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WINDOWS OPERATION FOR RESIDENTS' THERMAL COMFORT IN NATURALLY VENTILATED RESIDENTIAL BUILDING IN MALAYSIA

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ABSTRACT

Field environmental measurements were conducted for the indoor environment as well as the microclimate surrounding the building. Part of the indoor measurements was performed in two spaces for a full day with opened windows and another day with closed windows. One of the spaces' facade is exposed to direct solar radiation while the other is shaded by a balcony. The objective was to investigate the effect of windows operation on the indoor environment under the direct exposure to solar radiation. Results showed that opening windows helps to reduce the indoor operative temperature in space under direct solar radiation, whereas it causes an increase in space under shadings. Occupants must understand that windows operation is highly influenced by direct exposure to solar radiation. Additionally, this indicates the importance of building orientation, geometry, shading devices and thermal insulation to avoid the effects of solar radiation and reduce the indoor temperature.

1. INTRODUCTION

As people spend most of their time in buildings, the indoor environment is needed to be more comfortable and healthy (Daghigh, 2015). According to ASHRAE, (2004), to be thermally comfortable means to be satisfied with the thermal environment. The last one is influenced by many factors that can be categorized into three groups, namely environmental factors, individual factors, and contributing factors (Nicol, 1993). The environmental factors include air temperature, relative humidity, air movement, and mean radiant temperature. These factors play primary role in the thermal comfort of the occupants.

In hot and humid climates, thermally discomfort conditions will occur if ineffective strategies are applied to reduce heat penetration into a building (Zain *et al*., 2007). Sunlight penetrating to

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buildings will increase the mean radiant temperature of building's surfaces comparing to body temperature, thus results in the body heat gain causing discomfort conditions. In addition, a lot of energy will be required to flush out the penetrated heat in order to improve the thermal environment and provide comfortable conditions.

Natural ventilation is an attractive alternative that can provide and maintain a comfortable and healthy indoor environment. Air movement can influence the body heat loss to the surrounding environment by improving the convection and evaporation processes, which will result in improving the comfort level. Studies in hot-humid climate for naturally ventilated buildings indicate that with higher indoor air velocity, an increase in the comfort temperatures voted by respondents is observed (ASHRAE, 2004; Hooi *et al*., 2013). Additionally, moderate air velocity (>0.25 m/s) in the range 32-40°C reduce both thermal discomfort and skin moisture (Nicol, 2009). As a result, a study proposed the lower limit for air velocity for three ranges of operative temperature; 0.4 m/s for 24-27 °C, 0.41-0.8 m/s for 27-29 °C and >0.81 m/s for 29-31 °C (Cândido *et al.*, 2011). In addition, natural ventilation helps to alleviate the associated problems with air-conditioned buildings and reducing energy consumption (Montazeri *et al.*, 2010).

Operable windows and doors are the main sources of natural ventilation in buildings. In some cases, windows and doors together are needed to be opened to encourage and facilitate cross ventilation. According to Mishra & Ramgopal (2013), opening windows is one of the most favored adaptive techniques for people across countries, which can be attributed to its ease, effectiveness, and economy of use. Indraganti (2010a) stated that although windows opening behavior is more dependent on the indoor temperature (i.e. the direct environment of the subject), the percentage of using windows opening was increased with outdoor mean temperature until it reached 31–32 °C, then slowly decreased. As the outdoor mean temperature increased, the occupants' modification was to close the windows, since opening windows would allow more heat to go in and increase the indoor temperature. Windows opening behavior was also influenced by several other factors including privacy, safety and security, suitability, sun penetration, etc. Inkarojrit and Paliaga, (2004) linked windows usage to the local zone and stated that it is highly correlated with indoor operative temperature.

In addition, Indraganti (2010a) also noted that the percentage of open windows was found to increase when occupants' votes in thermal sensation scale move from slightly cool to slightly warm, while it remained stable at the maximum value when the votes are between slightly warm and warm. Furthermore, the proportion of open windows was highest in the morning and lowest at midday during the hot summers, while it stayed at the higher percentage throughout the day when the indoor temperature was around the skin temperature and humidity was relatively higher. Similarly, he found the doors opening had same adaptive usage as windows. H. Zhang et al. (2007) found that the three most common reasons to open windows are "to feel cool", "to feel more air movement" and "to let in fresh air", while the primary reason to close windows was "to reduce outdoor noises".

