a Coefficient of Performance equals three. The calculated energy consumption for the fans is then added to that estimated for this strategy. In comparison to the estimated energy consumption from the cooling load of the baseline, a saving of 31% is realized when using this strategy. This seems very promising. However, the cost implication of this strategy is beyond the scope of this paper and will be considered in the next stage of the study. Unlike the other strategies, converting the cooling load to energy consumption is necessary for studying the impact of this strategy. The addition of the fans hardly impacts the cooling load but do increase the energy consumption. Depending on the reduction in cooling load can give false impression on the actual saving.

7. Split the mosque into two zones

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This strategy depends on studying the schedule of use for the mosque. The building capacity is designed to accommodate the one hour per week Friday prayer and the two hours daily night prayer during the month of Ramadan. Therefore, the building is almost empty most of the time (See Figure 2 and Figure 3). Yet, the whole building is air conditioned during the day (for the baseline, it is air conditioned starting one hour before the dawn prayer until one hour after the night prayer).

It makes sense to split the mosque architecturally into two separate zones. A small zone (20% of the area) that is used for all prayers and a large zone that is used only for Friday prayer, Ramadan night prayers, and other large group prayers such as Eid prayer (three hours per year).

Table 6 illustrates the possible reduction in the cooling load as a result of this strategy. A reduction of 75% can be achieved if the large zone has no air conditioning during the no-occupancy periods. However, the investigation shows that the temperature inside this zone can reach 38°C during summer and relative humidity can be above 75% for long periods of time. Such high temperature and humidity can cause damage to internal finishing, furniture, and books. Therefore, the study investigated setting the thermostat at a higher temperature than the baseline during the no-occupancy periods. With a reasonable 30°C and maximum relative humidity of 60%, a reduction of about 44% of the cooling load can be achieved.

Table 6. Impact on the cooling load due to splitting the mosque into two zones

Temperature control in two separate zones	% Reduction in cooling load
Single space at 22°C (Baseline) & (Current Design)	0.00%
Splitting the mosque into two zones. Small zone operates at 22°C. Larger zone is kept at the below temperature with no occupancy except for Friday prayer and Ramadan night prayers where temperature is kept at 22°C	
25°C	5.99%
28°C	30.03%
30°C	43.62%

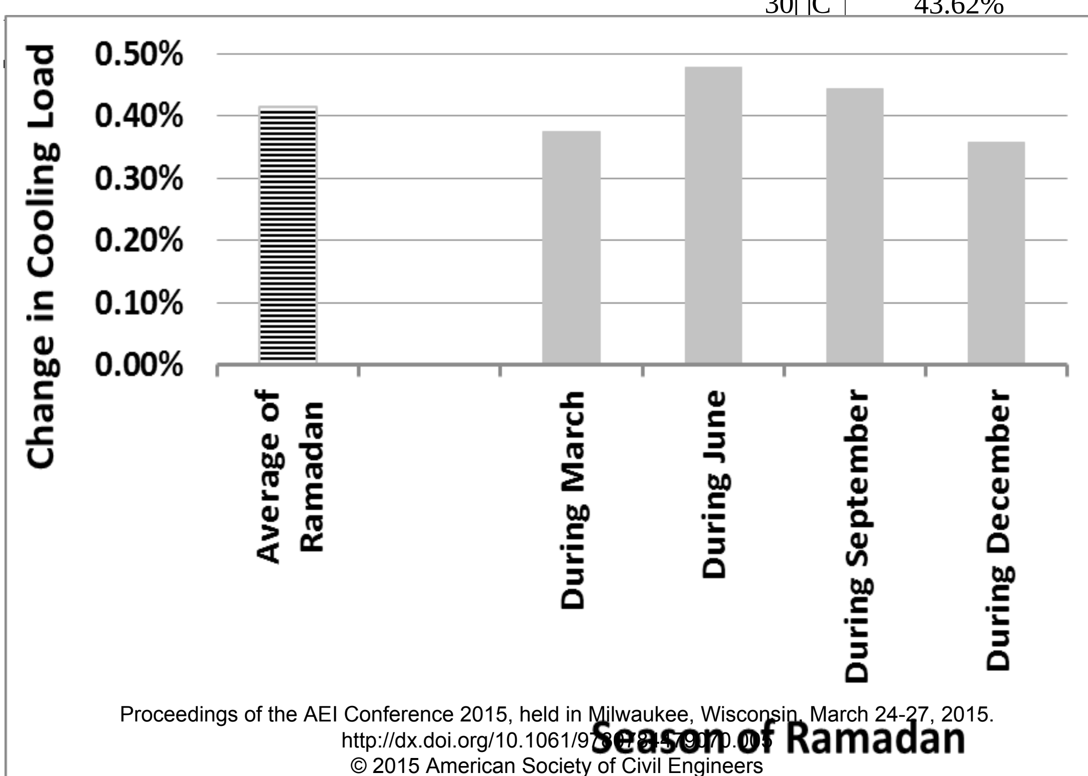

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Figure 4. Change in the cooling load when considering Ramadan

