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Thermal Comfort of Residential Building in Malaysia at Different Micro-Climates

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Abstract

This study examines the level of the thermal environment in residential building in Malaysia at various urban micro-climates which are Kuala Lumpur (KL), Bayan Lepas (BL) and Kuching (K). A simulation model of a typically-designed residential building in Malaysia was constructed to determine the indoor temperatures in the indoor living spaces, namely living cum dining area (DL), wet kitchen (K) and master bedroom (MB). Findings suggest that the highest indoor temperature of 32.6 °C was obtained in a master bedroom (MB) in under KL climate at 1400 hours. Overall, indoor temperatures are higher than the indoor design conditions recommended in Malaysian Standard; MS1525:2007.

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1. Introduction

Indoor thermal environment is part of the indoor environmental quality component that close influence by the climatic condition. Nowadays, the climate change phenomenon has caused a threat to the human environment. Occupants' behavior and activities relatively contribute to the effect of global warming, as a result, of building energy consumption and carbon emission (Ismail, Abdul Samad, Rahman, & Yeok, 2012). Malaysia is located near to the equator experience the warm and humid climate condition. The

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most crucial climatic impact in Malaysia buildings are high intensity of solar radiation and high daily air temperature (Al-Tamimi & Syed Fadzil, 2011, Sadafi, Salleh, Chin, & Jaafar, 2011). Other than these climatic elements, a little wind movement and higher relative humidity has greatly affect occupants' indoor thermal comfort in buildings. Due to excessive heat and high air temperature, building designers prefer to adopt mechanical system in building design such as air-conditioning in achieving required indoor thermal comfort which resulting in increased energy consumption in building (Hien, Poh, & Feriadi, 2000, Kubota, Jeong, Toe, & Ossen, 2011 and Zr & Mochtar, 2013). This study attempts to identify the level of indoor thermal environment and indoor living spaces in a typically-designed residential building model in urban areas of Malaysia. A simulation of the hourly weather data in existing residential building design was carried out to analyse the indoor air temperatures. Hence, the finding addresses the issues of thermal discomfort condition in residential building at different urban micro-climates and indoor living spaces in Malaysia.

2. Literature Review

A building in tropics means a confrontation of construction and function with intense climatic condition. Tropical climate regions characterized as high humidity, excessive rainfall and considerable sunshine. Typical features of tropical climate have the negative impact and positive impact to the building design. The extreme impacts caused by the tropical climate through its climatic parameters such as temperature, solar radiation, relative humidity, rainfall and wind. It is ideal medium state for rich of tropical plants and rainforest. A successful indoor environment much depends on an understanding of the environmental factors, including building design and setting. Healthy and comfortable indoor environment have become important in sustainable built environment. Major factors determining the ecosystems that develop, but within any ecosystem itself comprise complex interactions and minor variations that result in smaller communities within which call as a micro climate (Yeang, 2006). The microclimate around the building, establishing through the interaction with other buildings or the natural environment, is a significant factor in the building energy consumption and indoor building environments.

2.1. Malaysia climatic condition

Malaysia is a tropical country characterized as warm and humid located within the Tropic of Cancer and Capricorn. The latitude of 1° - 7°N and longitude 100° - 119°E. The climatic elements categorized as high temperature and uniform diurnal pattern throughout the year. The annual mean temperature is 26.4°C with average daily maximum temperature is 34°C and average daily minimum at 23°C (Al-Tamimi & Syed Fadzil, 2011). The annual relative humidity value ranges within 74% to 86%. Malaysia has a complete, clear sky in the day for the whole year, ranging from 3.7 hours to 8.7 hours per day. On the average, sunshine receives about six hours a day ("<http://www.met.gov.my>," 2012). Malaysia also experiences high solar intensity and duration. Weather data analysis in term of building design for warm-humid climate is overheating is not as great as in hot-dry areas but it is aggravated by high humidity and small diurnal temperature variation (Haase & Amato, 2009). There are two main factors; high air temperature and relative humidity affects comfort and health of occupants living inside building without good ventilation system (Sookchaiya, Monyakul, & Thepa, 2010). As a consequence, the changes of heat balance in the environment will increase air temperature especially in built-up urban areas compared to suburban or rural areas (Priyadarsini, Hien, & Wai David, 2008). The inverse relationship between forest cover and built-up area in affecting land surface temperature shows the importance of vegetation coverage in minimising the thermal energy response in urban areas. However, building form, site plan and road layout in most new housing development area have been unconsidered strongly a hot, humid

