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Thermal Comfort in Naturally Ventilated Classroom: A Literature Review

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Abstract

A phenomenon of global climate change and global warming led to an increase of study on indoor thermal comfort as it causes an increase in air temperature in both outdoor and indoor environments. Thermal comfort of indoor condition had a significant impact on occupants' performance, especially in the educational building. The impact is more crucial in a natural ventilated building as it is influenced by both outdoor and indoor condition. This paper presents an overview of a study on thermal comfort over the past ten years in the classroom that use the passive ventilation system. The study is divided into two sections; the first reviews the variables that are measured to determine thermal comfort and the second section reviews the other factors that could influence the thermal comfort. The factors that have been reviewed include climatic condition, design of ventilation system of the building, building envelope design and occupants behaviour that had influence the thermal comfort in the building, hence influenced the occupants' performance. Most of the studies had found that the occupants were dissatisfied with the indoor environment and the results of the studies found that thermal comfort is not in the comfort range, as stated in the standards. The ventilation factor has been highlighted in most studies to be the crucial factor that influences the indoor environment and thus influence the thermal comfort of the building.

Keywords: Educational building, classroom, thermal comfort, natural ventilation

1.0 INTRODUCTION

Climate change and global warming is a worldwide issue that affects human-being nowadays as well as future generations. One of the impacts is the phenomenon is the rise of world air temperature that has resulted in occurring discomfort issue of the indoor air environment. U.S. Global Change Research Program 2017 (USGCRP 2017), found that the global annually averaged surface air temperature has increased about 1.0°C over the last 115 years (1901–2016), this temperature was the warmest in the history. Due to increases of awareness to save the environment, a study of environmental quality and indoor air quality in a building has increased as well. One of the issues that had been discussed by many researchers around the world concerning this phenomenon is thermal comfort (Kwong, 2013; Yang, 2013; DeDear, 2013; Yang, 2014). Rupp et al. (2015) mentioned in their study that the research in thermal comfort had attracted the attention of many researchers in the world due to the increase of public discussion regarding thermal comfort.

Schools or educational building supposedly provide a comfortable environment in the classroom for teaching and learning activities. The educational buildings are different from other types

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of the building due to its intermittent use, the density of occupants and the full range of activities that are carried out (DOE, 1997). However, a lot of discomfort issue in the classroom has been found in previous studies around the world, which could influence students and teachers' activities in the classroom. The research conducted by many scholars had agreed that the condition of classroom environment has significant implication to the teaching & learning process and may improve students' performance (Huang, 2015; Montazami, 2017; Samad, 2017). Discomfort environments in the classroom may disrupt teaching and learning activities, reduce teachers' performance and cause lethargic to the students (Mendell, 2005; Puteh, 2012; Ameerudin, 2014). It then causes lack of concentration of the students on their lesson. Corgnati et al. (2007) concluded in their study that schools with a high level of environmental quality could improve students' attention, concentration, learning, hearing and performance. Toftum et al. (2015) found in their study that the poor condition of the classroom had resulted in the poor achievement of the students. The finding was supported by Stazi et al. (2017), which concluded in their study that students usually suffer from poor indoor air quality and influence their performance in learning activities.

A review in thermal comfort study had been done by many researchers across the world in related field such as Fanger's theory and adaptive model, different type of building, different climatic and country, indoor and outdoor environment and human physiological model (Djongyang et al., 2010; Zhang et al., 2010; Halawa & Hoof, 2012; Mishra & Ramgopal, 2013; Yang et al., 2014; Kwong, 2014; Rupp et al., 2015; Zomorodian et al., 2016; Enescu, 2017 & Wang et al., 2018). This paper is focused on the review of literature on the indoor environment in a naturally ventilated classroom, especially in a tropical climate. Therefore, this paper will review the previous literature regarding thermal comfort in two sections, which are;

(i) The variables in measuring thermal comfort in a naturally ventilated building
(ii) Other factors related to the building affecting thermal comfort.

