University-industry Research Collaboration on Development of Green Mosque Design

環境にやさしいグリーン・モスク開発を通して実証された「産学協同」の有効性。その始まりから、活動、成果を発表。

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Abstract

University-industry (U-I) research collaboration is an important channel for knowledge transfer between academia and the practitioner in a profession. In the architectural profession, many architects or designers have lack of exposure to research-based design process. Meanwhile, the research knowledge among academics requires a platform for application and demonstration to the profession. Since the last decade, there has been an increasing amount of research carried out on green building design in tropical climates within Malaysian universities. This paper presents new insights into the role of a research university in green building knowledge and technology transfer to the building industry. The process, challenges and benefits of the U-I collaborative research project on development of a green mosque design are discoursed. The interactive design review process between the two parties has stimulated innovative design ideas and strategies for a green mosque by considering energy efficiency and renewable energy. Green strategies such as daylighting, solar shading, rainwater harvesting and photovoltaic were explored and applied into the project. This paper concludes that U-I research collaboration is a powerful driver of innovation in architectural profession.

Keywords Green building; Research-based design; Energy efficiency; Renewable energy

Introduction

University-industry (U-I) collaborative research has been increasingly promoted as an important channel for technology and knowledge transfer between the academia and practitioner in a profession. However, many challenges have been identified by previous surveys. One of the major factors contributing to the conflict is dissimilar organizational goals. Universities aim to create new knowledge and to educate; meanwhile industry's primary focus is to capture valuable knowledge that can be leveraged for competitive advantage (Muscio et al., 2012; Motohashi and Muramatsu, 2012).

Bruneel et al. (2010) categorized the challenges in U-I collaboration as 'orientation-related barriers' and 'transaction-related barriers'. The first one refers to the barriers related to differences in the orientations of universities and industry; while the latter refers to those related to conflicts over IP, and dealing with university administration. Nevertheless, the modes and types of collaboration projects determine the intensity of the each barrier. Inter-organizational trust is the strongest mechanism for reducing the barriers to U-I collaboration.

In architecture or building industry in Malaysia, green technology has been one of the most rapidly developing aspects which require more research efforts. Since the 1990s, there has been increasing research projects carried out on green building design in tropical climate among the Malaysian universities. Therefore, the research knowledge within academia requires a platform for application and demonstration to the profession.

Malaysian Standard 1525 was drafted in year 2001 and revised in 2007 for building energy efficiency (Department of Standards Malaysia, 2007). Green Building Index (GBI) was introduced in Malaysia in year 2009 as sustainable building rating system for both non-residential new construction (NRNC) and residential new construction (RNC) buildings (Chen, 2008; GBI, 2009). Thus, there has been more awareness on green building design and technology among the building profession.

Several prominent green buildings were built in Malaysia. For instance, Low Energy Office (LEO) at Putrajaya in year 2004, Green Energy Office (GEO) at Bangi in year 2007 and Energy Commission (EC) Diamond Building at Putrajaya in year 2010. These buildings have become the showcases of energy efficiency and renewable energy in office buildings in tropical climates. These buildings have achieved lower Building Energy Index (BEI) of 65 to 135 kWh/m^2/yr in comparison with the typical Malaysian office buildings BEI of 250 kWh/m^2/yr. (Chan, 2009; Loewen et al., 1992).

The development of some of these green buildings involved U-I collaboration. For instance, Universiti Kebangsaan Malaysia (UKM) and Universiti Teknologi Mara Malaysia (UiTM) collaborated with RKA architect and Malaysian Green Technology Corporation or formally known as PTM (Pusat Tenaga Malaysia) in conducting research on GEO building in Bangi (Mansour et al., 2006). Besides, Universiti Teknologi Malaysia (UTM) collaborated with Public Works Department Malaysia (JKR) to study daylighting performance in existing Malaysian government office buildings to develop daylighting design guideline (Lim et al., 2012a).

In the past, U-I collaborations in green building sector focused on office buildings. This paper presents a U-I research collaboration on development of a green mosque design, for the first time in Malaysia. Research-based design process of the project is explained. The challenges and benefits of the project are explained.

