Thermal comfort analyses of naturally ventilated university classrooms

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Abstract

Purpose – The purpose of this paper is to analyse thermal comfort and the thermal environment in naturally ventilated classrooms. Specifically, the aims of the study were to identify the thermal environment and thermal comfort of respondents in naturally ventilated university classrooms and compare them with the ASHRAE and Indonesian National Standard (SNI); to check on whether the predicted mean vote (PMV) model is applicable or not for predicting the thermal comfort of occupants in naturally ventilated university classrooms; and to analyse the neutral temperature of occupants in the naturally ventilated university classrooms.

Design/methodology/approach – The study was carried out at the new campus of Faculty of Engineering, Hasanuddin University, Gowa campus. A number of field surveys, which measured thermal environments, namely, air temperature, mean radiant temperature (MRT), relative humidity, and air velocity, were carried out. The personal activity and clothing properties were also recorded. At the same time, respondents were asked to fill a questionnaire to obtain their thermal sensation votes (TSV) and thermal comfort votes (TCV), thermal preference, and thermal acceptance. A total of 118 respondents participated in the study. Before the survey was conducted, a brief explanation was provided to the participants to ensure that they understood the study objectives and also how to fill in the questionnaires.

Findings – The results indicated that the surveyed classrooms had higher thermal environments than those specified in the well-known ASHRAE standard and Indonesian National Standard (SNI). However, this condition did not make respondents feel uncomfortable because a large proportion of respondents voted within the comfort zone (+1, 0, and −1). The predictive mean vote using the PMV model was higher than the respondents' votes either by TSV or by TCV. There was a huge difference between neutral temperature using operative temperature (T_o) and air temperature (T_a). This difference may have been because of the small value of MRT recorded in the measured classrooms.

Originality/value – The research shows that the use of the PMV model in predicting thermal comfort in the tropic region might be misleading. This is because PMV mostly overestimates the TSV and TCV of the respondents. People in the tropic region are more tolerant to a higher temperature. On the basis of this finding, there is a need to develop a new thermal comfort model for university classrooms that is particularly optimal for this tropical area.

Keywords Thermal comfort, Air temperature, Neutral temperature, Relative humidity, Tropic area, University classroom

Paper type Research paper

Introduction

The new campus for the Faculty of Engineering, Hasanuddin University, was constructed in cooperation between the Indonesian and Japanese governments. The contract *Yen-Loan Agreement* IP-541 between the Faculty of Engineering and the Japan Bank for International Cooperation (JBIC) was signed in July 2007. The project

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included a master plan, a detailed engineering design, and four phases of construction. The project involved coverage of a total land area of 38.32 ha with a building gross area of 83.829 m^2. The new campus was intended to accommodate complete faculty level facilities, including several buildings, that is, an administrative office, a library, classrooms, departments, a sports hall, and student accommodation facilities.

The project designer claimed that the building was a green building concept or a green campus. As a green campus, the buildings should be designed, built, and operated under green building principles. The main aims of green buildings are to reduce environmental impact by reducing the use of non-sustainable energy, water, and material resources; to promote the use of natural ventilation and lighting; and to increase the comfort, productivity, and health of the building users.

One important indicator of the green building concept is thermal comfort, that is, to provide an indoor air environment that is comfortable to building users. This will enable them to work effectively and efficiently to achieve good performance and high productivity. Most green building rating tools, such as the US green building tool leadership in energy and environmental design (LEED), provide a credit to conduct a post-occupancy survey to measure users' thermal comfort performance. The green building tool requires the owner to conduct a thermal comfort survey within six to 18 months of occupancy. LEED uses the ASHRAE thermal comfort to evaluate the thermal comfort of respondents. The owner is required to develop a plan for corrective action if more than 20 per cent of occupants are dissatisfied with the thermal comfort of the building (USGBC, 2009).

This is a preliminary study of thermal comfort analyses of naturally ventilated (NV) classrooms carried out at the new campus of the Faculty of Engineering, Hasanuddin University. The present study aimed to analyse the effect of the thermal environment on the thermal comfort response of the occupants in NV classrooms. To achieve this, the following objectives have been proposed:

(1) to identify the thermal environment and thermal comfort of respondents in NV university classrooms and compare them with the ASHRAE and Indonesian National Standard (SNI);

(2) to determine whether the predicted mean vote (PMV) model is applicable or not for predicting the thermal comfort of occupants in NV university classrooms; and

(3) to analyse the neutral temperature of occupants in NV university classrooms.