climate for their master design (Givoni, 1997). The wind flow pattern over the country is generally light and inconsistent with uniform intermittent changes. Due to this climatic change, distinguish the four seasonal monsoons in Malaysia known as the northeast monsoon, southwest monsoon, and two shorter periods of inter-monsoon seasons.

2.2. Thermal comfort in urban residential building

In the urban environment, a thermally comfortable indoor condition is essential for a healthy indoor living environment and quality of life. Human thermal comfort is found to be related with several factors such as air temperature, air movement, amount of clothing worn, and activity level including a human body itself (Randall, 2006). Rapid urbanization in Malaysia has gained increased attention in impact to the environmental issues. For example, it effects on outdoor and indoor thermal comfort, energy use for heating and cooling, and of air pollution. The most distinctive of urban climate is that air temperatures are higher than those in the surrounding rural areas, especially at night. As a consequence, an indoor temperature will be relatively higher than the outdoor temperature. Apparently without mechanical system for thermal control, the room conditions can adversely affect to the occupants' health and productivity (Zr & Mochtar, 2013). Thus, most buildings in an urban area depend on mechanical systems to achieve required levels of comfort and health has obscured the essential performance implications of other critical building design decisions (Hien et al., 2000). The human body temperature needs to be maintained at a constant $37\pm 5^{\circ}\text{C}$ regardless of the prevailing ambient condition. Department of Standards Malaysia, 2007 has published a guideline for a standard indoor environment design for Malaysian climate recommends indoor temperature to be in the range of 23°C - 26°C . Room comfort conditions considered to depending on various factors including air temperatures, mean radiant temperature, humidity, clothing, metabolic rate and air movement preference of the occupant. Nonetheless, other studies on the comfort temperature in the tropical region is higher than other climate regions having concluded that the comfort temperature is higher in tropical regions, because of humans' ability on acclimatization (Li et al., 2010). Research on terraced house in Malaysia by (Zain, Taib, & Baki, 2007) proposed that the thermal comfort could be achieved below 28.69°C . Other study reported that the comfort band for Malaysia for all building types is between 23.6°C and 28.6°C (Sabarinah & Steven, 2007). In this study, the lower and upper air temperatures for thermal comfort was taken to be 26°C and 23°C , respectively, as according to Department of Standards Malaysia, 2007.

2.3. Urban microclimates issues

Developments for urbanization either for residential or commercial sector for the improvement of life, have the negative impacts that prevalent in many urban areas. Urbanization changed the land surfaces from natural surfaces to man-made and reduced the green areas. The lands are crowded with concrete buildings, premix streets but less of vegetation and trees. Development to fulfill human settlements further modifies the local climate into urban microclimate with temperatures varied considerably and formation of urban heat island phenomenon (Sharuddin, Noorazuan, Yaakob, Kadaruddin, & Mahamod, 2011, Shahidan, Jones, Gwilliam, & Salleh, 2012). Microclimate conditions in the urban environments also differ significantly from rural areas (Gulyás, Unger, & Matzarakis, 2006). The differences include the adjustment of the surface structure in terms of proportion of the built up area, 3D geometry of the buildings and vegetation (Shashua-Bar, Hoffman, & Tzamer, 2006, Johansson, 2006). Urban heat islands phenomenon cause discomfort condition to the urban occupants in the tropical climate and increase air-conditioning loads. It has been reported that most of the electricity consumption in residential building is due to space cooling due to urban lifestyle, rapidly rising domestic income and plunging electrical

