Recent Trends in Civil Engineering and Built Environment Vol. 2 No. 1 (2021) 008–016

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

A Study of Thermal Comfort in Classroom Under Natural Ventilation and Air-Conditioner Condition in Hot and Humid Climate Country

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DOI: https://doi.org/10.30880/rtcebe.2021.02.01.002
Received 30 January 2021; Accepted 28 April 2021; Available online 30 June 2021

Abstract: Thermal comfort significantly affects the productivity and satisfaction of classroom occupants. A comfortable learning environment should be provided as it affects the teaching and learning process of students. Thermal system must be improve to increase the minimum level and evaluate the most suitable of comfort for students and lecturers in the classroom. This paper reviews study on the thermal environment of classroom under natural and air conditioner condition in hot and humid climate.The main objective is to identify thermal comfort range for classroom by natural and air-condiioned means in hot and humid climate. The data colletion involve two main phases where the first phase is by systematic review for both survey and field measurement types of studies. While the second phase focused on data abstraction and analysis. The result shows that majority respondent in the studies prefer 24°C to 26°C environment condition which is within the recommended temperature by ASHRAE Thermal Comfort Standard. Some students could have higher heat tolerances (27°C to 28°C) in the air-conditioned classrooms as they may accept heat levels that exceeded the standard although, there were about 17% students who preferred in cooler environments (21°C to 23°C) and more sensitive to warm conditions. Meanwhile, in the natural ventilation classroom, it seems that the range of temperature acceptable (23°C to 30.9°C). As conclusions, an adaptive thermal comfort strategies were identified as strategies to adjust the comfortable temperature ranges under air-conditioning system and natural ventilation condition for energy saving in classrooms.

Keywords: Thermal Comfort, Natural Ventilation, Air-Conditioner, Hot And Humid Climate

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1. Introduction

Thermal comfort significantly affects the productivity and satisfaction of classroom occupants. A comfortable learning environment should be provided as it affects the teaching and learning process of students. An excessively warm or cold in the classroom can cause thermal discomfort and physical stress, thus cause sickness and poor performance of the students [1]. Generally, ventilation system in classroom can either by using windows that can be manually controlled, or by using mechanical ventilation system such as air conditioner [2]. Natural ventilation can be obtained by opening the windows and allowing outside air to enter and making changes to indoor air quality. If the window is open, the air moves inside the room and the outside temperature decreases, and the indoor temperature drops [2]. Meanwhile, mechanical ventilation uses blowers, ventilators, filters and ducts to convey and expel air from space, usually referred as the HVAC system to provide thermal comfort in the environment. However, mechanical ventilation systems also will not guarantee satisfactory on air quality if design is poor and the system is not operated correctly [3]. Most ventilation levels in the classroom do not always comply with established standards, even if it is extremely important to improve indoor air quality. Poor air quality indoors can affect health and performance of students [4].

There is a lot of analysis in building thermal comfort based on past studies covering broad spectrum of building types. However, there is still a lack of proper documentation that focuses on thermal comfort in classrooms, particularly in hot, humid climates [5]. From the previous studies, most researchers focussed on thermal comfort in NV or AC classrooms and was aimed at incorporating thermal comfort and preference for students into development of energy-efficient air conditioning and natural ventilation system for classroom in hot and humid tropical region. It is important to consider the recent variety of comforts and techniques that can be used to achieve comfort in classrooms in hot humid climates, where they can also be used as a measure to minimise energy for cooling in classrooms [6]. This paper conducted a reviewed study that focused on thermal comfort surveys and field measurement in typical hot and humid climate classrooms.These studies have been classified based on parameters: relative humidity, air velocity, behavioral activity and metabolic rate and the thermal comfort approach. Current comfort standards, such as the ASHRAE Standard 55 were used as a guide for determining design values for operative temperatures and comfort equations based on rational and adaptive thermal comfort models. Current comfort standards such as the ASHRAE Standard 55 have been used to establish design values for operative temperatures, as well as comfort equations based on thermal comfort approach.

