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THE RELATIONSHIP BETWEEN VENTILATION AND OPENING STRATEGIES OF DOMED MOSQUE FOR INDOOR COMFORT

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Abstract

A mosque is an important communal space for the Muslim community. Instead of focusing on physical aesthetics, mosque designs should be more focused on passive means for indoor comfort such as to study how natural ventilation and envelope designs could improve indoor comfort. This study aims to examine the relationship between ventilation and opening strategies of a domed mosque for indoor comfort in Malaysia. This investigation is done by running wind tunnel simulations on the various domed mosque design strategies and configurations to draw conclusion as to which variation provides the highest rate of air movement within the mosque. The study concludes that openings on domed roofs would be considered a good ventilation inducer and smaller inlet-outlet could provide an alternative for warmer regions with good wind flow. The results of this study provides a basis for future mosque designers to ensure that natural ventilation systems are considered thoroughly, simultaneously taking into account the thermal comfort aspect within their design in order to achieve a sustainable design solution.

Keywords: Mosque design, indoor comfort, dome design, air movement

1.0 INTRODUCTION / BACKGROUND OF THE STUDY

Mosque design is a prominent aspect that determines worshippers' overall experience within the mosque. This not only covers the aesthetic aspect expected of a mosque, but the functional and sustainable attributes it provides as well. The function of a dome in a mosque as not only for decorative purposes and a symbol to the place of worship for Muslims, but also to aid ventilation and natural lighting (Baharudin & Ismail, 2014). This further enhances the need for multiuse of form in the design of mosques. Hence, a communal space that is of importance to the Muslim community in Malaysia should not only provide an aesthetic value to the space but also provide the user with the best environmental experience; simultaneously providing a sustainable approach to energy consumption. This is where the application of a natural ventilation system has always been the go-to option for mosque designers. This study aims to analyse the relationship between natural ventilation and envelope opening design strategies of a domed mosque for improved indoor air movement performance. The findings lead to recommendations for envelope opening design strategy for domed mosque to improve indoor air movement performance in hot-humid climate.

2.0 LITERATURE STUDY

This study is conducted within Malaysia, a country with a climate that demands satisfaction of thermal comfort. Thermal comfort is affected by many factors such as relative humidity, air temperature, and air movement of the surrounding space, relative to the person. This air movement is commonly associated with the ventilation system of the building. Within a space that has a large number of occupancy, such as a mosque, thermal comfort of the users is a major concern (Ahmad, Ahmad, Syed, Oluwole, & Nik, 2012). Therefore, the ventilation system installed must be capable in terms of maintaining good air movement within and outside of the building.

2.1 Thermal Comfort in Malaysian Climate

Malaysia is a country located near the equator with an equatorial climate and an average temperature of 27°C. The high level of humidity and temperature poses a challenge for designers to design a space that caters to the various needs of the occupants in such conditions. A poorly insulated and ventilated building will suffer from discomfort (Ibrahim, Baharun, Nawi, 2014). Thermal comfort is defined as when one's body temperature and skin perspiration is at a low (Djongyang, Tchinda, & Njomo, 2010). A person's thermal comfort is usually affected by air temperature, radiant temperature, humidity, air velocity, clothing insulation and activity within the surrounding (ASHRAE Std-55, 2004; Alwetaishi, 2016). Therefore, it is safe to assume that comfort is achieved by manipulations made to the surrounding in order to ensure a constant and decent amount of air movement.

2.2 Mosque

A mosque is a religious structure that accommodates the various needs of the Islamic community, which includes functioning as a place to gather for prayer, a meditative sanctuary, for religious gatherings, discussions and education as well as for spreading da'wah (Noordin, Sani, Masrek, Mohamad, & Shamsuddin, 2017). Most importantly, the mosque is a symbol representing the Muslim identity, which is why it is incredibly important to ensure such a place is deemed sustainably and aesthetically pleasing (Baharudin et al., 2014). One of the typical design layouts of the mosque consists of the domed roof and rectangular layout. As far back as the Ottoman period, mosques known as the single dome layout had the simplest form of all. It is the common roof type applied to traditional buildings, including mosques (Najafi & Yaghoubi, 2015). In the past, the curved or domed roofs would be built with masonry or bricks, along with its low costs and good thermal performance (Bahadori & Haghighat, 1986; Runsheng, Meir, & Etzion, 2003). The domed roof design is considered a passive cooling system as it could circulate cool air throughout the building and keep water and ice frozen during the country's arid central (Bahadori, 1978; Gómez-Munoz, Porta-Gándara, & Heard, 2003). They were able to do such things without any sort of energy input other than rely on a natural phenomenon.

2.3 Natural Ventilation in Mosque

A mosque is a sacred place for Muslims to seek tranquillity and peace. Thus, it is vital to achieve optimum thermal comfort in mosques for the occupants as they execute their activities (Noman, Kamsah, & Kamar, 2016). Hence, the study of mosque envelope is important to provide a comfortable indoor (Bakhlah & Hassan, 2015). The roof is part of a mosque envelope that is most exposed to the sun. Means should be explored as ways to reduce the solar radiation, such as through an increase in air movement in order to provide a well-designed mosque.