ANALYSIS AND CONCLUSION

The results of the first five strategies can be understood when analyzing the relative contribution of each cooling load source in the baseline as indicated in Figure 5. The Figure illustrates the importance of infiltration and conductance through the external walls and the roof. Therefore, manipulating the construction of these items resulted in a reasonable reduction in the cooling load. Controlling infiltration in particular seems promising. It can achieve a high reduction in the cooling load (reaching 20%), and it does not require a high cost to do so. Rather, it is achievable through good architectural detailing and good construction workmanship. The architectural detailing can be easily standardized. Good construction workmanship is a bit of a challenge in the UAE but can be achieved if its value is clearly demonstrated. It certainly makes sense to pay more attention to infiltration control in mosque building codes.

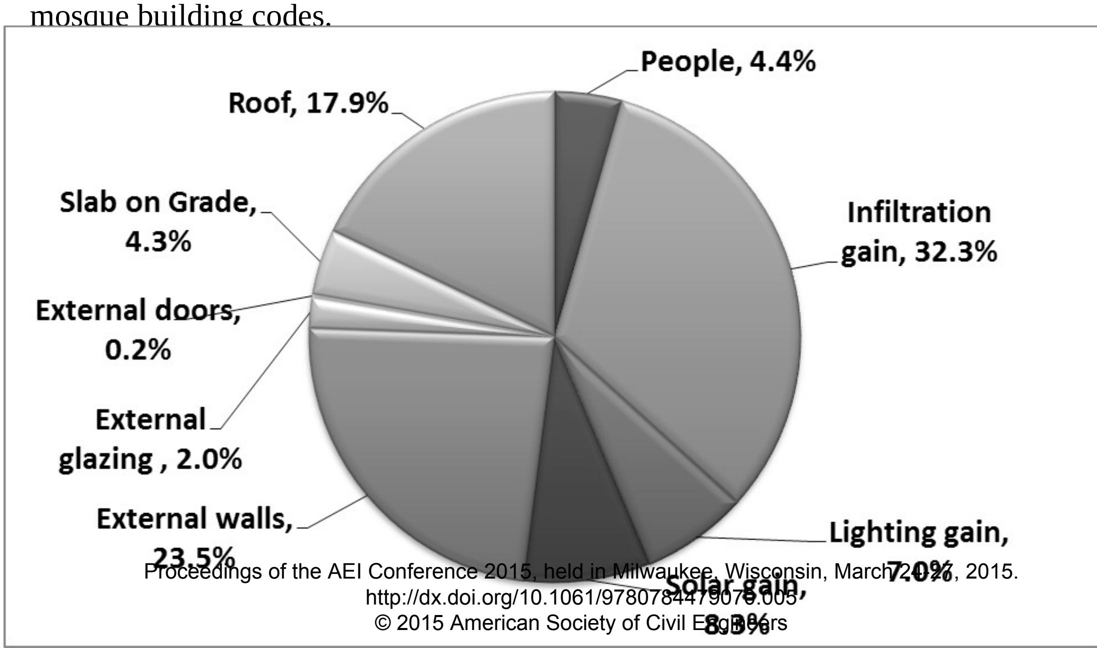

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Figure 5. Percentage impact of each cooling load component to the total (baseline case)

The strategy of using fans along with a high set temperature for the air conditioning (strategy number 6) is a shift from current practices. The estimated reduction in energy consumption is certainly very valuable and therefore this strategy should be considered seriously. Similarly, splitting the mosque in two temperature zones (strategy number 7) is also very promising and should be looked at seriously as well. Both of these strategies require design changes but should not result in a high cost relative to the potential saving. However, this will be investigated in detail in the next stage of the study.

The results indicate the possibility of ignoring the impact of the month of Ramadan. If such an impact is desired, Ramadan can be modelled once during any season of the year. This is because the difference between any season and the average of the four seasons is negligible.

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