2. Methodology

2.1 Filtering and analysis

Thermal comfort studies were used to measure the thermal comfort level of quantitative (objective) as well as subjective assessments. Those surveys were conducted in accordance with ISO 7730 or ASHRAE 55 standard rules which set out the range of indoor conditions in order to achieve an adequate thermal comfort for building occupants [5]. The classrooms were different in design dimensions (e.g. classroom size, window wall ratio, shadings) and ventilation system. The cases examined are mostly NV and AC, or a few cases were mechanically ventilated by fans. The value of air movement, relative humidity, metabolic rate, and clothing value were recorded to define the preferred or comfort temperature for a classroom.

3. Results and Discussion

3.1 Analyses of preferred neutral temperature in classroom (T_n)

Results The analysis is based on the previous studies that were conducted in both natural ventilated (NV) and air-conditioned (AC) schools, primarily in hot and humid countries, and a few studies have been conducted throughout the year. Seven point of ASHRAE scale were used in the research to obtain neutral temperature at which most people vote for “neutral” [7]. Referring to the

previous thermal comfort in NC, neutral temperature were obtained by analyzing the relationship between TSV and operative temperature and it is found that the neutral temperature were between 23°C–30.9°C [7]. The highest neutral temperature was reported in Vietnam and Bangladesh with an average neutral temperature of 30.9°C, which was affected by the weather in the country where the weather was hot without rainfall [8, 9]. While the lowest neutral temperature calculated using predicted mean vote (PMV) was reported in Indonesia with 23°C which is quite low when contrast with the operative temperature in the classroom [10]. According to Hamzah [10], the value of 23°C is smaller than the neutral temperature (T_n)obtained from the actual votes either by TSV or TCV. The neutral temperature obtained by the vote on thermal sensations (TSV) was 29.0°C and 28.5°C respectively.

The neutral temperature result obtained from the present study of Hamzah [10] were almost similar to Hussein [7] where 25.9°C was obtained based on PMV regression with a the range of comfort 24.4°C to 27.4°C. In the meanwhile, the neutral temperature based on TSV regression was 28.4°C with acceptable range of 26°C to 30.7°C. However, the neutral temperature value observed for all countries appears to have higher thermal tolerance and to be able to adapt to the environment they are used to, even though thermal conditions have beyond the standards. Based on the previous study in air-conditioner classrooms, the highest neutral temperature for air-conditioner condition was recorded in Thailand with an average of 28.1°C [11]. According to Hussaro [11], the higher the air speed, the neutral temperature for the TSV and PMV will be increased. However, the range of neutral temperature for TSV (26.7°C–28.3°C) and PMV (27.7°C–28.4°C) at all air velocity were corresponded with thermal comfort acceptability of thermal sensation vote (26±0.5– 28±0.5 °C), which is the accepted temperature. This could mean that most Thai students will accept temperatures as high as 28±0.5°C by changing the air-conditioning speed. In the findings of Hussein [7], most respondents have voted "acceptable"/satisfied for both air conditioning as well as non-air conditioned buildings within the temperature ranges of the TSV regression. Meanwhile, the lowest neutral temperature was reported in Malaysia with 22°C which is lower than others [3].

3.2 Analyses of thermal comfort range

On the basis of the papers reviewed, most researchers focusses on thermal comfort in naturally ventilated classroom or in air-conditioned classrooms. This research was aimed at incorporating thermal comfort and preference for students into the development of energy-efficient air conditioning and natural ventilation system for classroom in hot and humid tropical region. The result in the Figure 2 shows that 58% of student in this research were within the recommended ranges by ASHRAE standard which is 24°C-26°C. The ASHRAE Standard 55 stated that 80% of occupants should have voted for the central three categories (slightly cool, neutral, and slightly warm) in an adequate thermal environment. However, based on the subjective assessment by respondents, 17% were also not comfortable with the indoor thermal state of the learning environment. Yatim [1] mentioned, these may due to the different of thermal sensations among occupant even in the same environment. Not all student were found to be pleased with the indoor thermal climate, even though all locations surveyed were fitted with air conditioning to provide a comfortable learning environment.

