© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Thermal Comfort Assessment of An Office Room Under High Air Conditioning Setting Temperatures with Fan-Assisted Ventilation

M. A. Zakaria[1*], M. S. Amran[1], S. A. Rozmi[1], M. N. Yasin[1], P. C. Leng[2], M. H. Hanipah[3]

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

[2]Faculty of Built Environment and Surveying,
Universiti Teknologi Malaysia, 81310 Skudai, Johor, MALAYSIA

[3]Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Panchor, Johor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2022.14.06.035
Received 27 January 2022; Accepted 15 August 2022; Available online 20 November 2022

Abstract: The usage of the air-conditioning system to provide comfortable indoor conditions is found necessary especially for hot-and warm countries. However, the excessive use of the air-conditioning system or without properly controlled will significantly affect the energy consumption of the building and also the environment badly. This study investigates the strategy to reduce energy for cooling in an office room by utilizing the high setting temperature of the air conditioning system with the addition of fan ventilation by field measurement. About 9 study cases have been investigated which includes the air-conditioning setting of 27°C to 28°C, with and without fan-assisted ventilation. The measured physical thermal comfort parameters are air temperature, relative humidity, wind speed, and black globe temperature. The operative temperature and Predicted Mean Vote value (PMV) have been calculated for each study case for analysis. The results revealed that the comfortable condition with neutral sensation can be achieved by air-conditioning setting of 28°C with an air speed of 1 m/s-1.2m/s. Moreover, the results showed that the room with 27°C-28°C setting temperature was in a comfortable condition before afternoon hours, while fan-assisted ventilation is required to enhance the comfortable hours through the rest working hour. By this practice, it is expected the energy consumption and cooling load of the building can be reduced.

Keywords: Thermal comfort, fan-assisted air conditioning system, high set point air-conditioning

1. Introduction

Countries worldwide are now continuing to undergo rapid urbanization as the growing population is increasing. The global energy consumption was increased almost double the average rate of growth from 2010 to 2018 [1]. For instance, in Malaysia, the total energy demand in all sectors has risen about two times for the past two decades from 29699 ktoe in 2000 to 57218 ktoe in 2016 [2], while the total population also steadily increase from 23.1 million in 2000 to 32.4 million in 2019 [3]. One of the contributing factors is the increasing need for heating and cooling for

*Corresponding author: azuanz@uthm.edu.my

buildings. It was reported that the worldwide interest in air-conditioner (AC) doubles every year especially in hot climates with low- and medium-income nations [4].

The interest towards the usage of air-conditioners is more significant especially in hot climates [4]. In the case of Malaysia, the climatic condition is hot and humid climate throughout the year with an annual mean temperature of 26°C with an average daily minimum to a maximum of 23°C and 36°C, respectively [5]. In this hot or warm weather, it is understood that one of the methods to achieve the desired indoor thermal condition is by using an air-conditioner system. However, while the system can provide an instant and uniform indoor comfort temperature for occupants in a building, it will also affect the total energy consumption of the building if not wisely used [6]. One of the building sectors that consume high energy for cooling is the office building. It was reported that the energy consumptions in office buildings are 10 to 20 times than of residential buildings at the rate of 70-300 kWh/m^2 annually [7]. For instance, the Malaysian office buildings that are equipped with air-conditioners consumed about 57% of their total energy for cooling [8]. Moreover, it was a rare case for the building occupants to obey the standard requirement setting for ventilation by air-conditioner which is between 24°C - 26°C and resulted in overcooling [9]. Therefore, the required low energy practices should be implemented to reduce energy consumption, especially in office buildings.

