TABLE OF CONTENTS

Editorial Preface
Green Building Movement In Malaysia: Past, Present And Future
Zalina Shari.................................................................................................................................................. 1

Assessing Green Practices And Their Impact On The Environmental And Financial Performances Of
Construction Projects
Nor 'aini Yusof And Anseya Osmadi ........................................................................................................ 7

Air Conditioning Energy Profile And Intensity Index For Retrofitted Mosque Building: A Case Study In Malaysia
Azman Hassan, Lim Chin How And Elias Sallab......................................................................................... 17

The Impact Of Air Gaps On The Performance Of Reflective Insulations
Lim Chin How And Chan Seong Aun........................................................................................................... 28

Comparison Of Measured And Modelled Mean Radiant Temperature In The Tropical Urban Environment
Nazeri G. A. Khiir, Kamaruzaman Sopian, Mohammad Afgh-brand, Lim Chin How, Nik Ludman Nik Ibranin And Abdulkarim Maftuh A. El-breki .................................................................................................. 35

Preliminary Evaluation Of Air Flow In Atrium Of Building In Hot And Humid Climate
Wardah Fatimah Mohammad Yusoff, Mohd Khairul Aqhari Mat Salehman And Fakhrulhaq Maluisin ............................................................ 43

Skewed Wind Flows Energy Exploitation In Built Environment
Ahmad FAzilizan, Wan Khairul Muzammil, Mohd Aslam Ismail, Mohd Fadhil Ramlee And Adnan Ibrahim ................................................................................................................................. 53

Building Information Modelling (BIM) For Sustainable Industry: The Malaysian Architect’s Perspective
Khairul Aziy Ahmad Jamal, Mohammad Fadhil Mohammad And Norfashiha Hashim .................................................. 61

Energy Efficiency Action Plan For A Public Hospital In Malaysia
Norzaklin Ahmad Ladin, Mirzaal Makmimah Junadi, Nurfauzan Alyssa Ahmad Affandi, Mohd Adli Ibrahim, Kamaruzaman Sopian, Mohd Aziq Mat Teridi, Saharul Sepeai, Mohd Saker Su’ait And Lim Chin How .......................................................................................................................... 73

Assessment Of Indoor Thermal Condition Of A Low-Cost Single Story Detached House: A Case Study In Malaysia
Ashref Awadi, Mohd. Farid Mohamed, Mohd Khairul Aqhari Mat Salimman And Wardah Fatimah Mohammad Yusoff .................................................. 80

Instructions to Authors
The sustainability development movement has been evolving worldwide for almost three decades, causing significant changes in building delivery systems in a relatively short period of time. A subset of sustainable development, sustainable construction, addresses the role of the built environment in contributing to the overarching vision of sustainability (Kibert, 2008). It contributes to the achievement of urban sustainability and as one of the integral processes of sustainable development. Sustainable building, on the other hand, is the subset of sustainable construction, as defined by Da Pietro (2001, p.10).

“Urban sustainability is the wider processes of creating human settlements and includes areas such as governance. Sustainable building concerns itself solely with the process of creating buildings, while construction includes infrastructure such as roads and bridges”.

Green building has been used as a term interchangeable with sustainable building and high-performance building. Its core message is to improve current design and construction practices and standards so that the buildings we build today will last longer, be more efficient, cost less to operate and maintain, and provide healthy, comfortable and working environments; significantly improve the quality of the built environment. To dramatically lowering energy consumption and increasing the use of renewable energy systems, green buildings need to be designed and the methods for their evaluation have been developed. However, the critical areas needing development for the future of green buildings in Malaysia (Kibert, 2008) are the issue of closing material and energy loops for infrastructure. Natural systems can provide cooling, wastewater processing, stormwater uptake, food production, and a range of other services for the community.

Today’s high-performance green buildings in Malaysia are a significant improvement over the conventional buildings of the past. They consume significantly less energy, water, and materials; provide healthy and working environments; significantly improve the quality of the built environment. The concept of green building materials may have been defined and the methods for their evaluation have been developed. However, the issue of closing material and energy loops for infrastructure is still considered as the most critical area need development for the future of green buildings in Malaysia. Green building is also about increasing the use of renewable energy systems, improving the efficiency of which with buildings and their sites utilize energy, water, and materials; protect natural resources; and improve the built environment so ecosystems, people, and communities can thrive and prosper. There are four pillars of green buildings, i.e. minimising impacts on the environment; mobility, and access) are an essential factor in the development of a more sustainable built environment. In short, progress has been made, but the problematic problems remain unsolved.

There have of course been plenty written on green, sustainable and resilient buildings in Malaysia, in this journal and many others. The theories and practices have been explored by, for example, Hulwicz (2015), Shant and Schulthi (2012), and Salam and Nih Brabum (2018). Urban and site planning and management have been addressed by, for example, Ghazali et al. (2012), and Salam and Nik Ibrahim (2018). Urban and site planning practices have been explored by, for example, Hellwig (2015), Shari and Parveez (2009), Abdul Shukor et al. (2012), Arabi et al. (2015), Lim et al. (2016), and management have been addressed by, for example, Ghazali et al. (2012), and Salam and Nik Ibrahim (2018). Urban and site planning practices have been explored by, for example, Hellwig (2015), Shari and Parveez (2009), Abdul Shukor et al. (2012), Arabi et al. (2015), Lim et al. (2016).
Mat Rashid et al. (2015), Rakhubindroo et al. (2017), and Raja Yahya et al. (2019) have investigated the impact of indoor environmental quality on students’ performance. Various methods have been conducted by various researchers; for instance, thermal comfort by Neama (2013), Mohammad Yusoff et al. (2012), and Ibiyeye et al. (2013), respectively. Comparisons of thermal comfort in the design of low-cost housing in Malaysia have always been neglected, leading to the uncomfortable indoor thermal environment. They suggest that adding bubble foil roof insulation is one of the solutions to reducing the indoor air temperature of this type of housing.

The second paper addressing the passive design strategies is “Preliminary evaluation of airflows in the atrium of building in hot and humid climate” by Mohamad Yussif, Mat Salamah and Mubin. It calls for greater awareness on the importance of providing sufficient airflow paths (i.e. access corridors that connect inside to outside) in appropriate locations to achieve adequate air velocities inside a naturally ventilated atrium.

Another two papers address building energy efficiency issue and recommend measures to improve energy performance. In ‘Energy efficiency of public hospital in Malaysia’, the first paper by Lim et al. titled ‘Energy efficiency action plan for a public hospital in Malaysia’. The authors address the electricity consumption issue of a public hospital in Kuala Lumpur. Their preliminary energy audit suggests that the hospital could save up to 3.8% of electricity consumption, equivalent to a cost saving of about RM150,000 per year if the hospital conducts an employing campaign; replace all existing desktops to laptops; carries out regular maintenance; replace its old refrigerators with energy-efficient ones.

The second paper related to energy efficiency, ‘Energy air conditioning profile and intensity index for retrofitted mosque building: case study of a public hospital in Malaysia’, by Hasson et al. They stated that the most of the existing mosques retrofitted with air-conditioning in the country have much higher energy indices than the typical office buildings. In their study, they selected five retrofitted mosques, the authors recommended a few energy conservation measures, namely synchronisation of air-conditioning operation hours, and very few products, tools, or publications supporting the local industry. The result is that big bubble foil with 50 mm top air gap performs better than 30 mm.

The third paper, ‘Comparative study of energy performance of reflective insulations’, by Lim et al. described that the thermal performance of reflective insulation depends greatly on their R-values. The result is that big bubble foil with 50 mm top air gap performs better than 30 mm.

The next extended papers for this special issue were selected from among all the accepted papers by the special issue guest editor based on the relevance to the journal and the scope of the conference version of the papers. The authors were asked to revise the conference paper for journal publication and in accordance with customary practice to add 30% new materials. The revised papers again went through the normal journal-style review process and are finally presented to the readers in the present form.

In the paper, the authors address the electricity consumption issue of a public hospital in Malaysia. The paper aims to improve energy efficiency in the public hospital. The authors address the electricity consumption issue of a public hospital in Malaysia. The preliminary energy audit suggests that the hospital could save up to 3.8% of electricity consumption, equivalent to a cost saving of about RM150,000 per year if the hospital conducts an employing campaign; replace all existing desktops to laptops; carries out regular maintenance; replace its old refrigerators with energy-efficient ones.

The second paper related to energy efficiency, ‘Energy air conditioning profile and intensity index for retrofitted mosque building: case study of a public hospital in Malaysia’, by Hasson et al. They stated that the most of the existing mosques retrofitted with air-conditioning in the country have much higher energy indices than the typical office buildings. In their study, they selected five retrofitted mosques, the authors recommended a few energy conservation measures, namely synchronisation of air-conditioning operation hours, and very few products, tools, or publications supporting the local industry. The result is that big bubble foil with 50 mm top air gap performs better than 30 mm.

The third paper, ‘Comparative study of energy performance of reflective insulations’, by Lim et al. described that the thermal performance of reflective insulation depends greatly on their R-values. The result is that big bubble foil with 50 mm top air gap performs better than 30 mm.

The next extended papers for this special issue were selected from among all the accepted papers by the special issue guest editor based on the relevance to the journal and the scope of the conference version of the papers. The authors were asked to revise the conference paper for journal publication and in accordance with customary practice to add 30% new materials. The revised papers again went through the normal journal-style review process and are finally presented to the readers in the present form.

In the paper, the authors address the electricity consumption issue of a public hospital in Malaysia. The paper aims to improve energy efficiency in the public hospital. The authors address the electricity consumption issue of a public hospital in Malaysia. The preliminary energy audit suggests that the hospital could save up to 3.8% of electricity consumption, equivalent to a cost saving of about RM150,000 per year if the hospital conducts an employing campaign; replace all existing desktops to laptops; carries out regular maintenance; replace its old refrigerators with energy-efficient ones.

The second paper related to energy efficiency, ‘Energy air conditioning profile and intensity index for retrofitted mosque building: case study of a public hospital in Malaysia’, by Hasson et al. They stated that the most of the existing mosques retrofitted with air-conditioning in the country have much higher energy indices than the typical office buildings. In their study, they selected five retrofitted mosques, the authors recommended a few energy conservation measures, namely synchronisation of air-conditioning operation hours, and very few products, tools, or publications supporting the local industry. The result is that big bubble foil with 50 mm top air gap performs better than 30 mm.

The third paper, ‘Comparative study of energy performance of reflective insulations’, by Lim et al. described that the thermal performance of reflective insulation depends greatly on their R-values. The result is that big bubble foil with 50 mm top air gap performs better than 30 mm.

The next extended papers for this special issue were selected from among all the accepted papers by the special issue guest editor based on the relevance to the journal and the scope of the conference version of the papers. The authors were asked to revise the conference paper for journal publication and in accordance with customary practice to add 30% new materials. The revised papers again went through the normal journal-style review process and are finally presented to the readers in the present form.

In the paper, the authors address the electricity consumption issue of a public hospital in Malaysia. The paper aims to improve energy efficiency in the public hospital. The authors address the electricity consumption issue of a public hospital in Malaysia. The preliminary energy audit suggests that the hospital could save up to 3.8% of electricity consumption, equivalent to a cost saving of about RM150,000 per year if the hospital conducts an employing campaign; replace all existing desktops to laptops; carries out regular maintenance; replace its old refrigerators with energy-efficient ones.

The second paper related to energy efficiency, ‘Energy air conditioning profile and intensity index for retrofitted mosque building: case study of a public hospital in Malaysia’, by Hasson et al. They stated that the most of the existing mosques retrofitted with air-conditioning in the country have much higher energy indices than the typical office buildings. In their study, they selected five retrofitted mosques, the authors recommended a few energy conservation measures, namely synchronisation of air-conditioning operation hours, and very few products, tools, or publications supporting the local industry. The result is that big bubble foil with 50 mm top air gap performs better than 30 mm.
increased use of renewable energy will further facilitate the growth of green buildings in Malaysia.

Materials and products for construction remain primarily the traditional “mineral-based” materials. However, the environmental impacts of materials extraction, importation, transport, and waste disposal are rising. These impacts include long-term effects on land, air, and water quality as well as biodiversity that lead to erosion and other local and global consequences. Although the Malaysian government has put an effort to prioritise the management of construction and demolition wastes to mitigate potential impacts, the recycling rate is still as low as 15% (Esa et al., 2017). Local architectural design trends are subject to the demand of Industrialised Building System (IBS) to reduce wastages of building materials, but the move needs to shift from conventional IBS that still needs substantial manpower, to digital IBS. For example, instead of using precast products that only results in dull aesthetics, BIM (BIM)-integrated digital design system can provide clients with customised solutions. Hopefully, BIM will one day be able to facilitate the green building certification process as well. The advanced information technology and pre-engineering processes will help to avoid costly changes in the future. The design that is meant to avert the environmental impacts will be able to create a more suitable environment for the green building in the country. Furthermore, many studies also emphasise the importance of using BIM during the various life cycles of the green building delivery that is suitable to the local context. In parallel, themes such as deconstruction, durability, reprocessed materials in the construction material loops, Factors 4 and 10, and dematerialisation, which are almost non-existent in the local green building sector, will slowly be practised. Certainly, these green strategies are imperative for the sector to achieve sustainable future in the building sector.

One of the outcomes of the green building has been better communication and collaboration among stakeholders to enhance the quality of their decision-making in the building and construction processes to incorporate the principles of sustainable design. Technically, the knowledge of sustainable design development is multidisciplinary in its nature and is covered by various bodies of knowledge. Some of the common aspects in green building design is the application of an integrated design process where multiple stakeholders (planners, architects, engineers, landscape architects, facility managers, and others) collaborate and communicate in the early stages to develop a holistic design that addresses design requirements are considered simultaneously. In addition, it is important to ensure that these professionals have the skills to function in “silos”, each optimising the outcome for their own benefit, is in transformation in the curricula to support sustainable construction, including substantially more cross-disciplinary instruction and collaboration. Developers and building owners cannot ignore the importance of equipping the design professionals with the tools to help maximise the chances of green building success. For a building that meets the criteria of more than 50% of a system of performance-based fees that incentivizes collaboration and performance.

Although the pace of high-performance green building has been increasing, the rate of change has not been fast enough in terms of adapting local, and global environmental degradation, and other negative consequences of transforming land and materials into infrastructures and buildings. Although GBB has resulted in noticeable change after its introduction, it is time for a significant shift in government policy, from voluntary to mandatory measures, coupled with incentives, that will dramatically accelerate the transformation of the Malaysian construction industry and its products. It is now time for the environmental measures advocated by rating tools to be made as standard practices. This is because, without such a transformation of the industry, the associated benefits of green buildings. Due to limited understanding and much and is economically non-viable” would persist.

Some local green building advocates claim that green building does not mean green architects or green engineers or green contractors. Green building requires a shift of mindset that is more ambitious and innovative and move well beyond current green building certification systems that are driven by the satisfaction of restoration and regeneration, as advocated by Attia (2018). The cost factor remains the most significant barrier that leads to a low level of green home development in Malaysia (Samat et al., 2013; Mohd Norlaili, 2013). Green home development does increase the housing costs as they involve higher capital upfront. Additionally, it is difficult to obtain green materials in the country, and most of these products are priced higher. Extra expenses are also incurred for appointing environmental consultants, green rating assessment fees, and procurement of new technology. Most speculative developers aim to maximise their profits rather than investing money in the rating assessment fees, and procurement of new technology. Most speculative developers aim to maximise their profits rather than investing in the green building. Although the pace of high-performance green building has been increasing, the rate of change has not been fast enough in terms of adapting local, and global environmental degradation, and other negative consequences of transforming land and materials into infrastructures and buildings. Although GBB has resulted in noticeable change after its introduction, it is time for a significant shift in government policy, from voluntary to mandatory measures, coupled with incentives, that will dramatically accelerate the transformation of the Malaysian construction industry and its products. It is now time for the environmental measures advocated by rating tools to be made as standard practices. This is because, without such a transformation of the industry, the associated benefits of green buildings. Due to limited understanding and much and is economically non-viable” would persist.

Ref:
Construction activities have been blamed as one of the environmental pol-
ners. Industry players are urged to adopt green practices by construction projects, it is still unclear whether such practices have improved projects’ environmental and financial performances. The aim of this study was to investigate the relation-
ship between green practices implemented in construction projects and their impact on the projects’ environmental and financial performances. A struc-
ture questionnaire survey was distributed to members of a project team to gather information on the impact of green practices on construction projects’ performances. The results revealed two areas of green practices: green pro-
ject integrated practice and waste management practice, which had a signifi-
cant and positive relationship with the project’s environmental and financial performances. The results rebut the previous findings regarding the negative relationship between green practices implemented in construction projects and their impact on the projects’ environmental and financial performances. The results revealed two areas of green practices: green pro-
ject integrated practice and waste management practice, which had a signifi-
cant and positive relationship with the project’s environmental and financial performances. The results rebut the previous findings regarding the negative relationship between green practices implemented in construction projects and their impact on the projects’ environmental and financial performances. The results revealed two areas of green practices: green pro-
ject integrated practice and waste management practice, which had a signifi-
cant and positive relationship with the project’s environmental and financial performances. The results rebut the previous findings regarding the negative relationship between green practices implemented in construction projects and their impact on the projects’ environmental and financial performances. The results revealed two areas of green practices: green pro-
ject integrated practice and waste management practice, which had a signifi-
cant and positive relationship with the project’s environmental and financial performances. The results rebut the previous findings regarding the negative relationship between green practices implemented in construction projects and their impact on the projects’ environmental and financial performances. The results revealed two areas of green practices: green pro-
ject integrated practice and waste management practice, which had a signifi-
can
regulations are indirect but costly will lead to a higher environmental perfor- mance (Chegut et al., 2016). Meanwhile, green practice in construction projects will result in less pollution and lower carbon emissions (Shen et al., 2011). In contrast, it was argued that green practices will not necessarily result in bet- ter environmental performance, as reported also by Ferrón-Vílchez (2009). Similarly, it was found that ISO 4001 did not address pollution re- lated to the management of waste (Weber et al., 2016). In the case of the link between green practice and financial performance, green practices were reported to increase the profitability. For instance, the use of environmentally friendly materials in construction projects can result in longer product life and hence lead to increased profit margins. In this way, green practices in construction projects can improve the firm’s financial performance (Kawsar and Kusuma, 2014; Re- nard et al., 2013).

The need for another study to shed light on the relationships between green practices implemented in construction projects and their impact on the pro- ject’s performance has been revealed in several studies. The need was especially highlighted in projects where the project key members is at the beginning of the project (Yusof et al., 2016). In line with the environmental mission (Lam et al., 2011), the implementation of green practices is expected to result in cost saving due to compliance and better revenue (Tan et al., 2011). Therefore, the study’s primary hypothesis is:

H1: Green practices in project integrated practices significantly influence the project’s environmental performance.

Likewise, the effective adoption of green practices in each project phase will lead to less wastage, avoidance of charges due to non-compliance, and result in higher profits (Rao and Holt, 2005). In Hong Kong, buildings with green design features, such as balconies and terraces, which are less than 8% of the gross floor area, enjoyed a ten per cent, attracted more users due to the building’s pleasant indoor environment, thereby increasing the market- ability of the building (Zhang et al., 2015). In addition, there have been im- provements in government regulations supporting green buildings (Shen and Wu, 2015). Green buildings also mean less wastage, avoidance of charges due to non-compliance (Tan et al., 2011). Acknowledging the impor- tance of economic measures, it was argued that the financial benefits of green practices could help to motivate environmental pollutants to adopt green prac- tices (Zhang et al., 2015). Supporting this point of view, emphasis was laid on the need to overcome cost barriers of green practices to motivate construction firms to adopt green practices (Chan et al., 2018). Regarding the independent variables, three dimensions were used to conceptualise green practices in construction projects: green practice integrated prac- tices (Shen et al., 2017); environmental performance (Li et al., 2017); and support green practice. In project integrated practice, the participation of the project team is crucial, including assessment methods (Ding, 2008; Kneifel, 2010) to promote and support green practice implementation. The third and final dimension is waste management, which includes the monitoring of waste production during project implementation and ensuring that the third hypothesis is:

H2: Green practices in project integrated practices significantly influence the project’s environmental performance.

H3: Green practices in project integrated practices significantly influence the project’s financial performance.

The third and final dimension is waste management, which includes the moni- toring of waste production during project implementation and ensuring that the third hypothesis is:

H4: Resource minimisation significantly influences the project’s financial performance.

In relation to resource minimisation, the fact that some firms are reluctant to adopt green practices is highlighted (Shen et al., 2017). An important factor influencing this reluctance is the consciousness of their environmental and financial performances. For instance, the need to overcome cost barriers of green practices to motivate construction firms to adopt green practices (Shen et al., 2017); environmental performance (Li et al., 2017); and support green practice. In project integrated practice, the participation of the project team is crucial, including assessment methods (Ding, 2008; Kneifel, 2010) to promote and support green practice implementation. The third and final dimension is waste management, which includes the monitoring of waste production during project implementation and ensuring that the third hypothesis is:

H2: Green practices in project integrated practices significantly influence the project’s financial performance.

The second dimension is resource minimisation, which refers to the optimisa- tion of the use of resources that also covers the 3Rs: reduce, reuse, and recy- cle activities throughout the project cycle (Oyedele et al., 2014; Yafo et al., 2016). A vital challenge in resource minimisation during project implemen- tation is the coordination of the use of resources throughout the project cycle. In terms of purchases, there have been green criteria in the selection of sup- pliers (Erbas et al., 2017), such as compliance with environmental standards, minimising waste, and reduction of pollution as conceptualised in a project’s environmental performance (Li et al., 2017); environmental performance (Li et al., 2017); and support green practice. In project integrated practice, the participation of the project team is crucial, including assessment methods (Ding, 2008; Kneifel, 2010) to promote and support green practice implementation. The third and final dimension is waste management, which includes the monitoring of waste production during project implementation and ensuring that the third hypothesis is:

H2: Green practices in project integrated practices significantly influence the project’s financial performance.

The second dimension is resource minimisation, which refers to the optimisa- tion of the use of resources that also covers the 3Rs: reduce, reuse, and recy- cycle activities throughout the project cycle (Oyedele et al., 2014; Yafo et al., 2016). A vital challenge in resource minimisation during project implemen- tation is the coordination of the use of resources throughout the project cycle. In terms of purchases, there have been green criteria in the selection of sup- pliers (Erbas et al., 2017), such as compliance with environmental standards, minimising waste, and reduction of pollution as conceptualised in a project’s environmental performance (Li et al., 2017); environmental performance (Li et al., 2017); and support green practice. In project integrated practice, the participation of the project team is crucial, including assessment methods (Ding, 2008; Kneifel, 2010) to promote and support green practice implementation. The third and final dimension is waste management, which includes the monitoring of waste production during project implementation and ensuring that the third hypothesis is:

H2: Green practices in project integrated practices significantly influence the project’s financial performance.

The second dimension is resource minimisation, which refers to the optimisa- tion of the use of resources that also covers the 3Rs: reduce, reuse, and recy- cycle activities throughout the project cycle (Oyedele et al., 2014; Yafo et al., 2016). A vital challenge in resource minimisation during project implemen- tation is the coordination of the use of resources throughout the project cycle. In terms of purchases, there have been green criteria in the selection of sup-pliers (Erbas et al., 2017), such as compliance with environmental standards, minimising waste, and reduction of pollution as conceptualised in a project’s environmental performance (Li et al., 2017); environmental performance (Li et al., 2017); and support green practice. In project integrated practice, the participation of the project team is crucial, including assessment methods (Ding, 2008; Kneifel, 2010) to promote and support green practice implementation. The third and final dimension is waste management, which includes the monitoring of waste production during project implementation and ensuring that the third hypothesis is:

H2: Green practices in project integrated practices significantly influence the project’s financial performance.

The second dimension is resource minimisation, which refers to the optimisa- tion of the use of resources that also covers the 3Rs: reduce, reuse, and recy- cycle activities throughout the project cycle (Oyedele et al., 2014; Yafo et al., 2016). A vital challenge in resource minimisation during project implemen- tation is the coordination of the use of resources throughout the project cycle. In terms of purchases, there have been green criteria in the selection of sup-pliers (Erbas et al., 2017), such as compliance with environmental standards, minimising waste, and reduction of pollution as conceptualised in a project’s environmental performance (Li et al., 2017); environmental performance (Li et al., 2017); and support green practice. In project integrated practice, the participation of the project team is crucial, including assessment methods (Ding, 2008; Kneifel, 2010) to promote and support green practice implementation. The third and final dimension is waste management, which includes the monitoring of waste production during project implementation and ensuring that the third hypothesis is:

H2: Green practices in project integrated practices significantly influence the project’s financial performance.
waste reduction through 3R among contractors. It was simulated by Wang et al. (2015) that the offsite construction technology produces the better result in reducing construction waste, the synergy of multi-design strategies provides the highest waste reduction; thus, a better environmental perfor-
mance. The loadings for all items were higher than 0.5 with the P values significant at 0.001, fulfilling Kock’s (2014) miles for indicator reliability. The conver-
gence validity of the latent variable was evaluated using the average variance extracted (AVE), and the AVE of all of the latent variables exceeded 0.5, in accordance with Fornell and Larcker’s (1981) criteria; suggesting the mea-
Sure model’s convergent validity. Composite reliabilities (CR) was used to evaluate the internal reliability of the reflective latent variables. All latent variables showed a CR of above 0.8 fulfilling the minimum criteria of Kock (2011) and Hair et al. (2011). Table 2 presents the results of the indicator reli-
bility, convergent validity, and internal consistency tests for the reflective latent variables.