appliances cost (Ahmad & Abdul-Ghani, 2011). Urban areas and their inhabitants also play a key role in the global climatic change. Cities emit the primary anthropogenic carbon dioxide due to energy used for industrial processing, transportation and building operations, affecting greenhouse gas sources and sink both directly and indirectly. Nowadays in a modern living lifestyle consume high energy usage for daily activities and comfort conditions (air conditioning, electrical appliances, PC, gadgets). In addition, the urbanization needs more development for the new township and buildings due to the rapid growth of the economy and the increasing demand of the population. This hasty development without control and awareness of sustainability will contribute a higher emission of greenhouse gas (GHG) and global warming. Consecutively these phenomena will impact on the environment, climate locality and in return will effect on the human comfort and health which is been recognized as indoor environmental quality. The demand of goods and resource for economic activities has driven to regional land-use change such as deforestation, buildings, surface pavements and drainage patterns (Grimmond et al., 2010). These severe environmental conditions would further negatively impact human comfort, health and productivity. Sustainable urban areas may be achieved if it reduces the resource use and negative effects on an ecosystem with integrating meteorological information in urban planning and design without threatening the health and well-being of its inhabitants (Mills et al., 2010).

2.4. Climatic data for thermal comfort

Macroclimate refers to the overall climate of the region generally it covers a vast geography area such as a continental climate region, temperate climate, Japan climate or Malaysia climate. Macroclimate data and weather data is the same and can be obtained from the meteorological department. These data usually contain information on temperature, relative humidity, air velocity, mean radiant temperature for a day at a certain location and can be divided into morning and afternoon. Microclimates are any climatic condition or uniformly local climate of relatively small geographic area, site or habitat. It could be a few miles or as of a confined space like houses, garden bed or of urban communities that may be different from that in a general region. The microclimate is likely the outcome of the local physical features or terrain. For instance, the site might be flat, hilly, beside the lake or sea. The physical characteristics of the site will indicate the climatic element surrounding that particular site. Therefore, microclimate of a specific location is different with macroclimate in the region. At a global level, climates are formed by the differential solar heat input and the almost uniform heat emission over the earth's surface. Equatorial regions receive more energy input than areas nearer to the poles. Up to 30 degree North and South latitudes the radiation balance is positive; the solar income is greater than the radiant loss. At higher latitudes, the heat loss far exceeds the solar input. Climate can be defined as the integration in time of weather conditions, characteristic of a certain geographical location. Weather is the set of atmospheric conditions prevailing at a given place and time. For the purpose of building design a simple system (after Atkinson, 1953) distinguish four basic types that based on the nature of the human thermal problem in a particular location; cold, temperate, hot-dry and warm humid. An important stage in the design is gaining an understanding of the influence of local conditions on the climate. The local factors that will influence the site climate are called microclimatic condition (Szokolay, 2008). Expected changes in climatic variables are increase in surface temperature, sea level rise, increase precipitation, and extreme weather. Thus, this will change the local climate many cities in the world, known as urban microclimate.

3. Methodology

Building simulation tools address support for interactive and intermittent use and report performance metrics in a comprehensive way. The tools assist in design decision support within the constraints of a

consulting practice. Improvements in the user interface and simulation capabilities have resulted from the observation of simulation use in practice. This advantages together with enhanced practitioner skills and procedures, should lead to further integration of simulation within the design process (Hand, Clarke, & Strachan, 1999). In this study, the utilization of Autodesk Ecotect and Meteonorm were applied on the thermal analysis in typically-design residential building in Malaysia.

3.1. Computer simulation program

Two (2) softwares were utilized in this study, which are Ecotect and Meteonorm. Ecotect is software that can carry out thermal, lighting and acoustic analyses of buildings (“www.usa.autodesk.com/ecotect-analysis/,” 2012). In this study, Ecotect is utilized to generate temperatures in three (3) indoor living spaces in a residential building model under Kuala Lumpur (KL), Bayan Lepas (BL) and Kuching (KU) climates. On the other hand, Meteonorm stores and generates weather data using stochastic models. Data stored in Meteonorm is taken from weather stations placed at 8,300 locations worldwide. The data consist of hourly wet and dry bulb temperatures, relative humidity, wind speed and direction and cloud cover (“Information on www.meteonorm.com,” 2012). In this study, Meteonorm is utilized to generate hourly outdoor air temperatures in KL, BL and KU to be used in Ecotect simulation. These computer simulation programmes enable to measure the thermal performance of a typically-designed residential building modeled at three different urban areas selected in Malaysia.

