BUILDING HEIGHT EFFECTS ON INDOOR AIR TEMPERATURE AND VELOCITY IN HIGH RISE RESIDENTIAL BUILDINGS IN TROPICAL CLIMATE

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Abstract: Natural ventilation as a passive design strategy has been considered recently as an effective way to reduce energy consumption and create better indoor thermal condition. Different architectural elements and techniques have been applied in previous studies to increase the efficiency of ventilation systems in naturally ventilated buildings. However, limited researches have been carried out on the application of building characteristic such as form and height of building and their effects on overall indoor ventilation. Current study looks into the impact of building heights on the indoor air temperature and velocity and indicates that how this building character influences on indoor thermal condition. The field experiment was applied to evaluate indoor thermal condition in a high-rise building in Kuala Lumpur, Malaysia. Selection of units is based on the orientation and height with emphasis on outdoor prevailing wind direction. The results show that there are significant differences between mean air temperature and velocity within units in the lower and higher floors. The air temperature differences in the living and dining rooms in units are 1.2 C° and 1.54 C° respectively. The air temperature within the unit at higher floor is cooler than the unit at lower floor. This can be justified due to significant difference of indoor air velocity in the lower and upper levels. The results demonstrate that the amount of indoor wind in the living room at unit in the upper floor is four times higher than the amount for same room at unit in the lower floor. However, this value for the dining room is just two times more.

Keywords: Building height; Natural and mechanical ventilation; Passive design strategies; Residential building; Tropical climate

INTRODUCTION

Improvement of building services and comfort level and growth in population have increased building energy consumption to the level of transport and industry [1]. Studies by [2, 3] indicate that buildings consume about 40% of the world energy. The huge amounts of energy in buildings spend for cooling and heating by air-conditioners. Statistics show that the heat, ventilation and air conditioning (HVAC) systems in standard buildings represent more than 50% of the annual energy consumption [4]. This percentage may be higher in hot-humid regions, where high temperature and humidity increase air-conditioner usage. However, these mechanical systems which control air temperature, velocity and humidity cannot provide comfort properly for building occupants. Study by [5] confirms that unpleasant odour due to returning air circulation inside the mechanically ventilated buildings causes uncomfortable condition for occupants. This situation shows the design failure in HVAC systems for buildings.

Natural ventilation as an effective passive design strategy is a best alternative to moderate indoor temperature. Study by [6-8] confirm that natural ventilation is the best approach in providing indoor thermal comfort to dwellers. Previous studies approve that this strategy offers several advantages to occupants. Indoor air quality modification, thermal comfort satisfaction and reduction on operation costs are summarized as the main advantages for naturally ventilated buildings [9, 10]. In a tropical region like Malaysia, natural ventilation is the best strategy to

remove the heat which is trapped into indoor environment. Study by Aynsley [11] demonstrates that small offices and residential buildings are the most applicable buildings for operation of natural ventilation. Generally, the operation of natural ventilation in buildings is based on the air pressure ventilation known as wind force and the stack effect ventilation or thermal force [12]. Several studies have been carried out to highlight the relevant ventilation approaches and elements which impact on ventilation efficiency. In overall, the elements have been evaluated for sufficient ventilation rate can be classified to physical and non-physical elements. Air well design, ventilation openings, corridors and façade design are some physical elements. On the other hand, nighttime ventilation, some adjustment works such opening windows or types of clothes to maintain the comfort level are considered as non-physical element.

Air well design which works based on the stack effect process is one of the most ancient passive designs. It works by taking the fresh air through the opening in building façade, discharging the warm air through the vertical duct from the basement up to the roof level in buildings [13]. By application of air pressure difference between indoor and outdoor environment, ventilation openings play a major function by directing fresh air from windward side and discharging from the rearward side of the building. Opening sizes, location and orientation of windows have been evaluated to highlight their effects on air velocity ratio and pattern [14, 15]. Louvers windows as an alternative for ventilation opening were applied in a study by [16] to find out the influence on indoor air velocity. Transferring the outdoor wind to indoor environment by corridors is another strategy to ensure maximum ventilation in building. This element has been evaluated in a study by [17] in Malaysia and the study found that integrated corridors inside a building can deliver adequate local air flows. Air pressure intensification and air change requirements can be further improved by integrating such corridors with other passive design strategies [18]. Turbulent effect by creating "rough" surfaces in building façade is innovative strategy to induce wind into indoor environment in previous researches. The "rough" surfaces increase the pressure difference between the outdoor and indoor and increase air velocity ratio in building [19].Nighttime ventilation as non-physical element improves the indoor temperature due to higher ventilation rate and less heat loss. Studies by [20, 21] in Malaysia show nighttime ventilation is the best strategy to cool down building if compared with day time and full time ventilation.