2.0 METHODOLOGY

A desktop study was conducted to search the relevant article to thermal comfort which then analysed the finding through the desktop analysis method (Al Horr, 2017; Awuzie, 2017). Selected articles regarding thermal comfort in a naturally ventilated classroom were reviewed through online scientific journals publications in Building and Environment which include Scopus and ScienceDirect. The keyword used were; "thermal comfort" and "naturally ventilated classroom" to search the published article in the past ten years (Giridharan, 2018). Scopus database generated 15 articles, but only 11 relevant articles were selected for this paper. While ScienceDirect generated 43 articles of the same period, but only 17 relevant articles were selected. There were several same articles found on both databases. Besides, the method of "reference by reference" or "snowball" was also used to find the relevant articles based on the articles that had reviewed earlier (Wang et al., 2018). The articles were selected as they were related to this paper. All of the selected articles well-gathered from Scopus, ScienceDirect, Researchgate.net and GoogleScholar databases. In total, 23 relevant articles for this paper had been reviewed.

As stated in the introduction above, the objectives of this paper are to review the variables and the building-related factor of thermal comfort. Therefore, all selected articles were analysed to extract the variables of thermal comfort and the building-related factors of thermal comfort (Al Horr, 2017). The keywords used were; "variables" or "parameters" and "building-related factors" or "other factors". The findings of the analysis are summarised in Table 1.

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3.0 LITERATURE ON THERMAL COMFORT IN NATURALLY VENTILATED BUILDING

3.1 Thermal Comfort Variables in Naturally Ventilated Building

Thermal comfort is a vital parameter to determine a healthy and productive workplace (Taylor, 2008). The comfortable indoor environment contributes to high performance and excellent work quality of the occupants. According to Peeters (2009), thermal comfort is a result of an adaptation of parameters of the environment and the human body. The previous studies regarding thermal comfort showed that there are many parameters testified by the researchers to measure thermal comfort. The parameters might differ from each other, but most of the researchers use the same parameters to measure thermal comfort. Taylor (2008) measure air temperature and the parameter of building's energy efficiency to determine thermal comfort in their study. While Peeters (2009) measured the parameter of air temperature, relative humidity, airspeed, metabolic rate and clothing index to determine thermal comfort in their study.

According to Malaysian Standard MS 1525: 2014, thermal comfort of a room depends on various parameters, which include air temperature, air movement, mean radiant temperature, humidity, clothing insulation and metabolic rate. In line with MS 1525, Liang (2012) measured the parameter of air temperature, relative humidity, air speed, radiant temperature, clothing level and metabolic rate to determine thermal comfort in their studies. All of the parameters are commonly used by many researchers to measure thermal comfort, such as Memon et al. (2008), Teli (2012), Mishra (2014), Nematchoua (2014), Yun et al., (2014), Mishra (2015), Buonocore et al., (2018), Jindal (2018), Kumar et al. (2018) and Singh et al. (2018). However, there were previous studies that only measures air temperature and relative humidity to determine thermal comfort namely Chithra (2012), Montazami et al., (2012), Alfano (2013), Agarwal (2016), Montazami et al., (2017), Pereira et al., (2017), Asif et al., (2018) and Subhashini (2018). On the other hand, Chithra (2012) conducted a study on indoor air quality and the relationship with a thermal parameter, includes air temperature and relative humidity to measure thermal comfort. It is also found that Griffiths (2008), Santamouris (2008), Yang (2009), Teli (2012), Nematchoua (2014), Agarwal (2016), Mamat (2016), Pereira (2017), and Asif (2018) use the same parameters in their studies.

However, there is a different perspective from McMullan (2016) in determining the parameters of thermal comfort. He suggested that the parameters of thermal comfort are divided into two variables, which are physical variables and personal variables. The physical variables include air temperature, mean radiant temperature, relative humidity and air movement, while the personal variables include activity, clothing, age and gender. In line with McMullan (2016), other researchers that have used all of eight variables to determine thermal comfort in their study include the work by Jindal (2018), Hamzah (2018) and Fang (2018). All the variables have a significant impact on the measurement of thermal comfort in a naturally ventilated classroom.

3.2 Building-Related Factors That Influence Thermal Comfort

Many previous studies have been conducted by many researchers and found that other factors could affect thermal comfort. The factors are related to the building itself such as the building orientation (Montazami, 2012; Teli, 2012; Asif, 2018; Subhashini, 2018), building envelope (Memon, 2008 & Yang, 2009), door and windows closing and opening behaviour (Santamouris, 2008; Montazami, 2012; Mishra, 2015; Agarwal, 2016; Montazami, 2017; Asif, 2018; Jindal, 2018; Kumar, 2018; Singh, 2018 & Subhashini, 2018), window to wall ratio (WWR) (Liang, 2012; Teli, 2012 & Pereira, 2017), wall and roof materials (Yang, 2009; Jindal, 2018 & Subhashini, 2018), shading device (Teli, 2012 & Subhashini, 2018) and average window solar gain (AWSG) (Liang, 2012).