Table 2: Reliability and validity of the reflective latent variables

<table>
<thead>
<tr>
<th>Latent variable</th>
<th>Items</th>
<th>Number</th>
<th>Sums</th>
<th>Loadings</th>
<th>P values</th>
<th>AVE</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste management</td>
<td>W1, W2, W3</td>
<td>57</td>
<td>0.829</td>
<td>0.852</td>
<td>0.788</td>
<td>0.580</td>
<td>0.474</td>
</tr>
<tr>
<td>Financial performance</td>
<td>FP1, FP2, FP3</td>
<td>30</td>
<td>0.832</td>
<td>0.877</td>
<td>0.761</td>
<td>0.499</td>
<td>0.392</td>
</tr>
</tbody>
</table>

Both formative latent variables showed VIFs of less than 5 and all items had significant outer weights, fulfilling Chin (2010) and Hair et al. (2011) rules. The full collinearity VIFs of the environmental performance and the financial performance variables were much lesser than 3.3, which fulfilled the thresh-
old of Kock and Lynn (2012). Thus, the formative latent variables presented a satisfactory level of the measurement model. Table 4 depicts the measurement model evaluation for the formative latent variables.

Table 4: Measurement model evaluation for formative latent variables

| Formative latent variable | W2, W3, W4 | 57 | 0.420 | 0.474 | 0.327 | 0.237 | 0.152 |

In stage 2, the structural model and the hypotheses were evaluated using the R2 measurement. The model of the study showed 37% and 39% of the variances in the project’s
environmental and financial performances, respectively, suggesting a mod-
erate relationship between green practices and the project's environ-
mental and financial performances. Also, the Stone–Geisser's Q2 (cross-validated redundancy) for the project's (Q2=0.408) and financial perfor-
mance (Q2=0.389) were greater than zero, displaying the model's satisfactory predictive relevance and its explanatory power; thus, complying with Hair et al. (2011). Table 5 presents the results of the PLS by hypothesis.

Table 5: Results of hypothesis testing

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Path coefficient</th>
<th>p-value</th>
<th>Effect size (f²)</th>
<th>Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>0.041</td>
<td>0.001</td>
<td>0.201</td>
<td>No</td>
</tr>
<tr>
<td>H2</td>
<td>0.488</td>
<td>0.001</td>
<td>0.290</td>
<td>Yes</td>
</tr>
<tr>
<td>H3</td>
<td>0.841</td>
<td>0.001</td>
<td>0.312</td>
<td>Yes</td>
</tr>
<tr>
<td>H4</td>
<td>0.195</td>
<td>0.001</td>
<td>0.170</td>
<td>Yes</td>
</tr>
<tr>
<td>H5</td>
<td>0.341</td>
<td>0.001</td>
<td>0.312</td>
<td>Yes</td>
</tr>
<tr>
<td>H6</td>
<td>0.060</td>
<td>0.001</td>
<td>0.179</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The present study revealed the positive and significant effect of green project integrated practice and waste management practice on project's environ-
mental and financial performances. The results have provided empirical evidence on the benefit of green practices in a project's environmental and financial perfor-
mances. The construction projects that integrate their planning-design-
construction phases with green practices and the local ecosystem, and imple-
ment waste management practices such as waste monitoring, sorting, reuse, and recycling, will benefit in terms of a better environmental outcome, such as low carbon emission; less air, water, and soil pollution; and enhanced fi-
ancial performance, such as reduction in project costs, greater profits, and

improved investment yield. The results support the work of Bambahemi et al. (2017) on the positive impact of green project integrated practice on project's environmental performance. The results also support the work of Tan et al. (2013) on the positive influence of green pro-
ject integrated practice on project's financial performance. Furthermore, they support the work of Freitas and Magini (2014) on the positive effect of waste management on project's environmental performance and finally support the work of Regun et al. (2006) on the positive effect of waste manage-
ment on project's financial performance. At the same time, the results rebu-
to the previous findings on the negative impact of the general green practices on performances accomplished by Fernandi-Vilchez (2017), Kusuma and Koseinid-
tio (2014), and Remond et al. (2013).

However, the present study provides insufficient evidence on the relationship between resource minimisation and project's environmental and financial perfor-
mances, indicating that the link between the two remains vague and war-
rants further investigation. Optimising the use of water, materials and energy is a great challenge for construction managers. The unskilled labour and the traditional construction management method used on the construction projects of developing countries may be the reasons for the insubstantial link between resource minimisation and project's environmental and financial perfor-
mance. The aforementioned results imply that not all types of green practices will have a similar impact on project's environmental and financial perfor-
mance. In other words, the different types of green practices will have a varying degree of effect on the project's environmental and financial performances.

Construction projects should be allowed to key players in the pro-
ject, architects, engineers, contractors and suppliers, along with the client to be involved at the earliest stage to ensure that environmental goals are understood and considered throughout the project. The implementation of inte-
grated project management rather than the traditional project organization mode or as suggested by Zhang et al. (2015), an appointment of the envi-
ronmental specialist in a project team, together with a clear understanding of project's environmental values and measures (Tan et al., 2011) and sup-
ported by the necessary environmental regulations for construction projects (Bambahemi et al., 2017) are examples of green project integrated practices that may improve project's environmental and financial performances. In addi-
tion, waste management practices such as waste sorting, reuse and recycling, the use of offsite construction technology or prefabrication, and innovative waste recovering through industrial symbiosis, are suggested to increase pro-
ject's environmental and financial performance. Clients and project manager should focus on these two aspects of green practices: green project integrated

practices and waste management to boost the project's environmental and fi-
ancial performances.

5. CONCLUSION

As a measure to address the negative impact of construction activities on the environment, construction firms are required to adopt green practices. The relationship between green practices implemented in construction projects and project's environmental and financial performances were investigated in this study. The results revealed two areas of green practices: green project integrated practice and waste management practice, which had a significant and positive relationship with the project's environmental and financial perfor-
mances. Theoretical work by Shen et al. (2011) and Miroshnychenko et al. (2017) earlier postulation on the impact of green practices on environmental and financial performances. Practically, the re-
sults are useful to clients, project managers and policy makers. To achieve better environmental performance and higher profit, they must ensure that en-
vironmental and financial performances are better founded in the construction phases, and focus on waste management practices. The profes-
sional bodies of architecture, engineering and project management practice, together with the CIDB, can provide training to its members and construction players on the best practices for integration and waste management. The results also guide policy makers to focus on green practices on project's economic and envi-
ronmental performance approaches. Proper guidance and monitoring should be in place on how green project integrated practice and waste management can be implemented. Local authorities should provide the necessary facilities for waste sorting, reduce, reuse and recycling. An example of monetary incentives is tax reduc-
tion, while that of non-monetary incentives is faster approval.

A few constraints can be found in the study. First, insufficient evidence on the relationship between resource minimisation and the project's environ-
mental and financial performances was shown in the study. How resource minimisation was implemented should be investigated in future studies and ways to encourage such practice in Malaysian construction projects should be found. Secondly, the study's model explains 37% and 39% of the vari-
cances in environmental and financial performances, respectively. Although such predictive levels are adequate, future studies should embark into other research methods, such as the mixed method or semi-structured interviews in qualitative research to identify other green practices that may affect project's environmental and financial performances. Thirdly, the effect of project size that may influence the relationship between green practices and project's en-
vironmental and financial performances is not considered in the present study.
Project size is usually measured based on the economic value of a project, the number of people involved, or the duration of the project (Kärnä and Junnonen, 2017; CIDB, 2015). Project size is usually measured based on the economic value of a project, the number of people involved, or the duration of the project (Kärnä and Junnonen, 2017; CIDB, 2015). The authors sincerely appreciate the financial support from the Malaysian Government and Universiti Sains Malaysia through the Exploratory Research Grant Scheme (ERGS) and the Graduate on Time Incentive. Part of the work was published in the Proceedings of the 2nd Malaysian University-Industry Green Building Collaboration Symposium (MU-IGBC 2018), May 8, 2018, Bangi.

REFERENCES


AIR CONDITIONING ENERGY PROFILE AND INTENSITY INDEX FOR RETROFITTED MOSQUE BUILDING: A CASE STUDY IN MALAYSIA

Azman Hussain1, Lim Chin Haw1 and Elias Saleh2
1Solar Energy Research Institute, University Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.
2Kulliyyah of Architecture & Environmental Design, International Islamic University Malaysia 50728 Jalan Gombak Kuala Lumpur, Malaysia.

Abstract

Mosques generally consume far lesser energy than other types of buildings owing to their functional and operational characteristics. Since an effective energy management with a proper handling of the air-conditioning system can offer benefits such as the reduction of energy consumption as well as contributing to a sustainable development of the mosque, this paper has therefore presented a field case study on the energy usage and optimization strategies from a few selected retrofitted air-conditioned mosques in Penang, Malaysia. The results derived from the study indicate that energy consumption in the non-domestic sector, which can be influenced by the adjacent buildings and its surrounding environment (Ascione, 2017). For that reason, a few strategies and measures had been proposed in the reduction of energy consumption in the mosque, which can be implemented by the management committee of the mosque in not only providing optimum thermal comfort for the worshippers but also without incurring the high energy costs.

Keywords: Mosque, air-conditioning, comfort, energy and cost.

1. INTRODUCTION

The mounting energy use in developing countries that seek to meet the world’s growing energy needs has been social and economic concern. As a result of economic development and a higher standard of living, Saudi Arabia had shown an annual average increase of 13% in the energy consumption of the building sectors over the last 30 years, while in Malaysia, the growing economic growth has led to a dramatic increase of energy consumption in the recent years. Generally, commercial buildings consume almost 32% of total generated energy with the office buildings making up the other 18.5% of total energy consumption (Saidur, 2009). The percentage is almost similar to the other developed countries in Asia, where energy consumption had been about 21% of the total energy usage (Chiratratammat and Tawoesan, 2003).

According to Pérez-Lombard et al., (2008), Heating, Ventilating and Air-Conditioning (HVAC) systems make up the largest building energy demand in the non-domestic sector, which can be influenced by the adjacent buildings and its surrounding environment (Ascione, 2017). For that reason, a few strategies and measures had been proposed in the reduction of energy consumption such as by improving the energy efficiency and conversion process which also practice cooling techniques as well as the application of renewable energy resources. In one of their studies, Lin and Hong (2011) had included the indoor temperature (thermostat set-point), window type, air infiltration and internal loads in a detailed description of the HVAC’s energy consumption.

Journal of Cleaner Production, 136, 345-354. doi:http://dx.doi.org/10.1016/j.jclepro.2016.07.014


Most of the recent studies had focused on permanently occupied buildings as a means for potentially reducing its energy consumption. Of consuming up to 57% of energy usage from an air-conditioning system of its high energy intensity. With commercial buildings showing a tendency systems (Hussin et al., 2015), are required to undergo energy audits because of lightings and small fans. On the contrary, the newer mosques that were low average operational energy intensity as most of the load had only consist-

In Malaysia, most of the old and traditional mosques with excellent air venti-

For their daily and weekly prayers, but is also regarded as a social centre for Muslims to congregate during the annual Eidul Fitri (fasting month) and Eidul Adha (holy annual prayer) celebrations as a way of reducing electricity consumption. In 2010, Al-ajmi had conducted a field study on six air-conditioned town mosques in Kuwait provinces. The study had recommended increasing the indoor temperature setting to a neutral temperature, which shown to have saved up to 20% of energy consumption. As for Buddali and Badru (2013), they had revealed the potential of HVAC system operational strategies in reducing the energy consumption of the mosque in the Eastern Province of Saudi Arabia by up to 25% Appliance use and intensity index through a field measurement study of a few selected mosques. The optimization of the HVAC system in the hospitals, while Afram and Janabi-

Although numerous studies had provided different strategies in the op-

Figure 1: Workflow

Figure 2: Geometrical configuration of a commonly built Penang State mosque

(a) Rectangular shape

(b) Circular shape

2.1 Mosque characteristics

Generally, the design geometry of a mosque is based on a simple rectangular shape that is made up of various sizes (Budaiwi and Abdou, 2013). The design geometry usually consists of wall enclosures that are complemented with a roofed prayer hall, where one of the walls (usually described as a qibla wall) is oriented towards the direction of the Kaaba mosque in Mecca, Saudi Arabia, and a niche wall or the mihrab that is located in the inner qibla wall. The mihrab also contains pulpits known as a mimbar, which is usually located on the right side of the mihrab but on an elevated floor and serves as a place for the Imam of the mosque to deliver his Friday sermons (or qutba). The mihrab is a prominent feature of mosque architectural designs. Its position is determined by the qibla or the holy direction in which the mosque is oriented. The mihrab is usually located on the right side of the mihrab but on an elevated floor and serves as a place for the Imam of the mosque to deliver his Friday sermons (or qutba). The mihrab is a prominent feature of mosque architectural designs. Its position is determined by the qibla or the holy direction in which the mosque is oriented. 

Generally, the design geometry of a mosque is based on a simple rectangular shape that is made up of various sizes (Budaiwi and Abdou, 2013). The design geometry usually consists of wall enclosures that are complemented with a roofed prayer hall, where one of the walls (usually described as a qibla wall) is oriented towards the direction of the Kaaba mosque in Mecca, Saudi Arabia, and a niche wall or the mihrab that is located in the inner qibla wall. The mihrab also contains pulpits known as a mimbar, which is usually located on the right side of the mihrab but on an elevated floor and serves as a place for the Imam of the mosque to deliver his Friday sermons (or qutba). The mihrab is a prominent feature of mosque architectural designs. Its position is determined by the qibla or the holy direction in which the mosque is oriented. 

2.2 Energy profile and intensity case study

Based on the previous research study that was carried out from January until March 2017, an energy profile was created based on 15% of the 273 regis-

termed mosques located in the entire state of Penang in 2016. The work flow of this study is shown in Figure 1. During the first stage, a total of 44 mosques had been evaluated by using standard questionnaires that were collected based on its current information and operational processes. Figure 2 shows the geometrical mosques configuration that is commonly built in the Penang State. Thus, this another study completely divided according to its cooling area namely G1, G2, G3, G4 to G5. 

FIGURE 1: Rectangular shape

FIGURE 2: Geometrical configuration of a commonly built Penang State mosque

Most of the recent studies had focused on permanently occupied buildings such as offices and facilities with very few energy monitoring studies due
In the second stage of the process, five sampled mosques from each of the groups were selected for the energy profile and energy intensity case study. The sorting samples had been based on those suggested by Saidur (2009):

- Highest annual electricity consumption
- Daily operation time of more than 5 hours continuously
- Daily operation of a cooling system (daily/Friday prayers)

The Penang State Mosque was retrofitted with an air-conditioning system in 2003. Each of the three identical air-cooled chillers with a capacity of 100 RT (nos) had been synchronized with a proper timer step control by using the single ON/OFF button, are located in a special box panel near the chiller unit. The air cooled chiller component had relied on a reciprocating (semi hermetic) compressor with a maximum power input of 235kW, an air system condenser with six main entrance doors using the same glass type. The floors are fully insulated with reflective insulation that is placed in parallel to the walls, while the dome is being used as the roof for the grand tower. The mosque can also fully accommodate up to 5,000 of worshippers at one time and is currently managed by the Penang Religious Affairs Department.

The Energy Intensity Index (ACEII) in kWh/year/m^2 is estimated by using the following equation:

\[ ACEII = \frac{\sum_{i=1}^{n} AEC_i}{\sum_{i=1}^{n} CFA_i} \]

where AEC is the sum of the annual energy consumption of equipment i to n and CFA is the cooling floor area (m^2).

The Penang State Mosque from the G5 group was then selected as a case study model. The mosque is centrally located in the Penang Island with GPS coordinates of 5.406N, 100.3006E, which was built and opened to the public in 1981. The mosque is built like a dome and contains the ground and mezzanine floors. With a total floor area of 2920 m^2, the main prayer hall on the ground floor is opened every day for praying purposes, while the mezzanine floor area that spans a total of 65.49 m^2 is only opened for special events and ceremonies such as the Idul Fitri prayers and celebrations. Each of the walls had used a single layer shad glass type with six main entrance doors using the same glass type. The floors are fully furnished with the salaf carpets that are placed in parallel to the western part of the wall, while the dome is being used as the roof for the grand tower. The mosque can also fully accommodate 5000 of worshippers at one time and is currently managed by the Penang Religious Affairs Department.

The following table gives the list of sampled mosques.

<table>
<thead>
<tr>
<th>Mosque Name</th>
<th>Group</th>
<th>Floor Area (m^2)</th>
<th>Cooling Floor Area (m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masjid Jame’ Al Ihsaniah S.P.S</td>
<td>G1</td>
<td>2920</td>
<td>67.5</td>
</tr>
<tr>
<td>Masjid Jame’ Bakar Kapor Penaga</td>
<td>G2</td>
<td>576</td>
<td>89.5</td>
</tr>
<tr>
<td>Masjid Pongsu Seribu Kepala Batas</td>
<td>G3</td>
<td>160</td>
<td>378</td>
</tr>
<tr>
<td>Masjid Sembilang Seberang Jaya</td>
<td>G4</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Masjid Negeri Pulau Pinang, Georgetown</td>
<td>G5</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

2.4 Description of the air-conditioning system

The Penang State Mosque was retrofitted with an air-conditioning system in 2003. Each of the three identical air-cooled chillers with a capacity of 100 RT was installed to provide thermal comfort in the main prayer hall. The main air-conditioning system had consisted of a chiller (compressor, condenser, thermal expansion valve and evaporator), air handling unit (AHU), water pump system, air distribution system (ducting and diffusers) and an electrical control panel. A detailed explanation of an air-cooled chiller system in the literature had been described by Teke and Timur (2014). The air-cooled chiller component had relied on a reciprocating (semi hermetic) compressor with a maximum power input of 235kW, which is an air-conditioning system that uses the surrounding ambient air for cooling down the heat rejection as well as a shell-and-tube evaporator. The cool water had been designed with an entering water temperature of 54°C and leaving water temperature of 44°C from the shell-and-tube evaporator that is circulated to the Air Handling Unit (AHU) by a 3 nos centrifugal end-suction pump (10 horsepower (HP) motor pump each) at the rate of 235 USGPM. The five air handling units are located in the AHU room, which is located beside the mosque, where all the controls and power panels for the chiller component, including the ONSOFF button, are located in a special box panel near the chiller unit.

The sequence of the start-up components such as chillers, pump and AHU had been synchronized with a proper timer control unit by using the single ONS OFF button, where the air conditioning system had been set to operate (ON) at 3:00 PM and shutdown (OFF) at 9:30 PM from Sunday to Thursdays and from 10:00 in the morning until 9:30 at midnight on Fridays. The air-conditioning system and its physical data are shown in Table 2.
The evaluation of the actual energy profile had been based on the measurement that was automatically recorded by the energy data logger, which is connected to the power supply panel of the air-conditioning system. The site measurement at the Penang State Mosque was carried out from 17 May 2017 until 21 May 2017 (n=5 days) with a laptop connected to the power and energy data logger (PEL) Version 102 as a way of measuring the electric power consumption from the air-conditioning system. As shown in Figure 5, the PEL Ver.102 is kept in the electrical room, which is located in front of the air-conditioning electrical power panel.

The MA193 flexible current sensors and black safety leads with black alligator clip voltage sensor were used to measure the instantaneous electric variables from the incoming 415V terminal wire supply without exposing the circuit. The 3 units of black alligator clips together with the voltage sensor had been clipped at the power supply terminal, while another 3 units of the MA193 flexible current sensor were round clamped at the red, yellow and blue power supply wires. The PEL Ver.102 had been enabled to record and measure the electrical power parameters such as the instantaneous electric variables (Root Mean Square (RMS) current, RMS voltage, and phase angle) as well as the power (kW and kVA) used. The accuracy of the current and voltage sensors had been set to a ±1% and ±2.5% ± 0.4V, respectively. As shown in Figure 6, all of the instantaneous data were captured automatically at a 5-minute interval and saved directly in the PEL memory card.

As shown in Figure 6, all of the instantaneous data were captured automatically at a 5-minute interval and saved directly in the PEL memory card.

Figure 6: The PEL instrument and sensors used

3. RESULTS AND DISCUSSIONS

3.1 Cost and energy intensity impact

As illustrated in Figures 7 and 8, the actual Tenaga Nasional Berhad (TNB) utility bills (energy and cost) that had incurred from Jan-Dec 2016 had shown the yearly energy consumed from the corresponding air-conditioned mosques group G1, G2, G3, G4 and G5 to be 22 MWh, 39 MWh, 63 MWh, 44 MWh and 942 MWh with a respective electricity cost of RM64,000, RM254,000, RM282,000, RM230,000 and RM446,000. As seen from the data, the mosque from the G3 group had exhibited the highest average monthly utility cost usage of RM 37,177.00, which were followed by those from the G3 (RM28,000), G4 (RM20,000) and G5 (RM446,000) groups, respectively. The results had also indicated the total energy consumed by the mosques from each of the group to be equivalent to half of the electricity costs. Furthermore, with the exception of the G4 mosque, a significant difference could be observed between the energy and costs usage with the increasing cooling floor area of each mosque. This may be due to the actual air-conditioning capacity (horsepower) of the G4 mosque that had been installed below the estimated values as those indicated in Table 1.

All of the mosque samples had shown a fluctuation of the monthly energy usage, which could be due to the energy wastage (energy loss) associated with less efficient equipment. The actual horsepower of the retrofitted air-conditioning system was actually found to have operated below the capacity level. This meant that although the air-conditioning system had seemed to work normally, it had hardly achieved the desired thermal comfort with its high energy consumption as shown by a similar case reported by Al-homoud et al., (2009) in Saudi Arabia. As part of the countermeasure, Al-homoud et al., 2009 had suggested for the height of the supply air outlets to be adjusted as low as and as close as possible to the occupied zone as a way of reducing the energy requirement that resulted in air stages in the system.

Another reason for the fluctuation in the monthly energy usage had been due to the operation time of the air-conditioning system. According to a majority of the mosque officers who were also assigned with the task of handling the air-conditioning system, the increment of the operation time (ON/OFF system) had been due to the daily preaching session conducted at the main prayer hall. The mosque in the G3 group for example, had showed a 50% increase of energy usage and costs between the months of January and July. The highest usage was found to have occurred in the month of July, where it had coincided with the Ramadan fasting month, during which intensive activities such as the breaking the fast, special tarawih (pre-midnight) and qamari (after midnight) prayers as well as the iktiqaf (spiritual retreat) had been carried out in the mosque. As such, the air-conditioning system had been set to operate fully in meeting the comfort expectations of the devotees during the implementation of such activities, while neglecting the air-conditioning system’s energy usage. The fluctuation of the energy usage had also been due to the untrained personnel in handling the system facilities, as corroborated by the study conducted by Terrill & Raunwater, (2016), as well as the different standard operating procedures in the operation of the air-conditioning system of the mosques.

Figure 7: The actual annual energy consumption (kWh) for G1-G5 (Jan-Dec)

Figure 8: The actual annual TNB cost (RM) for G1-G5 (Jan-Dec 2016)

As illustrated in Figures 7 and 8, the actual Tenaga Nasional Berhad (TNB) utility bills (energy and cost) that had incurred from Jan-Dec 2016 had shown the yearly energy consumed from the corresponding air-conditioned mosques group G1, G2, G3, G4 and G5 to be 22 MWh, 39 MWh, 63 MWh, 44 MWh and 942 MWh with a respective electricity cost of RM64,000, RM254,000, RM282,000, RM230,000 and RM446,000. As seen from the data, the mosque from the G3 group had exhibited the highest average monthly utility cost usage of RM 37,177.00, which were followed by those from the G3 (RM28,000), G4 (RM20,000) and G5 (RM446,000) groups, respectively. The results had also indicated the total energy consumed by the mosques from each of the group to be equivalent to half of the electricity costs. Furthermore, with the exception of the G4 mosque, a significant difference could be observed between the energy and costs usage with the increasing cooling floor area of each mosque. This may be due to the actual air-conditioning capacity (horsepower) of the G4 mosque that had been installed below the estimated values as those indicated in Table 1.