Natural ventilation performance in buildings relies on outdoor spaces effects as well. Wind direction, building orientation and shape may affect the volume of air ratio on indoor space [3]. Study by [10] confirm that the north-south is the best orientation in Singapore. The results show that the cooling load can be decreased 8.57-11.54% by changing the building orientation from west-east to the north-south. Furthermore, building characteristic can influence on ventilation effectiveness according to building form and heights. Study by Tantasavasdi et al. [14] shows air velocity in the squared-shape houses can circulate better than the rectangular-shape houses in Thailand. A study by Wong et al. [22] in Singapore confirms the significant effect of building height on surface temperature. The results show the difference of surface temperature between lower floor and higher floor is more than 2° C. The findings of study can be rationalized due to high amount of wind speed at higher floors.

Although previous studies focus on innovative techniques and elements to explore their effects on indoor ventilation, to date few studies have been carried out to investigate the effect of building height on ventilation efficiency in tropical climate. Whilst the wind speed increases in the higher levels of building, it influences on the indoor thermal condition and overall comfort. Therefore, current research aims to evaluate the impact of building height on indoor air velocity and temperature in a residential building. Therfore, field experiment was carried out to compare two units in lower and upper levels of a high-rise residential building in Kuala Lumpur, Malaysia.

**RESEARCH DESIGN AND METHOD**

Microclimate data

The case study is located in Kuala Lumpur, Malaysia within equatorial region. Uniform temperature and high amount of humidity are common condition through the year. Figure 1 shows ten years monthly mean temperature data as the hottest months are May, Jun and July respectively.
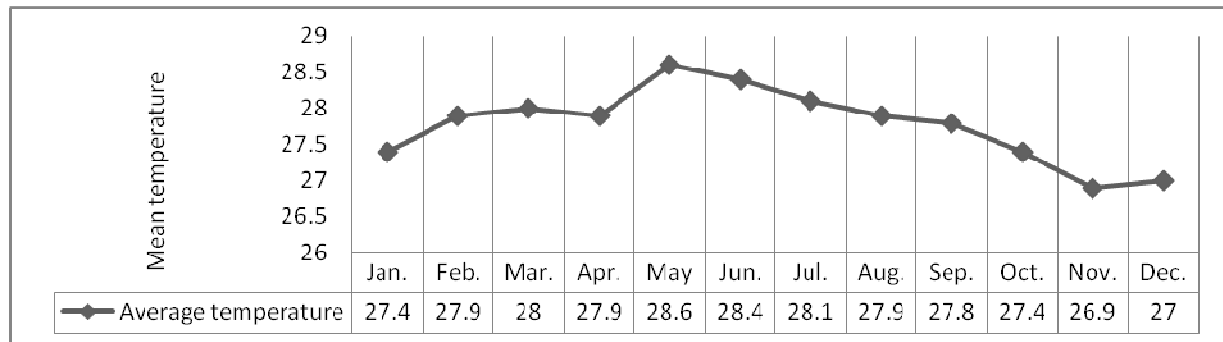
Figure 1: Mean temperature, unit C° for period of ten years (2002 to 2012) [23]

Figure 2 presents the mean surface wind speed since 2006. The maximum value is recorded for August whilst the minimum is for November and December. However the values for three hottest months are in the medium range. Therefore, a period of two weeks in the July is selected for field measurement as the condition of this month could represent overall condition of the year.