There are several strategies to reduce cooling load for low energy consumption by the air-conditioner system which included the application of fan-assist ventilation [10], maintaining an indoor setting point of 26°C with 50-60% RH level [6], and providing a well-insulated room [11]. Another interesting method is by increasing the air-conditioner setting temperature of more than 26°C. A study from [12] highlighted that for every 1°C increase in setpoint temperature, roughly about 6% of energy saving. High setting air-conditioner temperature has been implemented in Japan with the name of ‘COOL BIZ’ concept during summer where it supports relaxed dress codes and raising the cooling set point to 28°C in public buildings [13]. By increasing the air-conditioner setting point temperature, the air conditioning system can reduce the energy consumption from 6% to 17.2% for each degree increase in thermostat set-point, and air velocity may “offset” a part of the estimated cooling requirement [6]. For the case in Malaysia especially, a 2°C raise in the thermostat set point can roughly save about RM 730 million per annum [6]. This shows the potential of high setting temperatures to reduce energy consumption in building especially in office buildings.

This paper presents the thermal comfort assessment of an individual office room under a high setting of air-conditioning temperature with fan-assisted ventilation.

2. Methods

2.1 Field Measurement: Case Study Building

Field measurement has been conducted in a case study building which is an individual office room in the Faculty of Civil Engineering and Built Environment of Universiti Tun Hussein Onn Malaysia. The office building was equipped with an air-conditioning system with manual adjustment control, operable windows, and an internal curtain. The size of the office room is about 3.3 m in length, 4.6 m in width, and 2.8 m in height. The area of the window is about 1.2 m^2. The office walls are made of brick with plaster and the ceiling is from ceiling board. During the measurement, the light was turned off and the curtain was closed.

2.2 Data Collection

The measured parameters are the air temperature, relative humidity, black globe temperature (25 mm), and wind speed. As illustrated in Fig. 1, all measuring equipment was positioned at the center of the room at the height of 1.1 m above the floor level as suggested in AHSRAE 55 [14] for sedentary position. Nine study cases have been developed which consisted of the control condition (no ventilation) and ventilation with high air conditioner setting temperature (27-28°C) with and without fan-assisted ventilation (basic and basic + fan) as shown in table 1. In the case of fan-assisted ventilation, the fan was located at the edge of the room which is about 2 meters from the measurement point with the size of 12 inches in diameter. The fan-assisted ventilation was measured at speeds of 1, 2, and 3. The recorded average wind speed for speeds 1, 2, and 3 are 1 m/s, 1.2 m/s, and 1.3 m/s, respectively. Furthermore, all parameters were recorded in one minute of interval time from 8:00 to 18:00 for two days in each case.

2.3 Method of Analysis

The measured data were analyzed to assess the thermal comfort condition by using the predicted mean vote method (PMV). Predicted Mean Vote was defined as the index to predict the mean thermal sensation vote for the combination of the thermal environmental variables, activity levels, and clothing values that involves a big group of occupants [15]. In this study, the PMV value was calculated by using CBE Thermal Comfort Tool [16] which can be accessed through http://comfort.cbe.berkeley.edu/. The values for clothing level and metabolic rate for a typical office building in hot and humid climates were estimated at 0.65 clo and 1.08 met respectively [14]. To be noted that, the recommended PMV value for the comfortable indoor condition should be ranged between -0.5 to +0.5 which indicates neutral sensation [14]. Moreover, the analysis will be based on the operative temperature index where it can be calculated by the following equation [17]:

$$t_o = \frac{\left(t_{mr} + \left(t_a \times \sqrt{10v}\right)\right)}{1+\sqrt{10v}} \tag{1}$$

where, v = Air velocity, t_a = Air temperature, and t_{mr} =Mean radiant temperature. While t_{mr} was calculated using the following equation [17]:

$$t_{mr} = \left[\left(t_g + 273\right)^4 + \frac{1.1\times10^8 \times v^{0.6}}{\varepsilon_g \times D^{0.4}}\left(t_g - t_a\right)\right]^{1/4} - 273 \tag{2}$$

where, t_g = globe temperature, D = diameter of globe, and ε_g = emissivity of black globe.