All of the mosque samples had shown a fluctuation of the monthly energy usage, which could be due to the energy wastage (energy loss) associated with less efficient equipment. The actual horsepower of the retrofitted air-conditioning system was actually found to have operated below the capacity level. This meant that although the air-conditioning system had seemed to work normally, it had hardly achieved the desired thermal comfort with its high energy consumption as shown by a similar case reported by Al-homoud et al., (2009) in Saudi Arabia. As part of the countermeasure, Al-homoud et al., 2009 had suggested for the height of the supply air outlets to be adjusted as low as and as close as possible to the occupied zone as a way of reducing the energy requirement that resulted in air stages in the system.

Another reason for the fluctuation in the monthly energy usage had been due to the operation time of the air-conditioning system. According to a majority of the mosque officers who were also assigned with the task of handling the air-conditioning system, the increment of the operation time (ON/OFF system) had been due to the daily preaching session conducted at the main prayer hall. The mosque in the G3 group for example, had showed a 50% increase of energy usage and costs between the months of January and July. The highest usage was found to have occurred in the month of July, where it had coincided with the Ramadan fasting month, during which intensive activities such as the breaking the fast, special tarawih (pre-midnight) and qamari (after midnight) prayers as well as the iktiqaf (spiritual retreat) had been carried out in the mosque. As such, the air-conditioning system had been set to operate fully in meeting the comfort expectations of the devotees during the implementation of such activities, while neglecting the air-conditioning system’s energy usage. The fluctuation of the energy usage had also been due to the untrained personnel in handling the system facilities, as corroborated by the study conducted by Terrill & Raunwater, (2016), as well as the different standard operating procedures in the operation of the air-conditioning system of the mosques.
Table 3: Study mosques Building Energy Index and Cost Index

<table>
<thead>
<tr>
<th>Description</th>
<th>BEI</th>
<th>ACCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>This Study, mosque G1</td>
<td>446134.11</td>
<td>27844.64</td>
</tr>
<tr>
<td>This Study, mosque G2</td>
<td>28845.60</td>
<td>153.61</td>
</tr>
<tr>
<td>This Study, mosque G3</td>
<td>127752.00</td>
<td>57705.03</td>
</tr>
<tr>
<td>This Study, mosque G4</td>
<td>19/5/2017</td>
<td>18/5/2017</td>
</tr>
<tr>
<td>This Study, mosque G5</td>
<td>153.61</td>
<td>32.26</td>
</tr>
<tr>
<td>Base reference</td>
<td>187.77</td>
<td>191.83</td>
</tr>
<tr>
<td>Note:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFA</td>
<td>Cooling floor area</td>
<td></td>
</tr>
<tr>
<td>ACCI</td>
<td>Air conditioning cost Index</td>
<td></td>
</tr>
<tr>
<td>BEI</td>
<td>Building Energy Index (BEI)</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Actual energy usage from the Penang State Mosque (G5)

As shown by the measured air-conditioning current (A) and power (kW) consumption as a function of time in Figures 9 and 10, the results had also shown that the mosque in the G5 group had produced the highest indices of 333 kW/yr and RM 153/year/m² in order to provide a sufficient comfort ambience of the main prayer hall. As shown by the measured air-conditioning current (A) and power (kW) consumption as a function of time in Figures 9 and 10, the results had also shown that the mosque in the G5 group had produced the highest indices of 333 kW/yr and RM 153/year/m² in order to provide a sufficient comfort ambience of the main prayer hall.

Table 4: Summary power consumption (kW) usage, n=5 days

<table>
<thead>
<tr>
<th>Description</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>S.D</th>
</tr>
</thead>
<tbody>
<tr>
<td>17/5/2017</td>
<td>161.15</td>
<td>13.15</td>
<td>191.83</td>
<td>13.5</td>
</tr>
<tr>
<td>18/5/2017</td>
<td>161.15</td>
<td>13.15</td>
<td>191.83</td>
<td>13.5</td>
</tr>
<tr>
<td>19/5/2017</td>
<td>161.15</td>
<td>13.15</td>
<td>191.83</td>
<td>13.5</td>
</tr>
<tr>
<td>20/5/2017</td>
<td>161.15</td>
<td>13.15</td>
<td>191.83</td>
<td>13.5</td>
</tr>
<tr>
<td>21/5/2017</td>
<td>161.15</td>
<td>13.15</td>
<td>191.83</td>
<td>13.5</td>
</tr>
</tbody>
</table>

As such, apart from being well-informed on the proper operation of the air conditioning system at regards to the prayer times, the committee members of the mosque can also consider applying for energy audits as a way of checking the equipment’s energy efficiency. Based on the findings of the Penang State Mosque, the average energy consumed by the air cooled chillier system had been an approximate 126.63 kW, with a temperature of 7ºC set in the thermostat controller. According to the ASHRAE Standard (2013), the temperature level of 22ºC – 26ºC is regarded with a temperature of 15ºC set in the thermostat controller. The air-conditioning system of the Penang State Mosque was also found to have operated continuously for 6.5 hours on a daily basis during both prayer and non-prayer times, where the emphasis had been on keeping the entire floor area cooled instead of considering the thermal comfort for the worshippers. Since no work hours were observed during the intermittent prayer times and especially after the Azor prayers, the continuous operation time had therefore led to a high wastage of energy use. As such, apart from being well-informed on the proper operation of the air conditioning system with regards to the prayer times, the committee members of the mosque can also consider applying for energy audits as a way of reducing energy wastage in the building (Sheikh et al., 2017). The overall findings as well as the suggested short and long term strategies that had considered the availability of budgets and resources of related departments in the Penang State Mosque are listed in Table 5.


4. CONCLUSIONS

This paper describes the evaluation of the energy profile and the optimization strategies for mosques that had been retrolit with air-conditioning systems. To achieve high efficiency, these air-conditioning systems were found to be below the required efficiency level and led to energy wastage as a result of certain factors that had influenced its energy consumption. While providing the best thermal environment for the main prayer hall area, most of these mosques had demonstrated energy indices that were higher than those of the MS 1525 standard and consequently, higher cost expenses. For this reason, this study had proposed several short and long-term strategies by considering the available resources and budget as the upgrading of the system and system knowledge in the optimization of energy usage. Apart from the installation of a timer that automatically operates the ON/OFF switch of the air-conditioning system at a specific time, the setting up of a new thermal comfort and temperature adjustment will also provide advantages in terms of intermittent operation heat load and load saving. Last but not least, an internal maintenance of the air-conditioning system as well as the zoning of operation was also suggested to reduce the energy wastage of the main prayer hall area in the Penang State Mosque.

ACKNOWLEDGEMENTS

We would like to acknowledge the cooperation given by the Penang State Mosque, the Penang Religious Affairs Department, Department of Works (Mechanical) Penang, Tenaga National Berhad Penang as well as the worshippers for their continuous support and participation during the operation of the field study.

REFERENCES


Table 5: The findings and optimization strategies for the Penang State Mosque

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Optimization</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>inconsistent operation time</td>
<td>Establish Standard of Operating Procedures and practical training to prepare the mosque officer (Muhib).</td>
</tr>
<tr>
<td>2.</td>
<td>High energy consumption and wastage from possible faulty cooling efficiency and heat transfer</td>
<td>To replace the existing chiller.</td>
</tr>
<tr>
<td>3.</td>
<td>Prevalence of inexperienced mosque officers and maintenance conducted in the air-conditioning system</td>
<td>To train the manual operation of the air-conditioning system to ensure a consistent operation time.</td>
</tr>
<tr>
<td>4.</td>
<td>Defined temperature limit determined for the controller for the air-conditioning system</td>
<td>To fix the required temperature limit in the air-conditioning system.</td>
</tr>
<tr>
<td>5.</td>
<td>Proposed segregated zones</td>
<td>Concept 2: Zone 2 – Cooling is required for the prayer area portion.</td>
</tr>
<tr>
<td>6.</td>
<td>Improper maintenance and operating time of the air-conditioning system</td>
<td>To replace the existing chiller.</td>
</tr>
<tr>
<td>7.</td>
<td>Improper temperature and load distribution in the mosque</td>
<td>To ensure the required energy level and load level for the specified temperature.</td>
</tr>
<tr>
<td>8.</td>
<td>High energy consumption from possible faulty cooling efficiency and heat transfer</td>
<td>To replace the existing chiller.</td>
</tr>
<tr>
<td>9.</td>
<td>Improper maintenance and operating time of the air-conditioning system</td>
<td>To replace the existing chiller.</td>
</tr>
</tbody>
</table>

The existing chiller was found to be the lowest energy tariff at an operational level. The bleachers that were found in the mosque had also comprised the operating efficiency and heat transfer processes.
Solar heat gain is the primary issue for cooling energy which accounts for the highest energy consumption in building particularly in hot and humid climate like Malaysia. Approximately 93% of the solar heat gain through a roof is by radiation compared to conduction and convection methods. One of the most effective passive strategies to reduce radiative heat transfer in building is by using reflective insulation. Generally, reflective insulations are insulation materials that have low emissivity which ranges from 0.10 to 0.04 with high reflectance values. The performance of reflective insulation is commonly evaluated in accordance to ASTM C518 Standard using Heat Flow Meter. The objective of this paper is to analyze the performance of four different types of reflective insulations to ASTM C518, the heat flow meter apparatus test method under ASTM C518 and the hot-box apparatus test method under ASTM C163. The heat flow meter test method is commonly accepted as a method to characterize the reflective insulation layer itself whereas the guarded hot-box test method is used to determine the total thermal resistance of a building component or assemblies including radiant barrier (Escudero et al. 2013). In this study, the heat flow meter characterization method is used to determine the R-Value of different thermal insulation assemblies. Researchers have evaluated a double roof prototype insulation assemblies using reflective insulations and it was discovered that the reflective insulations was effective in reducing the radiant heat transfer from the roof to the ceiling (Chang P.C. et al., 2008). In order to obtain the value of the thermal resistance of different reflective insulations in building, the heat flow meter apparatus and the guarded hot box method were extensively used by researchers (Escudero et al. 2013). The two different configurations have been tested and compared with simple analytical model according to ISO9046 standards using CFD analysis. It was found that both of the experimental lab methods were suitable for characterization of reflective insulations.

Researchers also have studied the effect of energy saving of reflective insulation on exterior building envelopes based on different weather conditions (Gou et al. 2012). The study was carried out under both summer and winter weather conditions. In the experiment, reflective insulation materials was applied to the exterior envelope as a coating layer. The experimental study was carried out on an actual building room conditions to cater for different rooms or orientations. The indoor test results showed that the insulation coating performs better than the non-insulating coating with temperature difference of 0.5°C and annual energy saving of 5.8 kWh/m².

In this study, the thermal characteristics performance of reflective insulation materials has been tested experimentally using Heat Flow Meter (HFM) method in accordance with ASTM C177 test method. The objective of this study is to analyze the performance of four different types of reflective insulation materials were used namely: big bubble aluminum foil, small bubble aluminum foil, woven foil and metalized foil. Based on the measurement and analysis, it was discovered that the big bubble foil with 50mm top air gap and 70mm bottom air gap has the highest R-value of 2.38.

**Keywords:** Reflective insulation, solar heat gain, radiation, emissivity, R-value.

1. INTRODUCTION

One of the most effective passive strategies to reduce cooling energy consumption in a building is by using thermal insulation. Generally, high solar radiation in tropical countries is being absorbed by buildings external envelope which causes high amount of solar heat gain emitted inside the building that increases the energy consumption due to higher cooling load (Escudero et al., 2013). Therefore, for this reason, decreasing the solar heat gain became a big challenge especially in designing green and low energy buildings (Filho and Oliveira Santos 2014).

The insulation materials or products that are used in tropical buildings should have high thermal resistance. Hence, characterization of the insulation properties is to be undertaken before consideration during designing its installation assemblies on building components (Hasar et al., 2013). The insulation materials and assemblies are commonly found on roofs, façade, walls and floors components. For tropical countries, the high solar radiation and high temperature, it was discovered that the most effective method to reduce the solar heat gain and energy consumption is by installing the insulation on the roof component (Hernández-Pérez et al. 2014). Researchers have also discovered that reflective insulation installation on the roof was able to reduce heat flux by 26% to 50% and cooling load by 6% to 16% (Lee S.W. et al., 2016).

Therefore, most of the studies found that building installations were conducted on roofs as compared to other building components like walls, façade and floors components. Based on previous research, large size roof of buildings in hot and humid conditions such as airports, shopping malls, industrial factories and exhibition halls with proper thermal insulation could able to reduce up to 50% of thermal heat gain inside the buildings (Hernández-Pérez et al. 2014). This high percentage of thermal heat gain is normally due to high solar radiation exposure of the large roof area as compared to the other building components such as external walls and façade. Researchers have also discovered that the internal rate of return (IRR) for installation of reflective insulation on a typical hypermarket is approximately 15.85% (Lee S.W., et al. 2017).

There are mainly two major categories of building installations namely the mass or bulk insulation and reflective insulations. Studies have found that heat transfer by radiation is the primary mode of heat transfer in buildings envelope in hot climate as compared to other heat transfer methods like conduction and convection (Chang, P.C. et al., 2008). Therefore, reflective insulation is considered the most efficient method in reducing radiant heat transfer. The thermal performance of reflective insulation is highly dependent of the thermal properties of its materials and assemblies as building components (Al-Homoud 2003). The key parameters that influence the performance of reflective insulations because of its low emissivity and surface temperatures. There are several characterization methods that can be used to determine the thermal performance of the insulation assemblies for reflective insulations. The standard thermal characterization methods to evaluate the performance of reflective insulation are the guarded hot plate apparatus test method under ASTM C177, the heat flow meter apparatus test method under ASTM C518 and the hot-box apparatus test method under ASTM C163. The heat flow meter test method is commonly accepted as a method to characterize the reflective insulation layer itself whereas the guarded hot-box test method is used to determine the total thermal resistance of a building component or assemblies including radiant barrier (Escudero et al. 2013). In this study, the heat flow meter characterization method is used to determine the R-Value of different thermal insulation assemblies. Researchers have evaluated a double roof prototype insulation assemblies using reflective insulations and it was discovered that the reflective insulations was effective in reducing the radiative heat transfer from the roof to the ceiling (Chang P.C. et al., 2008). In order to obtain the value of the thermal resistance of different reflective insulations in building, the heat flow meter apparatus and the guarded hot box method were extensively used by researchers (Escudero et al. 2013). The two different configurations have been tested and compared with simple analytical model according to ISO9046 standards using CFD analysis. It was found that both of the experimental lab methods were suitable for characterization of reflective insulations.
The main objective of this research is to determine the performance or the thermal resistance (R-value) of four different types of reflective insulations namely the big bubble aluminum foil, small bubble foil, woven foil and metalized foil with different configurations of air gaps. Figure 2 shows the types of reflective insulations.

The heat flow meter is a steady state technique for measurement of thermal conductivity and it is also commonly used by researchers and industry professionals to determine the R-VALUE of insulation materials. In order to measure the thermal conductivity of the assemblies of the reflective insulation, the heat flow meter, a sample is positioned in between two temperature controlled plates. The plates establish the temperature difference (ΔT) across the sample. The sample thickness (L) can be manually keyed into the heat flow meter control panel or allowing the heat flow meter to automatically measure the thickness of the sample. The temperature settings are based on the requirement by MS 2095:2014 Radiant barrier and reflective insulation building materials – Specification (First revision). The heat flow meter was set to 35°C and the bottom plate to 20°C respectively. The temperature settings were based on the requirement by MS 2095:2014 radiant barrier and reflective insulation building materials – Specification (First revision). The heat flow direction of the sample assembly was based on downwards flow direction as shown in Figure 5. The sample size was 600mm x 600mm with different configurations of air gaps that ranges from 25mm, 50mm, 75mm, 100mm, 125mm and 150mm.

3. METHODOLOGY

The application of heat flow meter for thermal characterization on reflective insulation has been considered as one of the most reliable method in determining the performance of reflective insulation (Saber 2012). In this characterization study, LaserComp Heat Flow Meter model FOX 600 was used to determine the thermal conductivity and subsequently for R-value calculation as shown in Figure 3.

The heat flow meter measurement settings for small bubble foil, big bubble foil, woven foil and metalized foil are as shown in Table 1. There were total of 14 different types of configurations for this study. All the heat flow meter measurement settings for small bubble foil, big bubble foil, woven foil and metalized foil with different air gaps configurations are as shown in Table 1. There were total of 14 different types of configurations for this study.

4. RESULTS AND DISCUSSION

Table 1: Top and Bottom Plate Temperature Settings and different Air Gaps Configurations for Heat Flow Meter Measurement

<table>
<thead>
<tr>
<th>Top plate temperature (°C)</th>
<th>Bottom plate temperature (°C)</th>
<th>Top air gap (mm)</th>
<th>Bottom air gap (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>20</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td>75</td>
<td>125</td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td>100</td>
<td>25</td>
</tr>
</tbody>
</table>

Figure 3: LaserComp Model FOX 600 Heat Flow Meter [11]
configuration for MP2 is 0.63 m²K/W with 75mm for top air gap and 75mm for bottom air gap. The thermal performance of the MP2 was the lowest compared to the big bubble foil, small bubble foil and woven foil. The study found that the highest R-value for Small bubble foil was 2.32 m²K/W with top air gap of 50mm and bottom air gap of 75mm. The analysis also shows that the R-value decreases when the air gap exceeded 75mm.

Figure 6 shows the R-value of the Big Bubble Foil with different air gaps. The analysis also showed that the R-value for the woven foil decreases as the air gaps increased 75mm. Based on the results of the heat flow meter measurement and the R-value calculations for Big bubble foil, the optimum R-value of 2.38 m²K/W was achieved with top air gap of 50mm and bottom air gap of 75mm as shown in Figure 6. The analysis also revealed that as the air gap exceeded 75mm, the R-value began to decrease. The effect of bigger air gaps influencing the R-value could be due to the occurrence of convective heat transfer or heat loss in the air gaps that caused both top and bottom air gaps as ineffective insulation layer. In order for the air gaps to act as an effective insulation layer, it needs to avoid any convective heat transfer to occur.

The thermal performance of the three types of reflective insulations and the bottom air gap was 50mm and 75mm. Any lesser or bigger air gap does not assist in increasing the R-value of the reflective insulation. The analysis also found that the highest R-value for Small bubble foil was 2.32 m²K/W with top air gap of 50mm and bottom air gap of 75mm. The analysis also shows that the R-value decreases when the air gap exceeded 75mm.

Table 2 shows the summary of the performance of all the 3 types of reflective insulation with optimum air gaps configurations. Based on the analysis, the top air gap of 50mm was the optimum air gap for the three types of reflective insulation and the bottom air gap was 50mm and 75mm. Any lesser or bigger air gap does not increase the R-value of the reflective insulation. The study found that the highest R-value for Small bubble foil was 2.32 m²K/W with top air gap of 50mm and bottom air gap of 75mm. The analysis also showed that the R-value for the woven foil decreases as the air gaps increased 75mm.

Figure 9 shows the R-value of the metalized foil (MP2) with different air gaps configurations. Based on the measurement results, the optimum air gap configuration for MP2 is 0.63 m²K/W with 75mm for top air gap and 75mm for bottom air gap. The thermal performance of the MP2 was the lowest compared to the big bubble foil, small bubble foil and woven foil. The research also discovered that when the air gaps for top and bottom of the reflective insulation exceeded 75mm, the R-value decreases. This effect was also encountered by other researchers in the studies on reflective insulation using heat flow meter method and it was generally due to the convective heat transfer that occurred when both the top and bottom air gaps of the reflective insulation were larger than 75mm.

ACKNOWLEDGEMENT

The authors would like to extend their gratitude towards the Arus Perdana Grant AP-2017/001 of Universiti Kebangsaan Malaysia and Greenbuildings Bhd for the financial assistance and without which this research would not have been possible.

REFERENCES


COMPARISON OF MEASURED AND MODELLLED MEAN RADIANT TEMPERATURE IN THE TROPICAL URBAN ENVIRONMENT

Naser G.A. Khrit1*, Kamaruzzaman Sopian1, Mohammad Alghouf2, Lim Chin Haw2, Nik Lukman Nik Ibrahim3 and Abdelnaser Muftah A. Elbreki3

1Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
2Center of Research Excellence in Renewable Energy (CoRERE), King Fahd University of Petroleum and Minerals (KFUPM), Dhahran 31261, Saudi Arabia.
3Corresponding author: nassrjak@hotmail.com

ABSTRACT
RayMan is the most popular software package for thermal comfort research and urban planning. RayMan simulates the mean radiant temperature (Tmrt) and provides assessment of the human-biometeorology for urban areas. In this study Tmrt simulated by RayMan (version 1.2) has been validated with results from the six-directional radiation measurements in tropical urban settings in Malaysia. In addition, a validation of the physiologically equivalent temperature (PET) simulated by RayMan is conducted for the first time in the tropical context. Tmrt values from RayMan1.2 show some agreement with the measured values during middle of the validated days; however there was high fluctuation over that time due to rapid changes in radiation by cloud appearance. The results also show that RayMan1.2 considerably underestimated Tmrt during morning and evening. The simulated PET values followed the same pattern of the simulated Tmrt. However the simulated PET had a closer estimation to the experimentally obtained PET. The study also noted that RayMan1.2 accuracy seems to be site-related. Its simplification to the 3-D radiation environment led to variations in simulation accuracy depending on urban morphology. Therefore improvements of the RayMan software for simple and complex urban settings and tropical climates are required.

Keywords: mean radiant temperature; six-directional radiation method; RayMan 1.2 software; tropical urban environment.

1. INTRODUCTION
Consideration of human-biometeorology and thermal comfort for the assessment of urban areas has increased in recent years in response to different issues (Lee and Mayer, 2016, 2018a, 2018b; Lee, Mayer, and Chen, 2016; Lee, Mayer, and Schindler, 2014). First, the rates of world population living in cities are growing. In addition, urbanization has imposed significant changes to the natural ecosystem and landscape through the creation of largely impermeable urban surfaces (Arnfield, 2003). Such changes to urban landscape have caused alteration in the local climate. The most obvious indicator of the alteration in urban climate is the increase in urban air and surface temperatures, a well known effect of Urban Heat Island (UHI) (Arnfield, 2003). Alteration in urban climate and the increase in urban air and surface temperatures are directly affecting outdoor comfort conditions, which can be worsened by climate change events (Changnon, Kunkel, and Reinke, 1996; You et al., 2017). The lack of effective urban planning and design can further exacerbate this situation (Ali-Toudert and Mayer, 2007; Johansson and Emmanuel, 2006; Thami, Mohumad, & Jamaledean, 2013). Hence, human-biometeorological methods for the quantification of urban climatic impacts as well as to assess the effectiveness of adaptation and mitigation measures in improving outdoor conditions have become increasingly important (Ketterer and Matzarakis, 2014; Kutter, 2011; Lee and Mayer, 2010a, 2010b; Lee et al., 2016; Wamsler, Brink, and Rivera, 2013).
For assessment of urban-humibiotemperatur and thermal comfort, de- tailed information of different parameters and processes governing micro - meteorological conditions are required. These parameters and processes are often difficult to quantify in complex urban environments. Hence the use of numerical methods which involved parameters and processes are supplemented and enhanced with numerical calculations and simulations. A further advantage of the numerical modelling is the ability to as - sess urban-human-humibiotemperatur and thermal comfort conditions in relation to urban land-use planning scenarios (Yang, Cebalos-Laurent, and Spengler, 2014; Lee and Mayer, 2014a, 2018b; Lee et al., 2016). Howe - ver, modelling of microclimate often emerges with simplifications and limi - tations. This is due to the required spatial resolutions and possible grid - based approximations. The main feature for the modelling of microclimate is the determination of the 3D radiation fluxes for human beings and the calculation of the mean radi - ation temperature (Tmrt), one of the important parameters for the assess - ment of thermal comfort of buildings and outdoor environments (Ali - Toudert and Mayer, 2006; Thomson, Lindberg, Eilson, and Holmer, 2007). The mean feature for the modelling of microclimate is the determination of the 3D radiation fluxes for human beings and the calculation of the mean radi - ation temperature (Tmrt), one of the important parameters for the assess - ment of thermal comfort of buildings and outdoor environments (Ali - Toudert and Mayer, 2006; Thomson, Lindberg, Eilson, and Holmer, 2007). The main feature for the modelling of microclimate is the determination of the 3D radiation fluxes for human beings and the calculation of the mean radi - ation temperature (Tmrt), one of the important parameters for the assess - ment of thermal comfort of buildings and outdoor environments (Ali - Toudert and Mayer, 2006; Thomson, Lindberg, Eilson, and Holmer, 2007). The main feature for the modelling of microclimate is the determination of the 3D radiation fluxes for human beings and the calculation of the mean radi - ation temperature (Tmrt), one of the important parameters for the assess - ment of thermal comfort of buildings and outdoor environments (Ali - Toudert and Mayer, 2006; Thomson, Lindberg, Eilson, and Holmer, 2007). The main feature for the modelling of microclimate is the determination of the 3D radiation fluxes for human beings and the calculation of the mean rad - ation temperature (Tmrt) is that the calculation procedures are based on simplified methods and formulas (Lee and Mayer, 2016; Naboni, Meloni, Cucolo, Kauppi, & Scharzein, 2017). This, the modelling is not evident particularly in complex urban environments (Ali-Toudert and Mayer, 2006; Thomson et al., 2007). 2. RAYMAN 1.2 RayMan 2.0 is a software package for the assessment of urban - scale microclimate (Holst, Dostal, Imbery, & Schindler, 2008). It is also considered the most spatially variable parameter compared to other pa - rameters. Therefore, the issue of modelling the 3D radiation fluxes and the Tmrt is that the calculation procedures are based on simplified methods and formulas (Lee and Mayer, 2016; Naboni, Meloni, Cucolo, Kauppi, & Scharzein, 2017). Thus, the modelling is not evident particularly in complex urban environments (Ali-Toudert and Mayer, 2006; Thomson et al., 2007).