The Green Mosque at Johor Bahru, Malaysia

The Green Mosque research project is a U-I collaboration between Institute Sultan Iskandar, Universiti Teknologi Malaysia (ISI-UTM) and the developer Mudra Tropika Sdn. Bhd. (MTSB). The building is designed by Rashdan Maahfar Architect (RMA) while the owners are *Majlis Agama Islam Negeri Johor* (Johor State Islamic Religious Council) and *Perbadanan Setiausaha Kerajaan Johor* (Johor Government Secretariat).

It is located at Jalan Kolam Ayer, Johor Bahru, Malaysia (latitude 1.45° N and longitude 103.76° E), which has a tropical climate. The site area is approximately 5018.42 m^2 (1.24 acre). This on-going project consists of several main spaces: 1. Main Prayer Hall, 2. Open Prayer Hall, 3. Sub-basement Car Park, 4. Landscape Deck, and 5. Office. The form and spaces of the mosque are shown in Fig. 1. This building has 2 levels (ground floor and mezzanine floor) and a sub-basement, with total built-up area of 2239.02 m^2.

Building Performance Simulation

In the initial stage, the original building design as proposed by the architect was modeled in computer simulation software for building performance simulations. Shadow casting and surface solar insolation were simulated using Autodesk Ecotect Analysis to determine the area exposed critically to direct sunlight radiation. Daylighting simulation was performed in IES (Integrated Environment Solution) Radiance to study the daylighting levels in Main Prayer Hall, Open Prayer Hall and Sub-basement

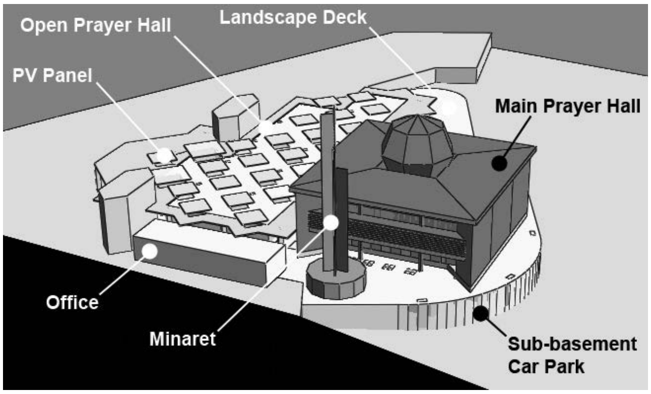

Fig. 1 Green Mosque 3D Modeling in IES <VE> computer simulation software.

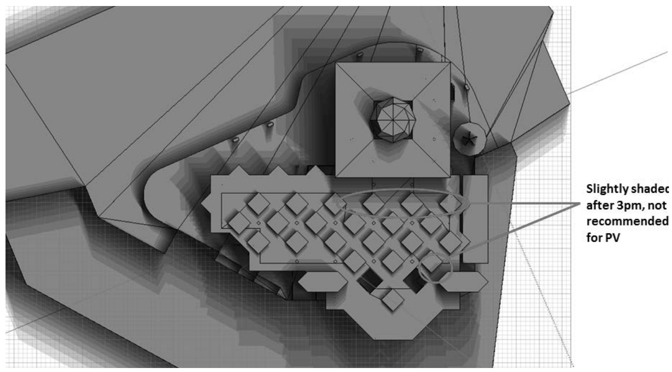

Fig. 2 Shadow analysis of 10am to 4pm on 22 June.

Car Park. Furthermore, CFD (computational fluid dynamic) simulation was conducted using IES MicroFlo to investigate natural ventilation air flow in the building, especially in the Main Prayer Hall. From the simulation results, review of the design was made by the team and finalized by the architect in order to improve the building performance for energy efficiency.

Shadow Analysis

In order to utilize renewable energy, the design team proposed the installation of photovoltaic (PV) panels on the open prayer hall roof slab. It is essential to assure the PV panels are not shaded by the building. Hence, Autodesk Ecotect Analysis was employed to simulate building shadow casting during various times to determine the suitable locations of PV panels.