Literature review

Thermal comfort is defined in the ISO 7730 (ISO, 1995) standard as "That condition of mind which expresses satisfaction with the thermal environment". This statement makes it clear that thermal comfort is a product of people's response to their thermal environment, which is based on their personal condition. Auliciems and Szokolay (2007) further explain that thermal comfort is determined by several factors, that is, environment, personal, and contributing factors. Environmental factors include air temperature, air velocity, humidity, and radiation. Personal factors include the clothing and the activity (metabolic rate). The contributing factors include food and drink, acclimatization, body shape, subcutaneous fat, age and sex, and state of health. Because the contributing factors are more complicated, this research only focussed on the thermal environment and personal factors. Thermal comfort is not just determined by the thermal environment condition but also by the personal condition. The same thermal environment might provide different thermal comfort for people who have a different personal condition.

ASHRAE provides a guideline for designing comfortable rooms (ASHRAE, 2004). This standard ensures that the operative temperature (T_o) is between 22 and 25°C as recommended by the standard to ensure a comfortable indoor environment for the occupants. However, as this standard is derived specifically for American people, it may not be suitable for others, especially for those who live in the tropical region.

For thermal comfort zones for persons in the tropics, Mom *et al.* (1947) have suggested a new thermal comfort zone. This thermal zone was suggested based on laboratory studies carried out in Bandung, West Java Province Indonesia. This research enabled them to reconstruct effective temperature charts for tropically acclimatized persons. The effective temperatures (T_e) obtained from their new charts were higher than those obtained under the same temperature conditions and air velocities from the charts produced in America and when the air velocity was increased from a still condition to about 100 ft/min. T_e is defined as the temperature of a stagnant and saturated atmosphere, which would, in the absence of radiation, produce the same effect as the atmosphere in an inquiry. Therefore, it combines the effect of dry air temperature and humidity (Auliciems and Szokolay, 2007). Mom and Wiesebron (cited in Soegijanto, 1999) suggested a thermal comfort zone for Indonesia that varies according to the effective temperature (T_e) as follows:

(1) comfortably cool: 20.5-22.8°C (T_e);

(2) comfortable: 22.8-25.8°C (T_e); and

(3) comfortably warm: 25.8-27.1°C (T_e).

Based on the Mom and Wiesebron, the Indonesian National Standard proposed an SNI 6390:2011 for energy conservation of ventilation systems in Indonesia (Badan Standarisasi Nasional (BSN), 2011), which specifies the thermal comfort for Indonesians. This standard is also divided into three thermal comfort zones. In this standard, the effective temperature (T_e), as specified in the Mom and Wiesebron, is not used. It was superseded by the relative humidity (RH) value. The thermal comfort zones as stated in the SNI 6390:2011 are as follows:

(1) comfortably cool: 20.5-22.8°C, RH 50-80 per cent;

(2) comfortable: 22.8-25.8°C, RH 70-80 per cent; and

(3) comfortably warm: 25.8-27.1°C, RH 60-70 per cent.

Thermal comfort is a complex phenomenon. However, for simplification, to predict this thermal comfort, Fanger (1970) proposed a PMV model, which only makes uses of six variables (thermal environment and personal variables) to estimate the thermal comfort of occupants. The six variables are four variables in the thermal environment category, that is, air temperature, meant radiant temperature (MRT), RH, and air velocity; the two variables related to the personal condition are the clothing index and the metabolic rate.

Several researchers, however, have found that this PMV model was not applicable for NV rooms, especially in tropical areas. On the basis of the extensive surveys carried out in Yogyakarta (Feriadi and Wong, 2004) showed that the prediction of thermal comfort using a PMV model overestimated the thermal sensation vote (TSV) and the thermal comfort vote (TCV) of the respondents. More than 95 per cent of the respondents were predicted by the PMV method to have thermal sensation in the warmer (+1 to +3) region and only very little (less than 5 per cent) in the "neutral" to cooler (0 to −3) region.

In contrast, only less than 50 per cent of respondents' votes were in the warmer region for the TSV and TCV methods.

Another study of thermal comfort in Indonesia was carried out by Karyono (2000). The study was based on an extensive survey of 596 office workers from seven high-rise office buildings in Jakarta. The study showed that most of the office workers were still comfortable in room temperatures between 26.7 and 28.6°C. Karyono (2000) found a neutral temperature of 26.7°C (T_o) for air conditioning (AC) office buildings in Jakarta.

Two previous studies been carried out in two Southeast Asian countries of Thailand and Bangkok found a higher neutral temperature for NV buildings (Busch, 1990; de Dear *et al.*, 1991). On the basis of the research carried out in office buildings in Bangkok, Busch (1990) found a neutral temperature of 28.5°C (T_e). A similar result was found in Singapore. On the basis of the research carried out in office buildings, de Dear *et al.* (1991) found a neutral temperature of 28.5°C (T_o) for NV buildings. Both neutral temperature values for these tropical countries were higher than those established by the ASHRAE standard.