Several researchers validated the performance of RayMan by performing the validation of Tmrt based on field measurements (Andrade and Alcorde, 2008; Chen, Lin, and Matzarakis, 2014; L.-R. Hwang, Lin, and Matzarakis, 2013; Krüger, Minella, and Raua, 2011; Niletto and Matzarakis, 2017; Nilsa et al., 2019). Most of these validation studies however have been conducted in moderate to high-altitude locations. A total of three days of measurements were carried out at the sites: on 14 Feb - 2017 and 2017 and 25 February 2018 at the site 2. The measurements were recorded on each day from 8:00 am to 8:00 pm. The weather during the days brought hot, humid conditions with intense solar ra - diation and occasional cloudy skies. The average air temperature at the meas - ured was between 29.6 and 31.4°C and the average RH was between 55 and 60%. The average wind speed was 1.8 ms\(^{-1}\). The average global radiation was between 450 and 550 W/m\(^2\) and the highest recorded global radiation was 160 W/m\(^2\). These conditions are representative of the local tropical climate in Malaysia where there is no distinct seasons. As the RayMan1.2 takes vegetation and building morphology into account, the distribution of sunshine, shadow and temperature is very accurate. As the RayMan1.2 takes vegetation and building morphology into account, the distribution of sunshine, shadow and temperature is very accurate. As the RayMan1.2 takes vegetation and building morphology into account, the distribution of sunshine, shadow and temperature is very accurate.

![Figure 1](https://example.com/figure1.png)

Figure 1. (a, b) Photographs of the measurement sites (left) and fieldwork im - ages (right) generated by RayMan1.2.

3.1 Measurements and Methods

Micrometeorological station and Measurements

The micrometeorological station shown in Figure 1a, b was equipped with instruments as defined in Table 1. This includes sensors to measure air tem - perature, relative humidity, and wind speed. Three net-radiometers, each con - sisting of two pyranometers and two pyrgeometers, were set up on the roof to measure the six-directional short and long-wave radiation fluxes. All in - stuments were fixed at a height of 1.1 m a.g.l representing the height of the weighting center of a standing person (Thornson et al., 2007). The recording interval was set to 1 min.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measurement</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta OHM: AP3203</td>
<td>Temperature</td>
<td>±0.15°C - 0.35°C</td>
</tr>
<tr>
<td>Delta OHM: AP3203</td>
<td>Relative humidity</td>
<td>±0.05 m/s (0.05-1 m/s)</td>
</tr>
<tr>
<td>Delta OHM: AP3203</td>
<td>Wind speed</td>
<td>±0.15 m/s (1-5 m/s)</td>
</tr>
<tr>
<td>Delta OHM: AP3203</td>
<td>Radiation</td>
<td>0.15°C - 0.35°C</td>
</tr>
<tr>
<td>Delta OHM: AP3203</td>
<td>Temperature</td>
<td>0-100 %</td>
</tr>
<tr>
<td>Pyrgeometers: -300 - +300 W/m2</td>
<td>Spectral range: 5.5 µm ÷ 45 µm</td>
<td>0.15°C - 0.35°C</td>
</tr>
<tr>
<td>Pyranometers: 0-1000 W/m²</td>
<td>Spectral range: 300-1000 nm</td>
<td>0.15°C - 0.35°C</td>
</tr>
</tbody>
</table>

Table 1: Measured parameters and instruments

An accurate determination of Tmrt is very difficult and mostly impossible in complex urban settings because this requires measurements of all short- and long-wave fluxes along with angle factors between a person and the surround - ing. An alternative way for Tmrt is by limiting the measurements of radiation from the four perpendicular directions surrounding a person, i.e., from four lateral directions, upwards and downwards (Holst and Mayer, 2011; Kint - tor, Ković, and Lin, 2015; Lee, Holst, and Mayer, 2013; Holm Mayer, Holst, Dostal, Imbery, & Schmidt, 2008; Thorsson et al., 2007). To date...
this method is the most reliable measuring method to determine $T_{\text{mrt}}$ (Kan
et al., 2015; Kanter, Lin, & Matzarakis, 2014). Lee et al. (2016) used six individu- 
al measurements of short-wave radiation fluxes $K_i$ and long-wave radiation 
fluxes $L_i$ multiplied by the angle factors $F_i$ between a person and the sur-
rounding (six-directional method). Following the Stefan–Boltzmann law in 
equation [1] (Thorsén et al., 2007):

$$T_{\text{mrt}} = \frac{1}{\varepsilon_{\text{ref}}} \sum \left( \alpha_k T_k^4 + \alpha_l T_l^4 \right) + \alpha_p T_p^4$$

where $\varepsilon_{\text{ref}}$ is the Stefan–Boltzmann constant ($5.67 \times 10^{-8}$ W/m²K⁴), $\alpha_k$, $\alpha_l$, and $\alpha_p$ are the absorption coefficients for short-wave fluxes (standard values is 0.7) and long-wave fluxes (standard values is 0.97). To calculate $T_{\text{mrt}}$ for a standing person, $F_i$ is set to 0.22 for radiation fluxes from the lateral directions and 0.06 for upwards and downwards radiation fluxes (Thorsén et al., 2007).

The results of $T_{\text{mrt}}$ by the six-directional method ($T_{\text{mrt (rad.)}}$) along with the meteorological data of air temperature, wind speed, and water vapour pressure were used to determine the experimentally obtained PET.

Application of RayMan1.2 to simulate $T_{\text{mrt}}$ and PET

The meteorological data of air temperature, wind speed, and water vapour pressure (relative humidity), global radiation and cloud cover were used as inputs in RayMan1.2 to simulate $T_{\text{mrt}}$ and PET. The default values of the albedo, Bowen ratio and the ratio of diffuse and global radiation have been used. An input of the urban structures of the sites has been considered in RayMan1.2.

The simulation results of $T_{\text{mrt}}$ and PET were validated by comparison with the experimentally obtained results.

4. RESULTS AND DISCUSSION

Validation of the simulated $T_{\text{mrt}}$ by RayMan1.2

As shown in Figure 2, the variations in $T_{\text{mrt}}$ values during the middle of the measuring days can be explained by rapid changes in weather conditions from clear to cloudy conditions. The maximum values of the measured $T_{\text{mrt}}$ were between 37-39°C. The simulated $T_{\text{mrt}}$ followed the same patterns during this time but with more fluctuation with maximum values between 75-80°C. In morning and evening $T_{\text{mrt}}$ in morning and evening but drastically overestimated it during middle of the measuring days. Thorsén et al. (2007) reported similar results based on measurements and simulations done in the high latitude city of Göteborg, Sweden. Both reflected and diffused short-wave fluxes as well as the emis-
tance of long-wave fluxes from the surrounding surfaces are important for the estimation of $T_{\text{mrt}}$. The formulation used by the RayMan to simulate the 3D radiation fluxes are simplified and does not consider the horizon (Lee and Mayer, 2016). These aspects should be considered for the determination of $T_{\text{mrt}}$.

Validation of simulated $T_{\text{mrt}}$ by RayMan1.2

Figure 2 (a-c): $T_{\text{mrt}}$ calculated by six directional radiation method and the simulated $T_{\text{mrt}}$ by RayMan1.2: (a) at the site 1; (b, c) at the site 2.

As shown in Figure 3 a the simulated and measured $T_{\text{mrt}}$ values were strongly correlated, with $R^2$ values ranging between 0.95 and 0.97. It is evident that the RayMan1.2 tends to underestimate $T_{\text{mrt}}$ at lower ranges of $T_{\text{mrt}}$ values, and overestimated it at higher ranges of $T_{\text{mrt}}$ values. The magnitude of the $T_{\text{mrt}}$ underestimation was higher than that of its overestimation particularly in site 2. Also in all three days the RayMan1.2 gives a scatter in $T_{\text{mrt}}$. The scatter is increasing at higher ranges of $T_{\text{mrt}}$, i.e., at the middle of the days, which can be interpreted by rapid change in radiation fluxes by cloud appearing.

Furthermore, Figure 3 a-c indicates two differentiated systematic errors in the regressions between simulated and measured $T_{\text{mrt}}$. The simulation results show systematically lower $T_{\text{mrt}}$ values at the site 2 compared to the site 1. Probably, the differentiated systematic errors reveal that the accuracy of RayMan1.2 is influenced by urban morphology and the quantification of clouds in urban areas and the turbidity estimation environments is also important.

By adjusting the default Bowen-ratio, albedo and the ratio of diffuse and global radiation for the local context, the RayMan 1.2 still underestimated $T_{\text{mrt}}$ in morning and evening but drastically overestimated it during middle of the days. Therefore, RayMan needs to be improved to consider the radiative fluxes for applications in simple and complex urban settings. Further-
more, the quantification of clouds in urban areas and the turbidity estimation need to be enhanced. Improvement of atmospheric turbidity for tropical envi-
ronments is also important.
The simulated results of PET by RayMan 1.2 were validated by comparison with those obtained by experimental procedures. As shown in Figure 4, the scatter and systematic error in the regressions between simulated and measured PET followed the same pattern as the Tmrt. This was expected because Tmrt is the main factor affecting PET in outdoor environments. Nevertheless the simulated PET by RayMan 1.2 is less affected by inaccuracy of the simulated Tmrt. The R² values ranging between 0.96 and 0.98 indicate stronger correlations between simulated and experimentally obtained PET. The simulated PET values have closer approximations to the experimentally obtained PET followed the same pattern of the simulated Tmrt. The R² values ranging between 0.96 and 0.98 indicate stronger correlations between simulated and experimentally obtained PET. Also the simulated PET values have a closer estimation to the measured PET vs. simulated by RayMan 1.2: (a) at the site 1; (b, c) at the site 2.

5. CONCLUSION

In this study the RayMan 2.1 software was validated by comparison with field measurements for the tropical outdoor urban environment. As the Tmrt can be determined by field measurements and modelling, the consistency between measured and simulated Tmrt was utilized as a criterion for the validation of the RayMan 2.1 software. The simulated Tmrt results by the RayMan 2.1 software were compared with the six-directional radiation method as a reference method. The results are for three day at two different sites in a tropical urban environment.

The study shows that RayMan 2.1 software gives reasonable results during the middle of the day. However, in morning and late afternoon the RayMan 2.1 software drastically underestimates Tmrt data. The study also shows that the software simulation of different urban settings leads to different systematic errors depending on the urban morphology and SVF. The reflected and diffused shortwave fluxes as well as the longwave fluxes from the surrounding surfaces, which are highly correlated with urban morphology, are simplified by RayMan 2.1 (Laal and Mayer, 2016; Nisho et al., 2017). The results suggest that the accuracy of RayMan 2.1 may be dependent on SVF, i.e., the simulation for spaces with different SVFs may achieve different levels of accuracy.

The effect of the simulated Tmrt on the thermo-physiological index PET is also analyzed. The index has been chosen for validation because it has been employed in several studies of outdoor thermal comfort. The simulated PET values from RayMan 2.1 software followed the same pattern of the simulated Tmrt. Nevertheless the simulated PET values have a closer estimation to the experimentally obtained PET. In addition, the RayMan 2.1 gives slightly less scatter in PET in comparison to Eq. (3).

Therefore, based on the results of the validation, improvements to the RayMan 2.1 simulation for the short- and longwave radiant flux densities from the surrounding 3D environment is required. Moreover, there are some other parameters whose assessments have to be improved e.g. the quantification of the clouds and atmospheric turbidity.

REFERENCES

Preliminary Evaluation of Air Flow in Atrium of Building in Hot and Humid Climate

Wardah Fatimah Mohammad Yusof1, Mohd Khairul Azhar Mat Sulaiman1 and Fachrul Mohsin2

1Centre for Innovative Architecture and Built Environment, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor.
2Architecture Programme, Department of Civil Engineering, Politeknik Port Dickson, Km 14, Jalan Pantai, 71050 Si Rusa, Negeri Sembilan.

* Corresponding author: wardahyu@ukm.edu.my

ABSTRACT

Atrium is one of the passive design strategies that is known to have certain effects to the indoor environment of a building. These effects can be beneficial or detrimental, depending on the atrium design in response to the climate where it is located. One of the important criteria for designing a building in hot and humid climate is the ventilation aspect. Hence, this study was executed to investigate the air flow in an atrium of a building in hot and humid climate. The investigations were executed using numerical simulation method, which was validated by field measurement. The software used for the numerical simulation was Computational Fluid Dynamic (CFD) which was ANSYS CFD v14.5. The findings indicated that the existence of more air flow paths such as the access corridors that connect the atrium with the outdoor will also has openings, which normally located on top, that allow the air to flow in and out from the building.

Air flow in and out from the building. Wardah is widely applied all over the world. It is always incorporated in large buildings such as shopping malls, office headquarters and hotels. This is due to many benefits provided by atrium, whether environmental or social benefits. Atrium is normally located at the front part of a building, and it becomes a welcoming or introductory space that usually portrays the image of the building. Due to its significant role, atrium also becomes an area for socializing, gathering, and conducting activities such as exhibition and performance. Besides social benefits, atrium also contributes to the controlling of indoor environmental conditions. Due to its significant role, atrium also becomes an area for socializing, gathering, and conducting activities such as exhibition and performance. Atrium is widely applied all over the world. It is always incorporated in large buildings such as shopping malls, office headquarters and hotels. This is due to many benefits provided by atrium, whether environmental or social benefits. Atrium is normally located at the front part of a building, and it becomes a welcoming or introductory space that usually portrays the image of the building. Due to its significant role, atrium also becomes an area for socializing, gathering, and conducting activities such as exhibition and performance. Besides social benefits, atrium also contributes to the controlling of indoor environment of a building.

1. INTRODUCTION

Atrium can be defined by three characteristics, which are a) a small court in a Roman House surrounded by a roofed area or roofless opening in the centre; or b) an open court surrounded by a roofed arcade or colonnaded walk, and c) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, the definition gives an open area surrounded by walls or buildings (J. S. Curl, 2006), while air an open court surrounded by a roofed arcade or colonnaded walk, and c) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, the definition gives an atrium can be defined by three characteristics, which are a) a small court in a Roman House surrounded by a roofed area or roofless opening in the centre; or b) an open court surrounded by a roofed arcade or colonnaded walk, and c) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, the definition gives an open area surrounded by walls or buildings (J. S. Curl, 2006), while air an open court surrounded by a roofed arcade or colonnaded walk, and c) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, the definition gives an open area surrounded by walls or buildings (J. S. Curl, 2006), while air an open court surrounded by a roofed arcade or colonnaded walk, and c) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, the definition gives an open area surrounded by walls or buildings (J. S. Curl, 2006), while air an open court surrounded by a roofed arcade or colonnaded walk, and c) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, the definition gives an atrium can be defined by three characteristics, which are a) a small court in a Roman House surrounded by a roofed area or roofless opening in the centre; or b) an open court surrounded by a roofed arcade or colonnaded walk, and c) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, the definition gives an open area surrounded by walls or buildings (J. S. Curl, 2006), while air an open court surrounded by a roofed arcade or colonnaded walk, and c) a top-lit internal space that is surrounded by several storeys (J. S. Curl, 2006). Therefore, the definition gives an open area surrounded by walls or buildings (J. S. Curl, 2006), while air
In the previous studies of atrium are shading configuration, roof aperture, type of ventilation mode, type of building fabric, properties of building fabrics, building geometry, geometry of sun, and orientation (Wang, 2012). Among these parameters, the most important factors are the building orientation, geometry of sun, and orientation regarding the effect of the solar heat gain and heat loss during summer and winter, respectively (Abdullah and Wang, 2012). Moreover, the building area and position of the atrium such as the greenhouse effect and the chimney effect. The greenhouse effect provides positive role during winter, and negative role during summer. Meanwhile, the chimney effect is opposite to the greenhouse effect (Verheijen et al., 2017). For hot and humid climate countries like Malaysia, the chimney effect is more predominant during the summer season as the sun and sun angle are higher. There are three type of ventilation modes usually applied in atrium, namely air infiltration, air convection and air circulation. Among them, the latter two are most commonly applied in Malaysia due to the benefits mentioned in the previous studies of atrium such as the lighting, ventilation, air temperature and air quality.

There are three type of ventilation modes usually applied in atrium, namely air infiltration, air convection and air circulation. Among them, the latter two are most commonly applied in Malaysia due to the benefits mentioned in the previous studies of atrium such as the lighting, ventilation, air temperature and air quality.

Besides the worldwide study and application of atrium, this strategy is also being adopted in Malaysia due to the heat and humidity condition. For hot and humid climate countries like Malaysia, the chimney effect is more predominant during the summer season as the sun and sun angle are higher. There are three type of ventilation modes usually applied in atrium, namely air infiltration, air convection and air circulation. Among them, the latter two are most commonly applied in Malaysia due to the benefits mentioned in the previous studies of atrium such as the lighting, ventilation, air temperature and air quality.

In the previous studies of atrium are shading configuration, roof aperture, type of ventilation mode, type of building fabric, properties of building fabrics, building geometry, geometry of sun, and orientation (Wang, 2012). Among these parameters, the most important factors are the building orientation, geometry of sun, and orientation regarding the effect of the solar heat gain and heat loss during summer and winter, respectively (Abdullah and Wang, 2012). Moreover, the building area and position of the atrium such as the greenhouse effect and the chimney effect. The greenhouse effect provides positive role during winter, and negative role during summer. Meanwhile, the chimney effect is opposite to the greenhouse effect (Verheijen et al., 2017). For hot and humid climate countries like Malaysia, the chimney effect is more predominant during the summer season as the sun and sun angle are higher. There are three type of ventilation modes usually applied in atrium, namely air infiltration, air convection and air circulation. Among them, the latter two are most commonly applied in Malaysia due to the benefits mentioned in the previous studies of atrium such as the lighting, ventilation, air temperature and air quality.

In the previous studies of atrium are shading configuration, roof aperture, type of ventilation mode, type of building fabric, properties of building fabrics, building geometry, geometry of sun, and orientation (Wang, 2012). Among these parameters, the most important factors are the building orientation, geometry of sun, and orientation regarding the effect of the solar heat gain and heat loss during summer and winter, respectively (Abdullah and Wang, 2012). Moreover, the building area and position of the atrium such as the greenhouse effect and the chimney effect. The greenhouse effect provides positive role during winter, and negative role during summer. Meanwhile, the chimney effect is opposite to the greenhouse effect (Verheijen et al., 2017). For hot and humid climate countries like Malaysia, the chimney effect is more predominant during the summer season as the sun and sun angle are higher. There are three type of ventilation modes usually applied in atrium, namely air infiltration, air convection and air circulation. Among them, the latter two are most commonly applied in Malaysia due to the benefits mentioned in the previous studies of atrium such as the lighting, ventilation, air temperature and air quality.

In an air-conditioned atrium of Malaysian building, the indoor air temperature and relative humidity for thermal comfort are between the range of 20.8°C to 26.8°C and 40% to 80%, respectively (Abdullah and Wang, 2011). However, the air temperature for naturally ventilated atrium is slightly higher. This depends on the activity level and the presence of movement, which is caused by the increased air exchange caused by clerestory windows’ height. This is also in agreement with the study of thermal comfort in naturally ventilated atrium conducted by Yusoff (2017). The study indicated that the presence of air velocity between 0.9 m/s to 1.5 m/s had improved the thermal comfort condition inside the atrium. Although people felt slightly warm during the afternoon hours, they were still satisfied with the indoor thermal condition. Meanwhile, the study by Yusoff (2006) had found that lower air velocity was needed to achieve thermal comfort for sedentary activities in hot and humid climate, which was 0.8 m/s. This is also in accordance with Candlides, DeDear and Lamberts (2012) who stated that the presence of air velocity higher than 0.8 m/s was able to enhance thermal comfort for indoor air temperature between 29°C to 31°C.

The implementation of natural ventilation in atrium should be promoted as there are many benefits derived from it. Among them are the reduction of energy consumption, and the reduction of indoor air pollution, especially in the case of air renewal (Sachi and Lakunaiwich, 2017). In a naturally ventilated atrium, normal alternative such as mechanical fan is provided in case the atrium’s indoor environment does not achieve thermal comfort (Yusoff, 2017). However, with the correct strategies of natural ventilation, the atrium’s indoor environment need not to receive thermal comfort, especially with the presence of sufficient air velocity.

Due to the concern for wrong strategy applied in the hot and humid climate of Malaysia, this study intends to examine the air flow inside the atrium with various numbers of access corridors. The access corridors are selected due to the current scenario where they are normally regarded as the pedestrian walkways that connect the atrium with the outdoor, without considering their importance in functioning as air flow paths. These corridors act as air flow paths that connect the atrium with the outdoor environment. The access corridors are able to create Venturi effect, as they provide controlled areas for the air flow. In Venturi effect, there is a reduction in the fluid pressure and an increase in the fluid velocity when the fluid passes through a constricted area (Fox and McDonald, 1998). In this study, the wind that hits the building facade will be channeled into the access corridors. The air velocity of the wind increases as it has to flow into a smaller area compared to the previous area. Therefore, it is expected that there is velocity increase of the air flow that flows into the atrium.

In a naturally ventilated atrium, the wind and buoyancy driven ventilations are able to remove the heat that is accumulated at the top of the atrium (Abdullah and Wang, 2012). Nevertheless, the presence of both, the wind and buoyancy driven ventilations is not enough to drive the atrium ventilation. It is generally less to drive the air flow inside the building, as it depends on many factors such as the positions of inlet and outlet (Yusoff, 2010). However, for this preliminary evaluation, the investigations are focusing on the wind driven ventilation only, where the results, analysis, discussion and conclusion are purely based on this wind driven condition. The reason for considering the wind driven ventilation only is to ensure this study is a preliminary investigation conducted with the purpose of deriving an initial idea on how the access corridors affect the air flow inside the atrium. The findings from this study are hoped to provide knowledge that can benefit many people in designing atriums, especially in hot and humid climate. Therefore, this study does not provide a total solution to the right atrium strategy for hot and humid climate, at least it is hoped to give initial idea on the air flow inside the atrium.

2. RESEARCH METHODOLOGY

The research methodology employed in this study was a numerical simulation. The CFD software used for the numerical simulation was ANSYS CFX 14.5. This CFD software is able to simulate fluid flow, heat and mass trans-
The validation results of numerical simulation presented in this study are based on the studies conducted in Muhsin et al. (2017) and Cheung and Liu (2011). The validation results showed good agreement between the numerical simulation and field measurements, as mentioned in Muhsin et al. (2017). Hence, the present numerical simulation, the similar grid characteristic was applied. For the preliminary evaluation, the study focused on the wind driven ventilation, and the ARM wind profile was set to have an exponent value of 0.28 (ε = 0.28), which was determined by the atmospheric boundary layer (ABL) profile equations. Where y is the wind speed (m/s) measured at the height of z (meter). The windward and the leeward distances were set based on the building height (H), in which the windward distance was five times of the height (5H), while the leeward distance was ten times of the height (10H), as shown in Figure 1(a). These were the minimum leeward and windward distances proposed by Montazeri and Motazed (2018) and Tominaga et al. (2008) in determining the domain size. The building and ground surfaces were set to be no slip wall condition. The numerical simulation in this study also employed steady-state airflow, turbulence model in the natural ventilation simulation were Shirzadi, Naghashzadegan and Mirzaei (2018), Yang and Jian (2017), Yusoff, Sapian, Zaidi, Adnan and Ahmad (2017), and Yousof, Sapian, Suliff, Adam, Hamzah and Sani (2014). The turbulence model used for this investigation was the standard k-epsilon (k-ε) model, which was widely used in the previous studies also (Muhsin et al., 2017; Montazeri and Montazeri, 2018; Cheung and Liu, 2011). Other studies that employed k-ε turbulence model in the natural ventilation simulation were Sheraazi, Nezafenagh et al., and Montazeri (2018). The numerical simulation in this study also employed steady-state airflow, and the ARM wind profile was set to have an exponent value of 0.28 (ε = 0.28), which was the value for suburban condition. The ARM wind profile was set to have an exponent value of 0.28 (ε = 0.28), which was the value for suburban condition. The windward and the leeward distances were set based on the building height (H), in which the windward distance was five times of the height (5H), while the leeward distance was ten times of the height (10H), as shown in Figure 1(a). These were the minimum leeward and windward distances proposed by Montazeri and Motazed (2018) and Tominaga et al. (2008) in determining the domain size. The building and ground surfaces were set to be no slip wall condition. The numerical simulation in this study also employed steady-state airflow, turbulence model in the natural ventilation simulation were Shirzadi, Zerin, and Motazed (2018), Yang and Jian (2017), Yusoff, Sapian, Suliff, Adam, Hamzah and Sani (2014) and Yousof, Sapian, Sallif, Adam, and Jinar (2015). The numerical simulation in this study also employed steady-state airflow, and the ARM wind profile was set to have an exponent value of 0.28 (ε = 0.28), which was the value for suburban condition. This value was selected by referring to the location of the building in the field measurement that was within the suburban area. The power law equation used for the ARM is as follows:

Where y is the wind speed (m/s) measured at the height of z (meter). Meanwhile, in this study, the wind speed roof was set to be 1 m/s, at the height, Zref of 10 meter. For this preliminary evaluation, the wind was set up to be from two directions only, which were 0° and 45° wind angles. The windward and the leeward distances were set based on the building height (H), in which the windward distance was five times of the height (5H), while the leeward distance was ten times of the height (10H), as shown in Figure 1(a). These were the minimum leeward and windward distances proposed by Montazeri and Motazed (2018) and Tominaga et al. (2008) in determining the domain size. The building and ground surfaces were set to be no slip wall condition. The meshing used in this simulation was tetrahedron mesh, as shown in Figure 1(b). The tetrahedron meshes were also utilized by Cheung and Liu (2011) and Farooq, Osen, AlaKaf and Kotani (2015) in their natural ventilation simulations. In this study, the maximum number of iteration was set up to be 1000. The building model constructed in the simulation consist of an atrium that is located at the middle. It is considered an atrium, and is a courtyard or an air well, as the top of the space is covered by a roof. As mentioned before, the investigation in this study focuses on the wind driven ventilation only, without any consideration of thermal factor. Therefore the top of the atrium is only specified as having a roof, with no materials specified for the roof. The investigated atrium was rectangular shape, with the dimensions of 68 m length, 40 m width and 14 m height (Figure 2). The size of the atrium was re-

![Figure 1](image_url)

Figure 1: (a) The boundary condition set up for the simulation, and (b) the tetrahedron mesh.