Natural ventilation is a passive strategy that has been long applied; before the appearance of mechanical ventilation systems. Now it is an option and is known as a passive cooling strategy used to counter excessive energy consumption (Sacht & Lukiantchuki, 2017). The main advantage of natural ventilation is the possibility of achieving a high ventilation rate during the hot period for cooling without requirements of active cooling in order to provide a comfortable indoor space (Di Turi & Ruggiero, 2017; Schulze, Gürlich, & Eicker, 2018). The stack effect phenomenon should be taken advantage of and be used as one of the main systems of natural ventilation in a mosque. By having an opening on the dome, when the air is in a still condition, the heated dome would release the hot air out and allow for cooler air to enter through the lower areas. Such a system has been applied on cisterns to allow outflow of moist air and inflow of dry air to cool the water at the bottom of the cistern (Najafi et al., 2015). This study focuses mainly on determining which opening strategies in mosque designs, including roof openings and window to wall (WWR) ratios, would be the ideal configuration that is able to provide the maximum value of wind velocity within the mosque.

3.0 METHODOLOGY

The research approach of this study is the quantitative method. A base case model of a typical domed mosque is established, then variations to the base case models are created. The models were then run with wind tunnel simulation software, Autodesk Flow Design. The software is able to visualise the air movement surrounding and within the respective. This study was focused mainly on the different configurations of basic ventilation and opening strategies on a typical domed mosque to find the design that would provide a good mean of natural ventilation. The simulation was run on a basic test model without any reference of a specific location in Kuala Lumpur, Malaysia. Therefore, the results can be applied as a basis for further detailed studies.

4.0 RESULT AND DISCUSSION

4.1 Introduction

The results of the natural ventilation simulations in terms of wind velocity are recorded in the unit of metre per second (m/s) where the highest wind velocity during each simulation was observed, recorded and analysed to compare which design configuration would be best. Results in Table 1 show a gradual increase of velocity when the inlet and outlet size decreases in size. Table 1 presents the highest value of wind velocity produced by model A3-IO5 sized at 20% WWR at 3.689 m/s. The table also shows roof design A3, the dome with the top opening, having produced higher wind velocity compared with the other two configurations. In other words, larger openings on the top of the dome could provide much better airflow within the mosque compared with domes with openings on the side and no openings at all. The result at the bottom of the fourth column shows that roof design A3 with top opening and inlet-outlet set IO5 at 20% WWR produces the best velocity value at 3.689 m/s.

Table 1. Indoor Wind Velocity of Domed Roof Mosque with Opening, without Opening and with Top Opening, paired with similar sized inlet-outlet size measured in meter per second (m/s)

Inlet-Outlet Size % of WWR	A1 m/s Without Opening	A2 m/s With Side Opening	A3 m/s Top Opening
IO1 – 60%	2.847	2.858	3.287
IO2 – 50%	2.89	2.904	3.334
IO3 – 40%	2.994	3.004	3.435
IO4 – 30%	3.049	3.08	3.567
IO5 – 20%	3.224	3.294	3.689

Therefore, the study further elaborates on whether having different sizes of inlet and outlet would also contribute to the increase in wind velocity. Focusing on only three of the outlet sets so that the ranges of differences are more visible. Therefore, the study elaborates on set O1, O3 and O5. The inlet and outlet sizes are paired alternately and the results are recorded in Table 2. Table 2 shows that configuration A3-I5-O3 obtains the highest reading. However, it is still a losing value when compared with the previous configuration of A3-IO5 by itself. Therefore it can be deduced that inlet-outlet set IO5 can produce a high velocity without a different sized outlet.

Table 2. Indoor wind velocity of pairings between different configurations of roof design, inlet size and outlet size (m/s)

	Inlet size					
Outlet size % of WWR	**A1-I1 m/s 60%**	**A1-I5 m/s 20%**	**A2-I1 m/s 60%**	**A2-I5 m/s 20%**	**A3-I1 m/s 60%**	**A3-I5 m/s 20%**
O1 – 60%		3.148	2.858	3.185	3.287	3.43
O3 – 40%	2.979	3.209	2.986	3.201	3.35	3.584
O5 – 20%	3.23	3.224	3.34	3.294	3.58	

The results prove having a larger opening on the dome induces a higher velocity and a smaller inlet-outlet opening increases the velocity within the space. Although the optimum speed deemed comfortable for indoor comfort is not more than 2 m/s, further fine-tuning is recommended for more accurate results. This would be a positive feat if the indoor air movement is activated despite a very still outdoor conditions. The study has proven for the smaller inlet, even if the outdoor air is at a smaller value, the indoor air movement is increased. Figure 1 shows how the smaller inlet increases the velocity of the wind within the space compared with Figure 2, where a larger inlet results in a similar velocity progression into the space.