3.2. Climatic data

Meteonorm software is a suitable tool for generating hourly outdoor air temperatures throughout 2012 for KL, BL and KU. Then the climatic data exported as EnergyPlus files (.EPW). Finally, the .EPW format files are converted using Ecotect into files that are compatible for Ecotect simulation that in (.WEA) extension. The building simulation was carried out during the hottest month of the year which is on 20th May, generated from Ecotect analysis. The hottest month is considered to represent the highest air temperature from weather data and will contribute a higher indoor temperature distribution in naturally ventilated building. Therefore, the thermal performance of the actual condition of the modeled building could be identified.

3.3. Thermal analysis

A double-storey residential building model with a floor area of 159.80 m² and a height of 3.0 m is developed (Fig.1. (a)). The indoor space layout (Fig. 1. (b)) of typical terraced houses is used in this model, which consists of a living cum dining area (DL), wet kitchen (WK) and a guest room on the ground floor and three (3) bedrooms and a hall on the first floor. The bedrooms consist of a master (MB) and two (2) smaller bedrooms. In Ecotect model, for thermal analysis purposes, spaces are divided into individual spaces named as ‘zones’. The zone properties have been considered according to literature review and actual house condition displayed in Table 1. The building simulation was carried out in a double storey terraced house on the hottest day peak data taken from the Meteonorm software. The house is not air-conditioned so that thermal performance in the real condition could be identified. The building materials and its thermal properties of the simulated residential building model are described in Table 2. Meteorological data used in Ecotect were obtained from Meteonorm software.

Table 1. Zone properties of the simulated residential building model

Zone properties	Description
The type of active or passive system used	Natural ventilation
Comfort band (environmental temperature range for comfort system):	(recommended by MS1525:2007)
Lower band	23°C
Upper band	26°C
The occupants' metabolic rate	Sedentary activity: 70W (5 persons)
The occupants' clo value (thermal insulation of clothing)	1.0

Table 2. Thermal properties of the residential building model

Element	Description	U value (W/m ² K)
Roof	Clay roof tiles with insulation	0.45
Ceiling	Suspended concrete ceiling / intermediate floor	1.45
	Plasterboard ceiling	0.55
Floor	150mm thick concrete floor with ceramic tiles	2.90
External wall	114mm brick wall with 20mm thick cement plaster on both sides	2.62
Door	Internal door	2.50
	Glass sliding door (external door)	5.35
Window	Single glazing 6mm thick	5.44

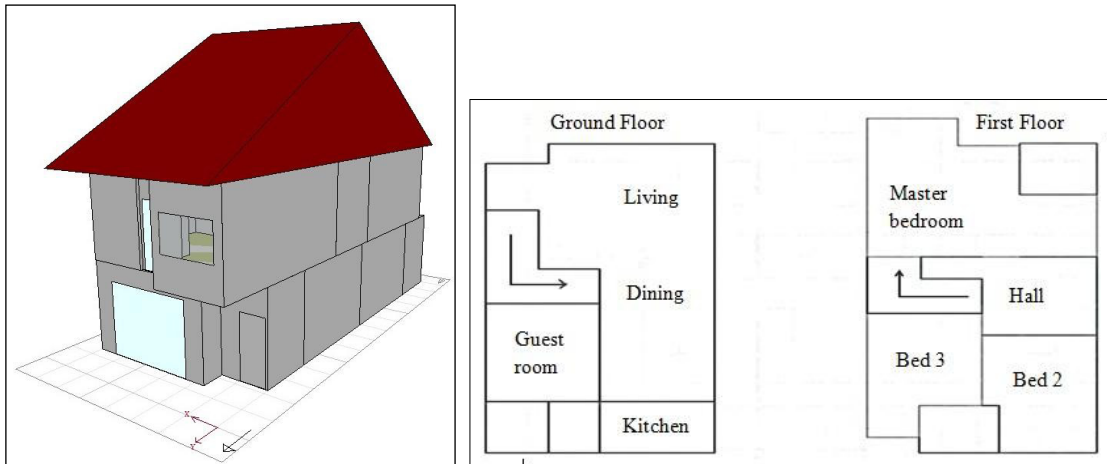


Fig. 1.(a) Perspective view of residential building model; (b) Indoor space layout of residential building model