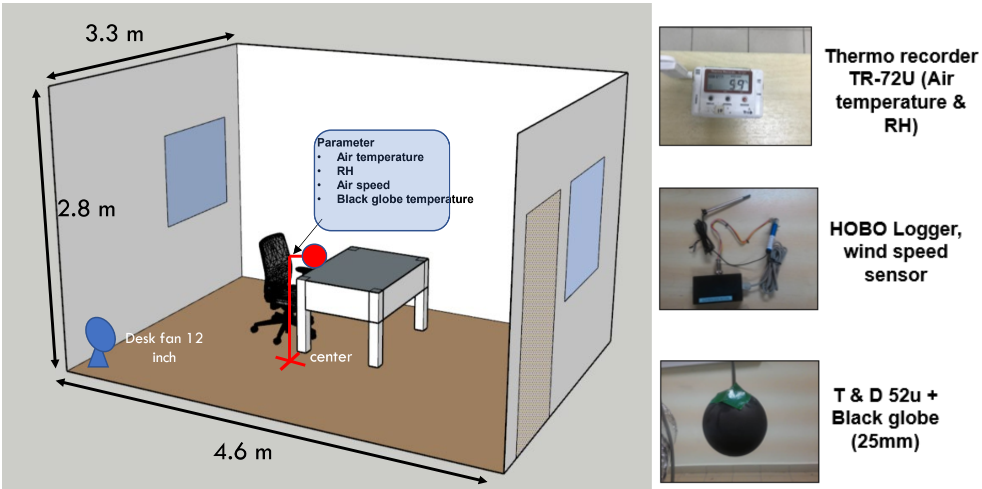

Fig. 1 - Field measurement setup

Table 1 - Study cases

Category	Air conditioner (A/C) setting	Fan speed (level)	Case study Number
Control (no A/C) and fan	-	-	1
Basic (only with A/C)	27 °C	-	2
	28 °C	-	3
Basic + fan	27 °C	1	4
	27 °C	2	5
	27 °C	3	6
	28 °C	1	7
	28 °C	2	8
	28 °C	3	9

3. Results and Discussion

In this section, the results are presented based on the average operative temperature (°C) and predicted mean value (PMV) of two days measurement period from 8:00 to 18:00.

3.1 Operative Temperature and PMV Value of Control Case (No Ventilation) and Air-Conditioning Without Fan-Assisted Ventilation

Fig. 2 shows the average operative temperature of case 1 (control case), case 2 (setting temperature of 27°C), and case 3 (setting temperature of 28°C). As shown, case 1 which is the non-ventilated condition (control case) recorded the operative temperature range of 27°C to 30.5°C. Specifically, the operative temperature rises above 28°C after 12:00. which indicated the effect of infiltrated solar radiation through windows and radiant temperature from the wall.

Meanwhile, case 2 shows the operative temperature range of 26 to 27.5°C. The result shows a period of over-cooling by the air-conditioning system from 12:00 to 14:00 which is lowered than the setpoint temperature (27°C).