The studies mentioned before were limited to office and residential buildings. None of them had focussed on the thermal environment of classrooms, especially university classrooms. However, several studies (Sensharma *et al.*, 1998; Mendell and Heath, 2005) showed a positive correlation between the qualities of classrooms, which include thermal environment and students' performance. Students who study in optimal classrooms tend to achieve good academic performances than students in poor-quality classrooms. Therefore, it is important to carry out a study of thermal comfort in NV classrooms in Indonesia as a tropical country.

Researchers on thermal comfort at classrooms have been carried out in many parts of the world. A number of thermal comfort studies have been carried out in Europe. Several of them were carried out in Italy. For example, Corgnati *et al.* (2007) studied the perception of the thermal environment in high school and university classrooms, Buratti and Ricciardi (2009) carried out research in university classrooms, Corgnati *et al.* (2009) analysed thermal comfort in Italian classrooms under free-running conditions during mid-seasons. Another study was carried out in the UK by Teli *et al.* (2012). This study shows that children are more sensitive to higher temperatures than adults.

In Asia, similar works have been carried out in Japan, Singapore, and Taiwan. Kwok and Chun (2003) carried out a research in high schools in Japan to determine students' thermal comfort. They found that the thermal environments in the surveyed schools were beyond the thermal comfort zone specified in the ASHRAE standard. The average air temperature was 26.9°C and MRT was 27.1°C. However, most of the students (74 per cent) voted within the neutral category ("slightly cool", "neutral", and "slightly warm"), while only less than 10 per cent voted for "warm" and "hot". About 72 per cent of respondents found this condition acceptable.

Similar results were found in Singapore. On the basis of the surveyed carried out in Singapore schools, Wong and Khoo (2003) found that none of the thermal performances of classrooms were within the thermal zone of the ASHRAE standard. However, students found these conditions acceptable. The acceptability rates were 72 per cent and 74 per cent for NV and AC classrooms, respectively. The neutral temperature found in this study was 28.8°C. The neutral temperature predicted by the PMV model was higher than the one obtained from TSV.

Hwang *et al.* (2006) carried out an extensive field measurement at 36 classrooms, of which ten were NV classrooms in Taiwan. The survey involved 944 students. They found that the thermal neutrality and thermal preference of students were 26.3 and 24.7°C T_e, respectively. This shows that the neutral temperature was higher than the thermal preference of students. The study shows that the neutral temperature in Taiwan was lower than the neutral temperature found in Singapore. The PMV model overestimated the TSV of students (TSV).

Another study in the tropical area was carried out in Hawaii by Kwok (1998). The study examined the acceptability of the ASHRAE thermal comfort standard for the tropical classroom. Kwok (1998) found that the majority of classrooms failed to meet the ASHRAE standard. However, the acceptability rate was more than 80 per cent irrespective of the thermal condition of classrooms. The neutral temperature values in these tropical classrooms were 26.8 and 27.1°C for NV and AC classrooms, respectively.

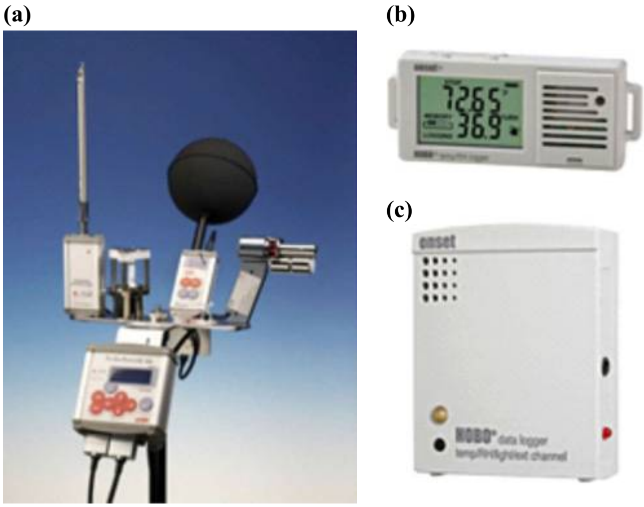
Research method

Case study selection

This is a preliminary study of thermal comfort analyses of NV classrooms carried out on the new campus of the Faculty of Engineering Hasanuddin University. The study was carried out at the classroom building, which is used for teaching and learning for all Faculty of Engineering students at Gowa campus. This is a four-storey building that consists of classrooms and basic science laboratories. Three classrooms were selected for the surveys including two rooms at G/F and one room at 1/F. At that time, only G/F and 1/F floor of classroom building were utilized for teaching. The reason why this campus was selected as a case study is that this new campus was designed on the basis of a green building concept. As a green campus, buildings should provide comfortable indoor environments including thermal comfort for occupants. Therefore, this is a way to verify the thermal comfort performance of the new campus.