The use of open balcony doors was found to have the same role as windows opening. However, the percentage of open balcony doors (58%-86%) was higher than the open windows (37%-75%). This can be explained by the privet space of the balcony compared to windows that in many cases were opened to the exterior of the building or into a public corridor (Indraganti, 2010a). Wafi (2012) found that thermal discomfort of students in their accommodations' room occurred when the doors are closed. He related that to the lower airflow results from closing the doors, which are the only available way that permits cross ventilation through the room. Additionally, he found that the closing of the doors was due to privacy and/or security requirements.

It can be concluded that buildings' windows operation is influenced by many factors, but mainly by the outdoor environmental conditions. Generally, occupants tend to open windows and possibly doors to allow natural ventilation. Once the outdoor air temperature increased, they usually tend to close windows. However, does this scenario work well under different exposure to direct solar radiation with the absence of thermal insulation in buildings' envelope. This paper is to investigate the influence of direct solar radiation on buildings' windows operation for providing comfortable indoor environment conditions in naturally ventilated residential buildings.

2. METHODOLOGY

This paper is part of a study for the thermal comfort of residents in naturally ventilated high-rise residential buildings in Penang, Malaysia. A quantitative approach was selected using questionnaire survey on thermal comfort along with measurements of the environmental parameters. For this paper, only the data related to building's windows are presented.

Measurements of the environmental parameters, namely Air temperature, Relative humidity, Air velocity, and Globe temperature were conducted to examine these parameters between indoor and outdoor microclimate environment, and between a space with external walls shaded from direct solar radiation (i.e. living area) and a space with external walls fully exposed to direct solar radiation (i.e. master bedroom). The measurements were performed using the following tools:

1. EXTECH Thermo-Hygro: to measure Air temperature and Relative humidity.
2. TESTO 415 Hotwire Anemometer: to measure Air velocity.
3. Globe thermometer: to measure Globe temperature.
4. SEKONIC ST-50 Hygrothermograph: to measure outdoor Air temperature and Relative humidity.

In addition, part of the thermal comfort assessment questionnaire was designed to investigate their daily use of windows opening on a scale represent the daily periods (i.e. morning, afternoon, evening, and night) as well as the people who never use windows opening.

2.1 CASE STUDY

N-Park, a high-rise residential building, was selected for this study. Building's layout (i.e.

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single loaded corridor type) can provide the optimum opportunity for cross natural ventilation and the orientation to north-south represents the recommended orientation in Malaysia. It is located on the east coast of the Penang Island, Malaysia. It consists of four blocks (Figure 1) and has a total number of 988 flats. Each flat has a built-up area of 700 sq. ft., and comprises a master bedroom, two children bedrooms, living room, kitchen and two bathrooms.