The annual frequency for various wind directions reveals that units in north-east orientation receive the maximum amount of air velocity through the year [23]. Hence, the living room windows in north-east units are facing to the prevailing wind; the impact of wind on indoor thermal condition can be more tangible. So, two units in level 3 and 13 in north-east orientation were selected for field measurement to represent the condition in the lower and upper floor respectively.
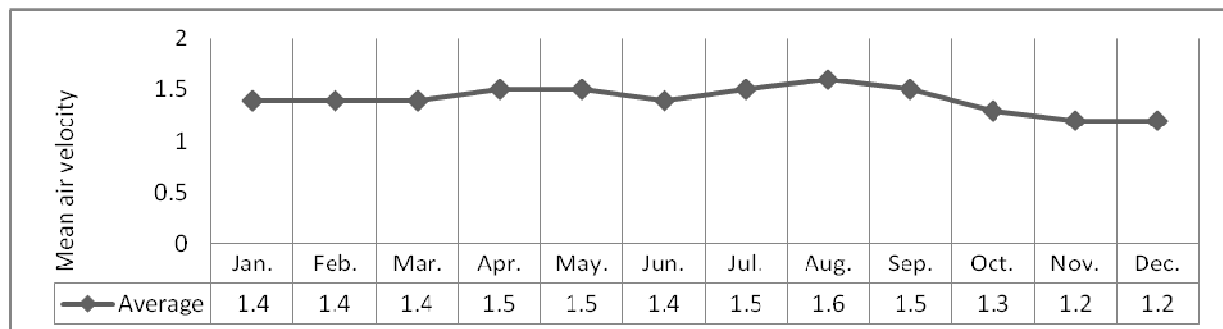
Figure 2: Records of mean surface wind speed for a period of seven years (2006 to 2012) [23]

Building description

A high-rise residential building was selected for the purpose of field measurement in Kuala Lumpur. Figure 3 shows the north-east side of selected case study which has fifteen stories. Two more floors on top of the building are penthouses. The building represents common development of high-rise residential building in terms of stories and shape of building. The living and dining rooms of selected units in lower and upper floors were studied to find out the real condition of units faced to the prevailing wind. The studied area for each unit was 32 Sq including corridor near the entrance. Figure 4 shows the interior space for selected unit where the sides roll windows in living room allow the external wind flows through the unit. Although the selected units were equipped by air-conditioner and ceiling fan, all mechanical ventilation systems were switched off during the experiment to allow units cool down naturally. In this case, all sides roll windows were opened and the external wind flows into indoor environment efficiently.

Figure 3 North-east side of selected case study

Figure 4 Interior space of unit, including dining and living rooms

Data collection

HOBO U12 series and external air velocity sensors (T-DCI-F900-S-O) were selected to record indoor air temperature and velocity. The temperature range for U12 series is -20° to 70° C and the speed range for F900 is 0.15 to 5 m/s respectively. Figure 5 shows data logger and sensor were used for data acquisition. The data loggers and sensors were set up at a height of 1.1 m from the floor and 0.8 m away from the internal walls using a stand pole. This height is considered as the typical human body level [24]. Figure 6 demonstrates the location of stand poles in living and dining rooms. The interval time for data recording was set to one minute. Data collection for two selected units was recorded simultaneously for the period of two weeks in July 2013. The collected data were initially sorted in HOBO pro software for further analysis in statistical package for social science (IBM SPSS 22).