Based on the review, it found that building orientation and closing to the opening of doors and windows behaviour are the most common factors that measured by many researchers in the studies on

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thermal comfort. Montazami (2012) and Teli (2012) concluded in their study that building orientation had a significant impact on occupants' thermal perception, although it did not affect the thermal condition directly. In addition, Subhashini (2018) concluded in their study that window orientation, which depends on the building orientation is an essential passive design solution to enhance thermal comfort in a building. In line with the finding, Asif (2018) found in their study that thermal comfort variables are highly related to building orientation.

Design of doors and windows influence heat gain and heat loss of the building resulting in increase and decrease of the temperature inside the room, thus affects the thermal comfort of the building. In support of that, Schulze (2013) found in their study that the control of the opening is a vital factor in achieving thermal comfort in a building. Rijal (2015) found in their study that occupants in a hot-humid climate adapted to the indoor environment by opening the windows to increase the air movement in the room. Kumar (2018) concluded in their study that students in a classroom preferred high air movement by opening windows and doors to restore their comfort. All of the findings were designed with the studies conducted by Oropezaperez (2014), Luo et al. (2015), Mishra (2015), Mirrahimi (2016), Montazami (2017), Stazi (2017), Jindal (2018) and Singh (2018).

The factors of heat gain and heat loss of the building led to a study of shading device influences on thermal comfort. According to Barbosa (2015), the application of shading devices is the most influential factor to determine building thermal performance. Kirimtat (2016), mentioned in their study that uses the proper type of shading devices is vital in a study of thermal comfort in a building. However, in this review, some fewer researchers measured the shading device factor on thermal comfort study. Teli (2012) included shading device factors in their study to predict the thermal sensation of the occupants in a building. Mirrahimi (2016) and Subhashini (2018) proved in their study that the application of appropriate shading device is the best practice to control heat gain in the building.

In naturally ventilated building, the design of the ventilation system is critical to provide adequate ventilation in a room. A proper opening design of a building determines a good ventilation system for the building. The opening design also influences air movement in the room, hence affects the thermal comfort as the air movement or air velocity is one of the variables to measure thermal comfort. It was supported by Huang et al. (2015) which stated in their research that sufficient internal air movement contributes to maintaining thermal comfort in a classroom. Similarly, Shimazaki (2015) stated in their study that air movement in a building influence human comfort. On the other hand, there are a few researchers that do not include building-related factors in their study which include the work by Tippayawong (2009), Chithra (2012), Alfano (2013), Mishra (2014), Nematchoua (2014) and Yun (2014).

Table 1 shows a summary of the variables measured by different researchers to determine thermal comfort in the naturally ventilated building.

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Table 1: Summary of Thermal Comfort Study in Educational Building In The Past Ten Years

