EFFECTS OF OPENING TO WALL RATIO (OWR) ON INDOOR THERMAL COMFORT OF PRAYING HALL IN URBAN MOSQUE, KUALA LUMPUR

BY

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ABSTRACT

Opening design and Opening to Wall Ratio (OWR) have significant effects on the thermal comfort level of a building. The design of façade openings in the mosque usually focuses on aesthetic consideration as opposed to work as a mechanism to control indoor thermal comfort. Nowadays, the majority of the mosques improve the indoor thermal comfort by installing air-conditioning systems. The mosques are primarily used daily at prayer times including Friday prayer. The usage of air-conditioning increases the energy consumption and electricity cost since the mosque deals with intermittent occupancy. Most of that time, the mosque is unoccupied. Therefore, the usage of air-conditioning systems for thermal comfort incur the unnecessary increase in energy usage and cost. Literature review in this research focuses on urban mosque, façade design and thermal comfort. The definition of urban mosque and façade openings identified in this research is significant to identify the typology and criteria of OWR of urban mosque. Moreover, the research uses a quantitative approach by means of Urban Mosque Façade Design (UMFD) based on OWR Inventory and computer simulation on thermal analysis of air temperature. The UMFD-OWR inventory is significant to determine the configurations of OWR of UMFD for thermal analysis, while computer simulation is used to investigate the effects of OWR on indoor thermal comfort in praying hall. The term opening adopted in this research are operable doors, fixed and operable windows and opening such as arch, void and etc. The OWR also focuses on middle section of the façade form of both North-West Façade (NWF) and South-West Façade (SEF). The final samples selected for thermal analysis are OWR M1, OWR M2, OWR M3 and OWR M4 on UM model for thermal simulation. The highest opening ratio is OWR M2 and the lowest is Base Case Model (OWR BM) which acts as a reference and comparison between the other models. All the models are simulated in ECOTECT and analysed based on Hourly Temperature (HT), Annual Temperature Distribution (ATD) and Passive Adaptivity Index (PAI). The research found that the indoor temperature for HT recorded in ECOTECT is within the comfort range for naturally ventilated building (23.6^{o}C -30.7^{o}C) during Subuh and Isya' on the hottest day, and Subuh, Maghrib and Isya on the coolest day. OWR BM (lowest opening ratio on UMFD) recorded highest comfort percentage (ATD) and better PAI compared with others models. All the findings on thermal analysis in ECOTECT showed that the variations of opening ratio influenced the heat gain through radiation and internal load (number of occupancies) and heat loss through the outdoor air movement (cross ventilation and stack effect). The comparison on OWR M2 between ECOTECT and IES-VE, IES-VE predicted lower indoor temperature reading in the praying hall. The accuracy of the results can be further investigated through field measurement in further research. Thus, further research is also encouraged to explore more on façade design strategies without specific on certain design (i.e. opening) in reducing the indoor temperatures in an urban mosque in order to fulfil the indoor design conditions.