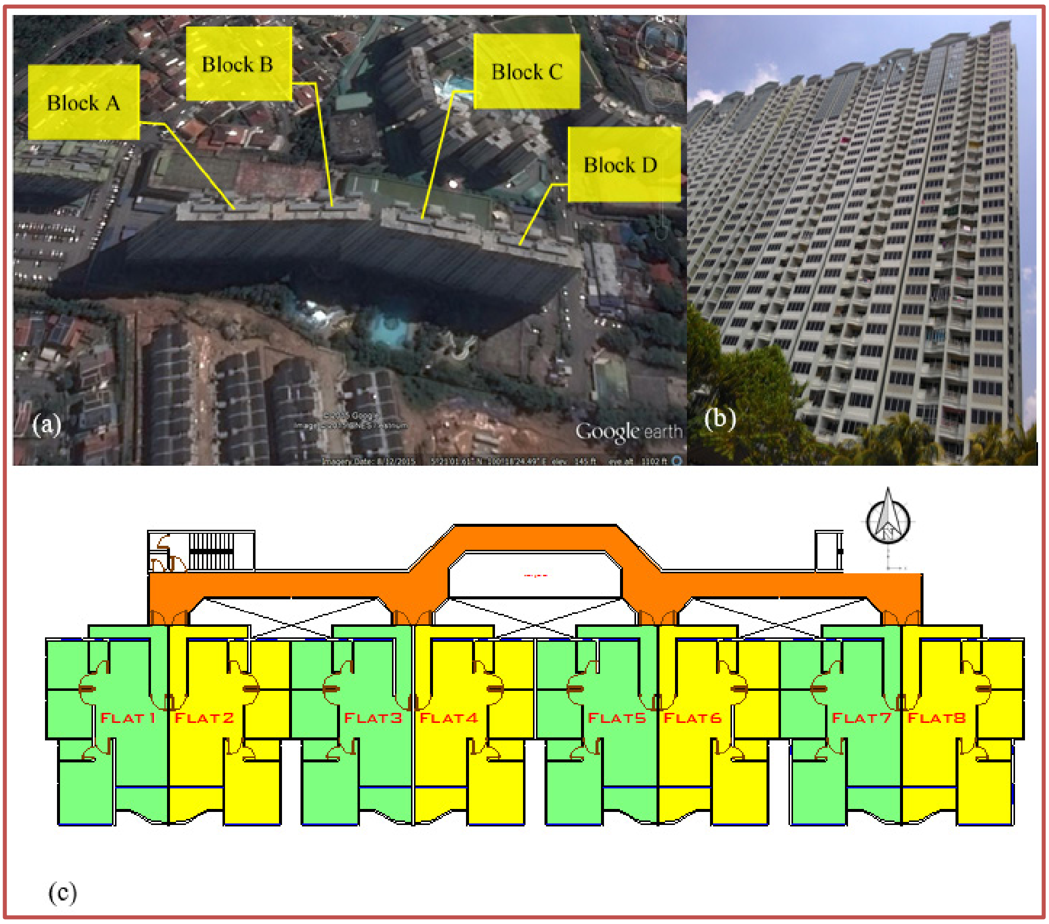

Figure 1: case study (a) Building's blocks (source: Google Earth, 2015), (b) Part of the south elevation, (c) Block layout

2.2 DATA COLLECTION

Measurements of the environmental parameters were conducted during February 2016, almost clear days, from 9.00 am to 9.00 pm, with an interval of 1 hour. The measurements were taken from the middle of the space at 1.1 m above the floor according to (ISO 7726, 2001; ASHRAE, 2004) (Figure 2). Air temperature, Relative humidity, and Globe temperature were recorded directly from the instruments. Air velocity was recorded as the average of 3 minutes period (ISO 7726, 2001). Mean radiant temperature and operative temperature were calculated also in accordance with (ISO 7726, 2001).

3. RESULTS AND DISCUSSION

Indoor measurements and outdoor measurements of the microclimate surrounding the building were performed on sunny and cloudy days with fully opened windows throughout the day. It was observed that Indoor air temperature followed outdoor air temperature with a difference not more than a half degree Celsius (Figure 3). It steadily rose up to reach the peak temperature at 4.00-5.00 pm and then decreased. The maximum and minimum indoor air temperatures were 32.8°C and 27.4°C respectively. Additionally, the maximum difference between sunny and cloudy days was 1.6°C.