4. Result and Discussion

Figure 2, 3 and 4 present the indoor temperatures profiles of Dining Living, Wet Kitchen and Master Bedroom indoor living spaces under Kuala Lumpur, Kuching and Bayan Lepas climates, respectively. Under all climates, Master Bedroom yields the highest indoor temperature, followed by Dining Living and Kitchen. The highest indoor temperature for Master Bedroom was under Kuala Lumpur climate. Findings show that the highest indoor temperature in Kuala Lumpur ($T_{i, \text{highest, KL}}$) of 32.60 °C, the highest indoor temperature in Kuching ($T_{i, \text{highest, KU}}$) of 31.10 °C and the highest indoor temperature in Bayan Lepas ($T_{i, \text{highest, BL}}$) of 31.60 °C were all yielded in Master Bedroom. The highest indoor temperature in KL climate obtained at 1400 hr, which is the peak of outdoor temperature in KL was 36°C. The higher urban temperature has important implication to the indoor environment in a naturally ventilated residential building; indoor temperature is influenced by the outdoor environment condition. The higher indoor temperature remains until midnight and cools down at 0200 hr to 29.5°C. Master Bedroom displays a slightly lower indoor temperature during midnight until early morning at 0700 hr compared to Wet Kitchen and Dining Living area. This trend is likely affected due to location of master Bedroom on the first floor, which the hot air could dissipate through the opening of the window and a sliding door in the room.