The simulations were carried out using Sun path at latitude 1.40° N and longitude 104.00° E (closest to Johor Bahru). The sun is closest to the equator during equinoxes (21st March and 23rd September) and farthest away from the equator during solstices (22nd June and 22nd December). Thus, these dates were employed for the experiment to represent the different locations of the sun throughout the year.

The shadow ranges were casted during the duration of 10am to 4pm, which was the optimum period to receive solar radiation for PV in tropical climate. Figure 2 shows an example of shadow analysis simulation results. The simulation results showed that there were 2 areas shaded during 21 March, 22 June and 23 September whereas only 1 area was shaded during 22 December. Subsequently, these 2 areas were not recommended for PV installation.

Solar Insolation

The building façade should be shaded from direct solar radiation to avoid unwanted heat gain and to achieve energy efficiency. Thus, Autodesk Ecotect Analysis was employed to simulate solar insolation on the building façade. The results were used to determine which building façade was most critically exposed to solar radiation and heat gain. Thus, the identified façade requires more shading. The yearly weather data of location at latitude 1.4° N and longitude 104.0° E was applied to simulate the average daily direct and diffuse solar radiation (as shown in Fig. 3).

The simulation result showed that the roof surfaces received higher solar intensity in comparison with the vertical façade. For instance, the flat roof slab at Open Prayer Hall yielded about 4000 Wh/m^2 daily direct and diffuse radiation; thus was potential for PV installation to harness solar energy. On the other hand, many vertical façades were shaded from direct solar radiation. The openings at the Main

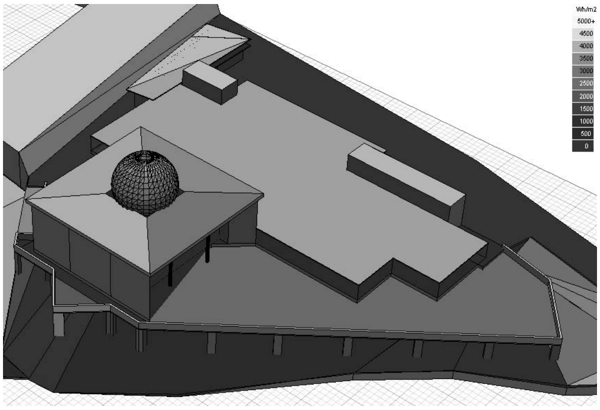

Fig. 3 Average daily direct and diffuse radiation (Range 0 – 5000+ Wh/m²)

Prayer Hall received average daily direct solar radiation lower than 80 Wh/m^2.

Daylighting

One of the important passive design strategies for building energy efficiency was utilizing daylight while avoiding direct sunlight which will cause glare and thermal problems (Lim et al., 2009; Lim et al., 2012b). Thereby, daylighting simulations were conducted for various spaces (Main Prayer Hall, Open Prayer Hall and Sub-basement Car Park) using IES Radiance. Illuminance levels were simulated on a horizontal plane at 300 mm height from the floor. Overcast sky with 10klx external illuminance was employed to represent the worst scenario when the sky was fully covered with clouds and dark. The simulated illuminance level can be converted to daylight factor (DF) using Equation 1. The targeted DF level for the prayer halls was 1.0 to 3.0%.

$$DF = \frac{\text{Internal Illuminance, } E_i}{\text{External Illuminance, } E_e} \times 100\% \qquad (1)$$

The Main Prayer Hall is a double volume space. Daylighting simulation results for various design options for the Main Prayer Hall are illustrated in Fig. 4. Fig. 4a shows that in the initial design, illuminance level was higher than 1000 lx (or DF 10.0%) in the area near the openings. This was because the upper level façade had no glazing or shading screen. According to MS 1525, DF higher than 6.0% will cause glare and thermal problem (Department of Standards Malaysia, 2007). Hence, the majority of the spaces in the initial design will have glare and thermal problems due to extremely high illuminance level. Therefore, the initial design was reviewed by adding a mezzanine floor for female prayer and clear