Year	Authors	Field of Study	Variables	Climate	Other Factors (Building-Related Factors)
2008	Griffiths & Eftekhari	Ventilation performance is naturally ventilated classroom	CO_2, ambient temperature, air change rate	Temperate (cold season)	Ventilation system
2008	Memon et al.	Thermal comfort and application of radiant cooling	air temperature, RH, air velocity, MRT, clothing, activity	Subtropical	Electrical equipment and load, building fabrics
2008	Santamouris et al.	Airflow and indoor carbon dioxide in classroom with intermittent natural ventilation	CO_2, air flow rate	Temperate (warm season)	Window opening/closing behaviour
2009	Tippayawong et al.	Indoor air quality in the naturally ventilated classroom	Air exchange rate, PM size, temperature, RH	Tropical	-NA-
2009	Yang et al.	Indoor air quality based on building age	CO, CO_2, PM, TBC, TVOCs, HCHO	Temperate (summer, autumn, winter)	Ventilation rates, furnishing
2012	Chithra & Nagendra	Indoor air quality in a naturally ventilated classroom located at urban roadway, the relationship between comfort parameter	CO, CO_2, particulate matter (PM), VOCs, air temperature, RH, wind speed, wind direction	Tropical wet and dry (winter & summer)	-NA-
2012	Liang, Lin & Hwang	Relation on occupants' thermal perception and building thermal performance in naturally ventilated building	air temperature, RH, air speed, radiant temperature, clothing level, metabolic rate of activity	Subtropical	Window to wall ratio (WWR), average window solar gain (AWSG)
2012	Montazami, Wilson & Nicol	Air quality in classroom affected by aircraft noise and overheating	Noise level, solar gain, air temperature, thermal mass level	Temperate	Window opening/closing behaviour, building location
2012	Teli, Jentsch & James	Assessment of existing comfort model for predicting thermal sensation	Humidity, air temperature, air speed, radiant temperature, CO_2, clothing insulation, metabolic rate	Temperate	Classroom orientation, WWR, solar shading solution, cross ventilation, floor level, room & furniture layout, room characteristic
2013	Alfano, Ianniello & Palella	PMV-PPD and acceptability in naturally ventilated school	Air temperature, air velocity, dew point temperature, radiant temperature, humidity	Mediterranean (summer & winter)	-NA-
2014	Mishra & Ramgopal	Analysis of occupants perception in laboratories	Air temperature, air velocity, mean radiant temperature, RH, metabolic rate, clothing	Tropical	-NA-
2014	Nematchoua, Tchinda & Orosa	Adaptation and comparative study of thermal comfort in naturally ventilated classrooms	Air temperature, wind speed, relative humidity, mean radiant temperature, CO_2, metabolic rate, clothing	Wet Tropical (summer & winter)	-NA-
2014	Yun et al.	Thermal comfort for kindergarten children	Air temperature, air velocity, mean radiant temperature, RH, metabolic rate, clothing	Temperate (summer)	-NA-
2015	Mishra & Ramgopal	Thermal comfort field study of naturally ventilated classroom	Air temperature, air velocity, mean radiant temperature, RH, metabolic rate, clothing, sound level	Tropical	Mechanical ventilation (ceiling fan), operable window
2016	Agarwal & Nagendra	Modelling of particulate matters distribution inside the multilevel urban classrooms in tropical climate for exposure assessment	PM mass (PM_{10} , $PM_{2.5}$, PM_1) , PNC, CO, CO2, temperature, RH	Tropical	Window opening behaviour
2017	Montazami et. al.	Developing an algorithm to illustrate the likelihood of the dissatisfaction rate with relation to the indoor temperature	Air temperature, metabolic rate, clothing	Temperate (cold season)	Window opening behaviour
2017	Pereira et al.	An integrated approach to energy consumption and indoor environmental quality performance	CO_2, air flow rate, air temperature, RH	Mediterranean	WWR
2018	Asif, Zeeshan & Jahanzaib	IAQ and CO2 levels assessment in academic buildings compare to thermal comfort	CO_2, air temperature, RH	Subtropical	Building orientation, window opening behaviour
2018	Buonocore et al.	Influence of relative air humidity and movement on human thermal perception in classrooms in a hot and humid climate	Air temperature, relative humidity, air speed, mean radiant temperature, metabolic rate, clothing	Tropical (hot & humid season and hot & dry season)	Mechanical cooling
2018	Jindal	Thermal comfort study in naturally ventilated school classrooms in composite climate	Air temperature, RH, air speed, mean radiant temperature, metabolic rate, clothing, age, gender	Composite (monsoon & winter season)	Window design, building material
2018	Kumar et al.	Evaluation of comfort preferences and insights into behavioural adaptation of students	Air temperature, RH, air velocity, mean radiant temperature, metabolic rate, clothing	Tropical	Window opening behaviour
2018	Singh et al.	Status of thermal comfort in naturally ventilated classrooms during the summer season	Air temperature, RH, air velocity, mean radiant temperature, metabolic rate, clothing	Composite (summer season)	Window opening behaviour
2018	Subhashini & Thirumaran	A passive design solution to enhance thermal comfort in an educational building	Air temperature, RH, air exchange rate	Tropical	Shading device, window orientation, size of window opening, insulation of wall and roof

**RH- relative humidity, MRT-mean radiant temperature, VOCs-volatile organic compounds, PM-particulate matter, PNC- particle number concentrations, TBC-* total microbial count, *HCHO-formaldehyde, Window to wall ratio-WWR*

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4.0 DISCUSSION

Based on the reviewed articles, this paper shows that building-related factors had a significant impact on the result of thermal comfort as well as the thermal comfort variables. Many researchers include the building-related factors in their study as they affect thermal comfort in the building as shown in Table 1. Although there were a few researchers that have not included building-related factors in their study, most researchers found that the building-related factors had significant influence on thermal comfort. Window design, window opening and closing behaviour are the most common factors studied by the researchers followed by building orientation as shown in Figure 1.