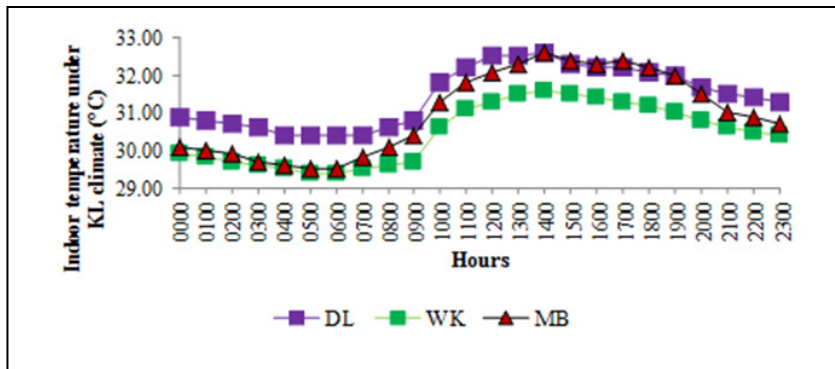


Fig. 2. Indoor temperature in Kuala Lumpur climate

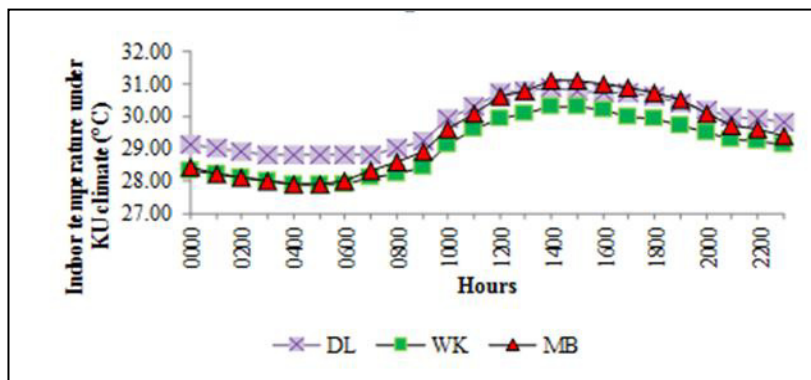


Fig. 3. Indoor temperature in Kuching climate

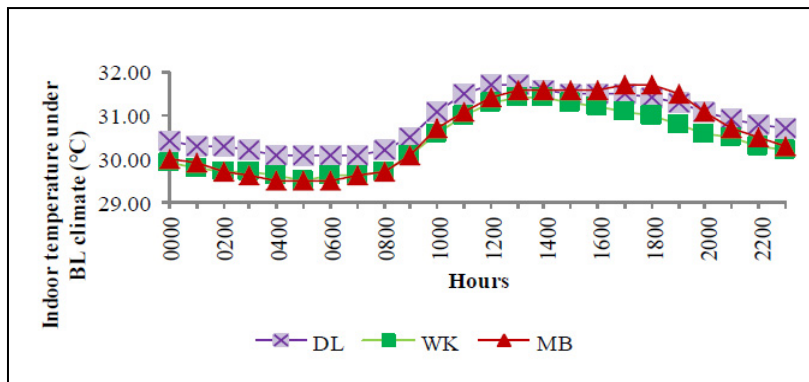


Fig. 4. Indoor temperature in Bayan Lepas climate

The lowest range of indoor temperature (T_i), which is in range of 28 °C – 31.1 °C, was obtained under Kuching climate. The results also suggest that the overall indoor temperature (T_i values) is higher than the indoor design conditions recommended in MS1525:2007. The data also demonstrated the uncomfortable condition experienced at 1300 hr until 2100 hr for all three selected urban area. This is probably reflected the microclimates have a significant effect to the indoor environment in a residential building and the higher urban temperatures of urban climates worsen the indoor environmental quality in the building.

Figure 5, 6 and 7 present the outdoor-indoor temperature difference profiles of Dining Living, Wet Kitchen and Master Bedroom indoor living spaces under Kuala Lumpur, Kuching and Bayan Lepas climates respectively. The highest temperature difference in KL ($\Delta T_{i, \text{highest, KL}}$) of 4.4 °C, KU ($\Delta T_{i, \text{highest, KU}}$) of 2.7 °C and and BL ($T_{i, \text{highest, BL}}$) of 4.8 °C were all obtained in Wet Kitchen between 1000 hr until 1900 hr. The temperatures differences could be influenced due to higher outdoor temperature during that period. In addition, the Wet Kitchen has little volume compared to Master Bedroom and Dining Living that kept the lower temperature in that area. The analysis shows a pattern of outdoor-indoor temperature trend in all climates that the large differences occur between 0000 hr to 0700 hr. This result indicates that between these periods, the indoor temperature is lower than the outdoor temperature. The analyses of outdoor and indoor temperatures were generally lower in Kuching than Kuala Lumpur and Bayan Lepas.