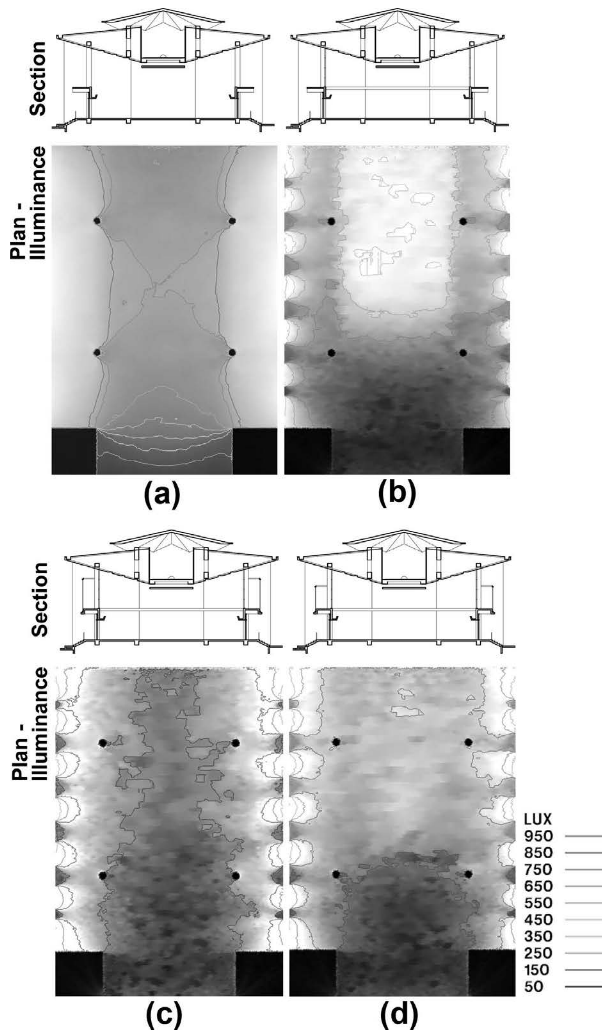

Fig.4 Daylighting illuminance simulation results for Main Prayer Hall under 10klx overcast sky: (a) Initial design without glazing at upper level; (b) With mezzanine floor and glazing; (c) With 3700 mm height decorative screen; (d) With 2800 mm height decorative screen height.

glass glazing at the upper floor façade. Then the DF at the area near to the openings was reduced to about 5.0% (Fig. 4b). Nevertheless, the centre part of the Main Prayer Hall still received high daylight level (DF > 3.0%) due to the double volume openings.

Further enhancement of the daylighting design was proposed by the architect. Decorative screens with 3700 mm height were added at the upper floor side openings to reduce the excessively high daylight level and glare problem. However, the simulation results showed that the DF at the centre part of the prayer hall was reduced to below 0.5% (Fig. 4c). Subsequently, the height of the decorative screen was reduced to 2800 mm in order to allow more daylight penetration and reflection on the ceiling. As showed in Fig. 4d, most of the spaces were able to yield DF of 1.0 – 3.0% which was within the recommended range. As a result, this final design was recommended for daylight utilisation while avoiding glare and thermal problem.

The daylighting design for the Open Prayer Hall was also investigated and improved. Fig. 5 shows the illuminance levels on horizontal plane for the initial design and the reviewed design with side-lighting openings at the concrete roof slab. The side-lighting opening was an integration of daylighting and PV system. The purpose of the side-lighting opening was to allow reflected daylight to penetrate into the Open Prayer Hall while providing spaces for PV panels installations.

The daylighting simulation results of the initial design (Fig. 5a) demonstrated that there was insufficient daylight in the Open Prayer Hall due to the deep planning. DF was even below 0.1% in the middle part of the hall. Thus, modification of the roof slab with side-lighting openings was introduced to increase the daylight availability. From the simulation results shown in Fig. 5b, the reviewed design demonstrated significant improvement. The DF at the middle part was increased to 0.5 – 1.5 %. Therefore, this roof design was recommended for both daylighting and PV installation.