The building model constructed in the simulation consist of an atrium that is located at the middle. It is considered an atrium, and is a courtyard or an air well, as the top of the space is covered by a roof. As mentioned before, the investigation in this study focuses on the wind driven ventilation only, without any consideration of thermal factor. Therefore the top of the atrium is only specified as having a roof, with no materials specified for the roof. The investigated atrium was rectangular shape, with the dimensions of 68 m length, 40 m width and 14 m height (Figure 2). The size of the atrium was re-fitted to the previous atrium, located in Bangi Gateway Shopping Mall, that was investigated by the author in Yusoff (2017). The atrium was surrounded by other spaces, and was accessed by corridors that also functioned as air flow paths. The dimensions of the access corridors were 16 m length, 8 m width and 4 m height (Figure 2).

![Figure 2](image_url)

Figure 2: The plans that indicate the dimensions of the atriums with (a) two access corridors, (b) and (c) four access corridors, and (d) ten access corridors.

The numerical simulation consisted of three stages. The first stage simulation encompassed the investigations executed for two conditions of atrium, which were the atrium with two access corridors, and the atrium with four access corridors. The access corridors were located opposite to each other (Figure 3(a) and (b)) and the second stage simulation involved the atrium with four access corridors only. This was due to the findings derived from the first stage simulation, where the higher amount of corridors resulted in greater air velocity. In the second stage simulation, the access corridors were relocated to be not opposite to each other (Figure 3(c)). Meanwhile, in the third stage simulation, the number of access corridors had been increased to ten numbers (Figure 3(d)). The purpose was to obtain larger distribution of high air velocity inside the atrium. Nevertheless, all the corridors had similar dimensions.
and volumes in all stages of simulations.

Figure 3. The isometric views of the atrium with (a) two access corridors, (b and c) four access corridors, and (d) ten access corridors.

3. RESULTS AND DISCUSSION

The results and discussion were presented for all the three stages of numerical simulations. The results and findings from the first stage simulation influenced the next steps conducted in the second stage simulation. Meanwhile, the third stage simulation was executed due to further enhancement needed to the air velocity resulted from the second stage simulation.

3.1 Numerical Simulation Stage 1

Figures 4 and 5, as well as Tables 1 and 2 indicate the results derived from the first stage simulation. The results of air velocity contours for atrium with two and four access corridors, simulated with 0° wind angle were depicted in Figure 4. Meanwhile, the results of air velocity contours for the similar atrium configurations, simulated with 45° wind angle were demonstrated in Figure 3. The air velocity contours were plotted at the height of 1 meter from the ground level. This height was selected as it is within the height of human scale.

From the Figure 4, it can be seen that higher air velocities were concentrated at the centre of the atrium for both; the atrium with two, and four access corridors. This was due to the Venturi effect created inside the corridor. However, the other areas of both atriums suffered low air velocities, which were less than 0.2 m/s. For the atrium with four access corridors (Figure 4b), the side facades experienced negative pressure which resulted in low air velocities that flowed in via the side corridors. However, for 45° wind angle, the atrium with four access corridors had more areas with air velocities of more than 0.4 m/s compared to the atrium with two access corridors (Figure 5). The comparison of average air velocities measured at the height of 1 meter, and at the centre point of the atrium indicated that for 0° wind angle, the atrium with four access corridors experienced higher average air velocity compared to the atrium with two access corridors, as shown in Table 2. However, in contrast, it was found that for the wind angle of 45°, the average air velocity (at 1 meter height, and at the centre of atrium) in the atrium with two access corridors was higher than the atrium with four access corridors (Table 2).

Nevertheless, the average air velocity of the whole area measured at 1 meter height was found to be higher inside the atrium with four corridors compared to the atrium with two corridors, as shown in Table 3. However, it seems that there were not much differences between the average air velocities inside the atrium with two and four access corridors, for both wind angles. Moreover, referring to Figures 4 and 5, it seems that there were many areas that suffered low air velocities which were less than 0.2 m/s for both atriums, and both wind angles. The higher air velocities only occurred along the air flow paths between the inlets and outlets.

Table 2: The average air velocities measured at 1 meter height from the ground level, and at the centre of the atrium

<table>
<thead>
<tr>
<th>Wind Angle</th>
<th>Atrium with two access corridors</th>
<th>Atrium with four access corridors</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° wind angle</td>
<td>0.635 m/s</td>
<td>0.694 m/s</td>
</tr>
<tr>
<td>45° wind angle</td>
<td>0.482 m/s</td>
<td>0.494 m/s</td>
</tr>
</tbody>
</table>

Table 3: The average air velocities of the whole atrium area measured at 1 meter height from the ground level

<table>
<thead>
<tr>
<th>Wind Angle</th>
<th>Atrium with two access corridors</th>
<th>Atrium with four access corridors</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° wind angle</td>
<td>0.691 m/s</td>
<td>0.695 m/s</td>
</tr>
<tr>
<td>45° wind angle</td>
<td>0.485 m/s</td>
<td>0.495 m/s</td>
</tr>
</tbody>
</table>

3.2 Numerical Simulation Stage 2

In the second stage simulation, only the atrium with four access corridors was selected. The access corridors were arranged to be not opposite to each other as depicted in Figure 3(c). Nevertheless, the sizes and dimensions of the access corridors and atrium were still similar to the first stage simulation (Fig 3(c)). The results of second stage simulation were shown in Figures 4 and 6.

Figure 6 demonstrated the air velocity contours distribution inside the atrium for 0° and 45° wind angles. For 0° wind angle (Figure 6(a)), it can be seen that high air velocities were still concentrated inside the corridor and the air flow path outside the corridor that faced the wind direction. Outside the mentioned area, the air velocities were very low. The average air velocity measured at the centre of the atrium and 1 m height from the ground level was 0.101 m/s (Table 4). In addition, the air velocities at most of the atrium areas were below 0.2 m/s, which were represented by the dark blue colour. Meanwhile, the average air velocity for the whole atrium area measured at 1 m height from the ground level was 0.543 m/s (Table 4).

For the 45° wind angle (Figure 6(b)), the air velocity contours seemed to be distributed widely inside the atrium, though the velocity values were only 0.082 m/s (measured at the centre of atrium and 1 m height from the ground level), and 0.379 m/s (for the whole atrium area measured at 1 m height from the ground level).

Figure 6: The air velocity contours in atrium with four access corridors that were located not opposite to each other for (a) 0° wind angle, (b) 45° wind angle.
Table 4: The average air velocities inside the atrium with four access corridors that were located not opposite to each other

<table>
<thead>
<tr>
<th>Wind Angle</th>
<th>Centrel of atrium measured at 1 m height</th>
<th>Whole atrium area measured at 1 m height from ground level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° wind angle</td>
<td>0.008 m/s</td>
<td>0.101 m/s</td>
</tr>
<tr>
<td>45° wind angle</td>
<td>0.345 m/s</td>
<td>0.579 m/s</td>
</tr>
</tbody>
</table>

From the second stage simulation, the findings show that such arrangement of access corridors were able to distribute wider air velocities of higher than 0.2 m/s for 45° wind angle. However, the amount of average air velocity for the whole atrium area measured at 1 m height from the ground level was still lower compared to the first stage simulation. Therefore, further simulation was executed, which was the third stage simulation, in searching the strategy to enhance air velocities inside the atrium with access corridors.

3.3 Numerical Simulation Stage 3

In the third stage simulation, the amount of access corridors had been increased, as shown in Figure 3(d). Nevertheless, the sizes and dimensions of the access corridors and atrium were still similar to the first and second stage simulations (Figure2(a) and (b)). The results derived for the third stage simulation were shown in Figure 7 and Table 5. Figure 7 indicates the air velocity contours inside the atrium with ten access corridors, for both 0° and 45° wind angles. It was found that there was greater distribution of air velocities more than 0.45 m/s inside the atrium for both wind angles. The results also indicated that for 0° wind angle, the average air velocity was found to be more than 0.8 m/s at the centre of the atrium. Meanwhile, the average air velocities for the whole atrium area measured at 1 m height from the ground level were found to be more than 0.5 m/s for both wind angles (Table 5). Though the velocities of air inside the atrium with ten access corridors were found to have not much differences with the other atriums, the advantage of this configuration is the distribution of higher air velocities inside the atrium, it is suggested to allocate as many access corridors as possible. The appropriate locations of the access corridors can be decided based on the area or space functions, as well as on analysis inside the atrium.

The findings from this study is expected to create awareness among the people in built environment such as designers, building owners, developers and many others who have high concern on the importance of appropriate arrangement of air and location of air flow paths in the atrium. This is due to the current situation where the access corridors in atrium are just being regarded as the pedestrian walkways, without considering their importance in determining the air flow inside the atrium. The study in this paper focuses on wind driven ventilation only, without considering buoyancy effect. Therefore, it is recommended in future to extend the investigations by examining the effects of both; the wind and buoyancy driven ventilations, to the air flow inside the atrium. The appropriate arrangements of access corridors and location of air flow paths in the atrium is due to this current situation where the access corridors in atrium are just being regarded as the pedestrian walkways, without considering their importance in determining the air flow inside the atrium.

4. CONCLUSION

The findings from the investigations of air flow inside atriums with two and four access corridors indicate that the increase number of access corridors that connect the inside and outside, and function as air flow path, will result in higher air velocities inside the atrium. However, the findings also demonstrate that higher air velocities are just concentrated at the area where the corridors are located, and along the air flow paths between the inlets and outlets. This is due to the Venturi effect created inside the corridors. Meanwhile, the areas inside the atrium that are far from the corridors and air flow paths between the inlets and outlets suffer lower air velocity. Therefore, in ensuring wider distribution of higher air velocities inside the atrium, it is suggested to allocate as many access corridors as possible. As the appropriate locations of the access corridors can be decided based on the area or space functions, as well as on analysis inside the atrium.

The findings from this study is expected to create awareness among the people in built environment such as designers, building owners, developers and many others who have high concern on the importance of appropriate arrangement of air and location of air flow paths in the atrium. This is due to the current situation where the access corridors in atrium are just being regarded as the pedestrian walkways, without considering their importance in determining the air flow inside the atrium. The study in this paper focuses on wind driven ventilation only, without considering buoyancy effect. Therefore, it is recommended in future to extend the investigations by examining the effects of both; the wind and buoyancy driven ventilations, to the air flow inside the atrium. The appropriate arrangements of access corridors and location of air flow paths in the atrium is due to this current situation where the access corridors in atrium are just being regarded as the pedestrian walkways, without considering their importance in determining the air flow inside the atrium.

The study in this paper focuses on wind driven ventilation only, without considering buoyancy effect. Therefore, it is recommended in future to extend the investigations by examining the effects of both; the wind and buoyancy driven ventilations, to the air flow inside the atrium. The appropriate arrangements of access corridors and location of air flow paths in the atrium is due to this current situation where the access corridors in atrium are just being regarded as the pedestrian walkways, without considering their importance in determining the air flow inside the atrium.

The findings from this study is expected to create awareness among the people in built environment such as designers, building owners, developers and many others who have high concern on the importance of appropriate arrangement of air and location of air flow paths in the atrium. This is due to the current situation where the access corridors in atrium are just being regarded as the pedestrian walkways, without considering their importance in determining the air flow inside the atrium.
SKEWED WIND FLOWS ENERGY EXPLOITATION IN BUILT ENVIRONMENT

Ahmad Fazlizan¹, Wan Khairul Muzammil ¹*, Mohd Azlan Ismail¹, Mohd Fadhli Ramlee¹ and Adnan Ibrahim¹

¹Solar Energy Research Institute (SERI), Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia,
²Energy Research Unit, Universiti Malaysia Sabah, Jln. UMS, 88400, Kota Kinabalu, Sabah, Malaysia

* Corresponding author: afazlizan@ukm.edu.my

1. INTRODUCTION

Developments on small wind turbines for urban areas have gained much attention due to the rising concern in global energy issues. Wind energy is not recognized as a potential source of clean and renewable energy, especially for use in urban cities where it is urged to place wind turbines closer to populated areas due to the increasing number of economic sites (Fazlizan, Chong, Yip, Hew, and Poh, 2015; Wagner, Barnell, and Gaaloul, 1996). A wind turbine is a device that converts energy from the wind into electrical power that can be used for various applications. Wind farms use large horizontal axis wind turbines (HAWTs) with long blades. These large turbines generate noise and vibration that are not suitable for use in urban areas. In recent years, small vertical axis wind turbines (VAWTs) have been employed in urban areas for local off-grid applications. It is widely known that the lower efficiency of the VAWT compared to the HAWT is due to the highly unsteady operating conditions of the VAWT at all wind speeds caused by the periodic variation of the rotor and the direction of the apparent wind velocity perceived by the blades (Brahimi, Allet, and Para-chet, 2015). It is widely known that the lower efficiency of the VAWT compared to the HAWT is due to the highly unsteady operating conditions of the VAWT at all wind speeds caused by the periodic variation of the rotor and the direction of the apparent wind velocity perceived by the blades (Brahimi, Allet, and Para-chet, 2015). Therefore, there is a potential for better diffusion of renewable energy in the urban built environment, especially in the implementation of vertical axis wind turbines on buildings. This paper provides a critical review of the skewed wind flow phenomena, the physical characteristics of the interaction between the skewed flow with the vertical rotor, and the state-of-the-art studies of wind energy devices in skewed flow, especially in the built environment.

Keywords: Building integrated wind turbine, On-site power generation, Skewed wind flow, Urban energy, Wind energy

Currently the available wind energy devices, either the horizontal or vertical axis wind turbines, are designed to operate in orthogonal wind flows to generate power. However, in an urban environment, the skewed axis wind flow is thought to be better suited for building integrated applications due to its durability and better performance in skewed and turbulent flows compared to the more common horizontal axis wind turbine. Application of wind turbines in skewed flow is a subject of increasing interest due to the improved power output of turbines in this wind condition. Skewed flow in the built environment can be referred to as the deflected wind vector at the roofs or edges of buildings that is not horizontal. Therefore, there exists a potential for better diffusion of renewable energy in the urban built environment, especially in the implementation of vertical axis wind turbines on buildings. This paper presents an extensive literature review of the skewed wind flow phenomena, the physical characteristics of the interaction between the skewed flow with the vertical rotor, and the state-of-the-art studies of wind energy devices in skewed flow, especially in the built environment.

ABSTRACT

Current energy issues have led to increased attention on renewable energy conversion technologies to combat global energy issues. Several studies have been conducted on wind energy generation, but studies on skewed wind flows have not been fully explored. This paper reviews the research on skewed wind flows and presents a critical review of the skewed wind flow phenomena, the physical characteristics of the interaction between the skewed flow with the vertical rotor, and the state-of-the-art studies of wind energy devices in skewed flow, especially in the built environment.

1. INTRODUCTION

Developments on small wind turbines for urban areas have gained much attention due to the rising concern in global energy issues. Wind energy is not recognized as a potential source of clean and renewable energy, especially for use in urban cities where it is urged to place wind turbines closer to populated areas due to the increasing number of economic sites (Fazlizan, Chong, Yip, Hew, and Poh, 2015; Wagner, Barnell, and Gaaloul, 1996). A wind turbine is a device that converts energy from the wind into electrical power that can be used for various applications. Wind farms use large horizontal axis wind turbines (HAWTs) with long blades. These large turbines generate noise and vibration that are not suitable for use in urban areas. In recent years, small vertical axis wind turbines (VAWTs) have been employed in urban areas for local off-grid applications. It is widely known that the lower efficiency of the VAWT compared to the HAWT is due to the highly unsteady operating conditions of the VAWT at all wind speeds caused by the periodic variation of the rotor and the direction of the apparent wind velocity perceived by the blades (Brahimi, Allet, and Para-chet, 2015). It is widely known that the lower efficiency of the VAWT compared to the HAWT is due to the highly unsteady operating conditions of the VAWT at all wind speeds caused by the periodic variation of the rotor and the direction of the apparent wind velocity perceived by the blades (Brahimi, Allet, and Para-chet, 2015). Therefore, there is a potential for better diffusion of renewable energy in the urban built environment, especially in the implementation of vertical axis wind turbines on buildings. This paper provides a critical review of the skewed wind flow phenomena, the physical characteristics of the interaction between the skewed flow with the vertical rotor, and the state-of-the-art studies of wind energy devices in skewed flow, especially in the built environment.

Keywords: Building integrated wind turbine, On-site power generation, Skewed wind flow, Urban energy, Wind energy

1. INTRODUCTION

Developments on small wind turbines for urban areas have gained much attention due to the rising concern in global energy issues. Wind energy is not recognized as a potential source of clean and renewable energy, especially for use in urban cities where it is urged to place wind turbines closer to populated areas due to the increasing number of economic sites (Fazlizan, Chong, Yip, Hew, and Poh, 2015; Wagner, Barnell, and Gaaloul, 1996). A wind turbine is a device that converts energy from the wind into electrical power that can be used for various applications. Wind farms use large horizontal axis wind turbines (HAWTs) with long blades. These large turbines generate noise and vibration that are not suitable for use in urban areas. In recent years, small vertical axis wind turbines (VAWTs) have been employed in urban areas for local off-grid applications. It is widely known that the lower efficiency of the VAWT compared to the HAWT is due to the highly unsteady operating conditions of the VAWT at all wind speeds caused by the periodic variation of the rotor and the direction of the apparent wind velocity perceived by the blades (Brahimi, Allet, and Para-chet, 2015). It is widely known that the lower efficiency of the VAWT compared to the HAWT is due to the highly unsteady operating conditions of the VAWT at all wind speeds caused by the periodic variation of the rotor and the direction of the apparent wind velocity perceived by the blades (Brahimi, Allet, and Para-chet, 2015). Therefore, there is a potential for better diffusion of renewable energy in the urban built environment, especially in the implementation of vertical axis wind turbines on buildings. This paper provides a critical review of the skewed wind flow phenomena, the physical characteristics of the interaction between the skewed flow with the vertical rotor, and the state-of-the-art studies of wind energy devices in skewed flow, especially in the built environment.

Keywords: Building integrated wind turbine, On-site power generation, Skewed wind flow, Urban energy, Wind energy
The complex fluid mechanics of such devices to estimate their performances (Albaladejo and Gallego, 2003; De Vriend, 2013; De Vries, van der Walt, van der Walt, and van der Walt, 2013). Furthermore, new concepts of vertical axis wind energy devices are being introduced to overcome the disadvantages of the conventional design of VAWTs. Some of these wind turbine concepts are being adopted in the design of the building (Meinhold, 2010; Sharpe and Proven, 2010) or mounted on top of a building for maximum exploitation of wind energy (Wong et al., 2014).

The complex nature of urban winds requires wind turbines that are designed to receive wind from various directions. Moreover, urban winds are erratic, insubstantial and inconsistent due to the many obstacles (e.g. buildings and other obstructions), creating blockages that can reduce wind turbine performances (Abdelah, Banez, and Dukic, 2013). Hence, necessitating wind turbines with excellent self-starting characteristics (Drew, Barlow, and Cockrell, 2013). For a wind energy generation system to be installed in urban areas, several factors need to be considered, i.e. blade failure, noise levels, visual impacts, structural issues, and electromagnetic interference (Knight, 2004; Möllerström, Ottermo, Hylander, and Bernhoff, 2015; Oppenheim, Owen, and White, 2003). Recent investigations on Darrieus vertical axis wind turbines (VAWTs) have, however, showed that in some cases the behavior of the rotor performance has been better than a horizontal axis wind turbine in misaligned flow conditions (arrow parallel to the vertical axis of the rotor), though this varies on the design and geometry of the turbine rotor (Mertens, van Kaik, and Van Buelt, 2006a; Simão Ferreira, Van Buelt, and Van Kaik, 2006; Simão Ferreira, Van Buelt, and Van Kaik, 2006).

2. SKEWED WIND FLOW IN BUILT ENVIRONMENT

Diffusion of wind energy technology, in particular, small vertical axis wind turbines can effectively be exploited for on-site power generation in the built environment. Theoretically, small wind turbines can be placed on top of buildings to harness a larger potential of wind energy due to the higher zone of wind profile, which is usually exploited by a large horizontal axis wind turbine (Figure 1). The atmospheric boundary layer is the lowest part of the atmosphere that contains most atmospheric gases and humidity (Panofsky and Dutton, 1984). From a climatological viewpoint, the urban atmosphere has been classified into two general layers, including a roughness sublayer and an inertial sublayer (Rotach et al., 2013). From a climatological viewpoint, the urban atmosphere has been classified into two general layers, including a roughness sublayer and an inertial sublayer (Rotach et al., 2013). These parameters directly affect the wind flow patterns in the respective areas, which alter the wind direction and wind energy. The wind in the internal boundary layer of urban locations is, in fact, different from the classical profile as shown in Figure 1 (Balduzzi, Bianchini, and Ferrari, 2012). This figure shows how buildings as the solid bodies slow the wind near the ground and increase the turbulence in the wind.

The boundary layer separates at the windward edge of the building, and the flow forms a separation bubble on the outer surface below the streamlines above the surface (Mertens et al., 2003b). Approach of a solid obstacle, the separation bubble makes an angle to the velocity vector with the building’s surface as shown in Figure 1(b). This angle is subsequently referred to as the skew angle. The wind is either rising up flow surfaces or toward the building’s surface on building corners or ridges. Several studies have shown that the Darrieus type VAWT’s power output increases while operating in skewed flow condition (Mertens et al., 2003a; Simão Ferreira et al., 2006a). This is due to the possibility of increased swept area based on the cosine angle of the skewed flow. However, further investigations must be carried out to fully understand the effects of skew angle on the performance of a VAWT in skewed wind flow, i.e. airflow profile, geometric ratios, turbine design structure, etc.

The basic expression for power generation by the wind energy devices, which is derived from the kinetic energy equation, is as below:

\[ P = \frac{1}{2} \rho A U^3 C_P \]  

where \( P \) represents the power generation, \( \rho \) is the air density, \( A \) is the turbine geometry, \( U \) is the wind speed, and \( C_P \) is the power coefficient. This coefficient represents the ratio of electricity produced by the wind device to the power available in the wind. However, there are many parameters that affecting a wind turbine aerodynamic characteristics along with the power coefficient. The lift and drag coefficient of an airfoil blade are the major parameters that determine its aerodynamic performance. These parameters vary with every angle of attack (AOA) of the airfoil blade. The AOA is a term used in windmill, as the angle between the chord line and the oncoming wind flow. Lift coefficient, \( CL \) is the factor that contributes to the flow lifting the blade (in positive AOA), whereas the drag coefficient, \( CD \) is used to quantify the drag, i.e. the resistance of an object in the air. These dimensionless units are expressed in the following equations:

\[ C_L = \frac{F_L}{\frac{1}{2} \rho U^2 S} \]  

\[ C_D = \frac{F_D}{\frac{1}{2} \rho U^2 S} \]

where \( F_L \) and \( F_D \) is the lift and drag force respectively. Figure 2 shows the pressure distribution on an airfoil. The ADA of an airfoil controls the distribution of pressure above and below it. An airfoil at positive AOA develops negative pressure on its upper surface and positive pressure below it. The result of this pressure difference creates lift. Whereas, an airfoil at negative AOA develops negative pressure on the upper and lower surfaces of the airfoil, and positive pressure at its leading edge. This leads to the separation of flow at its trailing edge resulting in higher resistance or drag. Aerodynamic performance is a function of lift and drag force. Lift-to-drag ratio is the ratio of lift generated by the airfoil over the aerodynamic drag that it creates while moving through the air. This is mainly due to the fact that the higher lift with lower drag leads to a better performance of wind turbine. Traditionally, wind turbine is tested experimentally to determine the aerodynamic lift and drag at zero AOA and Reynolds numbers. Wind turbine aerodynamic designs have been studied using computational tools with similar Reynolds number and section thickness that are suitable for conditions at the blade tip. However, due to the differences in operating conditions and mechanical loads, special considerations should be made for the design of wind turbine specific profiles and in low Reynolds number regime.