خلاصة البحث

إنَّ تصميم الفتحات وفتحة الجدار (OWR) لهما تأثير كبير في مستوى الراحة الحرارية للمبنى. عادةً ما يركّز تصميم فتحات الواجهة في المسجد على النظر الجمالي بدلاً من العمل كآلية للتحكم في الراحة الحرارية الداخلية في الوقت الحاضر، تعمل غالبية المساجد على تحسين الراحة الحرارية الداخلية من خلال تركيب أنظمة تكييف الههواء. تستخدم المساجد بشكل أساس في أوقات الصلاة بما في ذلك صلاة الجمعة. يزيد استخدام مكيف الهواء من استهلاك الطاقة، وتكلفة الكهرباء، حيث يتعامل المسجد مع إشغال متقطع معظم ذلك الوقت، المسجد غير مأهول. ولذلك؛ فإن استخدام أنظمة تكييف الهواء للراحة الحرارية يتحمل الزيادة غير الضرورية في استخدام الطاقة والتكلفة.
تركّز المراجعة الأدبية في هذا البحث على المسجد الحضري وتصميم الواجهة والراحة الحرارية. إن تعريف المسجد المدني وفتحات الواجهة التي تمَّ تحديدها في هذا البحث مهمّة لتحديد نوع ومعايير OWR للمسجد الحضري. علاوة على ذلك، يستخدم البحث منهجًا كميًّا عن طريق تصميم واجهة المسجد الحضرية (UMFD) استنادًا إلى مخزون OWR ومحاكاة الكمبيوتر على التحليل الحراري لدرجة حرارة الهواء. يُعَدُّ المخزون UMFD-OWR مُهمًا لتحديد تكوينات OWR لـ UMFDللتحليل الحراري، بينما يتمُّ استخدام محاكاة الكمبيوتر للتحقيق من تأثيرات OWR على الراحة الحرارية الداخلية في قاعة الصلاة. إن المصطلح الافتتاحي المعتمد في هذا البحث عبارة عن أبواب قابلة للتشغيل، ونوافذ ثابتة قابلة للتشغيل وفتحات مثل القوس والفراغ وما إلى ذلك. ويركّز OWR أيضًا على الجزء الأوسط من الواجهة للواجهة الشمالية الغربية (NWF) و (South-West Façade المؤسسة). العيّنات النهائيّة المختارة للتحليل الحراري هي OWR M1و OWR M2 و OWR M3 و OWR M4 على أنموذج UM للمحاكاة الحرارية. أعلى نسبة افتتاح هي OWR M2 وأدناها هيBase Case Model ((OWR BM) التي تعمل بوصفها مرجعًا ومقارنة بين النماذج الأخرى. يتمُّ محاكاة جميع النماذج في ECOTECT وتحليلها على أساس درجة الحرارة ساعة (HT) ، والتوزيع السنوي لدرجة الحرارة (ATD) ومؤشر التكييف السلبي .(PAI) أظهر البحث أن درجة الحرارة الداخلية لـ HT المسجّلة في ECOTECT تقع ضمن نطاق الراحة للمبنى ذي التهوية الطبيعيّة (23.6ºC -30.7ºC).خلال الصبح والعشاء Subuhو' Isya في اليوم الأكثر سخونة، و Subuh والصبح، والمغرب والعشاء، Maghrib وIsya في أروع يوم. سجلت OWR BM أقل نسبة فتح في (UMFD أعلى نسبة راحة (ATD) و PAI أفضل مقارنة مع نماذج أخرى. أظهرت جميع نتائج التحليل الحراري في ECOTECT أن تغيرات نسبة الفتحات أثرّت في كسب الحرارة من خلال الإشعاع والحمل الداخلي (عدد الإشغال) وفقدان الحرارة من خلال حركة الهواء الخارجي (التهوية المتقاطعة وتأثير المكدس). المقارنة بين و OWR M2 بين ECOTECT و IES-VE ، تنبأت IES-VE بقراءة منخفضة لدرجة الحرارة داخل قاعة الصلاة. يمكن مواصلة التحقق من دقّة النتائج من خلال القياس الميداني في مزيد من البحث. وبناءً عليه؛ يتمُّ تشجيع إجراء مزيد من الأبحاث لاستكشاف مزيد من استراتيجيات تصميم الواجهة دون تحديد تصميم معيّن (أي الفتحات) في تقليل درجات الحرارة داخل المسجد في المناطق الحضرية من أجل الوفاء بشروط التصميم الداخلي.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Built Environment).

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

2D	Two Dimension
3D	Three Dimension
AC	Air Conditioning
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AT	Air Temperature
ATD	Annual Temperature Distribution
AV	Air Velocity
BSEEP	Building Sector Energy Efficiency Project
CD	Coolest Day
DBT	Dry Bulb Temperature
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
DOS	Department of Statistic, Malaysia
HT	Hourly Temperature
HVAC	Heating, Ventilation and Air Conditioning
ISO	International Organization for Standardization
JAWI	Jabatan Agama Islam Wilayah Persekutuan
JPBD	Jabatan Perancangan Bandar dan Desa Semenanjung Malaysia
MOS	Mosque Occupancy Schedule
MRT	Mean Radiant Temperature
MS	Malaysian Standards
NEF	North-East Façade
NWF	North-West Façade
OWR	Opening to Wall Ratio
PAI	Passive Adaptivity Index
RH	Relative Humidity
SEF	South-East Façade
SWF	South-West Façade
UHI	Urban Heat Island
UM	Urban Mosque
UMC	Urban Mosque Capacity
UMD	Urban Mosque Design
UMFD	Urban Mosque Façade Design
UML	Urban Mosque Location
UNICEF	United Nations Children’s Fund
WWR	Window to Wall Ratio