However, 25% of occupant from this research can adapt to higher temperature between 27°C to 28°C which exceed the recommended temperature by ASHRAE. Zomorodian [5] also point out in their study that children were more sensitive to lower temperature compared to adult with tolerance temperatures 4°C and 2°C which lower than the rational adaptive comfort model predicted. The finding were similar to Le [12], where in a primary school, the teachers' thermal sensation mean vote was 0.77, which was higher than children's. As a result, teachers could see a higher thermal environment than children in the same space. This outcome was consistent with the results, suggesting that the kids are more tolerant of higher temperatures. The teachers also preferred a cooler thermal environment, similar to the children's preference.

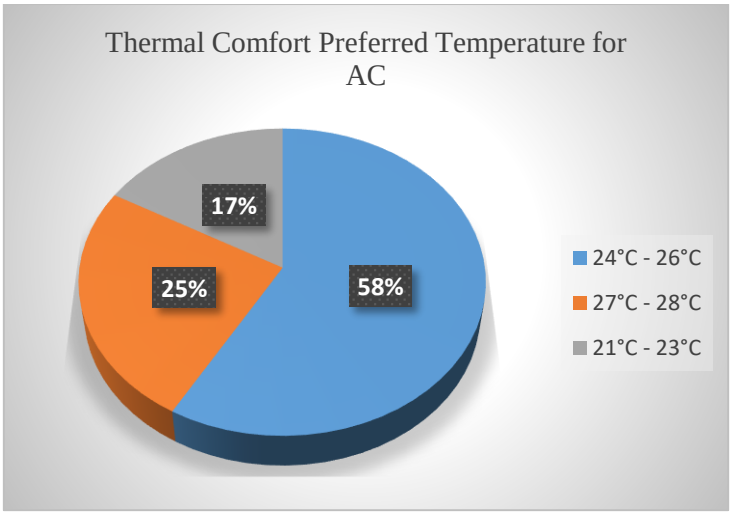

Figure 1: Percentage of Thermal Comfort Preferred Temperature for AC

Furthermore, as mentioned by Buonocore [13], there were no specific environmental condition for natural ventilation that clearly suited the preference for "no change" in thermal environment, although the thermal comfort of occupant responses showed that increased air speeds are sufficient for certain air temperature values. In this finding, there have a slightly different in comfort range between natural temperature and in air-conditioner condition which means the respondents in the tropic environment may have a higher heat tolerance since they accepted the thermal conditions which exceeded the standard thus there were different. Therefore it is convenient to use fans (mechanically ventilated) instead of air conditioning in natural ventilated buildings in tropic environment to improve the indoor thermal conditions in order to reduce the energy consumption in buildings

3.3 Relative humidity (RH)

Relative humidity has been observed in many studies performed in hot climates and has a major influence on thermal comfort. From the observation, the highest relative humidity were reported in Bangladesh with 78.4% in natural ventilation while 71.5% in Malaysia for air-conditioner condition [9,1]. Mamat [14] found, the indoor air humidity were influenced by occupants' activities. The growth of bacteria and moulds which cause disease can thrive and develop in humid conditions with high relative humidity. But Mamat [14] also mentioned in the finding, if humidity of air is less than 30%, inflammation in the throat, skin and nose of the occupants can occur, particularly in people with allergies and hyperactivity, due to the dry air. However, air humidity should stay between the upper and lower limits. According to ASHRAE [8], RH between 30% to 60% is considered as in the comfortable range and RH between 40% to 60% is optimal while RH 50% is considered ideal. From the Figure 3, it was found that 81% of respondent were preferred high humidity which is exceed than 60% of RH. However, relative humidity of between 40% and 70% does not have a significant impact on thermal comfort. RH may be higher than 70% in classrooms that are naturally ventilated, or where the weather conditions outdoors can influence the indoor thermal environment [15]. Humidity is important in warm environments because less sweat evaporates when moisture is high (80%+). The main method of heat control is the evaporation of sweat.