Research instrumentation

The research was carried out using several instruments as presented in Plate 1. The LSI-Lastem Thermal Comfort Multi Logger is an instrument that consists of



Notes: (a) LSI-Lastem thermal comfort logger (LSI TC); (b) Hobo temp/RH logger (HOBO-1), and (c) Hobotemp/RH /Light/External logger (HOBO-2)

Plate 1. Measurement tools

several sensors and a data logger. The arrangements of LSI-Lastem applied in this survey including two data loggers (one main and one slave logger) and four sensors. The sensors included a globe thermometric probe (BST131) to measure the MRT, a portable psychometric forced ventilation probe (BSU102) to measure air temperature and RH, a portable hot wire anemometer probe (BSV 105) to measure the air velocity, and a wet bulb temperature probe (BSU121) to measure wet bulb temperature.

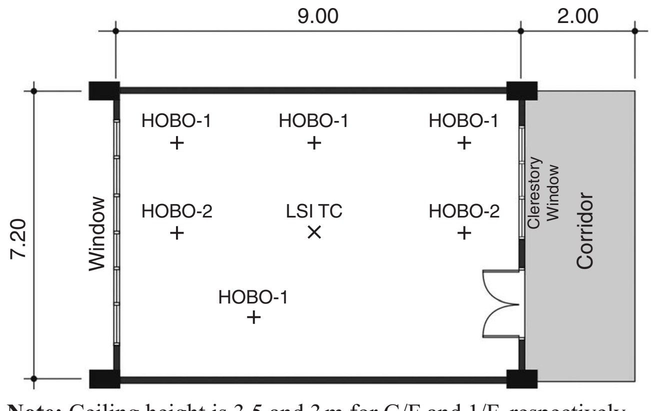
Because only one LSI-Lastem logger was used, which was not enough to capture the variations in thermal conditions inside the classrooms at the same time, additional instruments were needed. Six HOBO loggers, from Onset, were used for this research. This enabled us to measure the thermal environments at seven points in each classroom. Two types of loggers were used, that is, the HOBO temp/RH logger and the HOBO temp/RH/Light/External. Four HOBO temp/RH loggers were used to measure air temperature and RH and two HOBO temp/RH/light/external were used to measure air temperature, RH, and air velocity.

Data collection

The primary data were collected using survey and questionnaire methods. The collection of data was carried out as follows:

(1) A survey on objective measurement was conducted to collect personal and thermal environment data. Personal data were gathered by collecting information on the clothing and the activity of each respondent. The thermal environmental variables, that is, air temperature, MRT, RH, and air velocity were recorded using one LSI-Lastem Thermal Comfort Multi Logger (marked as LSI TC), four basic HOBO loggers, which only measure air temperature and RH (marked as HOBO-1), and two HOBO with external air velocity sensors (marked as HOBO-2). The placement of measurements tools in surveyed classrooms is shown in Figure 1. Two classrooms at G/F and one at 1/F were selected for the measurements. The sensors were attached at 100 cm above the floor level (Wong and Khoo, 2003). Because of the limitation of equipment, the MRT only recorded at one point, which was the centre of the room (point G), while the air velocity was recorded at three points (A, B, and G).

(2) A survey on subjective measurement was conducted to measure the level of thermal comfort of the respondents. The survey was carried out using the



Note: Ceiling height is 3.5 and 3 m for G/F and 1/F, respectively

Figure 1.
The placement of measurement tools in the surveyed classrooms

questionnaire technique, which was adapted from Wong and Khoo (2003). The questionnaire included six questions as listed in Table I, which captured the thermal sensation, thermal comfort, thermal preference, and thermal acceptance of the respondents. In addition, the questionnaire also aimed to obtain the respondents' votes on their perception of air velocity as well as the humidity of classrooms. The TSV responses were measured on the basis of ASHRAE standard 55, which uses a seven-point scale to measure the thermal sensation of the respondents. The seven-point TSV scales are hot (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (−1), cool (−2), and cold (−3). The TCV responses were measured using the Bedford scale (Bedford, 1936), which measures the thermal comfort of respondents. The TCV scale also uses a seven-point scale: much too warm (+3), too warm (+2), comfortably warm (+1), comfortable (0), comfortably cool (−1), too cool (−2), and much too cool (−3). Thermal comfort can also be measured by determining the thermal preference and acceptance of the occupants. Thermal preference related to the question of whether the occupants preferred to be warmer or cooler or no change. In addition, questions related to air velocity and humidity were also included in the questionnaire.

Data processing and analyses

Data analyses were carried out using spreadsheet software MS Excel. The spreadsheet was used to calculate the mean value of environmental variables and to generate tables showing the percentage of TSV, TCV, and PMV. For the statistical analyses, a statistical software SPSS version 16 was used to calculate the mean difference and regression analyses. The mean difference analyses were carried out to analyse the differences between PMV, TSV, and TCV. The regression analyses examine the correlation and the linearity of data between TSV and operative temperature (T_o) and between TSV and air temperature (T_a). The TSV and TCV were obtained from the respondents' responses in the questionnaire. The TSV votes were grouped according to the ASHRAE scale, while the TCV was grouped using the Bedford scale.