Figure 5 Data logger and sensor for data acquisition

**Figure 6 Locations of stand poles in living and dining rooms**

RESULTS ANALYSIS AND DISCUSSION

The analysis of results was carried out in IBM SPSS 22 to understand the effect of building height on indoor thermal condition. As all collected data were quantitative and distributed normally, parametric tests were selected for further data analysis. Independent sample T-test was applied in the current study whereas the building height of two different units was considered as the factor list. Indoor air temperature and velocity for living and dining rooms were the dependent variables for abovementioned test. Figure 7 shows descriptive results whereas indoor air temperature in the living and dining rooms of two selected units are compared to understand the impact of height on the indoor temperature. As it is shown in figure, indoor temperature for living room in level three is 1.2 C° higher than same room in level thirteen. The difference of mean temperature reaches up to 1.54 C° in the dining rooms as well. In overall, the indoor air temperature in the higher floor is meaningfully lower than the lower floor in all rooms. On the other hand, indoor wind at unit in thirteen floor is considerably higher than the unit in third floor. Figure 8 demonstrates that indoor air velocity in the living room of the unit in the higher floor is four times higher than same room in unit at the lower floor. Although the indoor wind decreases considerably in the dining room of both units, the amount of indoor wind for the higher floor is approximately two times more than the lower floor.
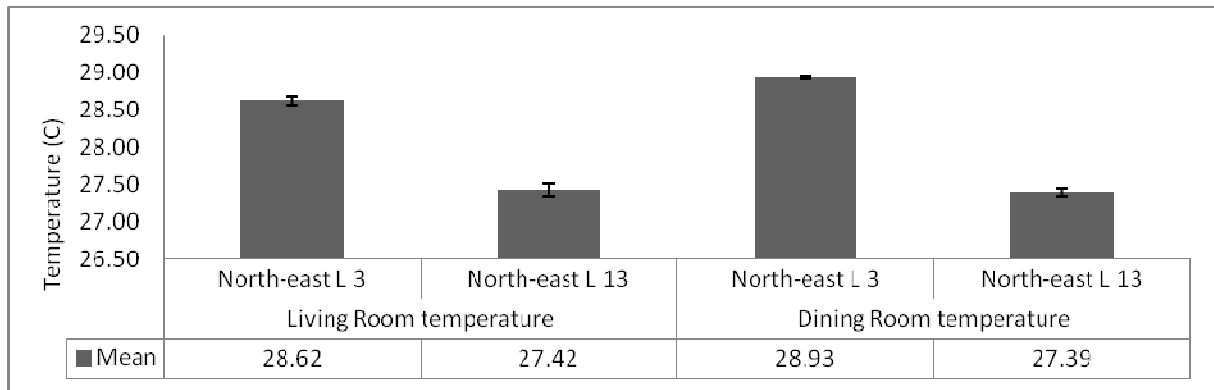
Figure 7 Indoor air temperature within living and dining rooms at lower and upper floors

Comparison of descriptive results at figure 7 and 8 reveals the effective role of building height on indoor air temperature and velocity. Results show that the indoor air temperature in the living room can be reduced by 1.2 C°as the indoor wind increases up to four times in the higher floor. Furthermore, the increase of indoor wind up to 0.1 m/s in the dining room of unit in the higher level causes the indoor air temperature drops down by 1.54 C°. According to the results, the need for air velocity to reduce indoor air temperature in the dining room is less than the living room. This is due to the direct effect of sun light in the living room. Based on the location of units, they receive considerable amount of solar heat in the morning time directly which is absorbed by the internal wall. During this time, the internal walls in the dining room which is not in close proximity to windows receive indirect heat. The internal walls in the living rooms release the heat during the day and increase the indoor temperature. Therefore, higher amount of wind could be applied in the living room to reduce indoor temperature.
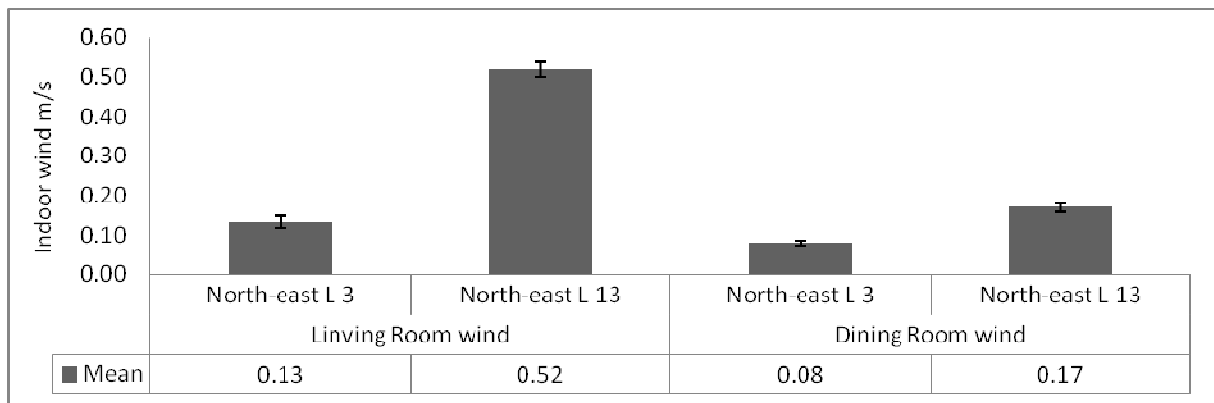
Figure 8 Indoor wind within living and dining rooms at lower and upper floors