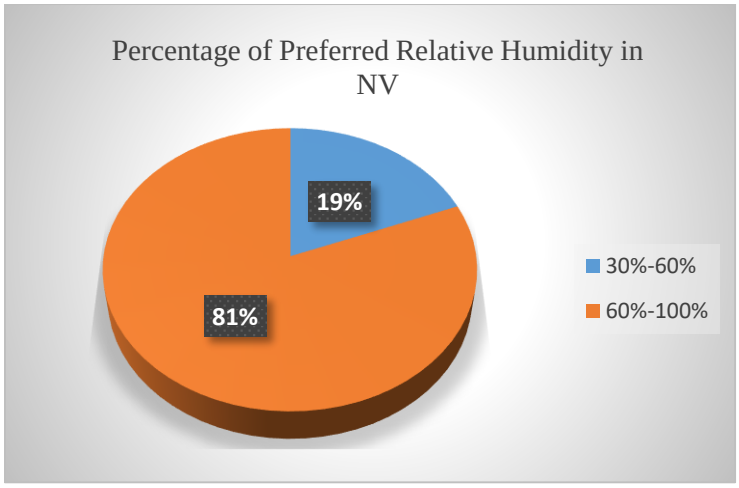

Figure 2: Percentage of Preferred Relative Humidity in NV

Even though most of the RH recorded in this study were slightly higher than the recommended range, but it still within the safety factor range. Besides, there were 19% from the studies were maintained within the comfortable range (30% to 60%). Referring to the Figure 4, in the classroom with air conditioner, 58% of respondent in the reviewed article are comfortable with relative humidity up to 60%. According to Air Comfort [16], this will lead to high humidity that cancels out the cooling effect of the air conditioner. Therefore the classroom will feel warmer than it is when the humidity is too high. The occupant might find their self-running air conditioner more difficult and not get the desired effects any longer. However, 42% from the studies feel comfortable on relative humidity between 30% to 60%. In these circumstances, the occupant will feel cooler and refreshed because the air conditioner don't have to work too hard, but it will be able to cool the classroom adequately.

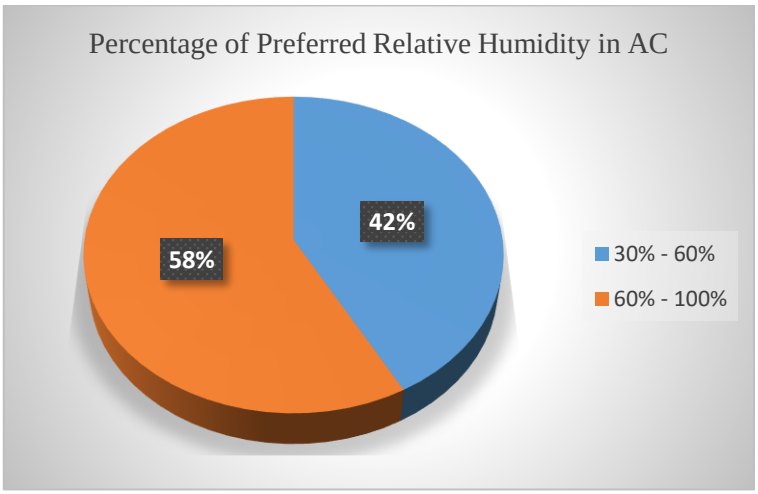

Figure 3: Percentage of Preferred Relative Humidity in AC

3.4 Air velocity

In the recent research, students favoured higher air velocity (0.5m/s-0.8 m/s) to be comfortable in the natural ventilated classroom but based on the observations from Talukdar [9], The high airspeed decreased discomfort during the study period due to high humidity. Thus, the respondent was highly adapted to summertime climates, even at extreme temperatures. Since the air velocity influenced the thermal comfort of occupant, it wold be better to use high to help in thermal adaptation and comfort in hot humid climates. Based on the finding by Hamzah [17], more than half of participant (56%) votes