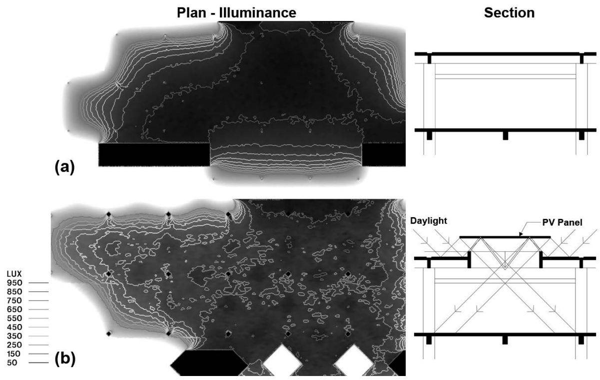

Fig. 5 Daylighting illuminance simulation results for Open Prayer Hall under 10klx overcast sky: (a) Initial design; (b) With side-lighting at roof slab.

Computational Fluid Dynamic

The Green Mosque utilizes natural ventilation as a means of passive energy saving strategy as air-conditioning system consumes high energy for building cooling. One of the most critical spaces for natural ventilation was the Main Prayer Hall because it had huge glazed volume. The air flow and velocity influence the users' thermal comfort. Thereby, CFD simulations were carried out using IES MicroFlo to improve the air flow and velocity in Main Prayer Hall (Fig. 6). Prior to the CFD simulation, the boundary conditions were simulated using IES Apache and IES MacroFlo to determine the outdoor and indoor air temperature, surface temperatures, glazing temperatures and air flow volume. Then, these boundary conditions were imported to IES MicroFlo for CFD simulation.

Without any mechanical ventilation, the air velocity in the Main Prayer Hall ranged from 0.0 to 0.5 m/s only (as illustrated in Fig. 6a). This was too low to achieve thermal comfort. Hence, exhaust fans were suggested to extract the hot air from the hall while increasing the air velocity. Several exhaust fans were installed at the centre of the ceiling to generate 160,000 CFM air flow as shown in Fig. 6b. The CFD simulation result indicated that the air velocity at the centre of the hall was increased to 0.8 m/s. The maximum air velocity of more than 3.0 m/s was achieved in the area near the exhaust fans. Because

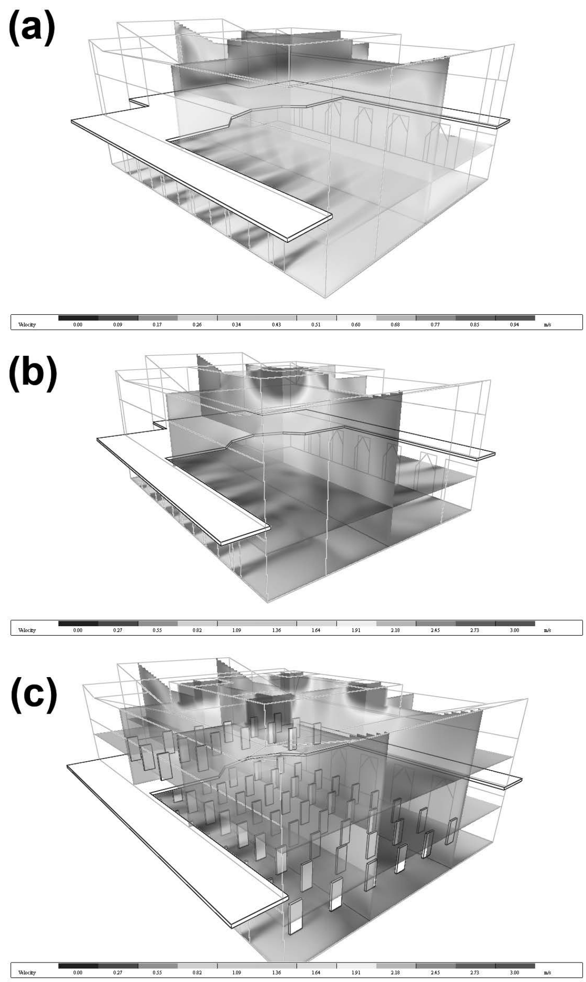

Fig. 6 CFD wind velocity simulation for Main Prayer Hall: (a) Initial design; (b) With exhaust fans of total 160000 CFM airflow at center; (c) With exhaust fans of total 50000 CFM airflow at each of the 4 corners.

the exhaust fans were installed at the centre of the ceiling, the increased air flow was concentrated at the centre of the hall.