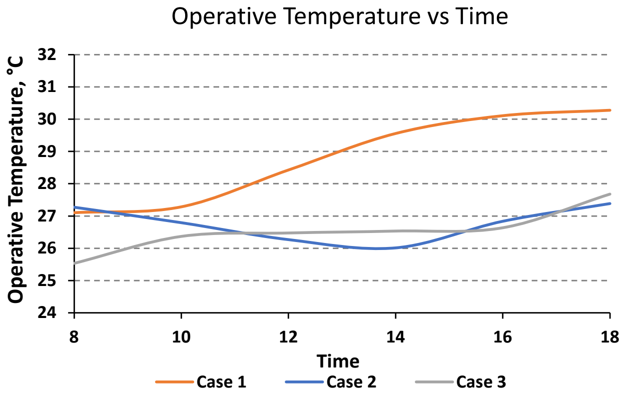

Fig. 2 - Average operative temperature for cases 1, 2, and 3

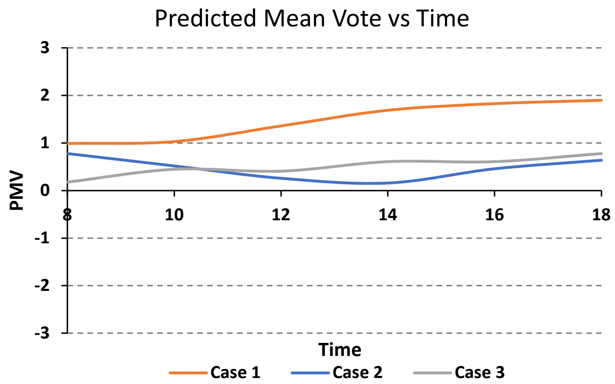

Fig. 3 - Average operative temperature for cases 1, 2, and 3

A similar trend of the over-cooling period was recorded in case 3 which the operative temperature maintains at 1.5°C lower than the setting temperature (28 °C) between 10:00 to 15:30. On the other hand, in case 3, the minimum and maximum recorded operative temperatures are 25.5°C and 27.5 °C, respectively. Based on this result, it shows that the operative temperature for case 1 was much higher than the other two cases across time due to non-ventilated conditions. In average, the operative temperature in case 1 was about 2°C higher than that of case 2 and case 3. This situation is clearly indicating that an office room without the usage of an air conditioning system will resulting in a non-comfort condition.

Fig. 3 shows the graph of PMV for the above-mentioned three cases. For case study 1, the recorded PMV values were in the range of 1.0 to 1.9 which exceeded the recommended comfort value (0.5) [14]. Meanwhile, for case 2, the highest PMV was 0.78 and the lowest was 0.16. The graph shows that the room reached neutral sensation (comfort, 0-0.5) only for 4 hours which from 12:00 to 16:00. The rest of the working hours recorded neutral to slightly warm sensation (0.5-1.0). As for case 3, the recorded PMV were ranged from 0.2 to 0.8. In this case, the comfort condition was achieved for 5 hours (10:00 to 15:00). These results indicate that without fan-assisted ventilation after the noontime such as in cases 2 and 3, the indoor condition tends to be slightly warm and the possibility to become uncomfortable (PMV>0.5).

3.2 Operative Temperature and PMV of Room with 27°C Setting Point with Fan-Assisted Ventilation

Fig. 4 shows the graph of operative temperature against time for cases 4, 5, and 6. For case study 4, the highest recorded operative temperature was 28.5 °C which is during the early hours. Then the temperature uniformly reduced to 25.0 °C-25.5 °C for 5 hours from 11:30 to 16:30. A similar pattern was observed for the operative temperature of case 5. For case study 6, the lower operative temperature was achieved earlier at 10:00 (25.3 °C). Then the temperature maintains almost the same value for about 6.5 hours until 16:30. To be noted that the temperature begins to increase at the later working hour (from 16:30) due to the main ventilation unit for the building (air-conditioning) was shut down.

Overall, even with different fan-assisted ventilation speeds, the operative temperature of all cases showed almost identical values from 11:30 to 16:00 with a difference of ±0.5°C.

Fig. 5 shows the results of PMV against time for case studies 4,5 and 6. For case study 4, the range of PMV values recorded was -0.74 to 0.32. In these cases, most of the time, the room condition was beyond the neutral sensation value which either in a slightly cool condition (8:00 to 14:00) or slightly warm (14:00-16:00). The neutral sensation condition was only reached within the last two hours of measurement time (PMV -0.5 to 0). Meanwhile, for case 5, the PMV value was ranged from -0.72 to 0.47. It was found that neutral sensation conditioned was achieved from 8:00 to 10:00. However, the rest of the PMV value shows the room was in a slightly cool sensation (PMV -0.5 to -1.0). A similar trend was observed for case 6, where the range of PMV values was 0.19 to -0.78. This indicates that with the set-point temperature of 27°C and wind speed of 1.2 m/s to 1.3 m/s, a relatively comfortable condition is possible to be achieved.