![Diagram showing the wind direction, the definition of rotor axial angle, and position of normal and tangential forces, as well as the relative positions of the rotors (Scherzach and Brown, 2011).](image-url)
In normal flow, the interaction between the wake and the blades in the downwind region suppresses the potential torque due to the turbulent and low-$Re$ flow and the convection of the wake on the loads produced by the blades. Therefore, the improved performance of the VAWT in normal flow is due to the wake convection that covers a larger area in the downstream and upstream regions of the rotor. The effect of skewed wind flows, and the resultant wakes is more significant in the higher $tip$ $speed$ ratios. At lower $tip$ $speed$ ratios, the convection of the wake relative to the motion of the blades is slower than at low $tip$ $speed$ ratios and the convection of the wake to improve the performance of the VAWT in skewed flow is due to the wake convection that covers a larger area in the downstream and upstream regions of the rotor.

In skewed flow, however, the understanding of the blade-to-blade interaction with each of the airfoil blades contributes to the overall increase of the rotor power output. Hence, the skewed flow condition presents a significant impact on the overall performance of the turbine.

Regarding the configuration, a lower height-to-radius (H/R) ratio turbine in a skewed flow has a slightly lower aerodynamic efficiency due to the lower aspect ratio ($AR$) of the blades. This is the fundamental reason for the lower power performance of turbines with small $AR$. From the swept wing theory (Jones, 2014), the vertical component of the oncoming wind that is parallel to the VAWT axis has no aerodynamic effects on the turbine. Therefore, the performance of the turbine in skewed flow is strictly influenced by the cosine angle of the oncoming velocity, with an increased effective $tip$ $speed$ ratio. Findings from the literature showed that the performance of the VAWT in skewed flow conditions could be further improved. However, this depends on the design and geometry of the rotor, and limited range of skew angles. In a skewed air flow, it was shown that the VAWT with the smallest H/R ratio could generate a higher power output than the other turbines with larger H/R ratios, especially in the higher $tip$ $speed$ ratios (Scheurich & Brown, 2011). The effect of skewed wind flows, and the resultant wakes is more significant in the higher $tip$ $speed$ ratio of the turbine. After the vortex filaments are shed by the blades, a coalescence of vorticity in the immediate surroundings of the blades in the downwind cycle was observed (Scheurich, Fletcher, & Brown, 2011). This coalescence enhanced the influence of the wake to improve the performance of the VAWT. A similar region of the oncoming flow in and around the rotor, and in the wake, is influenced by the skewed interaction with the blades of the vertical rotor in skewed flow conditions. In investigating the performance of an H-rotor VAWT in skewed flow conditions, Orlandi et al. (Orlandi, Collu, Zanforlin, & Shires, 2015) developed an unsteady RANS-3D approach to predict the performance of an H-rotor VAWT in skewed flow conditions. The results showed that the power output increased by 30% when the rotor was exposed to 10°-40° skewed angle wind flow. Mertens et al. (Mertens et al., 2003b) had shown that the rotor power output increased by 30% when the rotor was exposed to 10°-40° skewed angle wind flow. Mertens et al. suggested that in skewed flow conditions, the lift and drag forces generated by the airfoil depend only on the orthogonal component of the oncoming wind velocity, whereas the parallel component contributes to the zero effect on the surface of the airfoils. This is known as the cross-flow principle, which describes the wind speed interacting with the blades of the vertical rotor in skewed flow to become a function of both the induction factor of a stream tube and the skew angle. Liu et al. (Liu, Tao, Zhang, and Liu, 2017) investigated the influence of the vertical wind and wind direction on the performance of a small VAWT on the rooftop of a building. Their study showed that the VAWT should be focused on optimization of the struts’ shape and configuration, as the supporting structures can influence the performance of wind turbine rotors, particularly in small wind turbines (Bianchini, Ferrara, and Ferrari, 2015). Airfoil-shaped struts can reduce the parasitic drag commonly found in normal struts and produce additional torque from the vortices shed by the airfoil struts. Some suggest that the airfoil struts in skewed flow conditions can further influence the performance of the wind turbine (Blades, 2015), and Carré, 2008). However, many of the current research work only dealt with the conventional wind turbine in skewed wind flow conditions.

In the urban context, wind turbines operate close to the wakes induced by buildings that may cause skewed flow conditions. In investigating the performance of an H-Darrieus performance on a roof, Mertens et al. (Mertens et al., 2003b) had shown that the rotor power output increased by 30% when the rotor was exposed to 10°-40° skewed angle wind flow. Mertens et al. suggested that in skewed flow conditions, the lift and drag forces generated by the airfoil depend only on the orthogonal component of the oncoming wind velocity, whereas the parallel component contributes to the zero effect on the surface of the airfoils. This is known as the cross-flow principle, which describes the wind speed interacting with the blades of the vertical rotor in skewed flow to become a function of both the induction factor of a stream tube and the skew angle. Liu et al. (Liu, Tao, Zhang, and Liu, 2017) investigated the influence of the vertical wind and wind direction on the performance of a small VAWT on the rooftop of a building. Their study showed that the
vertical wind coming off from the sides of the building greatly influence the power output by up to 60% of the power was gained when the vertical angle is less than or equal to 45°, and when the horizontal wind speed is between 5 m/s and 8 m/s.

Up to now, not many researchers propose a design that specifically for skewed flows. wind flow analysis. Voss et al. (2013) studied the skewed flow, built in the downwind and upwind regions of the turbine. Figure 5 depicts a comparison between the CAWT and conventional wind turbines. According to the experiments, CAWT at 45° deflected flow produced a power coefficient 2.8 times higher than a VAWT.

Table 1: Performance of wind turbines in the skewed flow stream

<table>
<thead>
<tr>
<th>Reference</th>
<th>Turbine Type</th>
<th>Turbine</th>
<th>Battle</th>
<th>Relative power output increased by up to 12% for skewed wind flow. The power output increased by 30% compared to the 0° skew.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polinder, H. (2003)</td>
<td>New design of VAWT called Turby®: skewed angle wind flow.</td>
<td>Turby® VAWT</td>
<td>90%</td>
<td>The interaction between the skewed airflow and the blades of the vertical rotor describe a cylindrical volume, different from the planar surface generated by the horizontal rotor. Therefore, the total swept area of the vertical rotor is increased, mostly due to the contribution of the skewed flow.</td>
</tr>
</tbody>
</table>

There is increasing attention to the performance of wind turbines in skewed wind flow. Normally, the expected flow conditions are parallel to the rotor. Therefore, the interaction between the blades and the oncoming flow volume, the blades of the vertical wind turbine can produce more lift, hence producing higher torque and power output. In Energy Procedia (Vol. 81, pp. 122–132). https://doi.org/10.1016/j.egypro.2015.12.067

The authors acknowledge the financial supports from the Universiti Malaysia Sabah (UMS) Centre for Research and Innovation (PRI) under the research grant scheme (SLBE-1714-2016) and Universiti Kebangsaan Malaysia (UKM) under the Young Researchers Encouragement Grant, UKM (GUP-2017-094).

ACKNOWLEDGEMENT

Refereices


https://doi.org/10.1016/j.apenergy.2017.08.155
ABSTRACT

The Malaysian construction industry is steadily gearing its way towards the adoption of Building Information Modelling (BIM). Subsequently, architects hold a significant role being one of the key players in the industry. Despite rapid development, BIM adoption within the industry is extremely low and only a few organisations are putting it into practice. Previous research has concentrated a broader aspect of BIM in the context of the construction industry holistically, but merely a small number concentrate specifically on local architects having a knowledge gap. Therefore, this paper focused primarily on addressing the minimal BIM adoption amongst architects by exploring its current utilisation, benefits and driving factors as well as awareness. The study was quantitative, whereby a survey was created to study the trends and its current utilisation, benefits and driving factors as well as awareness. Several driving factors were identified relating to people, process, policy and technology which should be addressed in the future of the construction industry in which its potential use will result in greater benefits such as reduced construction delay, cost reduction, smoother project coordination, increased productivity and a better control of design and project coordination, increased productivity and a better control of design and project coordination, increased productivity and a better control of design and project coordination, increased productivity and a better control of design and project coordination, increased productivity and a better control of design.

Keywords: Building Information Modelling, BIM Adoption, Malaysian Architecture Industry

1. INTRODUCTION

The Malaysian construction industry is projected to grow by at least 10.3% for the year 2018. In order to achieve the projected growth rate, the federal government of Malaysia has set the Construction Industry Transformation Plan (CITP) to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the Construction Industry Transformation Plan (CITP) in 2015, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of BIM would transform the local industry into a highly productive and sustainable landscape in line with the strategic Vision 2020. To date, BIM has been associated with a rapid expansion process through numerous initiatives and programmes planned by public and private bodies alike. As stated in the CITP, the Malaysian construction industry is aiming to transform the domestic construction industry and achieve level 2 of BIM maturity by the year 2020. This will be reflected in a minimum of 40% of projects (Gardezi, Shafiq, Nuruddin, Farhan & Umar, 2014). The uptake of
of benefits identified (CIDB, 2017; Zahrizan, Ali, Haron, & Ganesh, 2014). According to the latest national BIM report by CIDB, despite extensive awareness and willingness of construc-
tion players to adopt BIM, the percentage of its adopters are extremely low at 17%. A majority of them are still reporting a low exposure to BIM usage, including the architects, whereby the implementation remains dependent on 2D drafting and the single disciplinary use of 3D modelling (CIDB, 2017). Currently, there is no tangible case study or report highlighting the benefits of BIM adoption so far. Therefore, understanding the benefits of putting it into practice (CIDB, 2017; Ghaffarianhosseini, Tokay, Ghaffarianhosseini, Niasar, Athar, Eltovma, & Ravanmehr, 2017). Although BIM is predominantly enforced by the government, only a few organisations have actively implemented it in their project deliverables. Moreover, some organisations prefer to outsource their BIM works rather than implementing the technology into their own organisation (Mohl-Nor & Grant, 2014). Numerous research have highlighted the potential benefits of BIM as a supplement-
tary tool to support the industrial evolution, but most of the industry players are not ready to move forward, architects included. Hence, it is essential for further empirical studies to ensure that the industry continuously strives to adopt sustainable and innovative construction methods throughout the value chain. This paper aims to address the issues of BIM, continuous emphasis to be placed in specific areas in ensuring that the industry related issues have been distinguished, such as limited inter-operability be-
tween relevant BIM software and the complexities of the software, which lead to ineffective collaboration and workflow (Kensek & Noble, 2014; Rahman, Menon, & Araman, 2014). BIM technology is often alleged to be costly for implementation and deployment (Eastman et al., 2011; Smith & Tarif, 2009; Menon, 2014). Its initial major cost for investment of cost to obtain the technology, as well as due to the additional costs of training and development. Meanwhile, Hohler and Bickel (2014) have stated that the difficulties of collaboration are caused by the expectation for the team to inter-operate and adopt the BIM system. This is difficult to be achieved due to the involvement of a large number of contractors in a project team. In the context of policy, Eastman et al. (2015) have highlighted legal and contractual problems as one of the challenges for BIM implementation, as the current laws and contracts are ambiguous on BIM matters, including the obligations for the entire BIM project duration. Then, Chien, Wu, & Huang (2014) reports that the legal liabilities and procedures relevant to BIM are un-
known in various areas, such as policies, standards, contract, ownership of data-
base management, risks, and allocation of roles and responsibilities. The allocation of rights and roles to the project is ambiguous, it is hard to achieve and ensure smooth project progression, thus imposing greater risks to the project. 2. Benefits of BIM within the Building Project Lifecycle BIM application in the construction industry contributes great benefits to the construction players, as well as facilitating a faster decision-making (Chao, Lee, Lee, Chao, & Nam, 2011). Figure 1 shows that BIM is capable of project managements at different stages namely Schematic De-
sign, Design Development and Construction Stage (Arayici, Coates, Koskela, Krippelou, Urban, & O’Reilly, 2011; Astar, Khalil, & Maqoud, 2015). In order to fully leverage the benefit of BIM, it needs to be implement in all construction stages (Newman, 2013; Weygant, 2011). Numerous benefits can be gained by implementing BIM during the pre-de-
sign stage, such as early visualisation, preliminary cost estimation, integra-
tion with Geographic Information System (GIS) to generate the site existing condition modelling, environmental and building analysis and spatial plan-
ning design (Eastman et al., 2011; Arayici et al., 2011; Astar, Khalil, & Maqoud, 2015; Abdollah, Salaman, Ahmad Latif, & David, 2014). BIM is also beneficial in mitigating risks through reviewing the clashes that occurred, highlighting potential errors and conducting a code and compliance review and supporting building component fabrication. (Eastman et al., 2011; Astar, Khalil, & Maqoud, 2015). Many researches significantly support work processes throughout the whole project lifecycle, which ensures better decision-making, reduction of costs, disputes and time delay. This af-
firms the quality control, minimises the working of the time and resources and working of work tasks (Kenehe & Noble, 2014). In the recent years, efforts have been made to leverage the potential benefits of BIM in supporting the industry’s development. Hence, Table 1 summarize the potential application of BIM in the actual architecture project life cycle ranging from Schematic Design Phase to the Post-Construction Phase.

Table 1: Benefits and Capabilities of BIM

2.2 BIM Adoption Issues in the Malaysian Architecture Industry

The local architecture industry has to face numerous issues in attaining suc-
cesful BIM adoption and emerge progressive, aligning with the construction industry’s initiatives and requirements. Several studies have highlighted the low rate of BIM adoption and architect awareness (CIDB, 2017; Mohd-Nor & Grant, 2014). Such considerably low uptake underscores the significance of BIM dissemination within the architectural landscape in understanding its characters. Currently, BIM adoption is hindered by several factors that is com-
prised of four core components namely people, process, policy and technol-
ygy. These factors have been identified as the potential causes of low adoption rate amongst architects (CIDB, 2017; NBS, 2017; Eastman et al., 2012; Smith & Tarif, 2009). In the context of the people, the salient factors encountered is the shortage of skilled and knowledgeable BIM workforce in construction or-
anisation (Zahrizan et al., 2014). This is attributable to the difficulties of the learning curve, especially for those completely unfamiliar with BIM, while resistant to change driven to its complexity and high monetary investments required. Inexperienced users may inadvertently change the content of the data, thus imposing risks to a project. In addition, many managers and organisational leaders lack the knowledge on adopting BIM in their respective organisations (Zahrizan et al., 2014). Moreover, the fragmented nature of construction projects contributes towards BIM resist-
ance among the project collaborators (Sanakuar & Gao, 2014). BIM demand changes in organisation’s working process whereby an integrated BIM model development requires efficient communication and greater collabora-
tive-efforts across multiple disciplines. Therefore, consented mutual protocols and standard procedures are required to initiate the BIM assignment and execute design reviews and validation (Kenehe & Noble, 2014). According to Eastman et al. (2011), the standard and guideline are still not well defined in the current practice which is a major hindrance to the implementation of BIM model exchange. Subsequently, CIDB has raised concerns regarding the need to develop national BIM standards and guidelines to manage workflow and adop-
tion (CIDB, 2017), however, many have overlooked the element of training (construction’s training) to be mandatory for government construction parties, as well as facilitating a faster decision-making (Cho, Lee, Lee, Chao, & Nam, 2011). Figure 1 shows that BIM is capable of project managements at different stages namely Schematic De-
sign, Design Development and Construction Stage (Arayici, Coates, Koskela, Krippelou, Urban, & O’Reilly, 2011; Astar, Khalil, & Maqoud, 2015). In order to fully leverage the benefit of BIM, it needs to be implement in all construction stages (Newman, 2013; Weygant, 2011).
3.3 Construction Phasing and Simulation

Kim, Anderson, Lee, & Hilfert. (2013) have stated that one of the important features of BIM is its ability to compute automated construction scheduling, work task distribution, duration of activity based on the production rates and the sequencing rules. These activities can be shared and extracted from an open data environment using various data exchange formats. This comprehensive 4D BIM data benefits the holistic manufacturing process, which includes material ordering, in-house logistics, packaging, stockage, and transportation to the construction site. With a streamlined data, a close coordination during the construction value chain is possible and may eventually impact greatly in terms of time and cost (Li & Yang, 2017).

3.3.1 Quantity Take-off and Cost Estimation

Eastman et al. (2011) have demonstrated the application of BIM in the estimation process of buildings for refurbishment and renovation. Utilising both technologies greatly benefits the designers in obtaining accurate data during the initiation of the preliminary design. Point cloud utilisation can produce an accurate and reliable documentation of buildings for refurbishment and conservation works. In a study by Dore & Murphy (2012), a Heritage-BIM model has been developed involving a 3D modelling stage. The 3D model simulation into a 3D GIS has allowed further building documentation management and analysis.

3.3.2 Construction Phasing and Simulation

BIM can also be used with its ability to produce constructability analysis via clash detection activities during the pre-construction stage. Zhang, Long, Lv, & Xiang (2016) observed made use of a case study regarding construction clash detection activities and noted increased constructability and reproduction issues happening on-site during the fabrication process. This has been used as a prime building component in designing a virtual construction environment. Through clash detection, the manufacturer has also obtained a comprehensive support on the design integration, fabrication, construction, and up to the operation and maintenance processes.

3.3.3 Construction Phasing and Simulation

Kim, Anderson, Lee, & Hilfert. (2013) have stated that one of the important features of BIM is its ability to compute automated construction scheduling, work task distribution, duration of activity based on the production rates and the sequencing rules. These activities can be shared and extracted from an open data environment using various data exchange formats. This comprehensive 4D BIM data benefits the holistic manufacturing process, which includes material ordering, in-house logistics, packaging, stockage, and transportation to the construction site. With a streamlined data, a close coordination during the construction value chain is possible and may eventually impact greatly in terms of time and cost (Li & Yang, 2017).

3.3.1 Quantity Take-off and Cost Estimation

Eastman et al. (2011) have demonstrated the application of BIM in the estimation process of buildings for refurbishment and renovation. Utilising both technologies greatly benefits the designers in obtaining accurate data during the initiation of the preliminary design. Point cloud utilisation can produce an accurate and reliable documentation of buildings for refurbishment and conservation works. In a study by Dore & Murphy (2012), a Heritage-BIM model has been developed involving a 3D modelling stage. The 3D model simulation into a 3D GIS has allowed further building documentation management and analysis.

3.3.2 Construction Phasing and Simulation

BIM can also be used with its ability to produce constructability analysis via clash detection activities during the pre-construction stage. Zhang, Long, Lv, & Xiang (2016) observed made use of a case study regarding construction clash detection activities and noted increased constructability and reproduction issues happening on-site during the fabrication process. This has been used as a prime building component in designing a virtual construction environment. Through clash detection, the manufacturer has also obtained a comprehensive support on the design integration, fabrication, construction, and up to the operation and maintenance processes.

3.3.3 Construction Phasing and Simulation

Kim, Anderson, Lee, & Hilfert. (2013) have stated that one of the important features of BIM is its ability to compute automated construction scheduling, work task distribution, duration of activity based on the production rates and the sequencing rules. These activities can be shared and extracted from an open data environment using various data exchange formats. This comprehensive 4D BIM data benefits the holistic manufacturing process, which includes material ordering, in-house logistics, packaging, stockage, and transportation to the construction site. With a streamlined data, a close coordination during the construction value chain is possible and may eventually impact greatly in terms of time and cost (Li & Yang, 2017).

3.3.1 Quantity Take-off and Cost Estimation

Eastman et al. (2011) have demonstrated the application of BIM in the estimation process of buildings for refurbishment and renovation. Utilising both technologies greatly benefits the designers in obtaining accurate data during the initiation of the preliminary design. Point cloud utilisation can produce an accurate and reliable documentation of buildings for refurbishment and conservation works. In a study by Dore & Murphy (2012), a Heritage-BIM model has been developed involving a 3D modelling stage. The 3D model simulation into a 3D GIS has allowed further building documentation management and analysis.

3.3.2 Construction Phasing and Simulation

BIM can also be used with its ability to produce constructability analysis via clash detection activities during the pre-construction stage. Zhang, Long, Lv, & Xiang (2016) observed made use of a case study regarding construction clash detection activities and noted increased constructability and reproduction issues happening on-site during the fabrication process. This has been used as a prime building component in designing a virtual construction environment. Through clash detection, the manufacturer has also obtained a comprehensive support on the design integration, fabrication, construction, and up to the operation and maintenance processes.

3.3.3 Construction Phasing and Simulation

Kim, Anderson, Lee, & Hilfert. (2013) have stated that one of the important features of BIM is its ability to compute automated construction scheduling, work task distribution, duration of activity based on the production rates and the sequencing rules. These activities can be shared and extracted from an open data environment using various data exchange formats. This comprehensive 4D BIM data benefits the holistic manufacturing process, which includes material ordering, in-house logistics, packaging, stockage, and transportation to the construction site. With a streamlined data, a close coordination during the construction value chain is possible and may eventually impact greatly in terms of time and cost (Li & Yang, 2017).

3.3.1 Quantity Take-off and Cost Estimation

Eastman et al. (2011) have demonstrated the application of BIM in the estimation process of buildings for refurbishment and renovation. Utilising both technologies greatly benefits the designers in obtaining accurate data during the initiation of the preliminary design. Point cloud utilisation can produce an accurate and reliable documentation of buildings for refurbishment and conservation works. In a study by Dore & Murphy (2012), a Heritage-BIM model has been developed involving a 3D modelling stage. The 3D model simulation into a 3D GIS has allowed further building documentation management and analysis.

3.3.2 Construction Phasing and Simulation

BIM can also be used with its ability to produce constructability analysis via clash detection activities during the pre-construction stage. Zhang, Long, Lv, & Xiang (2016) observed made use of a case study regarding construction clash detection activities and noted increased constructability and reproduction issues happening on-site during the fabrication process. This has been used as a prime building component in designing a virtual construction environment. Through clash detection, the manufacturer has also obtained a comprehensive support on the design integration, fabrication, construction, and up to the operation and maintenance processes.
BIM was comparatively fresh in the industry. The majority group lacked BIM experience, they remained to be relatively aware. 6.5% of the lowest group had more than 5 years of BIM experience. Although Table 3 shows that a majority of the respondents at 45.4% had no BIM work- experience, 40.4% had less than 2 years. The respondents in this question showed that the percentage of BIM users among the larger firms was higher (35%) than the medium firms (31%) and smaller firms (16%), accordingly this results was consistent with BIM reports conducted in the United Kingdom (UK) and Australia, whereby such trend-strengthened the claim that larger firms were more capable and willing to invest in BIM technology (NIB, 2017; Rodgers, 2019). Meanwhile, most of the small to medium firms did not use BIM in their practice (54.6%). As highlighted in Construction (2014), large firms had an added advantage to adopt BIM due to the high level of resources and expertise they possessed. In contrast, projects delivered by Small and Medium-Sized Enterprise (SME) firms might take better advantage of BIM than large-size projects (Ayati, 2014).

4.2 BIM Benefits and Capacities from the Architect’s Perspective

The research further studied the level of BIM awareness from the perspective of an architect, whereby the Cronbach’s alpha obtained for the set of inventory scale was highly reliable (0.901). Furthermore, the variables obtained from the secondary data were grouped into three (3) main stages of design project namely the Schematic Design (SD), Design Development (DD), and Construction Stages (CS). The respondents were requested to rate the scale of importance from 5 to the most important to 1 as the least important. The results are shown in Table 5 below.