To calculate the PMV for each respondent, the availability of four corresponding environmental variables as well as two personal variables for each respondent is essential. However, not all these variables were collected at all points of measurement because of the limitation equipment. The MRT was only measured at point G (centre of

1. How do you feel about the temperature in the classroom at this moment?						
cold	cool	slightly cool	neutral	slightly warm	warm	hot
2. Do you feel comfortable now?						
much too cool	too cool	comfortably cool	comfortable	comfortably warm	too warm	much too warm
3. What you like to be ...?						
cooler		no change			warmer	
4. How would you rate the overall acceptability of the temperature at this moment?						
acceptable			not acceptable			
5. How do you feel about the air velocity in the classroom at this moment?						
much too still	too still	slightly still	just right	slightly breezy	too breezy	much too breezy
6. How do you feel about the humidity in the classroom at this moment?						
much too dry	too dry	slightly dry	just right	slightly humid	too humid	much too humid

Source: Adapted from Wong and Khoo (2003)

Table I. Thermal comfort questionnaire the room), while air velocity values were only measured at three points, that is, A, B, and G. To simplify the procedure of calculation, the MRT values measured at point G were applied to all points. In terms of air velocity, the arrangements were as follows: the values of air velocity collected in G were shared with points D and F, while the ones collected at points A and B were shared with points C and E, respectively. By applying these arrangements, all respondents, who were sitting near the point of measurements, had all six required variables. These enabled us to calculate the PMV values. On the basis of the four environmental and two personal variables, the PMV for the 118 respondents was calculated. The calculation was carried out using the spreadsheet template developed by Tanabe (Farina, 2015).

Research results were subjected to statistical analyses using SPSS version 16. The statistical analyses in this research were carried out using a *t*-test (paired different) and regression analysis. Both analyses were based on the Pearson's correlation. The difference between the PMV and TSV, the PMV and TCV, and between TSV and TCV was determined by comparing the "sig." value and its probability (5 per cent). If the "sig." value < 0.05, then the two variables are significantly different, but if the "sig." value > 0.05, then the two variables are not significantly different. The regression analyses were carried out on the basis of two criteria, that is test of linearity of regression and the significance of the equation coefficient. The equation will be linear if the "sig." value is less than its probability (0.05) and the equation coefficients will be significant if the "sig." value is also less than its probability (0.05).

Before analysing the data using statistical analyses, the data should be verified. One method of verification is to check their normality and reliability. The checking required ensuring that the results are valid for drawing the conclusions. All data were checked for their normality and reliability.

Results and discussion

Respondent characteristics

A total of 118 respondents participated in this research: three lectures/assistant lecturers and 115 out of 175 students of the Architecture Study Programme who studied in the Gowa campus at that time. The majority of students (88 respondents) were first-year students, while others were second-year students. The first-year students were just using the classrooms for two months starting from the end of August 2013, while the second-year students had been using the classrooms for more than one year. Most of the students were originally from Sulawesi Island, especially South Sulawesi Province, and some of them were from the Eastern Part of Indonesia. A total of 79 males and 39 females participated in this research. The ages of the students ranged from 18 to 21 years, while the lectures' ages ranged between 23 and 53 years. The activity of all respondents involved just seating and reading, yielding a metabolic rate equal to 1.0. The first-year students wore a uniform of black trousers and white long sleeve shirts (males) and black long skirts and white long sleeves shirt (females) (see Plate 2(a)). Some of the female respondents wore a headscarf. The clothing index for them was approximately equal to 0.636 clo. The second-year students mostly wore trousers with short-sleeve shirts (see Plate 2(b)). Their clothing index was approximately equal to 0.57 clo.

Outdoor weather condition during the time of measurements

A graphical presentation of weather conditions during the time of the measurements is presented in Figure 2. The measurement on 22 October 2013 was carried out on a clear day.