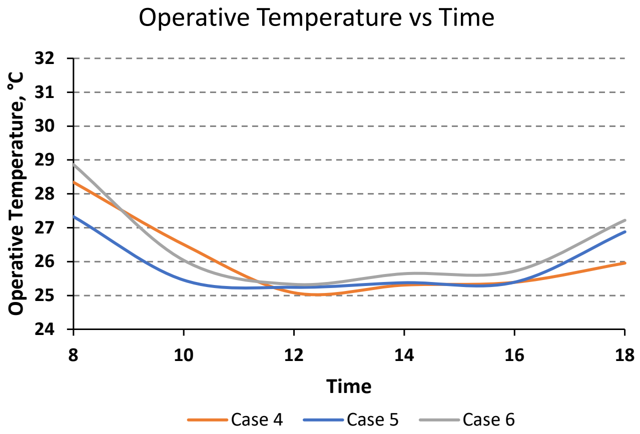

Fig. 4 - Average operative temperature for cases 4, 5, and 6

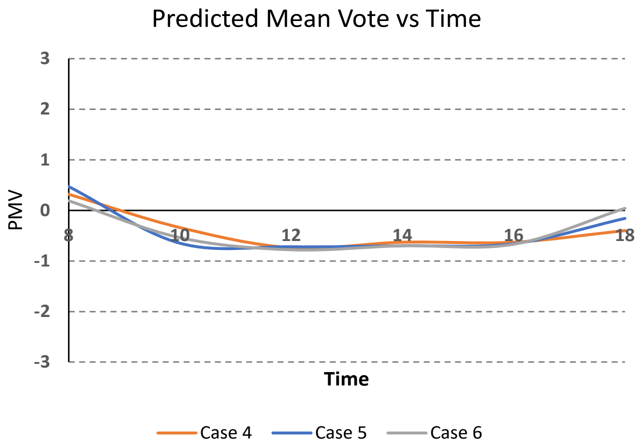

Fig. 5 - Average operative temperature for cases 4, 5, and 6

3.3 Operative Temperature and PMV of Room With 28°C Setting Point with Fan-Assisted Ventilation

Fig. 6 shows the results of operative temperature against time that represents case studies 7, 8, and 9. As shown, the range of operative temperature for cases 7, 8 and 9 are 26.1°C to 28.5°C, 26°C to 28.6°C and 26.1°C to 28°C, respectively. For cases 7 and 9, the operative temperature of the room was reduced to the steady-state condition of 26.3°C at 9:30 in the morning. Meanwhile, for case 8, the steady-state condition was only achieved from 11:30 at a similar temperature value. However, for most of the time, the room operative temperature was below the setpoint temperature (28°C). This indicates the air-conditioning system will overcool the building spaces way below the set temperature to ensure the cool condition will be achieved (similar with previous cases). However, a small difference in air temperature can be seen, for instance, at 28°C setting point where the average air temperature was about 0.5°C to 1.0°C higher than that of 27°C setting temperature. Also, it was found that no significant impact of ventilation speed on the operative temperature value between these cases where the difference is about ±0.5°C.

Fig. 7 shows the results of PMV against time for cases 7,8 and 9. As shown, for case 7, the range of PMV is -0.43 to 0.32. Meanwhile, the range of PMV for cases 8 and 9 were 0.5 to 0.35 and 0.05 to -0.52, respectively. Overall, these

PMV values indicate that, for most of the time, the room was in the state of neutral sensation condition which is within the recommended value of -0.5 to 0.5 (comfort). Case 9 tends to be in slightly cool condition (0.52) due to high wind speed conditions. Also, it can be seen that the comfort temperature can be achieved at a high setting temperature (28°C) with a minimum wind speed of 1.0 m/s.