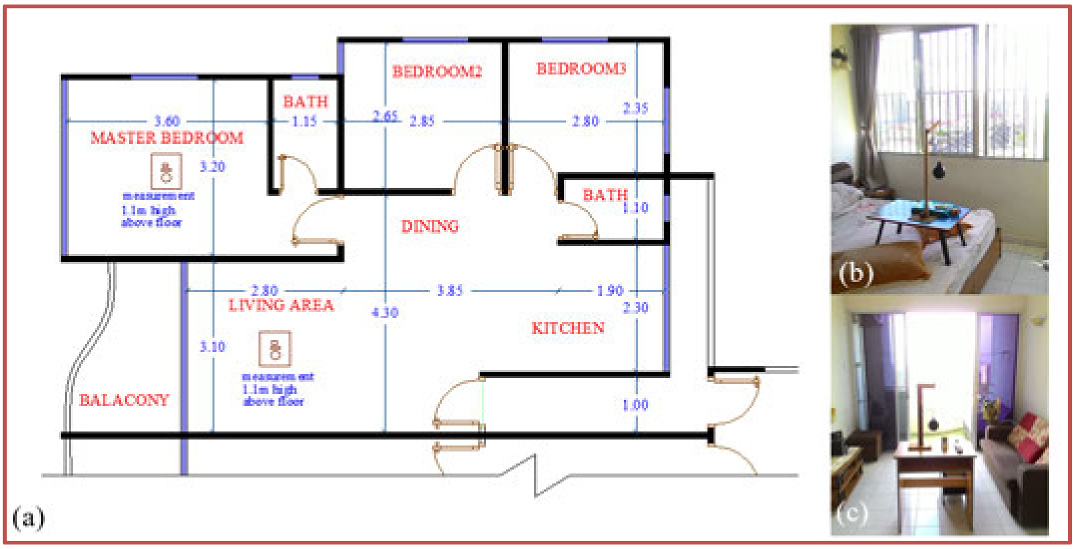

Figure 2: Data collection (a) location of measurement, (b) Master bedroom, (c) Living area

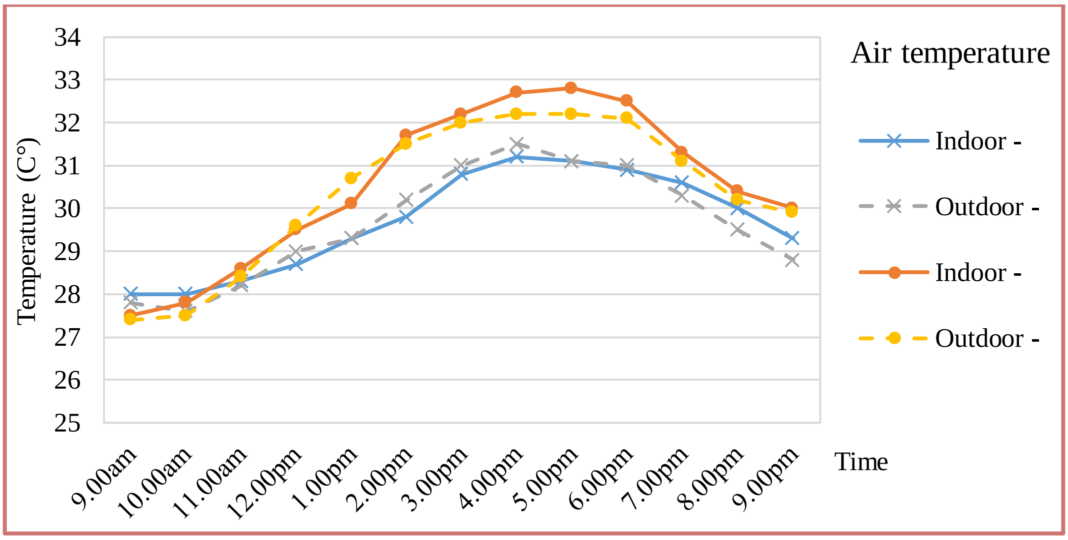

Figure 3: Indoor and outdoor Air temperature for sunny and cloudy days (9.00am to 9.00pm).

Similarly but with an adverse curve, Figure 4 shows that indoor relative humidity follows outdoor relative humidity, while the last one is generally higher with 3-5 %. It decreased rapidly from the highest point at morning to the lowest point around 2.00 pm to 4.00 pm, especially in the sunny day. This can be attributed to the higher temperature during this time. The difference in relative humidity between sunny and cloudy days was 10-15% until 5.00 pm where they became equal. Additionally, it is clearly shown how relative humidity is influenced by the air temperature. An increase in air temperature will result in a decrease in relative humidity and vice versa. Relative humidity describes the water vapor percentage in the air. As the air temperature increase, air expands and thus the spaces that hold water molecules increases. As a result, the relative humidity will decrease.