(a)

(b)

Notes: (a) First-year students, and (b) second-year students
Source: Photos taken by Arief

Plate 2.
Photos taken from the surveyed classrooms

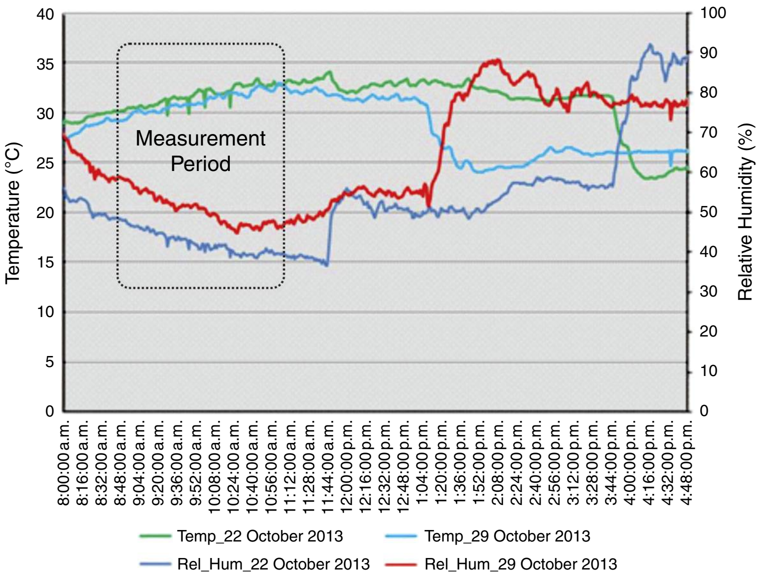


Figure 2.
The outdoor air temperature and relative humidity conditions on 22 and 29 October 2013

The air temperatures ranged from 30 to 34°C and the RH was 40-58 per cent. Thus, the measurement was carried out on a very hot day. Similarly, the second-day measurement was also carried out on a very hot day. The air temperature varied from 29 to 32°C in the morning; it reached 33°C at the time of measurement (11.30 a.m.). In addition, the solar radiation on both days was 1,000 w/m^2. The RH ranged from 45 to 58 per cent, which was within a comfortable zone. These, of course, influence the thermal environment performance inside the building, which affected the respondents' votes.

The analyses of thermal environments inside the classrooms

During the survey, four environmental factors (variables) affecting thermal comfort were determined at seven points inside NV classrooms. The variables were air temperature, RH, MRT, and air velocity. These variables are essential to enable calculation of the PMV as proposed by Fanger (1970). The average values of environmental variables are shown in Table II. As can be seen in the table, the average air temperature (T_a) inside the classrooms was high, which was almost 32 and 31°C during the measurement on 22 and 29 October 2013, respectively. The air temperatures were outside the thermal comfort zone as specified by the ASHRAE standard (ASHRAE, 2004) and also the Indonesian National Standard (BSN, 2011). However, the RH was already within the comfort zone of both standards. This might be one reason why most of the students still felt comfortable in this hot condition.

Table II.
The average value of environmental variables during measurements

Date	Time	Air temperature (°C)	MRT (°C)	Operative temperature (°C)	Air velocity (m/s)	Relative humidity (%)
22/10/2013	10:00-11:00	31.63	25.27	28.45	0.05	56.55
	11:15-11:45	31.96	27.10	29.53	0.09	52.57
29/10/2013	08:45-09:30	30.75	29.79	30.36	0.08	65.21

Thermal preference vs thermal acceptance

The analyses of thermal preference vs thermal acceptance are presented in Table III. As can be seen in the table, the majority of respondents (77 per cent) preferred a "cooler" temperature, while only just more than 22 per cent preferred "no change" in the condition. This indicated that the temperature conditions of classrooms were beyond the respondents' thermal preference. In all, 46 per cent stated that this hot condition was acceptable. This figure is quite low compared with the LEED requirements, which requires an 80 per cent acceptance rate. Among the 46 per cent of respondents who stated that they found the thermal condition acceptable, 26 per cent still preferred a lower temperature if they had an opportunity to change their thermal environment. Interestingly, more participants preferred "cooler" than "no change" conditions. As expected, no respondents chose a warmer temperature.

The majority of respondents (51 of 54 per cent) who did not accept this hot temperature preferred to have a lower temperature. Only a very small percentage of the respondents preferred "no change" in this group. This indicated that respondents consistently voted for their thermal preference.

Air velocity

The responses of participants in terms of the air velocity of the classrooms are presented in Figure 3. More than half of the respondents (56 per cent) believed that the air velocity was in the still categories ("slightly still" to "much too still"). Among the respondents who voted still categories, most of them felt "slightly still" (32 per cent) and about 24 per cent felt either "too still" or "much too still". Only less than 30 per cent believed that the air velocity was "just right". This indicated that the air velocity was stagnant or air movement was minimal. This indication was true when we compared the respondents' votes with the average air velocity measured inside the classrooms. The average air velocities only ranged from 0.05 to 0.09 m/s.

RH

The responses of participants on the humidity of the classrooms are presented in Figure 4. The majority of respondents (42 per cent) felt that the air was dry ("much too dry" to "slightly dry"), while only about 22 per cent felt that the air was "humid". More than one-third of the respondents felt that the humidity of air was "just right". About 88 per cent of respondents' votes were laid in the central position ("slightly dry", "just right", and "slightly humid"). If the votes in the central options are considered a comfort zone, it can be stated that the majority of respondents felt comfortable under RH. These votes were in agreement with the RH conditions of the classrooms, whose average ranged from 53 to 65 per cent (see Table II).