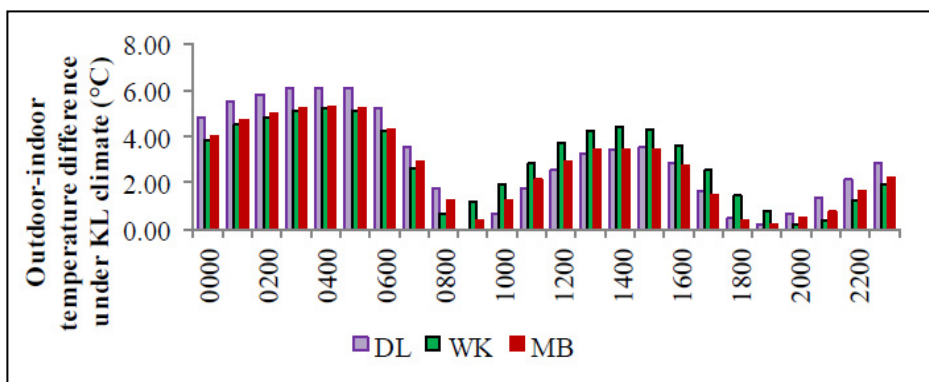


Fig. 5. Outdoor-indoor temperature difference under KL climate

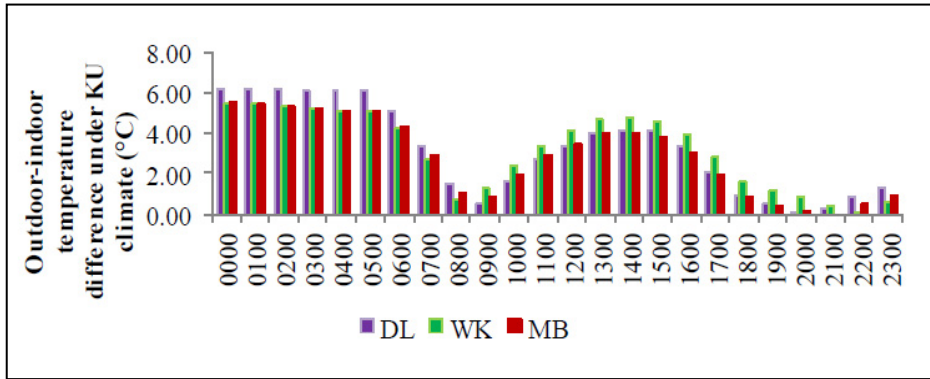


Fig.. 6. Outdoor-indoor temperature difference under Kuching climate

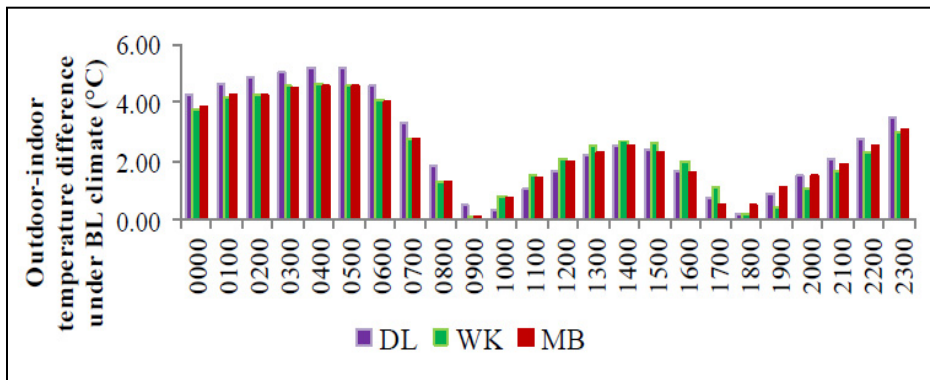


Fig. 7. Outdoor-indoor temperature difference under Bayan Lepas climate

5. Conclusion

Findings suggest that the highest indoor temperature of 32.6°C was obtained in Master Bedroom under Kuala Lumpur climate at 1400 hours. In general, indoor temperatures in Kuching are lower than Kuala Lumpur and Bayan Lepas. Overall, indoor temperatures simulated are higher than indoor design conditions recommended in MS 1525:2007 for thermal comfort. The findings address the potential thermal discomfort environment in residential building at different urban climates in Malaysia. The negligence of climatic design approach in residential building design could lead to uncomfortable indoor thermal conditions affect people productivity, health and quality of life. Occupants are apt to install air conditioning system as a solution for cooling purpose in their indoor environment comfort. In consequence increasing to existing energy demands in the building sector and extend the effort towards sustainable cities. Therefore, the research to develop strategies to reduce indoor temperatures in residential buildings in urban micro-climates is encouraged in order to fulfil the indoor design conditions recommended in MS 1525:2007. It is also important that awareness and preparedness of developers, the public and researchers in order to promoting the implementation of the strategies on a large scale and at the same time develop new strategies that can make greater positive impact in Malaysia residential building design at varying micro-climates. The findings of this study can be used as a basis for comparison to evaluate the effectiveness of proposed strategies for better indoor thermal environment. The investigation of this study limited to three selected urban areas. Further studies on the different urban

areas and various cases in Malaysia are recommended for more accurate evaluation on thermal comfort issues in tropical climate.

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