that air velocity in the classroom in the categories of 'slightly still' to 'much too still'. There were 32% of them felt slightly still and 24% felt either 'too still' or 'much too still'. However, the rest of occupant 30% votes 'just right/neutral' for the air velocity in the classroom. This caused the air velocity to stagnate or the air flow to be very slow. This indication was accurate as we contrast the votes of the respondents with the average air velocity measured in the classroom. The average air speed was between 0.05 and 0.09 m/s. In air-conditioned classrooms, Hussaro [11] studied that a higher percentage of TSV were shifted to cold sensation vote if the air velocity increased and air-conditioner temperature were constant. In the meanwhile, the percentage of sensation votes were shifted to the hot sensation vote side if the air-conditioner temperature has been raised with the air velocity remaining the same. As a result, by increasing the air speed in the classrooms, it will help to provide thermal comfort and subject will feel comfortable eventhough at a higher AC temperatures.

3.5 Behavioral activities

The movement of air in the indoor environment were also influence the occupant especially in NV classrooms, through the operation of windows, doors and fans. The subjective assessment done by Takludar [9] found, 26.2% (male) and 31% of student increase the level of fan whenever they felt warm. However, based on the observation, a typical adaptive activity at high temperatures during the summer is rising fan speeds. In order to adapt to the warm environment, a significant number of student included male (20.3%) and female (26.3%) open the window to get fresh air from outside enter the classroom. Besides, it was found that 18.9% and 14% of male and female student reduce their activity level when they felt warm. The minority of student estimated at 17.5 % (male) and 8.2% (female) students go outside classroom to get fresh air and about 15.4% and 14% changed their place when feeling hot, sitting in an airy place. Increasing ceiling fan speed, opening windows, and reducing activity are the most prevalent actions. Besides, in a primary school, Le [12] also provided a questionnaire section to collect the feedback from occupant on how they used building element facilities to adapt with the thermal environment in a secondary school. As a result, during the school period, the teachers opened the doors and switch on the fans. Some kids were try to open/close the curtains and windows especially kids that are near to the window to provide natural ventilation nearly all the time.

3.6 Clothing insulation and metabolic rate

Clothing (clo) and metabolic rate (met) were an important factor in achieving thermal comfort especially in the hot and humid climate. From the observations, the minimum and maximum clo in natural ventilation were 0.3 and 0.69 while 0.25 and 1.2 for AC condition. It can be seen that the clo in AC classroom were higher compared NV. According to Yang [18], when indoor air temperature rises during the summertime season, people will choose to wear lightweight clothes. Typical attire is the mixture of short T-shirts and long pants or short/long skirts in summer. However, in a secondary school, the typical students wearing five type of uniform as mentioned by Hamzah [10] which is regular uniform, batik uniform, pramuka uniform, Muslim uniform and sports uniform. For male students, they are wearing a shortsleeves shirt with trousers while for female students, were wearing long skirt or short skirt wit long-sleeves shirt. The dress code were almost similar in the finding of Puangmalee [19] where the occupants wore a typical school's uniform while various type of clothes were used in the university.

But some Muslim female, wore a regular uniform and hijab to cover head and chest. Therefore, the clothing insulation value would be higher for a Muslim female compared with others and it has been taken from ASHRAE Standard 55. Mamat[14] research also assumed that clothing insulation was constant where people used a similar clothing value for a similar sctivity at the same climate in the same typical interior applications. However, there were some respondent in the studies changed their clothing level in order to achieve their comfort level at different temperature. Metabolic rate (met) value were seems to be similar for both natural ventilation and air-conditioned condition which is between 1.0 to 1.2 met. Students were mainly seated, listening to lessons and reading during subjective examination. This form of enterprise has a metabolic rate of 1.0 met in the ASHRAE Standard.