LIST OF SYMBOLS

%	Percentage (Unit for Ratio in Percentage)
°C	Degree Celsius (Unit of Temperature)
clo.	Unit Measurement for Clothing Insulation
h	Unit Measurement of Hour
Icl	Clothing Insulation
km/h	Unit Measurement of Distance per Hour
lux	Unit Measurement of Illuminance
m	Meter (Unit Measurement of Length, Width, Height)
m/s	Meter per second (Unit Measurement of Air Velocity)
m^2	Meter square (Unit Measurement of Total Area)
Met	Unite Measurement of Metabolic Rate
mm	Unit of Measurement for Thickness
T_a	Air Temperature
T_i	Indoor Air Temperature
T_n	Thermal Neutrality or Comfort Temperature
T_o	Outdoor Air Temperature
W/m^2	Unit Measurement of Activity Level

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

This chapter discusses the relevance of selecting the urban mosque façade design to achieve thermal comfort. It describes the research background and the research problem that arises thereof. The chapter also elaborates the research aims, objectives, questions, significance, scope and limitations to achieve the desired outcomes of the research. In addition, a general overview of this research is explained by outlining the research structure.

1.2 RESEARCH BACKGROUND

According to 2016 census data, Malaysia has approximately 31 million people. The most populated is urban areas, which made up 74.8% of the population (24,509,005-est. 2016). This percentage is expected to increase in the future (www.worldometers.info, 2018). Muslims recorded the highest percentage in comparison with other religions (Department of Statistics Malaysia (DOS), 2011). Hence, the provision of the urban mosque is important to cater to a large Muslim population in urban areas.

The study of urban mosques in Malaysia is very limited. The only finding related to urban mosques is by Norhanis Diyana (2014 and 2015). The researcher focused on spatial, social and cultural aspects of urban mosques. Given the paucity of studies of urban mosques, the study on the façade design of urban mosque is significant.

Corresponding to the only study of urban mosques in Malaysia by Norhanis Diyana, the term “urban mosque” is the mosque located in an urban or city setting. This research adopts this definition. Kuala Lumpur is selected as the site area for urban mosques due to the high rate of urbanisation (Department of Statistics Malaysia, 2015).

The development of mosques and its functions in the Muslim community in Malaysia prioritises worshippers' comfort (Mohd Firrdhaus, 2016). Insufficient thermal comfort in the mosque causes discomfort for worshippers (Hussin, Salleh, Chan and Mat, 2014). Installing air-condition systems in the mosque in Malaysia has become a norm for cooling the worshippers. However, the lack of research and information on the level of comfort of the prayer hall in the mosque in Malaysia makes it difficult to improve its comfort (Hussin et al., 2014b).

Thermal comfort is one of the functional indicators identified by Jin (2013) for façade performance assessment. There is a significant relationship between façade design and thermal comfort. A good façade design can help optimise daylight and thermal comfort (Department of Standards Malaysia - MS 1525, 2014). Thus, this research focuses on the façade design of urban mosques to determine its effects on thermal comfort.

The façade design of urban mosques in Kuala Lumpur signifies the variety of façade designs in terms of design articulation (see Figure 1.1-1.4). MS 1525:2014 added that the façade of the building is the external face of the building that encompasses the fenestration and other elements that describe the building form and aesthetics, enables indoor climatic control and provides security to occupants from weathering. Nurul 'Athiqah and Alice Sabrina (2014) and Alice Sabrina (2008) also categorised the façade form of the mosque into the base, middle and top. These façades of mosques include the design elements for the floor, wall, opening, window, and roof or dome. Prior to the façade form or building the mosque, Shafizal (2014) researched the thermal comfort resulting from the roof design for Malaysian mosques.

Figure 1.1 Masjid Al Bukhary, Kuala Lumpur.

Figure 1.2 Masjid Jamek Kuala Lumpur.

Figure 1.3 Masjid Asy Syakirin, Kuala Lumpur.

Figure 1.4 Masjid Negara, Kuala Lumpur.

The opening is one of the design elements in the middle form of the mosque façade design. Figures 1.1-1.4 show that the opening element of the mosque’s façade is a significant design element. The opening or voids increase the air movement to ventilate the building and increase the air temperature. Noor Hanita, Mohd Shafiq, Zaiton, and Rosniza (2015) and Ogunjimi, Osunade, and Alabi (2007) supported that the opening design or the amount of ventilation of the opening has significant effects on the thermal comfort of a building. Thus, it is significant to investigate the effects of the opening area of the urban mosque façade design on thermal comfort.