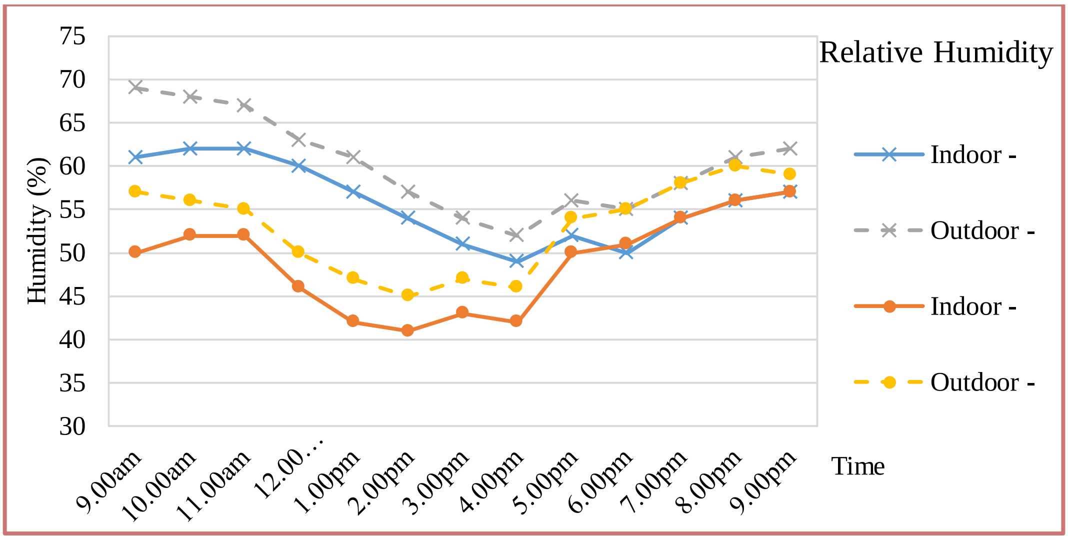

Figure 4: Indoor and outdoor Relative Humidity for sunny and cloudy days (9.00am to 9.00pm).

On the other hand, air velocity fluctuates throughout the day as can be seen in Figure 5. It reached as high as 3.6 m/s and decreased to 0.6 m/s. Also, it can be seen how indoor air velocity follows outdoor air velocity in its increases and decreases. However, there is no specific pattern that can be generalized to describe the air velocity.

Generally, it can be said that indoor measurements have same patterns as outdoor measurements, which reflect that indoor conditions in naturally ventilated buildings follow almost exactly outdoor conditions. This also indicates the importance of personal behavior for opening or closing windows in controlling indoor conditions. These findings are in line with Raja et al. (2001) and Dhaka et al. (2015)who stated that indoor and outdoor temperatures are well correlated and that the rate of change of indoor temperature with outdoor temperature is consistent. Humphreys et al. (2013) also indicated same results where the temperature within the building would correspond closely to the average outdoor temperature. Indraganti (2010) also stated that indoor environments followed outdoor conditions closely in naturally ventilated buildings.

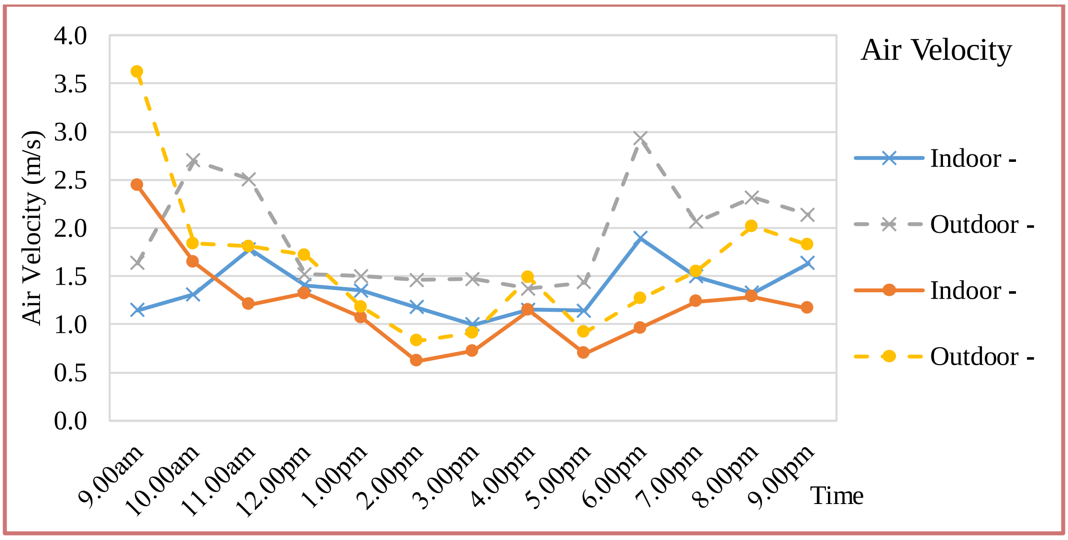

Figure 5: Indoor and outdoor Air velocity for sunny and cloudy days (9.00am to 9.00pm).