Another design alternative was proposed by installing the exhaust fans with a total of 50,000 CFM at the four corners of the ceiling as shown in Fig. 6c. The total generated air flow was 200,000 CFM. The CFD simulation result demonstrated that this design was successful in distributing the increased air velocity within the Main Prayer Hall. Thus, the users could feel the air movement when they are performing their prayers. This design was recommended in order to improve the users' thermal comfort.

Rainwater Harvesting

Rainwater harvesting was employed in this project to collect rainwater for ablution and toilet flushing usage. Apart from that, the grey water will be recycled for landscape irrigation. The rainwater harvesting system had been designed by researchers from ISI-UTM. Throughout the project, the researchers had worked together with the architect and contractor to determine the locations and sizes of the tanks, types of filtration system and use of landscape ponds as water storage. Eventually, the rainwater recycling system included landscape pond as bio-organic filtration system. The schematic design drawings were produced by the researchers and further developed for detail drawings by the M&E engineer.

Photovoltaic

In this project, PV installation was proposed on the roof-top of the Open Prayer Hall. In order to assure that the electricity generated by the PV will be sufficient to cover the daily usage, calculations of PV installation to supply the energy demands of the mosque had been produced by researchers from ISI-UTM. The total surface that can be covered by PV is approximately 300m^2. The calculations showed that the hourly PV electricity power which can be generated is 21 kW/h. Thus, the targeted electricity generation for 5 hours per day is 105 kWh/day. Besides, ISI-UTM also worked together with MTSB, RMA and other consultant teams on the application to SEDA (Sustainable Energy Development Authority of Malaysia) for grid-connection. As a result, the mosque successfully obtained the Feed-in Tariff (FiT) under the category of religious building.

Discussion

This project employed various kinds of computer simulations to study and improve the building performances during design development (detail) stage, whereas previous research (Goulding, 1992; Lim et al., 2008) suggested green building design should begin at the early design stage (pre-design / sketch). The overall building form and orientation had been determined by the architect before the simulation experiment. Thus, it limited the exploration of passive design strategies such as using self-shaded forms, north-south orientation, small volume spaces, etc.

In this project, the architect actually already considered a green design concept in the initial design stage. For example, most of the façades with openings were actually shaded with roof overhangs. Meanwhile, the façades that were facing direct sunlight had no openings, using storage and staircases as buffer zones. However, not all the spaces were given sufficient consideration for green design. For instance, the Main Prayer Hall had a large square volume space which was not recommended for tropical climate (Olgyay, 1963; Yeang, 1994). Besides, the deep planning for the Open Prayer Hall and sub-basement car park was not appropriate for daylight utilization.

Some of the considerations or ideas for green design as proposed by the architect were proven not to be appropriate through the simulation experiment. For example, the architect used openings without glazing in the Main Prayer Hall to allow daylight penetration and natural cross ventilation. The simulation results, however, demonstrated that the excessive use of openings without glazing caused DF above 10.0% which will cause glare and thermal problems (Department of Standards Malaysia, 2007). Subsequently, glazing and decorative screens were proposed to reduce the glare and thermal discomfort.

Due to the proposed building form and massing, some of the passive strategies could not be applied effectively. The use of natural ventilation in the Main Prayer Hall was very constrained due to the large volume space. As shown in Fig. 7, large square volume space has low opening area to space volume ratio in comparison with linear or clustered space planning. Apart from that, the outdoor wind velocity in Malaysia is also very low. According to Hui (1998), the range of indoor air velocity in low rise buildings in the country is between 0.04 m/s and 0.47 m/s. Hence, the simulation showed that the indoor wind velocity in the initial Main Prayer Hall design was below 0.5 m/s. As a result, the prayer hall had to rely on mechanical exhaust fans to increase the wind velocity to 0.8 m/s (60% increment) at the center part of the hall.