Further analysis by independent sample T-test shows the difference on indoor temperature and indoor wind within selected units. Table 1 shows the result of the test whereas the comparison of mean temperature and air velocity in each room is presented in different rows. The logarithm of data for wind was applied to normalize the collected data. The difference between the variables (temperature and wind) is considerable conventionally when the significant value (Sig. and Sig 2-tailed) is below or equal to 0.05 in the table [25]. According to the table, the Levene's test for equality of variances was carried out to justify the accurate results for T-test equality of means. Whilst the significant values in Levene's test for all variables in the selected rooms are equal to 0.00, it could be claimed that the equal variances of variables between the units are not assumed. Therefore, the highlighted results of

T-test were considered for further interpretation. Based on the results, the Sig 2-tailed is equal to 0.00 for all variables in compared rooms. In the other words, the difference of indoor air temperature in the living and dining rooms of two selected units is meaningful. Furthermore, the difference of indoor wind in all rooms in units at levels three and thirteen is significant. So, The current test confirms the considerable impacts of building height on the indoor air temperature and velocity in a high-rise building.

Table 1Independent sample T-test results divided by indoor temperature and wind within selected units

		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		
										Lower	Upper
Living room temperature	A[a]	68.03	0.00	12.13	288.00	0.00	1.20	0.10		1.01	1.40
	N/A[b]			12.13	234.85	0.00	1.20	0.10		1.01	1.40
Dining room temperature	A	168.4	0.00	26.69	288.00	0.00	1.54	0.06		1.43	1.65
	N/A			26.69	184.41	0.00	1.54	0.06		1.43	1.65
Log living room wind	A	25.30	0.00	-21.99	288.00	0.00	-0.74	0.03		-0.81	-0.67
	N/A			-21.99	235.89	0.00	-0.74	0.03		-0.81	-0.67
Log dining room wind	A	10.15	0.00	-5.21	288.00	0.00	-0.19	0.04		-0.27	-0.12
	N/A			-5.21	280.99	0.00	-0.19	0.04		-0.27	-0.12

[a] Equal variances assumed   [b] Equal variances not assumed

CONCLUSION AND RECOMMENDATION

Current study examines the influence of height as one of the building characteristics on ventilation effectiveness in high-rise residential building. Two units faced to the prevailing wind in the lower and upper floors were considered for field measurement. The indoor air temperature and velocity were recorded for a period of two weeks. The collected data were analyzed by independent sample T-test in IBM SPSS 22 to understand the effect of height as a design alternative for indoor temperature modification and indoor ventilation improvement in high-rise buildings.

The analysis of data shows the difference of indoor air temperature and velocity in selected units is considerable. According to the results, the air temperature differences in the living and dining rooms in units are 1.2 C° and 1.54 C° respectively. The air temperature within the unit at the higher floor is cooler than the unit at the lower floor. The independent sample T-test confirms the difference of mean air temperature between two units in different heights as the significant value (Sig 2-tailed) is equal to 0.00 for all rooms. This can be justified due to significant difference of indoor air velocity in the lower and upper levels. The results demonstrate that the amount of indoor wind in the living room at unit in the upper floor is four times higher than the amount for same room at unit in the lower floor. However, this value for the dining room is just two times more. It can be declared that the building height effects on the indoor air temperature and wind directly.

Furthermore, the study explores that the need for indoor wind to decrease the indoor air temperature in the dining room is less than the living room. Based on the results, the indoor air temperature in the living room can be decreased by 1.2 C° when the indoor air velocity reaches up to 0.52 m/s. However, the indoor air temperature can be reduced by 1.54 C° whilst the indoor air velocity goes up to 0.17 m/s. This is due to position of living room which is in the close proximity to windows. The study recommends further studies to understand the effect of other building characteristic such as shape and form of the building on the indoor air temperature and velocity through high-rise building in tropical climate.

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