Furthermore, an investigation was carried out on the daily use of buildings windows and how it may be influenced by the time periods of the day (i.e. morning, afternoon, evening and night). In addition, the possibility of not using windows opening for natural ventilation. The result is illustrated in Figure 6. Generally, it can be said that residents start their day with opening windows during the morning. It achieved the highest percentage throughout the day (i.e. 72.4%). This may be linked to their needs for fresh air, and since the ambient outdoor air temperature is low, it can provide a comfortable condition. As they move to the afternoon period, the percentage of using opened windows decreased to 56.2%. The highest air temperature throughout the day is recorded during this period (see Figure 3); thus, some residents tend to close windows in order to avoid the penetration of the hot outdoor air temperature to the indoor spaces and instead, they may rely on mechanical techniques to provide comfortable conditions.

During the evening, when air temperature decreases, the percentage of opening windows slightly increased to 62.9%. However, at night, it decreased again to 45.7%, which may be attributed to many reasons including security, insects, and privacy. In addition, 8.6% of respondents votes was never open the windows.

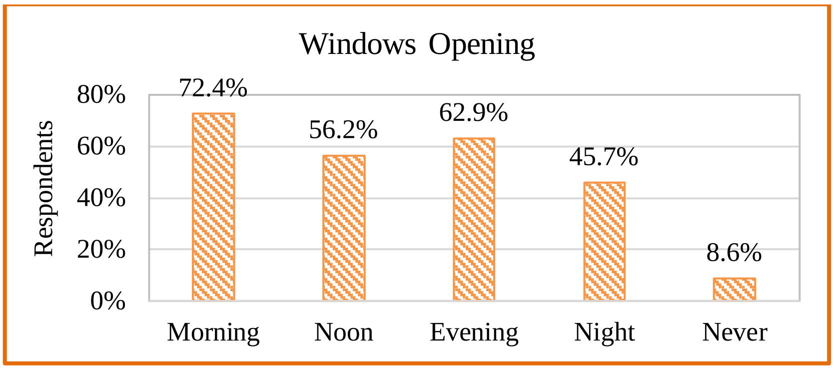

Figure 6: Daily usage of building windows.

Residents' behavior to operate buildings' windows reflects their dependency on outdoor air temperature. However, the role of direct exposure to solar radiation may affect this scenario. To investigate that, the operative temperature was calculated for the indoor environment to reflect the effect of both indoor air temperature and mean radiant temperature together. Figure 7 shows that operative temperature in the master bedroom was higher than the living area with a difference fluctuated between 0.6 C°- 2.0 C° for opened windows, whereas this difference increased up to 2.7 C° for closed windows. The maximum difference was during the afternoon period when the sun rays at the highest level. In addition, a steep increase in operative temperature with opened windows was observed, especially from 11.00 am to 5.00 pm when it reached the peak point, then followed by a steep decrease. However, with closed windows, the increase and decrease were roughly constant. The maximum operative temperature was with opened windows (i.e. 33.00 C° and 34.6 C° for the living area and the master bedroom respectively).