	Thermal acceptance		
Thermal preference	Not accepted	Accepted	Total
Cooler	60 (51)	31 (26%)	91 (77%)
No change	3 (2%)	23 (20%)	26 (22%)
Warmer	0 (0%)	0 (0%)	0 (0%)
No Answer	1 (1%)	0 (0%)	1 (1%)
Total	64 (54%)	54 (46%)	118 (100%)

Table III. Thermal preference vs thermal acceptance of respondents

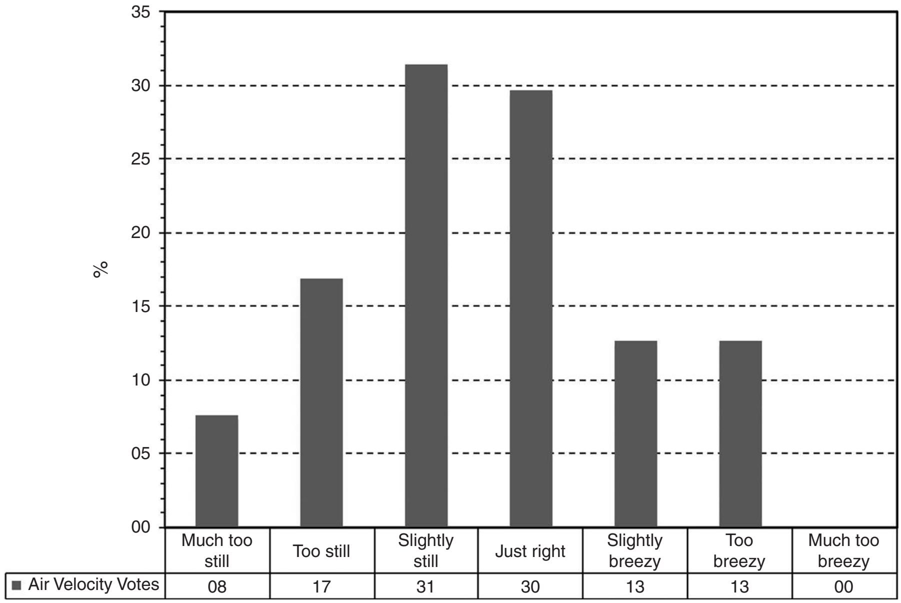


Figure 3.
The percentage of respondent votes on the air velocity condition

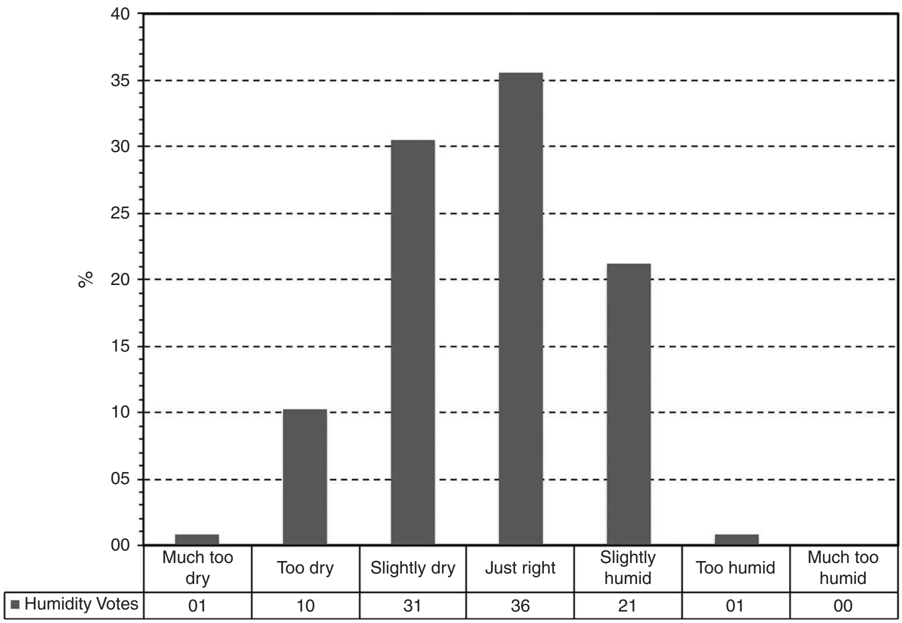


Figure 4.
The percentage of respondent votes on the humidity condition

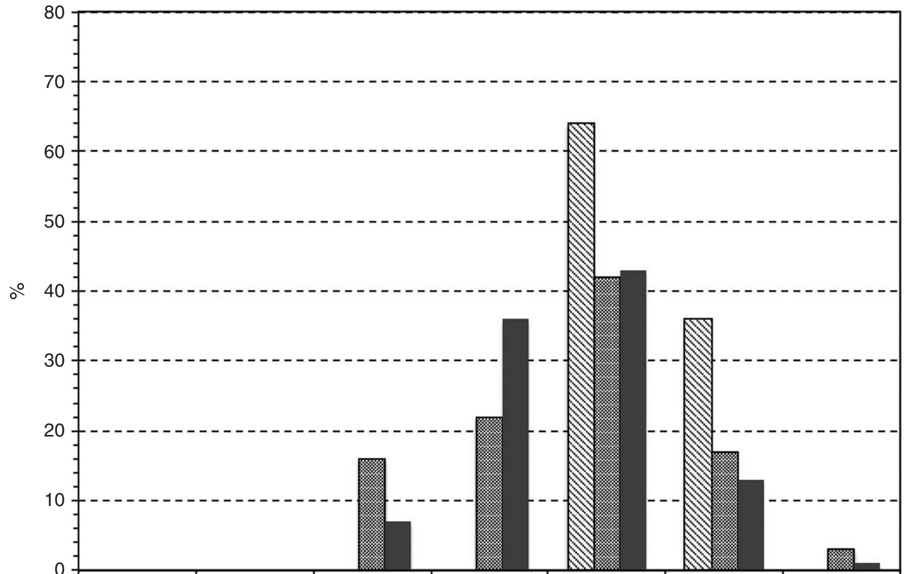
The comparison of predicted and surveyed respondents' votes

To analyse the applicability of the PMV model in predicting respondents' thermal comfort, the calculated PMV values have been compared with the respondents' votes obtained directly from the surveys. Two respondents' votes were used for the analysis, that is TSV and TCV.

The comparisons between calculated PMV, the TSV, and TCV are presented in Figure 5. As can be seen in the figure, the calculated PMV for all respondents were only located in the warmer region (+1 and +2), which meant that the predicted thermal comfort was "slightly warm" and "warm". However, the TSV and TCV votes showed different figures. The TSV values showed that the respondents' votes ranged from cool to the warm region ("slightly cool" to "hot"). The majority of respondents ($>$ 60 per cent) voted "slightly warm" and "neutral". Interestingly, more than 15 per cent respondents voted "slightly cool" and 3 per cent voted "hot". The respondents who voted "slightly cool" were might because they were came from the place of origin that hotter than this campus location. The TCV values showed that the respondents' votes ranged from cooler to warmer ("comfortably cool" to "much too warm"). The majority of respondents ($>$ 75 per cent) voted "comfortably warm" and "comfortable". Interestingly, more than 5 per cent voted comfortably cool. The same reason as mentioned in TSV might be the reason for this. It can be concluded that PMV model overestimated the observed TSV and the TCV of the respondents. This finding is in agreement with those of several researchers in the tropic area (Feriadi and Wong, 2004; Wong and Khoo, 2003) and also in the sub-tropical area (Hwang *et al.*, 2006).