Table 6: Company Size and BIM Usage

<table>
<thead>
<tr>
<th>Company Size</th>
<th>BIM Usage in Firm</th>
<th>Yes</th>
<th>No</th>
<th>Outsourced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 10 persons</td>
<td>7</td>
<td>19</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>10 - 30 persons</td>
<td>3</td>
<td>13</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>Above 50 persons</td>
<td>2</td>
<td>28</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td>52</td>
<td>7</td>
<td>78</td>
</tr>
</tbody>
</table>

Overall, the design development stage (DD) displayed the highest degree of importance compared to other stages. Ranked in first, the majority of respondents highly agreed that the most important BIM benefits was its ability to produce integrated 2D and 3D drawings (M: 4.46; SD: 0.79). Secondly, the respondents were highly aware that apart from the production tools, it also provided an information platform for better communication within the project team (M: 4.44; SD: 0.78). They also highly agreed that BIM required a high level of involvement between the stakeholders in a project team (M: 4.43; SD: 0.75). Meanwhile, in the context of the schematic stage, the respondents were highly aware that BIM model could be utilised to detect any information platform for better communication within the project team (M: 4.44; SD: 0.78). They also highly agreed that BIM required a high level of involvement between the stakeholders in a project team (M: 4.43; SD: 0.75). Meanwhile, in the context of the schematic stage, the respondents were highly aware that BIM model could be utilised to detect any clashes between various disciplines (M: 4.35; SD: 0.91). In the construction stage (CS), the respondents highly agreed that the most important BIM benefits was its ability to conduct complex building structural analysis (M: 4.28; SD: 0.88). The areas with the least degree of importance were identified as 1) the use of BIM for code and compliance review (M: 3.29; SD: 1.23) and 2) the point of cloud and laser scanning to produce accurate site condition modelling (M: 3.18; SD: 1.20). Meanwhile, the integration of BIM and GIS to produce accurate physical and non-physical representations of site conditions (M: 3.06; SD: 1.33). The architect’s awareness placed more emphasis on the benefits within the schematic and design development. Additionally, the construction stage (CS) displayed the most consistency of somewhat to moderate awareness, whereas all of its variables were within the intermediate ranking of 3 to 18 and most were below M: 4.00.

Table 5: Benefits of BIM Implementation

BIM organisational readiness can be expressed as the level of preparation, participation and capability to innovate (Saucier & Kasowo, 2015). The study further investigates the tendency of an organisation to adopt BIM. Figure 2 shows that the majority of organisations were generally positive towards adopting BIM at 59.8% of them were currently investing in BIM training and development within their organisation. Meanwhile, 66.2% had shown their readiness and driving factors.
The survey further identified the most impactful BIM improvements. As future of construction project management, with 96.3% representation, respondents also revealed significant confidence for BIM to further impact the readiness to adopt BIM by investing in BIM software and hardware. All respondents agreed regarding the need to establish relevant policies and incentives to support the change of processes in an organization for adopting BIM. In the context of policy, the respondents' agreed regarding the need to establish relevant policies and incentives to promote BIM (M=4.43, SD=0.78), as well as developing a standard legal or contractual agreement relating to BIM (M=4.25, SD=0.82). Several technology factors were also identified especially to address the technical complexity of BIM such as to standardize the open BIM standard for efficient interoperability (M=4.31, SD=0.79) and to establish a BIM technical group to resolve any BIM complexities (M=4.29, SD=0.78).

Table 6: Driving Factors of BIM Adoption

<table>
<thead>
<tr>
<th>Factors</th>
<th>Mean (M)</th>
<th>Standard Deviation (SD)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>People</td>
<td>4.26</td>
<td>0.836</td>
<td>11</td>
</tr>
<tr>
<td>Technology</td>
<td>4.48</td>
<td>0.767</td>
<td>2</td>
</tr>
<tr>
<td>People</td>
<td>4.34</td>
<td>0.788</td>
<td>7</td>
</tr>
<tr>
<td>People</td>
<td>4.51</td>
<td>0.704</td>
<td>1</td>
</tr>
<tr>
<td>People</td>
<td>4.61</td>
<td>0.708</td>
<td>4</td>
</tr>
<tr>
<td>Policy</td>
<td>4.45</td>
<td>0.726</td>
<td>3</td>
</tr>
<tr>
<td>People</td>
<td>4.42</td>
<td>0.822</td>
<td>12</td>
</tr>
<tr>
<td>Process</td>
<td>4.43</td>
<td>0.708</td>
<td>5</td>
</tr>
<tr>
<td>People</td>
<td>4.43</td>
<td>0.726</td>
<td>3</td>
</tr>
<tr>
<td>Process</td>
<td>4.25</td>
<td>0.822</td>
<td>12</td>
</tr>
<tr>
<td>People</td>
<td>4.38</td>
<td>0.817</td>
<td>6</td>
</tr>
<tr>
<td>Process</td>
<td>4.38</td>
<td>0.817</td>
<td>6</td>
</tr>
<tr>
<td>Technology</td>
<td>4.38</td>
<td>0.817</td>
<td>6</td>
</tr>
<tr>
<td>Technology</td>
<td>4.39</td>
<td>0.788</td>
<td>9</td>
</tr>
<tr>
<td>Technology</td>
<td>4.39</td>
<td>0.817</td>
<td>6</td>
</tr>
<tr>
<td>Technology</td>
<td>4.31</td>
<td>0.719</td>
<td>8</td>
</tr>
</tbody>
</table>

5.1 BIM Usage and Awareness from the Architect's Perspectives

The results show positive signs of BIM awareness by architects, as more than 80% of the respondents were aware of BIM and its capabilities. However, the level of BIM usage was still as low as only 17.4% of the architects had more than 2 years of experience working with BIM. The rate was significantly increased from the previous study conducted, whereby less than 50% of the construction players were aware of BIM (CIDB, 2017). The results show that 45.4% of the firms had the tendency to adopt BIM, but the practice, but the amount of BIM projects executed by these firms was still low at the capacity of below 20%. This clearly indicates that the BIM trend among architects has yet to reach the stage of a large scale project delivery by the overall construction industry (CIDB, 2017; Mohd-Noor & Grant, 2014). Furthermore, the findings identified the larger firms to relatively move prone towards using BIM as compared to SME firms. Therefore, it is an opportunity for SMEs to provide relevant BIM projects delivered by SME firms might take advantage of BIM as compared to large scale projects (CRIAM, 2014; Arayici et al., 2011). Besides, a majority of the respondents were collectively aware regarding the capability and the technical aspects of BIM. In the schematic design stage, key findings show that most respondents scored the lowest mean values on the technical aspects, such as the use of point cloud and 3D laser scanning technology, supporting existing condition modelling, and the integration of BIM and GIS technology. In many instances, the benefits of GIS especially in design and planning or organisations were perceived by an individual as a threat and an opportunity to enhance BIM education. Therefore there is a need to provide exposure to the archi-
BIM report that reported over 60% of companies within the industry were unwilling, unable, or uninterested in adopting BIM, as well as invest in BIM trains and assets (CIDB, 2017). As the implementation of BIM requires change to the organisational values and culture, the findings clearly showed the readiness and adoption within the industry. The study further identified the salient driving factors to be imposed for proposing the use of BIM within the industry. The people factor had the highest consistencies of agreement, whereby among the key highlights is the need to increase the overall awareness, and support the role of architectural professional bodies to play a leading role and support the development of BIM adoption within the industry. This has been highlighted by Rashed et al. (2013), claiming the lack of initiative and the role and influence of clients. Several studies have revealed that the adoption rate of BIM requires change to the organisational values and culture, the findings clearly show positive signs of future BIM adoption within the industry. Therefore, governmental and professional bodies (e.g. PAM and LAM) may organise a series of awareness and motivation programmes, to the education aspect, numerous research have highlighted the importance of having a structured BIM courses at the level of tertiary education (Rogers, Chen, & Prezuz, 2015; Haron, Soh, Ana, & Harun, 2017). Institutions of higher learning throughout Malaysia are encouraged to incorporate BIM courses in their syllabus to allow their graduates to understand BIM technology as a preparation to meet the challenging demands of the industry. In addition, the trend of low BIM usage by architects can be changed through the role and influence of clients. Several studies have revealed that the adoption rate by clients or developers is at the lowest amongst the construction players. The lack of demand is due to the reluctance to change, fear of increased work process and flow of an organisation. Thus, the previous subsidies to attain BIM was highlighted by the respondents to promote the use of BIM technology.

6. CONCLUSION

Despite the rapid development to harness the benefits of BIM as a means of sustainable project delivery in the construction industry, the current adop-
tion rate by Malaysian architects and engineers is at the lowest level of awareness was the potential of adoption between BIM with GIS, as well as for building code compliance and review. In contradic-
tory with previous studies in the construction industry, most of the architects believed that BIM would impact the future of design project management and subsequently initiate their commitment towards adopting BIM. Several driving forces were highlighted as the factors that would support the adoption of BIM in the industry. The low BIM uptake, revealed underscores the signi-
ificance of BIM diffusion within architectural organisations to further un-
derstand the barriers and drivers of BIM. The study provided further insight and findings regarding the adoption of BIM, which serves as a reference point for local architects to assess the changes and effects that are crucial in determining the progress of BIM in Malaysia. Finally, several limitations need to be acknowledged, specifically, time constraints and sample size, which may lead to concerns on generalisation of the research findings.

ACKNOWLEDGEMENT

Part of this paper was published in the proceedings of the 2nd Malaysia Un-
iversity-Industry Building Collaboration Symposium (MU-BIC 2018) on 8th May 2018 in Bangi, Selangor. Special thanks to the reviewers for their invaluable comments and much gratitude to the survey participants who had contributed their valuable input and time in completing the survey.

REFERENCES

Sustainable buildings are becoming a focus nowadays because they are cost-effective and affect our society and environment. Hospitals, which are categorized as commercial buildings, also aim to become sustainable. Sustainable hospitals hope to provide health facilities to humankind while reducing their greenhouse gas emissions to the environment. In terms of energy consumption, hospitals consume much electricity because of their non-stop operation 24 hours a day. This high electricity consumption leads to high electricity costs and adversely affects the environment. This study examines the electricity usage of a public hospital near Kuala Lumpur, Malaysia, through a preliminary energy audit. Energy conservation measures (ECMs) are recommended to the hospital to reduce its electricity consumption. The recommended ECMs, namely, unplugging or awareness campaign, replacement of existing personal computers with laptops and regular maintenance and replacement of refrigerators, are expected to achieve a total electricity saving, cost saving and CO2 emission reduction of 429,743.39 kWh/year, RM 152,127.57/year and 295, respectively.

Keywords: Energy Efficiency, Hospital, Sustainable Building

1. INTRODUCTION

In 2015, the overall electricity consumption of Malaysia was 132,199 GWh, from which industrial, commercial, residential, transport and agricultural sectors accounted for 45.9%, 32.2%, 21.4%, 0.2% and 0.4%, respectively [Suruhanjaya Tenaga (Malaysian Energy Comission), 2015]. The electricity in Malaysia is mainly supplied by power stations, and reports have shown that limited non-renewable energy sources, such as coal (47.2%), natural gas (4.9%), hydro-power (10.8%), diesel (8.0%) and fuel oil (0.3%), are projected to provide a total of 33,134 ktoe of energy to power stations in 2015 [Suruhanjaya Tenaga (Malaysian Energy Comission), 2015]. The commercial sector, especially buildings, is responsible for 29.2% of the total electricity consumption [Suruhanjaya Tenaga (Malaysian Energy Comission), 2015]. Therefore, commercial buildings are contributors to the country’s greenhouse gas emissions, which is projected to decrease by 23% and 30% in 2020 and 2030, respectively, relative to 2005 levels (Sion et al., 2013). Malaysia is concerned about the energy crisis and the important factor in achieving Malaysia’s target of reducing 40% of its carbon emission by 2020 whilst saving energy and costs; this importance has been proven by the construction of the Low Energy Office (LEO), Green Tech Malaysia Building and Diamond Building (Hamid et al., 2016; Sion et al., 2013).
Malaysia has been supporting energy-saving efforts through the Ministry of Energy, Green Technology and Water as the ministry aims to achieve considerable development in the building sector by adopting green technology in the construction, management, conservation and abolishment of buildings (Sektor Utama Daras Teknologi Hijau Negara, 2016). Additionally, other government agencies, such as Malaysia Green Tech Corporation (Who We Are - Green Technology Malaysia, 2016), Yayasan Hijau MY (Yayasan Hijau Malaysia (Yay Hijau), 2018), Energy Commission (National Energy Efficiency Action Plan, 2014), ‘Roles and Functions’, 2015 and Sustainable Energy Development Authority (SEDA) (‘Overview of SEDA’, 2018), strive to promote energy efficiency through their roles and projects. Meanwhile, non-governmental organizations (NGOs), such as Malaysia Green Building Confederation (MBGC), are promoting sustainable buildings (Hamerd et al., 2016).

1.2 Studies on the Energy Efficiency of Hospital Buildings

Commercial buildings, such as hospitals, have elicited the attention of researchers worldwide. Various energy efficiency strategies must be implemented in hospital buildings because they operate 24 hours a day, leading to high energy consumption (Table 1). These strategies may be in the form of engineering approaches (Karli, 2011), such as improvement of heating, ventilation and air-conditioning (HVAC) systems, the building envelope, electrical usage, central heating, cooling equipment, energy management control, compressed air, thermal energy storage (TES), charging/discharging of TES, cooperation, heat recovery and water management. Other strategies may involve financial schemes or policies/regulations (Yong and Hor, 2017).

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>ECMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>United States</td>
<td>- Building management regulations and programs to promote energy saving practices, - Shifting the electricity usage from peak time to off-peak time</td>
</tr>
<tr>
<td>2016</td>
<td>Italy</td>
<td>- Innovative financial strategies by providing capital investments respectively.</td>
</tr>
<tr>
<td>2016</td>
<td>Italy</td>
<td>- To improve indoor air quality in the radiology suite.</td>
</tr>
<tr>
<td>2016</td>
<td>Egypt</td>
<td>- Implementing a programme to recycle the packaging of hibernating machines at a certain times each day. - Install motion sensor to switch off lighting in the radiology suite.</td>
</tr>
<tr>
<td>2016</td>
<td>Egypt</td>
<td>- In the radiology department: suggest to upgrade the lightings and computers after work-hour.</td>
</tr>
<tr>
<td>2016</td>
<td>Egypt</td>
<td>- Adopt radiators thermostatic valves and AHU to improve indoor air quality.</td>
</tr>
<tr>
<td>2016</td>
<td>Hungary, Slovenia, Austria</td>
<td>- Implementing web-based online control system and improving the control system.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Use variable speed drive.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Use high-efficiency motors.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Use high-efficiency condenser coils.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Implementing a programme to recycle the packaging of hibernating machines at a certain times each day. - Install motion sensor to switch off lighting in the radiology suite.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- In the radiology department: suggest to upgrade the lightings and computers after work-hour.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Adopt radiators thermostatic valves and AHU to improve indoor air quality.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Implementing web-based online control system and improving the control system.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Use variable speed drive.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Use high-efficiency motors.</td>
</tr>
<tr>
<td>2016</td>
<td>Iran</td>
<td>- Use high-efficiency condenser coils.</td>
</tr>
</tbody>
</table>

In this study, a public hospital near Kuala Lumpur, Malaysia, was selected as the study case. The criteria of the selected hospital as the study case is based on the electricity consumption which is more than 1,000,000 kWh per month for six consecutive months based on the Efficient Management of Electrical Energy Regulation 2008 (EMEER 2008) enforced by the Energy Commission (Sumber Daya Tenaga (Malaysia Energy Commission), 2008). The hospital operates 24 hours a day (24/7) and consumes large amounts of electricity. The hospital’s bills showed that the hospital consumed 4,000,000 kWh per month of electricity and spent about RM 1.5 million monthly (from 2015 to 2017) on electricity. The electricity usage of the hospital was assessed through a preliminary energy audit in this study. This study highlighted the electricity-saving potential that can be obtained from the use of electrical equipment in various departments of the hospital. The research framework design, which includes the research objectives, data collection methodology, data analysis and research outcomes, is shown in Figure 1. Moreover, this section also describes the flow of data collection through a walk through energy audit, which is the process of energy audit and formulation used to calculate electricity consumption.

2.2 Electricity Consumption Formulation

To analyse the collected data, the formulation for electricity consumption was calculated. Suitable energy conservation measures were developed from the results.

The measurement of total electricity consumption was performed by using build load data collected through desktop and field collection methods. It is the summation of the electricity consumption of all equipment, which are assumed to operate in full capacity. Equation [1] shows the calculation of electricity consumption for each type of equipment (Saidit, Hasebawaran, Yogeswaran, Yogeewaran, Mohammed, and Hossain, 2010). In the equation, E is electricity consumption (kWh), P is the power rating of the equipment, M is operation hour and Neq is number of equipment. Moreover, the reading only covered working days, and we assumed that the total daily electricity consumption was similar throughout a year with only 260 days (52 weeks × 5 days).

$$ E = P \times M \times Neq $$

2.3 Data Collection: Walk-through Energy Audit

Based on the ‘Electrical Energy Audit Guideline for Buildings’ by the Energy Commission of Malaysia (Energy Commission, 2016), an energy audit was conducted to collect information on the equipment used in the hospital. Figure 2 shows the forecast of the audit.
3. RESULTS AND DISCUSSION

3.1 Electricity Consumption

The equipment that were audited in the walk-through audit were categorised into five groups: office equipment, medical equipment, electrical appliances, refrigerators and kitchen stools. In total, the total number of active and operating appliances (assets and non-assets) in the hospital was 3422 units.

Medical equipment had the highest electricity consumption throughout the year, as seen in Figure 3 (3) of the hospital’s total electricity cost, which was 11,255,203.45 kWh/year. The second highest was radiology equipment, medical equipment, psychology department, and nursing area and operation theatre complex consumed the largest amount of electricity on the basement floor, first floor and second floor, respectively.

3.2 Electricity Cost

The electricity usage was calculated based on the utility bills by Tenaga Nasional Berhad (TNB) Tariff C2-medium voltage peak/off-peak commercial tariff (Commercial tariffs, 2016). All kWs during peak and off-peak periods were calculated regardless the fact that each kW of maximum demand per month during the peak period and the off-peak period was considered. The cost of electricity was calculated by multiplying the total electricity consumption with the rate 10.5365 RM/kWh. For the period of the audit, the total electricity cost for electrical equipment in the hospital was determined to be RM 3,300,467.64/year. The electricity cost depended heavily on the electricity usage of the building.

4. ENERGY CONSERVATION MEASURES

Most of the audited floors showed similar result patterns. Medical equipment had the highest electricity consumption throughout the year, with 92.45% (Figure 3) of the hospital’s total electricity consumption, which was 11,255,203.45 kWh/year.

4.1 ECM #1: Unplugging/Awareness Campaign

A low-cost ECM that can be implemented for energy saving is to conduct a basic energy awareness activity within the centre and clinics in the building. The programme focuses on the cost savings and environmental issues associated with energy use. Information can be disseminated through websites or newsletters. This method is cost-effective and can be implemented on a regular basis.

4.2 ECM #2: Replacement of Existing Personal Computers with Laptops

We recommend an active ECM, i.e., replacing computers with laptops, under the assumption that the lifespan and investment/cost of renting computers and laptops are considered. Laptops are known to consume less electricity. For example, our calculation indicated that replacement with 319 laptops on first floor will consume about 14,852.32 kWh/year compared with the energy usage of personal computers, which is 15,386.80 kWh/year. This figure shows that 9% of electricity (132,968 kWh/year) can be saved from the replacement of existing personal computers by laptops. In terms of cost, RM 45,248.32 (1.16%) can be reduced annually from the total electricity cost in the hospital.

4.3 ECM #3: Regular Maintenance

The working conditions of equipment play a major role in their efficiency and energy consumption. Periodic maintenance of electrical equipment is important for these equipment to operate at the optimum level. Multi-functioning appliances are common in service departments and repair areas. Maintenance and repair of sub-par electrical equipment should be conducted immediately to minimise unnecessary losses. Energy savings can reach up to 7-10% if preventive and corrective maintenance are conducted for appliances relative to not conducting such maintenance (Koo and Hoy, 2003). Meanwhile, an additional maintenance cost will incur if this maintenance is conducted because this is an active ECM. We assume that 5% of the maintenance cost is from electrical consumption; hence, we can still achieve 2% cost saving each year. As a result, 22,104,094 kWh/year of electricity can be saved, which is equal to RM 8,162,992/year.

4.4 ECM #4: Refrigerator Replacement

During the walk-through energy audit, we found very old models of refrigerators without any energy-efficient star rating in various departments and clinics. Medical storage and general use (as in pantry) purposes were found on the ground floor, and they operate 24 hours a day for 365 days a year. The old models of refrigerators were found on the ground floor, and they operate 24 hours a day for 365 days a year. The old models of refrigerators are 20 years old, and doing so could save up to 20% of energy (5-Star Energy Appliances: How Much Can You Roughly Save Annually?, 2016). Refrigerators that are still in good condition need not be replaced immediately. Replacing refrigerators once they malfunction is virtually a cost-free strategy. As a result, energy savings can reach up to 7% if preventive and corrective maintenance are conducted for appliances relative to not conducting such maintenance (Koo and Hoy, 2003). A low-cost ECM that can be implemented for energy saving is to conduct a basic energy awareness activity within the centre and clinics in the building. The programme focuses on the cost savings and environmental issues associated with energy use. Information can be disseminated through websites or newsletters. This method is cost-effective and can be implemented on a regular basis.
The recommended ECMs.

<table>
<thead>
<tr>
<th>ECM</th>
<th>Electricity saving (kWh/year)</th>
<th>Cost saving (RM/year)</th>
<th>CO2 emission reduction (kg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECM #1</td>
<td>225,104.07</td>
<td>45,248.32</td>
<td>85.71</td>
</tr>
<tr>
<td>ECM #2</td>
<td>123,968.00</td>
<td>24,630.55</td>
<td>45.72</td>
</tr>
<tr>
<td>ECM #3</td>
<td>234.81</td>
<td>22.50</td>
<td>55.71</td>
</tr>
<tr>
<td>ECM #4</td>
<td>10,466.51</td>
<td>2,000.32</td>
<td>55.71</td>
</tr>
</tbody>
</table>

4. CONCLUSION

Four ECMs were recommended based on the recognised energy-saving potential of a public hospital near Kuala Lumpur, Malaysia. The total electricity consumption of the hospital is 11,255,203.45 kWh/year. This value is expected to decrease by 3.82% per year (equal to RM 152,127.57/year of cost saving) if the recommended ECMs are implemented, which results in a 3.82% reduction of electricity consumption, electricity cost and CO2 emission.

ACKNOWLEDGEMENT

We acknowledge the financial support provided by Universiti Ke- bangsaan Malaysia (grant number TD-2016-011).

REFERENCES


Thermal comfort is an important factor to ensure good thermal condition of a house. To understand the current indoor thermal situation of a typical low-cost single story detached house in Malaysia, several parameters of thermal comfort need to be measured. The main objective of this study is to analyse the indoor thermal condition of a low-cost single story detached house through measurement of the indoor air temperature. The methodology applied in this study was field measurement to validate the IESVE simulation model of a low-cost single story detached house of a rural area, located in Kuala Pilah. Field measurement was done under two different conditions: (i) windows and door closed and (ii) windows and door opened. Air temperature, air velocity, and relative humidity data were collected using thermal comfort meters and a weather station. The data were used to validate the model generated using the IESVE simulation software. Therefore, the objectives of this paper are to find out the statistical significance between the variables and to initiate passive design strategies using IESVE-softwares to make indoor thermal condition more comfortable. Statistical analysis revealed that indoor air temperature (Ta) is statistically significant with time but not with the conditions. In opposition, air velocity (Va) is correlated with the conditions but not with indoor air temperature and time. Afterward, the window sizes were enlarged, and roof insulation was added to the simulation model to observe the temperature changes. Results show that in both cases, the temperature reduced to some extent but was not satisfactory nor in the recommended indoor air temperature range. Therefore, more careful deliberation is needed to design the layout for the low-cost detached houses. Using roof insulation material is also important to improve the indoor thermal condition of the low-cost single story detached houses in Malaysia.

**Key words:** Indoor air temperature, low-cost single story detached house, thermal condition, IESVE-simulation.

## 1. INTRODUCTION

Low-cost housing had been a minor category of housing for both government and private sectors of housing in the early period of Malaysia. However, during the 7th Malaysian plan (Economic Planning Unit, 1996), 8th Malaysian plan (E. M. Plan, 2001; Unit, 2001) and 9th Malaysian plan (Baharuddin et al., 2013; N. M. Plan, 2008; Zaid and Graham, 2010), the government paid attention towards low-cost and low-medium-cost houses under the affordable housing category (Cagamos Holdings Berhad, 2013). In recent days, housing rules are being executed for masses of people and their development. The Malaysian government is trying to create an easy pathway for providing affordable housing for its people.

Besides, the climatic condition of Malaysia has a direct impact on the indoor thermal condition of a house. According to the Malaysian Meteorological Department, the daytime minimum and maximum temperature ranges are 25 °C to 27 °C and 30 °C to 34 °C respectively. The windows, roof surfaces of a house gain direct heat from solar radiation (Al-tammim, Fuarez, and Fadlul, 2011; Al-Tamim and Syed Fadlul, 2011; Datta, 2011). The relative humidity also remains very high, which is nearly 75% with heavy rainfall (Tinker, Ibrahim, and Ghani, 2004).