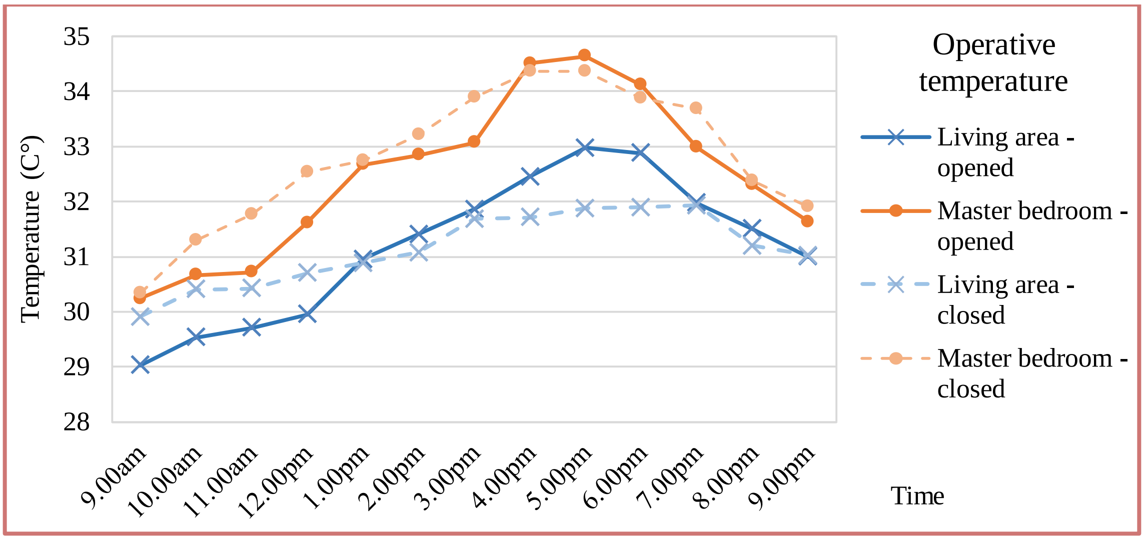

Figure 7: Operative temperature at living area and master bedroom with opened and closed windows.

In the living area, although the operative temperature was lower with opened windows compared to closed windows during the morning with a difference up to 0.9 C°, it became higher during the afternoon period with a difference up to 1.1 C° at 5.00 pm. This can be attributed to the ability of the indoor temperature with opened windows to follow the outdoor temperature, which is higher during the afternoon as discussed earlier in indoor and outdoor air temperature. However, closing windows plays as a barrier for the hot outdoor temperature and keeps the indoor temperature lower.

In contrast, the operative temperature at the master bedroom was almost lower throughout the day with opened windows compared to closed windows, with a difference up to 1.3 C°. However, it became higher just for two hours (i.e. 4.00pm to 6.00 pm) when it reached the peak point. Closing windows in the master bedroom, which is exposed to direct solar radiation with the absence of thermal insulation, causes the heat to build up, thus increasing the operative temperature, whereas opening windows help to dissipate this heat.

It can be said that opening windows helps to reduce indoor temperature where space's façade is exposed to direct solar radiation, whereas it causes an increase in indoor temperature where the façade is shaded from direct solar radiation. This shows the importance of shading devices to reduce the indoor temperature.

Relative humidity was almost equal in both living area and master bedroom with opened windows, while it slightly increased up to 4% with closed windows in the living area during the afternoon as shown in Figure 8. This can be linked to the higher indoor temperature in the master bedroom during this period, which caused relative humidity to be lower. The difference in relative humidity between opened and closed windows was due to the difference in outdoor humidity for the two days of the measurements. Furthermore, change in humidity throughout the day was steep with opened windows compared to steady change with closed windows.