3.7 Adaptive thermal comfort of occupant behaviour

As expected, thermal discomfort conditions were observed in both NV and AC. Occupants continuously adapt to real environments through different actions to control behaviour. Drinking beverages can be the most typical adaptive behaviour of the occupant to mitigate their thermal discomfort. Besides, by switching on the fan, opening and closing the windows and door also help to increase the airflow inside the classroom especially in the natural areas [20]. Thus, the use of personal fans has been effective in increasing air speeds locally in their immediate surroundings and also can reduce the thermal discomfort in the classrooms by changing clothing. In the finding of Mustapha [20], the occupant in NV consumed a considerably cool drink as the temperature increased. This indicates that the occupant of a natural classroom can adapt to higher temperatures by performing these behavioural actions. Besides, students in the AC classroom were suggested to do nothing or decrease their level of activity to imply the current indoor environment and balance with indoor temperatures [20]. Furthermore, the facilities such air conditioners need to be highly effective and installed into all the classrooms in appropriate numbers. The maintenance of AC is also necessary to ensure the AC can be used efficiently and provide sufficient thermal comfort for user satisfaction.

However, the representative occupant in the classroom must have metabolic values range from 1.0 to 1.3 met and can free to adjust their apparel to thermal conditions indoors and/or outdoors at least within a range of 0.5 to 1.0 clo as mentioned by ASHRAE [8]. Spaces of unconditioned air may provide mechanical ventilation, but opening and closing of the doors may be the primary means of thermal control and the average of mean outdoor temperature is greater than 10°C and less than 33.5°C. In the AC classroom, the system can be set at lower air temperature (T_a) values concomitantly with higher air speed (V_a) values in mixed mode operation (air-conditioning and fans simultaneously). By this way, it can contribute to energy saving especially for tropical buildings. Besides, air temperature is kept at around 22 to 26 °C rather than 21 °C could save precious cooling energy in well-insulated rooms and provide the inhabitants with light clothing and sedentary tasks with adequate thermal comfort conditions. Lastly, inhabitants must be able to respond to alter uneasy thermal conditions (e.g., by controlling the AC thermostats). These behaviour can lead to eliminating discomfort situations by creating new sets of environmental variables that can conserve energy in the buildings [8].

4. Conclusion

Thermal preferences and perceptions among the respondent about thermal and visual condition in the reviewed article has been assessed by using ASHRAE standard 55 to be adequate for classroom evaluation in thermal environments. The majority respondent in the studies prefer 24°C to 26°C environment condition which followed the ASHRAE Standard. Some students could have higher heat tolerances (27°C to 28°C) in the air-conditioned classrooms as they may accept heat levels that exceeded the standard although, there were about 17% students who preferred in cooler environments (21°C to 23°C) and more sensitive to warm conditions. However, in the natural ventilation classroom, it seems that the range of temperature acceptable.

Throughout the studies, the relative humidity and air velocity surpassed the threshold set by the sedentary indoor activity standard during the summer. Even though the relative humidity value measured in this study were slightly higher than recommended range, but still within the safety factor range and most of the respondents considered the relative humidity and air velocity they encountered to be appropriate. The clothing insulation and metabolic rate found in the research were 0.5 clo and 1.1 met. All the activity done by the respondent for both type of ventilation in the research were found to be same which is sitting, writing and listening. Some of respondent were adjusting their behavioral activities such as open windows, increase the level speed of fan and etc to adapt with the thermal environment condition. Finally, an adaptive thermal comfort technique was developed to modify the convenient air-conditioning system temperature range and conserve substantial resources.

Acknowledgement

A special thanks to Dr Mohd Azuan Zakaria for his guidance, experience, persistence and, above all for offering constructive motivation and a warm spirit in completing this research and deeply thank to my loved friends who were always support me through thick and thin. I would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

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