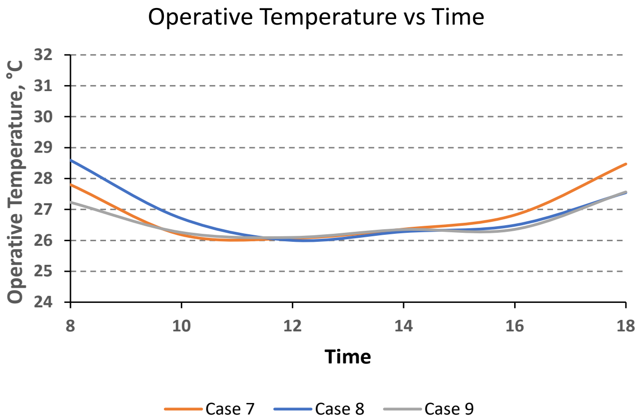

Fig. 6 - Average operative temperature for cases 7, 8, and 9

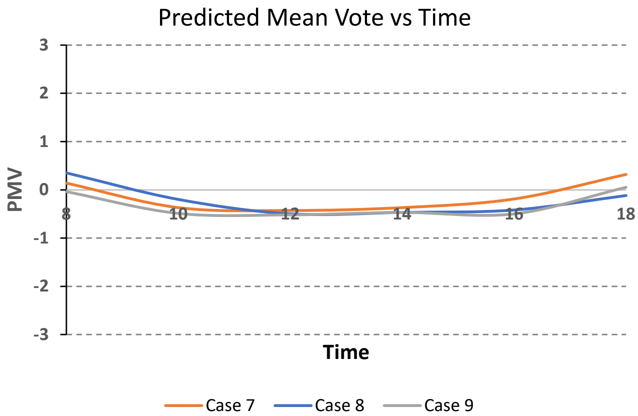

Fig. 7 - Average operative temperature for cases 7, 8, and 9

3.4 Comfortable Hours

Table 2 shows the summary of comfortable hours (neutral sensation) for all cases. As shown, a non-comfort condition was observed for case 1 due to the non-ventilated condition. The case with air-conditioning (A/C) but without fan-assisted (Case 2 and 3) can provide at least 4-5 comfortable hours, but the rest of the time tends to be slightly warm.

Table 2 - Comfortable hours

Study Case No	Condition	Comfortable Hours (neutral)/8hours	Remarks
1	Control: no ventilation	none	
2	A/C: 27°C	4 hours	
3	A/C: 28°C	5 hours	
4	A/C: 27°C+ fan speed 1	2 hours	Tends to be slightly cool most of the time
5	A/C: 27°C+ fan speed 2	2 hours	Tends to be slightly cool most of the time
6	A/C: 27°C+ fan speed 3	2 hours	Tends to be slightly cool most of the time
7	A/C: 28°C+ fan speed 1	8 hours	
8	A/C: 28°C+ fan speed 2	8 hours	
9	A/C: 28°C+ fan speed 3	7.8 hours	Tends to be slightly cool most of the time

Meanwhile, for cases 4,5, and 6, the comfortable hour is achieved for only 2 hours while the rest of the time tends to be slightly cool. On the other hand, the cases with 28°C setting points and fan-assisted ventilation showed comfortable conditions for most of the time. By comparing all the results, case 7 shows the ideal practice to be applied which consists of high setting temperature with minimum fan speed to reduce electricity for cooling in the office. On the other hand, the second ideal condition is to apply the setting as in case 2 or 3 but with fan assisted during non-comfortable hours. With this practice, the warm condition can be prevented.

4. Conclusion

This study aimed to determine the possibility of achieving comfort conditions in a small office room by using the high setting temperature of the air conditioning system with the addition of fan ventilation in the hot and humid climate. Therefore, field measurements were conducted in the office room with air temperature settings exceeding 26°C which is 27°C to 28°C, and with and without fan-assisted ventilation. As for the result, it was found that the most comfortable condition with neutral sensation can be achieved by air-conditioning setting of 28°C with an airspeed of 1 m/s-1.2 m/s (speed 1 and speed 2). On the other hand, the room can be maintained at a temperature of 27°C or 28°C without a fan during earlier working hours but requires fan-assisted ventilation from the afternoon to achieve comfortable working conditions. By this practice, it is expected the energy consumption and cooling load of the building can be reduced. To be noted that this experiment was conducted without occupants in the room and psychological thermal comfort assessment. Moreover, the air-conditioning system in the office room tends to provide an air temperature that is lower than the selected setting possibly due to the system design factor or affected by the thermostat readings. It is recommended to include the feedback of occupants or psychological assessment and to be tested in precise high-temperature conditions (27°C or 28°C) in future research.