Thermal comfort issues have always been one of the most discussed topics for architects and acclimatologists of tropical countries. As stated in MS 1525:2017, 23 °C to 26 °C is the recommended indoor air temperature range for the Malay conditions (Deaton et al., 2017). Furthermore, many researchers indicated the range of 23 °C to 28 °C as the recommended indoor air temperature for Malaysia (Hanafi, 2014; Healing, Reformation, Engineers, and Institute, 2004; Ibrahim, 2004; Madros, 1998; Zain-Adam, Asryf, and Ishman, 1997).

Henceforth, different experiments and studies were done for different categories of houses to determine the recommended indoor air temperature. An experiment by Jamaludin and Iruma (2015) revealed that under Kuala Lumpur’s tropical environment, the temperature was 32.6 °C. But in Kuching and Bayan Lepas, 31.1 °C and 31.6 °C were recorded respectively (Jamaludin & Iruma, 2015). For terrace houses, many researchers found that 23 °C to 28 °C could be the comfort range under the Malaysian climate (Jamaludin & Iruma, 2015; Zain, Tab, & Baki, 2007).

**1.1 The recent scenario of low-cost houses in Malaysia**

In Malaysia, the quality of low-cost housing has not been upgraded as compared to other categories of housing. One of the reasons for the difficulties faced by low-cost housing is the dissatisfaction of the residents with the quality of low-cost housing (Musa et al., 2015). Despite the government’s efforts, the quality of low-cost housing is still unsatisfactory. The climate includes the building standards, planning layouts, materials’ quality, and thermal comfort (Hanafi 2014; Iruma et al. 2012). However, in most cases, thermal comfort issues have always been neglected in low-cost housing design. As a result, the thermal condition of these houses lead to higher indoor air temperature during the daytime (Tinker et al., 2004; Liang et al. 2010) also enlightened that the indoor environmental quality of a low-cost house is always over-looked issue (Ismail et al., 2012; Liang, 2010). There was always a matter of cooling in choosing the materials for constructing the low-cost houses.

Furthermore, the indoor air temperature of low-cost houses is much higher than the recommended indoor air temperature for tropical climate (Hanafi, 2014). Incompetent thermal designs have affected the thermal comfort of low-cost houses as well as the residents of the houses (Hanafi 2014; Madros 1998; Ibrahim and Balam 2014).

A comparative study was conducted by Ibrahim et al. (Hanafi 2014; Madros 1998; Ibrahim and Balam 2014) on two different houses in Betong and Saratok. The houses under different conditions were 34.2 °C and 34.5 °C for Betong and Saratok houses respectively, which were far from the recommended indoor air temperature in Malaysia. However, after several years, the ambient temperature had increased but the indoor environmental condition was not comfortable at all.

The Malaysian government still puts the effort to improve the environmental quality of the low-cost houses (Musa et al. 2015). Typical layouts of single-story detached houses are shown in Figure 1 and 2. A standard guideline is available for low-cost houses to determine the recommended Industry Standard (CIS 1: 1998). The guideline is for one-to two-story buildings, compiled by the Construction Industry Development Authority (RISDA). As air temperature is one of the most important variables to determine human comfort (Kushandjai & Energy, 2011), this paper specifically focuses on the indoor air temperature measurement to find out the thermal condition of the house.

In opposition, air velocity (Va) is correlated with the conditions but not with the recommended indoor air temperature. As a result, the thermal condition of these houses lead to higher indoor air temperature during the daytime (Tinker et al., 2004; Liang et al. 2010) also enlightened that the indoor environmental quality of a low-cost house is always overlooked issue (Ismail et al., 2012; Liang, 2010). There was always a matter of cooling in choosing the materials for constructing the low-cost houses.

Furthermore, the indoor air temperature of low-cost houses is much higher than the recommended indoor air temperature for tropical climate (Hanafi, 2014). Incompetent thermal designs have affected the thermal comfort of low-cost houses as well as the residents of the houses (Hanafi 2014; Madros 1998; Ibrahim and Balam 2014).

A comparative study was conducted by Ibrahim et al. (Hanafi 2014; Madros 1998; Ibrahim and Balam 2014) on two different houses in Betong and Saratok. The houses under different conditions were 34.2 °C and 34.5 °C for Betong and Saratok houses respectively, which were far from the recommended indoor air temperature in Malaysia. However, after several years, the ambient temperature had increased but the indoor environmental condition was not comfortable at all.

The Malaysian government still puts the effort to improve the environmental quality of the low-cost houses (Musa et al. 2015). Typical layouts of single-story detached houses are shown in Figure 1 and 2. A standard guideline is available for low-cost houses to determine the recommended Industry Standard (CIS 1: 1998). The guideline is for one-to two-story buildings, compiled by the Construction Industry Development Authority (RISDA). As air temperature is one of the most important variables to determine human comfort (Kushandjai & Energy, 2011), this paper specifically focuses on the indoor air temperature measurement to find out the thermal condition of the house. **Figure 1:** Typical low-cost single-story detached house

---

**ASSESSMENT OF INDOOR THERMAL CONDITION OF A LOW-COST SINGLE STORY DETACHED HOUSE: A CASE STUDY IN MALAYSIA**

Ashrifa Amir1, Mohd. Farid Mohamed1, Mohd Khairul Azhar Mat Sulaiman1 and Wadudah Fatmah Mohd Haniffa2

1Department of Architecture, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi. 
2School of Architecture, University Malaysia Pahang, Pahang.

* Corresponding author: ashrifaamir@gmail.com

**ABSTRACT**

Thermal comfort is an important factor to ensure good thermal condition of a house. To understand the current indoor thermal situation of a typical low-cost single story detached house in Malaysia, several parameters of thermal comfort need to be measured. The main objective of this study is to analyse the indoor thermal condition of a low-cost single story detached house through measurement of the indoor air temperature. The methodology applied in this study was field measurement to validate the IESVE simulation model of a low-cost single story detached house of a rural area, located in Kuala Pilah. Field measurement was done under two different conditions: (i) windows and door closed and (ii) windows and door opened. Air temperature, air velocity, and relative humidity data were collected using thermal comfort meters and a weather station. The data were used to validate the model generated using the IESVE simulation software. Therefore, the objectives of this paper are to find out the statistical significance between the variables and to initiate passive design strategies using IESVE-softwares to make indoor thermal condition more comfortable. Statistical analysis revealed that indoor air temperature (Ta) is statistically significant with time but not with the conditions. In opposition, air velocity (Va) is correlated with the conditions but not with indoor air temperature and time. Afterward, the window sizes were enlarged, and roof insulation was added to the simulation model to observe the temperature changes. Results show that in both cases, the temperature reduced to some extent but was not satisfactory nor in the recommended indoor air temperature range. Therefore, more careful deliberation is needed to design the layout for the low-cost detached houses. Using roof insulation material is also important to improve the indoor thermal condition of the low-cost single story detached houses in Malaysia.

**Keywords:** Indoor air temperature, low-cost single story detached house, thermal condition, IESVE-simulation.
2.1 Equipment calibration

All the equipment was calibrated within a controlled environment before taking the on-site measurements to find out the error values. The list of the equipment used in the calibration is shown in Table 1 and Figure 3.

Table 1: Equipment calibration

<table>
<thead>
<tr>
<th>No.</th>
<th>Instruments</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Delta Ohm HD32.3 WBGT- PMV</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Weather station</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Calibration of all instruments in the indoor controlled environment

2.2 Field measurement

The field measurement was conducted on a low-cost single-story detached house located at ‘Kampung Parit Seberang’, ‘Kuala Pilah’, Negeri Sembilan (Latitude: 2°45’9.72” Longitude: 102°13’47.27”). The house had three bedrooms, one bathroom, one toilet, kitchen, dining and living room area of 57.88 square meter (623 square feet), as shown in Figure 4 and Figure 5. The measurement was conducted for three days from morning to evening for each condition (08:15 am to 19:15 pm). The first three days were under the setup where the door and windows were closed. The last three days, the door and windows were opened. During field measurement, a weather station was set outside the house to measure the outside meteorological conditions and two thermal comfort meters were set in different rooms of the house (labelled F2 and J1 in Figure 5).

Figure 4: Surroundings of the low-cost location single story detached house used for field measurement.

Figure 5 shows the location of both thermal comfort meters. The thermal comfort meters labelled as F2 was located in between the living and dining rooms and J1 was set to 1.1 meter above the floor level based on a similar study of Nguyen (Anh Tuan Nguyen 2012).

2.3 Data collection

After completing the field measurement, the measured data were transferred and analysed. Thermal condition assessment were carried out under two different conditions (Ibrahim and Baharun 2014; Tinker et al. 2004):

Condition 1: Windows and door closed
Condition 2: Windows and door opened

Table 1: Equipment calibration

<table>
<thead>
<tr>
<th>No.</th>
<th>Instruments</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Delta Ohm HD32.3 WBGT- PMV</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Weather station</td>
<td></td>
</tr>
</tbody>
</table>

The air temperature, wind speed, relative humidity and PMV data were collected for both conditions. However, in this paper only discusses the air temperature data. All data were statistically analysed using Microsoft Excel and SPSS.

2.4 Integrated environmental solutions <virtual environment> simulation

Integrated environmental solutions <virtual environment> (IES<VE>) is one of the efficient simulation software that can perform a detailed analysis of thermal performance (Doyle 2008; Nikpour et al. 2013). Three different models were developed to run three different simulations to attain a sound thermal condition of the house. Afterwards, changes were made to the base model to see the results. The window sizes were enlarged and different insulation materials like bubble foil and glass wool were used in the roof for the simulation model.

3. RESULTS AND DISCUSSIONS

The main emphasis was on the changes in the indoor air temperature under different conditions of the selected low-cost single-story detached house. At first, the obtained data from the field measurement were validated. Afterward, the validated data were analysed to see the relations between the variables. The indoor air temperature from both conditions was compared with the recommended temperature for Malaysia. Then, the base models of the IES<VE> simulation for two different conditions were improved to give further passive design suggestions.

3.1 Validation of IES<VE> model

Validation is very important for any kind of thermal simulation program. After comparing different simulation models, Hensen disclosed that IES<VE> validation is one of the best (Hensen 2004). Other than that, IES Apache simulation is also a trustable simulation tool for getting high accuracy (Ahmad et al. 2012; Attia 2010; Nikpour et al. 2013; Saleem et al.). However, the data from the field measurement and IES<VE> model simulation were compared for validation purpose (Saleem et al.).
For condition 1, the maximum uncertainty in calibrated data found in the living room area was 1.3 °C with the standard deviation at 2.3% (Table 2 and Figure 9). Under the setup of condition 2, the maximum uncertainty in calibrated data found in the living room area was 0.9 °C with a 3.2% standard deviation (Table 3 and Figure 10). The weather station was excluded from uncertainty estimation (Muhsin, Fatimah, Yusoff, and Farid, 2017).

Table 2: Uncertainty estimation of the indoor air temperature (°C) sensors as calibrated:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master bedroom (F2)</td>
<td>2.6</td>
</tr>
<tr>
<td>Living room (J1)</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Table 3: Uncertainty estimation of the indoor air temperature (°C) sensors as calibrated:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master bedroom (F2)</td>
<td>1.9</td>
</tr>
<tr>
<td>Living room (J1)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The results revealed that for both conditions, the deviation (%) between IES<VE> model and field measurement was less than 5% for indoor air temperature data which indicates that IES has the validity to calculate the thermal analysis (Ahmad et al., 2012; Nikpour et al., 2013).

3.2 Pearson’s correlation test

The Pearson’s correlation test was conducted to see the impact of time and condition on indoor air temperature. The test results in Table 4 show that the indoor air temperature increased throughout the day and highly correlated with time.

Table 4: Pearson Correlation test for different variables with time and conditions

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Time</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson</td>
<td>0.705**</td>
<td>.705**</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
</tr>
</tbody>
</table>

3.3 Comparison between indoor air temperature and recommended temperature

According to the guidelines of Department of Standard Malaysia, the recommended temperature range for Malaysian climate is between 23 °C and 26 °C that indicates an average temperature of 24.5 °C. The measured indoor air temperature of the house was listed to compare with the recommended temperature under condition 1 and 2, for three different times of day (Table 5 and Table 6).

Table 5: Condition 1: Indoor air temperature and recommended air temperature (°C):

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Morning 0900</th>
<th>Noon 1200</th>
<th>Evening 1700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor air temperature (°C)</td>
<td>29.2</td>
<td>31.4</td>
<td>33.1</td>
</tr>
<tr>
<td>Recommended temperature (°C)</td>
<td>24.5</td>
<td>24.5</td>
<td>24.5</td>
</tr>
</tbody>
</table>

In the morning (9:00 am), for Condition 1 and 2, 29.2 °C and 29.7 °C are the lowest indoor air temperature. Even being the lowest temperature recorded, both values were still higher than the recommended indoor air temperature. Otherwise, the average indoor air temperature of the house was compared with the monitored average outdoor temperature of 9.0 °C and the average outdoor temperature (Table 7).

Table 6: Condition 2: Indoor temperature and recommended air temperature (°C):

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Morning 0900</th>
<th>Noon 1200</th>
<th>Evening 1700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor air temperature (°C)</td>
<td>29.7</td>
<td>31.2</td>
<td>33.6</td>
</tr>
<tr>
<td>Recommended temperature (°C)</td>
<td>24.5</td>
<td>24.5</td>
<td>24.5</td>
</tr>
</tbody>
</table>

3.4 Comparison between indoor air temperature and outdoor air temperature

The average indoor air temperature was compared with the monitored average outdoor temperature of 9.0 °C and the average outdoor air temperature (Table 7).

Table 7: Condition 1: Indoors temperature and outdoor temperature (°C):

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Morning 0900</th>
<th>Noon 1200</th>
<th>Evening 1700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor air temperature (°C)</td>
<td>29.2</td>
<td>31.3</td>
<td>33.1</td>
</tr>
<tr>
<td>Outdoor air temperature (°C)</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

3.5 IES<VE> simulation with different design strategies

IES<VE> simulation was used to initiate further passive design strategies for this study. After doing different statistical analyses, the indoor air temperature was observed by developing different simulation models by making changes on the base models for both conditions. The selected typical low-cost single-story house was modelled in the IES<VE> simulation to provide further recommendations for the betterment of the indoor thermal comfort of the house using selective passive design strategies. The base model obtained from the IES<VE> software was improved to run different simulations with different passive design strategies for the betterment of the indoor environmental condition of the selected house (Figures 11 and 12).
3.5.1 Analysing different passive design strategies

For all cases, simulation results were not highly satisfactory. But the measured indoor air temperature values were higher than the simulated model obtained values of the study house. With larger windows, the temperature decreased the most at 2.4 °C and 1.3 °C for both tested conditions. Windows can be enlarged easily to reduce the indoor air temperature. However, the application of the roof insulation materials went well for condition 1 as all the windows were closed and the heat could not enter directly through the windows. But interestingly for condition 2, the temperature increased in the evening. For both conditions, the roof indoor temperature reduction is much higher in the roof with bubble foil insulation than in the roof with glass wool insulation. The roof insulation materials can be assessed under conventional metal deck roof for adding some extra cost by varying different strategies about the temperature to some extent but these strategies need to be improved and combined with other strategies to achieve a comfortable thermal environment inside the house.

4. CONCLUSION

The results from statistical analysis and IES<VE> simulation model analysis showed that the roof indoor air temperature was not in the range of the recommended air temperature. For improvement of the indoor thermal condition of a low-cost house, indoor air temperature should be reduced for more conducive thermal environment for the occupants. Although the indoor air temperature was dropped after the windows and door being opened, the results were neither satisfying nor falling in the suggested indoor air temperature range. Hence, there is a need for an alteration in the windows and roof materials and an implementation of the low-cost design strategies to make the indoor thermal environment of these houses more livable. The results showed that the passive design strategies have made positive impacts on the indoor thermal condition of the houses. The objectives have been fulfilled by initiating different low-cost passive design strategies from the methodology in reducing the indoor air temperature. Using bubble foil roof insulation materials could be one of the suitable strategies by spending a bit more to reduce the indoor air temperature of the low-cost single-story detached houses significantly. The findings of this study offer potential guidelines for the developers and builders to make the decision in building new low-cost houses more efficiently. This study focused on the indoor air temperature issue of single-story detached low-cost houses in Malaysia. Therefore, further studies involving different types of low-cost houses should be carried out in the near future to improve the indoor thermal quality of the low-cost houses in Malaysia.

ACKNOWLEDGMENT

The authors would like to acknowledge the Universiti Kebangsaan Malaysia (UKM) for supporting this research through University/Industry Research Grant (GUP-2017-1111) and Cuban Canara Grant (DCP-2017/086).

REFERENCES


Muhsin, F., Fatimah, W., Yusoff, M., & Farid, M. (2017). CFD modeling of
MANUSCRIPT PREPARATION
Manuscript Types
Manuscript Types
Alam Cipta accepts submission of mainly five types of manuscripts for peer-
1. REGULAR ARTICLE
These report critical evaluation of materials and methods, results and discussion, conclusions. Original work must provide references and an explanation on research findings that contain new and significant findings.
Sey: Generally, these are expected to be between 6 and 12 journal pages (excluding the abstract, references, tables and/or figures), a maximum of 80 references, and an abstract of 150–200 words.
2. REVIEW ARTICLE
These report critical evaluation of materials and methods, results and discussion, conclusions. Original work must provide references and an explanation on research findings that contain new and significant findings.
Sey: Generally, book review article is usually between 2 and 3 journal pages. The manuscript title must start with “Book Review.”
4. BOOK REVIEW
A book review paper offers a description and an evaluation of a book within the journal scope. The author must furnish the book information or bibliographic citation in full includes author(s), place, publisher, date of publication, edition statement, pages, special features (maps, colour plates, etc.), price and ISBN. A snapshot of the book cover is necessary. The manuscript title must start with “Book Review”.
5. OTHERS
Report, case studies, comments, concept papers, Letters to the Editor, and replies on previously published articles may be considered.
Please note: NO EXCEPTIONS WILL BE MADE FOR PAGE LENGTH.
Language Accuracy

Alan Cipta emphasises on the linguistic accuracy of every manuscript published. Articles must be in English and they must be competently written and properly edited. Authors are strongly advised to have the manuscript checked by a colleague with ample experience in writing English manuscripts or a competent English language editor.

Authors should provide a certificate confirming that their manuscripts have been adequately edited. A proof from a recognized editing service should be submitted together with the cover letter at the time of submitting a manuscript to Alam Cipta. All the costs must be borne by the author(s). This step, taken by authors before submission, will greatly facilitate reviewing, and thus publication if the content is acceptable.

Linguistically hopeless manuscripts will be rejected straightaway (e.g. when the language is so poor that one cannot be sure of what the authors really mean). This process, taken by authors before submission, will greatly facilitate reviewing, and thus publication if the content is acceptable.

MANUSCRIPT FORMAT

The paper should be submitted in one column format with at least 4cm margins and 1.5 line spacing throughout. Authors are advised to use Times New Roman 12-point font and MS Word format.

1. Manuscript Structure

Manuscripts in general should be organized in the following order:

Page 1: Running title

This page should only contain the running title of your paper. The running title is an abbreviated title used as the running head on every page of the manuscript. The running title should not exceed 60 characters, counting letters.

Page 2: Author(s) and Corresponding author information.

This page should contain the full title of your paper not exceeding 25 words, author's name, and full address (Street address, telephone number including extension), hand phone number, and e-mail address for editorial correspondence. First and corresponding authors must be clearly indicated.

Authors' addresses. Multiple authors with different addresses must indicate their respective addresses separately by superscript numbers:

- George Swan and Nayan Karvali
  - Department of Biology, Faculty of Science, Duke University, Durham, North Carolina, USA.
- Office of the Deputy Vice Chancellor (R&I), Universiti Putra Malaysia, Serdang, Malaysia.

A list of number of black and white/colour figures and tables should also be indicated on this page. Figures submitted in color will be printed in color. See "5. Figures & Photographs" for details.

Page 3: Abstract

This page should repeat the full title of your paper with only the Abstract (the abstract should be less than 250 words for a Regular Paper and up to 100 words for a Short Communication), and Keywords.

Keywords: Not more than eight keywords in alphabetical order must be provided to describe the contents of the manuscript.

Page 4: Introduction

This page should begin with the Introduction of your article and followed by the rest of your paper.

2. Text

Regular Papers should be prepared with the headings Introduction, Materials and Methods, Results and Discussion, Conclusions, Acknowledgements, References, and Supplementary data (if available) in this order.

3. Equations and Formulate

These must be set up clearly and should be typed doublespaced. Numbers identifying equations should be in square brackets and placed on the right margin of the text.

4. Tables

All tables should be prepared in a form consistent with recent issues of Alam Cipta and should be numbered consecutively with Roman numerals. Explanatory material should be given in the table legends and footnotes. Each table should be prepared on a new page, embedded in the manuscript.

When a manuscript is submitted for publication, tables must also be submitted separately as data—doc, rtf, Excel or PowerPoint files—because tables submitted as image data cannot be edited for publication and are usually in low-resolution.

5. Figures & Photographs

Submit an original figure or photograph. Line drawings must be clear, with high black and white contrast. Each figure or photograph should be prepared on a new page, embedded in the manuscript for reviewing to keep the file of the manuscript under 5 MB. These should be numbered consecutively with Roman numerals.

Figures or photographs must also be submitted separately as TIFF, JPEG, or Excel files—because figures or photographs submitted in low-resolution embedded in the manuscript cannot be accepted for publication. For electronic figures, create your figures using applications that are capable of preparing high-resolution TIFF files. In general, we require 300 dpi or higher resolution for colored and half-tone artwork, and 1200 dpi or higher for full-tone or halftone artwork. Failure to comply with these specifications will require new figures and delay in publication.

NOTE: Illustrations may be produced in colour at no extra cost at the discretion of the Publisher; the author could be charged Malaysian Ringgit S0 for each colour page.

6. References

References begin on their own page and are listed in alphabetical order by the last name of the author. Only references cited within the text should be included. All references should be in 12-point font and double-spaced.

NOTE: When formatting your references, please follow the APA reference style (6th Edition). Ensure that the references are strictly in the journal’s prescribed style, failing which your manuscript will not be accepted for pre-review. You may refer to the Publication Manual of the American Psychological Association for further details (http://www.apa.org/journals).
SUBMISSION OF MANUSCRIPTS

Owing to the volume of manuscripts we receive, we must insist that all submissions be made electronically using the online submission system ScholarOne™, a web-based portal by Thomson Reuters. For more information, please see our "Online Submission" on our website.

Submission Checklist
1. MANUSCRIPT: Ensure your MS has followed the Alam Cipta style particularly the first four pages as explained earlier. The article should be written in a good academic style and provide an accurate and succinct description of the contents ensuring that grammar and spelling errors have been corrected before submission. It should also not exceed the suggested length.

2. COVER LETTER: All submissions must be accompanied by a cover letter detailing what you are submitting. Papers are accepted for publication in the journal on the understanding that the article is original and the content has not been published or submitted for publication elsewhere. This must be stated in the cover letter. Submission of your manuscript will not be accepted until a signed cover letter (original pen-to-paper signature) has been received.

The cover letter must contain an acknowledgement that all authors have contributed significantly, and that all authors are in agreement with the content of the manuscript. The cover letter of the paper should contain (i) the title; (ii) the full names of the authors; (iii) the addresses of the institutions at which the work was carried out together with (iv) the full postal and email address, plus telephone numbers and emails of all the authors. The current address of any author, if different from that where the work was carried out, should be supplied in a footnote.

3. COPYRIGHT: Authors publishing the Journal will be asked to sign a copyright form. In signing the form, it is assumed that authors have obtained permission to use any copyrighted or previously published material. All authors must read and agree to the conditions outlined in the form, and must sign the form or agree that the corresponding author can sign on their behalf. Articles cannot be published until a signed form (original pen-to-paper signature) has been received.

Please do not submit manuscripts to the editor-in-chief or to any other office directly. Any queries must be directed to the Editor in Chief via email to alamciptaeditor@upm.edu.my.

Visit our Journal’s website for more details at http://alamcipta.upm.edu.my/.

HARDCOPIES OF THE JOURNALS AND OFF PRINTS

Under the Journal’s open access initiative, authors can choose to download free material (via PDF link) from any of the journal issues from Alam Cipta website. Under “Issue”, you will see a link, “Current Issues” or “Past Issues”. Here you will get access to all current and back-issues from 2000 onwards.

The corresponding author and authors for all articles will receive one complimentary softcopy (digital print) of the journal in which his/her articles is published. Additional copies of the journals may be purchased by writing to the Chief Executive Editor.

Contact us:
Editor In Chief
International Journal of Sustainable Tropical Design Research and Practice
Faculty of Design and Architecture
Universiti Putra Malaysia
43400 UPM Serdang
Selangor
Malaysia
Tel: 03-97694064/03-97694079
Email : alamciptaeditor@upm.edu.my
Website : http://alamcipta.upm.edu.my/