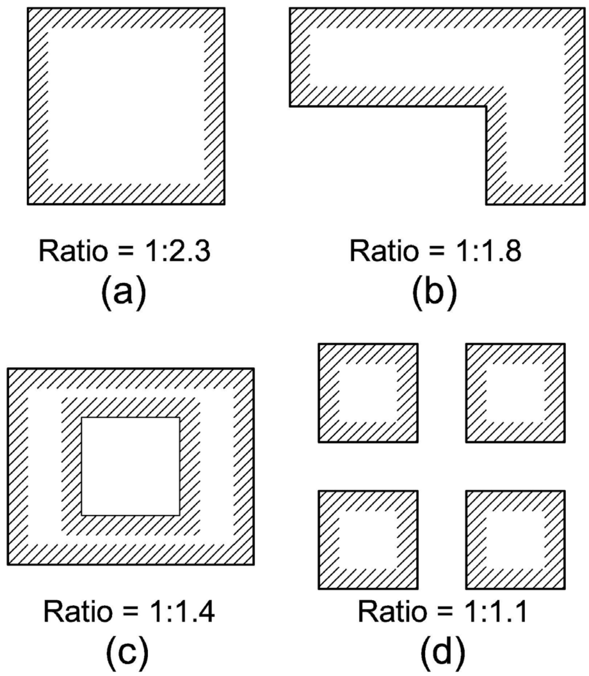

Fig. 7 Opening area to space volume ratios for different building forms: (a) Square; (b) Linear; (c) With center courtyard; (d) Clustered.

The Green Mosque project is a U-I collaborative research project that involved multi-disciplines with varied organizational orientations. Industry demanded immediate results to quicken the construction process while the university researchers took the project as a long-term effort to develop a green mosque design with energy efficiency and renewable energy. The building owner, architect and other consultant teams emphasized solving on-site issues and completion on time. On the contrary, the university researchers looked for potential academic outputs such as scientific publications. 'Orientation-related barriers' as mentioned by Bruneel et al. (2010) were the main challenge in conducting the project. Meanwhile, the 'transaction-related barriers' was not significant in the project.

Building performance study requires time-consuming modeling and simulation processes, with detailed information or data input to assure the accuracy of the results. However, this project was an actual development project under construction. In addition, a lot of detailed information such as the use of materials and finishes was not finalized. This will affect the scientific reliability of the research outputs. The balance between time constrainta and accuracy was vital to meeting the demands of both the U-I. As a result, simplification of the building modeling was needed to reduce the simulation time while still retaining acceptable accuracy.

Despite the 'orientation-related barriers', there were effective knowledge and technology transfer in the U-I collaborative research project. Industry was exposed to a new kind of architectural design process based on empirical research. Besides, various green building technologies were employed in the project such as PV, rainwater harvesting system, light tubing, etc. On the other hand, the university side was given a platform to apply the green design method and strategies on an actual development project.

Throughout the project, there were interactive communications between U-I via various technical meetings. The original mosque design was reviewed several times based on the research results. Integration of the professional and academician resulted innovative green design ideas to achieve energy efficiency and the use of renewable energy. For instance, combination of PV panels and skylight openings on the roof-top of the Open Prayer Hall, integration of rainwater harvesting system with landscape pond and the use of decorative screen to reduce glare problem in the Main Prayer Hall.

Conclusion

The findings indicated that without research basis, some of the initial green design concept determined by the architect were actually not performing as expected. Therefore, U-I collaboration for research-based design process is very important to prove and improve the building performance. Building modeling and simulation is an appropriate methodology which should begin during the early or pre-design stage rather than the design development or detailing stage when the possible design modifications are very limited.

The interactive research-based design review process between the U-I parties had stimulated innovative design ideas and strategies for a green mosque by considering energy efficiency and renewable energy. Green strategies such as daylighting, solar shading, rainwater harvesting and photovoltaic were explored and applied in the project. Thus, U-I research collaboration is a powerful driver of innovation in architectural profession.

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