Acknowledgments

Authors wishing to acknowledge assistance or encouragement from colleagues, special work by technical staff and financial support by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot H079).

References

[1] World Energy Outlook 2019, IEA (2019). https://www.iea.org/reports/world-energy-outlook-2019

[2] Suruhanjaya Tenaga (2020). Malaysia energy statistics handbook 2019. https://meih.st.gov.my/

[3] Department of Statistics Malaysia (2022). Population and Demography. https://www.dosm.gov.my

[4] Rodriguez C. M. & D'Alessandro M. (2019). Indoor thermal comfort review: The tropics as the next frontier. Urban Climate, 29, 100488. https://doi.org/10.1016/j.uclim.2019.100488

[5] Al-Tamimi N. A. M. & Syed Fadzil S. F. (2011). Thermal performance analysis for ventilated and unventilated glazed rooms in Malaysia (comparing simulated and field data). Indoor and Built Environment, 20(5), 534–542. https://doi.org/10.1177/1420326X11411

[6] Kwong Q. J., Adam N. M. & Sahari B. B. (2014). Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review. Energy and Buildings, 68, 547-557. https://doi.org/10.1016/j.enbuild.2013.09.034

[7] Yang L., Lam J. C. & Tsang C. L. (2008). Energy performance of building envelopes in different climate zones in China. Applied Energy, 85(9), 800-817. https://doi.org/10.1016/j.apenergy.2007.11.002

[8] Mustapa M. S., Shaikh Salim S. A. Z., Mat Ali M. S. & Rijal, H. B. (2017). Investigation of thermal comfort at different temperature settings for cooling in university building. Journal of Mechanical Engineering (JMechE), 4, 123-134. https://ir.uitm.edu.my/id/eprint/39145

[9] Sikram T., Ichinose M. & Sasaki R. (2020). Experimental study on thermal comfort towards increasing temperature set-points in air-conditioned office spaces in a tropical region: A case study in Thailand. Nakhara: Journal of Environmental Design and Planning, 18, 63-82. https://doi.org/10.54028/NJ2020186382

[10] He Y., Chen W., Wang Z. & Zhang, H. (2019) Review of fan-use rates in field studies and their effects on thermal comfort, energy conservation, and human productivity. Energy and Buildings, 194, 140-162. https://doi.org/10.1016/j.enbuild.2019.04.015

[11] Buonocore C., De Vecchi R. Scalco V. & Lamberts, R. (2020). Thermal preference and comfort assessment in air-conditioned and naturally ventilated university classrooms under hot and humid conditions in Brazil. Energy and Buildings, 211, 109783. https://doi.org/10.1016/j.enbuild.2020.109783

[12] Atthajariyakul S. & Lertsatittanakorn C. (2008). Small fan assisted air conditioner for thermal comfort and energy saving in Thailand. Energy Conversion and Management, 49(10), 2499-2504. https://doi.org/10.1016/j.enconman.2008.05.028

[13] Lakeridou M., Ucci M., Marmot A. & Ridley, I. (2012). The potential of increasing cooling set-points in air-conditioned offices in the UK. Applied energy, 94, 338-348. https://doi.org/10.1016/j.apenergy.2012.01.064

[14] ANSI/ASHRAE (2017) Standard 55:2017. Thermal Environmental Conditions for Human Occupancy. ASHRAE, Atlanta.
[15] Fanger P. O. (1970) Thermal comfort, analysis and application in environmental engineering. Danish Technical Press. https://doi.org/10.1177/146642407209200337
[16] Tartarini F., Schiavon S., Cheung T. & Hoyt T. (2020). CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. SoftwareX, 12, 100563. https://doi.org/10.1016/j.softx.2020.100563
[17] ISO 7726:1998 (1998). Ergonomics of the thermal environment—Instruments for measuring physical quantities. International Organization for Standardization.