Based on Table 1, the factor of the window to wall ratio (WWR) is less studied by the researchers. However, further study can be done with regards to this factor as a window to wall ratio (WWR) is one of the critical factors in thermal comfort study (MS 1525:2014). building material, shading device and building envelope are the fewer factors measured by the researchers in their study to determine thermal comfort.

Figure 2 shows the number of study on thermal comfort variables measured by the researchers. It found that air temperature and relative humidity are the most common variables that are measured by many researchers to determine thermal comfort in their study, followed by air velocity, mean radiant temperature, clothing and metabolic rate. Age and gender are the less common variables measured by the researchers to determine thermal comfort in which there is only one article from 23 articles that have reviewed the variables in their studies.

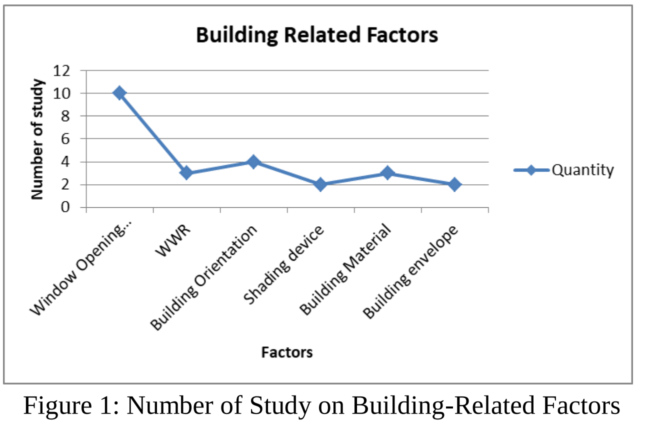

Figure 1: Number of Study on Building-Related Factors

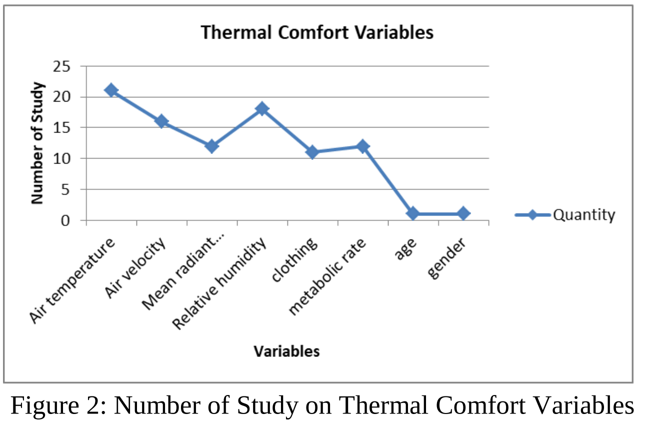

Figure 2: Number of Study on Thermal Comfort Variables

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5.0 CONCLUSION

Based on this study, it found that the thermal comfort variables and building-related factors have a significant relationship with each other in order to determine thermal comfort in a building. The design of the ventilation system in a building, which is the window and door opening design shows a vital influence in a study of thermal comfort. It can be concluded that:

- The most measured variables to determine thermal comfort are air temperature and relative humidity, while the less measured variables by the researchers are age and gender in studies on thermal comfort.
- The most common variables that are measured by researchers to determine thermal comfort in their studies includes air temperature, air velocity, mean radiant temperature and relative humidity.
- Clothing and metabolic rate are the most common variables that are measured by the researchers in order to determine human comfort perception in their study.
- Building-related factors have a significant influence in the study of thermal comfort as they affect the result of thermal comfort.
- The most common building-related factors that are measured by the researchers in their studies are window design and window opening and closing behaviour.
- The less common building-related factors that are measured by the researchers to determine thermal comfort are shading device and building envelope.

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