The findings of the relationship between opening on façade design and thermal comfort will contribute to providing more comfortable indoor spaces of urban mosques and insights into the development of mosque design.

1.3 RESEARCH PROBLEMS

There are two (2) research problems identified for this research. Section 1.3.1 and 1.3.2 describe the research problems.

1.3.1 Lack of Adequate on Opening Design Provision in Providing Thermal Comfort.

Architects maximise the use of the opening of the urban mosque façade in Kuala Lumpur (see Figures 1.1-1.4) to enhance how mosques look. The opening arrangement and configurations of the mosque's façades contribute to the variety of façade designs of urban mosques and are visually attractive.

Despite attracting people through the physical design of the opening, Aflaki, Norhayati and Zakaria Al-Cheikh (2012) added that the opening is an effective strategy to reduce the external heat in a tropical climate. They also stated that openings on the building façade play a significant role in controlling air flow which ensures the indoor air can be maintained through the combination of fresh outdoor air and indoor air. However, in designing building façades, architects usually pay more attention to the aesthetic aspects, while neglecting the influence of opening forms on energy consumption (You, Qin, and Ding, 2013). Besides, there is not enough attention paid to façade design from an operable aspect.

The design and performance of the façade openings that allow outdoor air to flow in and stale air to flow out of a building influence the success of the natural ventilation system in the building (Moghaddam, Amindeldar, and Besharatizadeh, 2011). These openings can take the form of simple holes, openable windows, trickle ventilators or through wall ventilators (Sharples and Chilengwe, 2006) or other types such as trickle vents or louvres (Heiselberg, Bjørn, and Nielsen, 2002). You et al. (2013)

also identified that the façade opening in the building design domain contains abundant content, like the fixed window which can only receive daylight, an operable window which can receive daylight and natural ventilation, and a ventilation cave which can only receive natural ventilation. To accurately quantify the influence of opening forms of building façades on thermal comfort, this research adopted computer simulation techniques.

Façade designs and natural ventilation are two passive design strategies recommended in MS 1525:2014 for non-residential buildings. Shafizal (2014) found that bigger openings allow a faster heating and cooling process until the indoor air temperature reaches the same temperature as the outside air. Consequently, the opening area of the building influences the heat gain in the indoor environment.

Properly designed building façades will minimise the usage of air-conditioning as cooling demand which leads to a decrease in electricity cost and energy consumption (Aksamija, 2014). However, there are limited studies on the effect of the opening of façade designs on thermal comfort particularly in the urban mosques in Malaysia.

1.3.2 Dependency on Air-conditioning System to Maintain Thermal Comfort.

The provision of thermal comfort for worshippers is a prime concern in mosque building (Hussin et al., 2014; Bakhlah, M. S. and Hassan, 2012). Najafi and Shariff (2011) also stated that the mosque with a good thermal comfort is preferred. However, it has been anecdotally observed that mosques with air-conditioning systems attract a more significant number of worshippers for the daily prayers compared to the non-air-conditioned mosque (naturally ventilated). Hussin et al. (2014) and Fauziah Hanum, Noor Hanita and Rosniza (2016) also identified that low-quality environments within the urban built environment such as thermal comfort in the mosque decrease levels of people's attendance.

It has become common practice that mosques in Malaysia are installed with air-conditioning (AC) systems to provide cooling and better thermal comfort for the worshippers. The increasing trend of AC use in Malaysian mosque buildings increases electricity consumption in the daily mosque operations. The function of the air-conditioning system is to address the heat load of buildings with cooling and increase the comfort of occupants (Siti Halipah, Azhaili, M. Nasrun and Ervina, 2014). The heat load in mosques have contributed to an overall poor thermal performance of mosque buildings which have become more dependent on artificial means to provide a comfortable thermal environment at high energy consumption. Thus, the provision of thermal comfort for naturally ventilated mosques requires research, especially urban mosques.

1.4 RESEARCH AIM AND OBJECTIVES

The main aim of this study is to investigate the effectiveness of the opening to wall ratio (OWR) of façade design on the indoor thermal comfort of urban mosque's prayer halls. To achieve this, the following objectives are targeted:

1. To define façade openings for urban mosque façade design (UMFD).
2. To determine the configurations of opening to wall ratio (OWR) of urban mosque façade design (UMFD) for thermal analysis.
3. To investigate the effects of the opening to wall ratio (OWR) on indoor thermal comfort in urban mosques' prayer hall in terms of thermal analysis in air temperature.