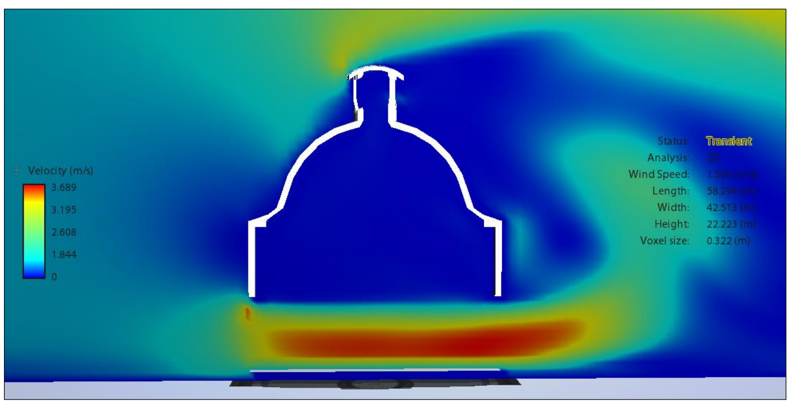

Figure 1. A3-IO5 – Top Opening on Domed Roof with 20% Inlet-outlet Size

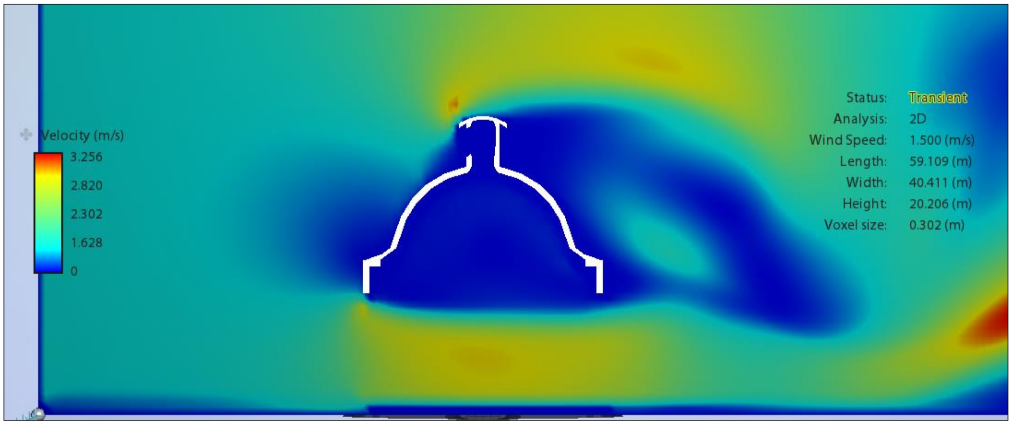

Figure 2 A3-IO1 – Top Opening on Domed Roof with 60% Inlet-outlet Size

As such, from Tables 1 and 2, it can be observed that the models with an opening on the domed roof generally recorded higher wind velocity when compared with the fully enclosed domed roof. While models with the larger top opening domed roof might produce higher wind velocity compared with models with side openings on the domes. The wind velocity increases gradually as the window to wall ratio of the two walls perpendicular to one another is decreased. In other words, the smaller the opening of the enclosing element, the higher the indoor wind velocity. This phenomenon is caused by the difference in pressure and the presence of solid enclosure. As the wind meets with a solid enclosure, it is forced to push its way around the solid and into the nearest void. When a massive amount of wind gets diverted into one small opening, it creates a gush of pressure released at once after it goes through the void. This creates a high-speed wind velocity within the space after the void. This phenomenon would prove good application for places with lesser air movement or warm countries with any wind flow as it will increase the air movement within the space.

5.0 CONCLUSION AND FUTURE WORKS

Designing a mosque is a challenging feat as the indoor comfort of the users is a very vital aspect. This study looks into various design strategies for a domed mosque. The various configurations of the domed mosque namely the roof opening strategies and window to wall ratio openings are looked into and the effect of each design configurations towards the air movement within the space is studied. This study has concluded that indoor wind velocity is increased when the inlet and outlet are smaller in size. However, if the smaller inlet is met with a larger sized outlet, the velocity inside drops slightly. Which concludes, the smaller the inlet-outlet size, the higher the velocity within the space. A large inlet would not increase the indoor air velocity, but would only maintain a similar air movement as the outdoor. This would be a good design to incorporate in cooler places with high wind rate that does not require the additional velocity indoor.

As for how the configurations with the smaller inlet all had provided higher readings of velocity, this can be incorporated into designs in warmer places with less wind flow. In general, the roof configuration that provided the model with a high air velocity is configuration A3, which is the top opening domed roof. This proves an opening on the top part of the dome is bound to increase the wind velocity indoor. There is only a small difference between the velocity of the domed roof without openings and the side openings. However, in general, air would not circulate within the space inside the dome at a low wind velocity. This can be seen as a slight waste although it could provide better thermal performance when compared with a flat roof (Tang et al., 2003). The mosque is a common aspect in the life of all Muslims, therefore it is important that further studies are conducted to ensure mosques perform as better urban structures while functioning as a communal space. This study is hoped to aid future studies on mosques design strategies, specifically on the openings and ventilation aspects.

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