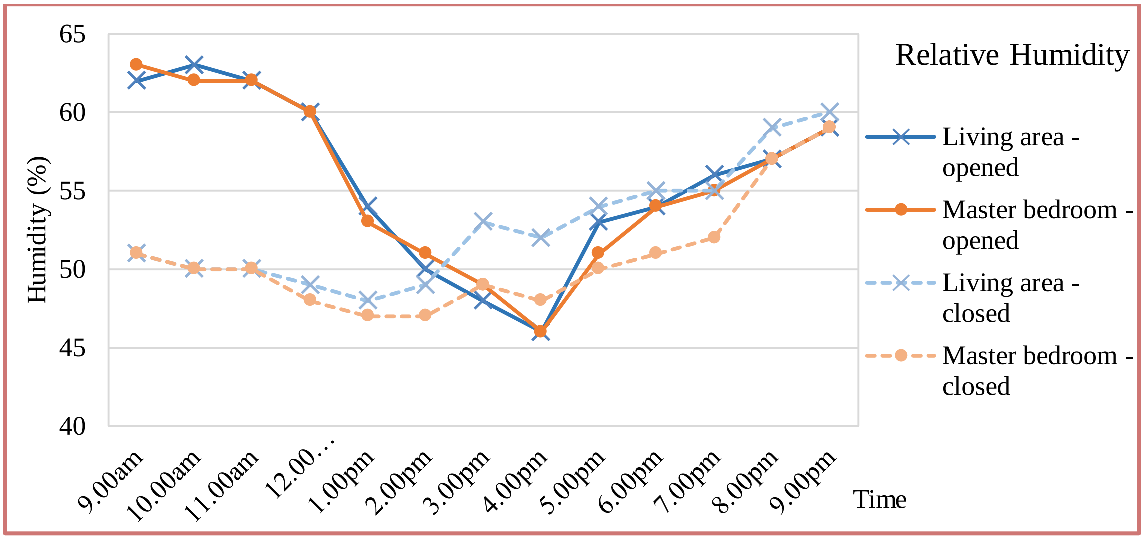

Figure 8: Relative Humidity at living area and master bedroom with opened and closed windows.

Finally, air velocity at the living area was generally higher than the master bedroom with a difference fluctuates between 0.2 m/s and 0.6 m/s, see Figure 9. This is due to the large windows on both sides of the living area that increases the cross ventilation, whereas the door is the only way in the master bedroom that may enhance the cross ventilation. The lowest reading for air velocity was 0.2 m/s in the master bedroom while highest reading was 1.4 m/s in the living area. Closing windows in both spaces caused air velocity to be as low as 0.02 m/s, which in turns will affect people's comfort.

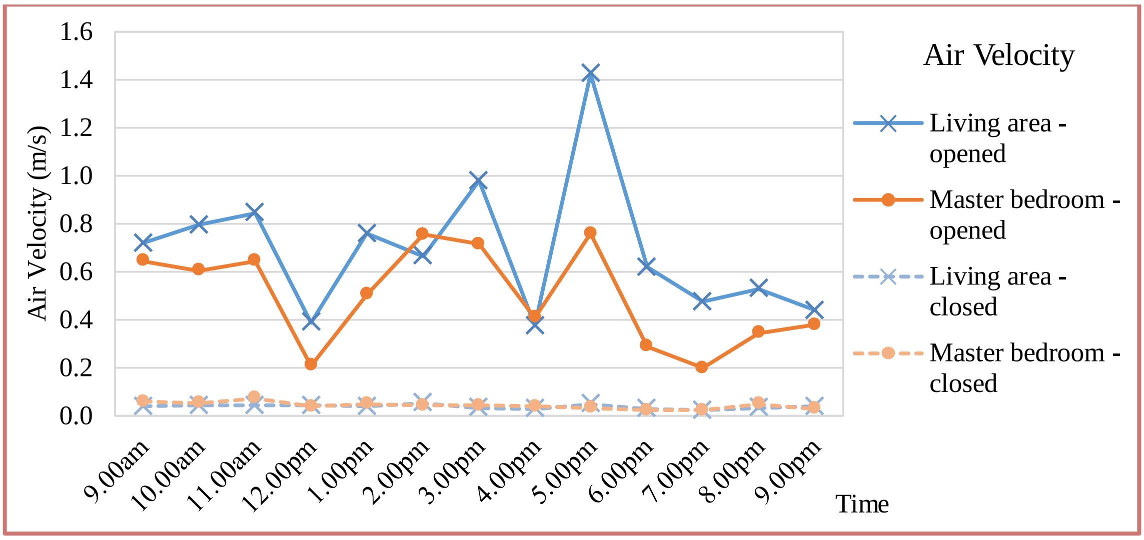

Figure 9: Air velocity at living area and master bedroom with opened and closed windows.

4. CONCLUSION

The objective of this paper was to investigate the influence of direct solar radiation on buildings' windows operation for providing thermally comfortable conditions. In buildings, windows are the main source of natural ventilation, which can help to provide a comfortable environment and reduce the energy consumption associated with mechanical conditioning. However, their operation must be controlled to achieve the optimum conditions. Windows in spaces without direct exposure to solar radiation may be opened as far as the outdoor temperature within an acceptable range. However, they will be needed to be closed once the outdoor temperature increases beyond this range, which is usually occured around the noontime. On the other hand, windows in spaces with direct exposure to solar radiation, especially with the absence of thermal insulation, are required to be opened most of the day to allow the heat penetrated into the indoor environment to be removed and dissipated to outside with the air movement. In addition, this indicates the importance of building orientation, building geometry, shading devices and thermal insulation to avoid the effects of solar radiation and reduce the indoor temperature.

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