According to the PMV model, none of the respondents reported feeling "neutral" or even "cold" in the classrooms' thermal environment conditions. However, the respondents' votes showed a different trend. More than one-third of the respondents in TSV and TCV voted −1 and 0.

The percentage of respondents who voted central positions (−1 to +1) was very high, namely 80 and 86 per cent for TSV and TCV, respectively, while only 64 per cent



	−3	−2	−1	0	1	2	3
PMV	0	0	0	0	64	36	0
TSV	0	0	16	22	42	17	3
TCV	0	0	7	36	43	13	1

Figure 5.
The comparison between PMV, TSV and TCV methods

of respondents were predicted (PMV) to be in this central position. These figures show that the TSV and TCV votes were significantly different from the PMV votes. The percentages of respondents who voted warm region were much less than the predicted votes using PMV method. It should be noted here that, even in the classrooms with a slightly low operative temperature caused by low MRT, the predicted votes (PMV) remained high.

In terms of TSV and TCV, the comparison of figures shows a very small difference. The slightly different percentage in the votes between TSV and TCV might be because of the different interpretations of the term used in the study for TSV and TCV scales. Both TSV and TCV votes might be a good indication that people living in hot and humid tropical regions are more tolerant to higher temperatures.

Further analyses to examine the difference between PMV and TSV, PMV, and TCV, and between TSV and TCV were carried out by a comparison of the means in the SPSS software. The results are shown in Table IV. The means were compared using a paired difference test; both pairs showed that the "sig. (two-tails)" were very small, $0.000 < 0.05$. These indicated that both pairs were significantly different. Another statistical parameter, namely, the Pearson's correlation, showed a very small correlation coefficient (r) 0.064 and 0.055 between PMV and TSV (pair 1) and between PMV and TCV (pair 2), respectively. This means that the PMV that is predicted using a thermal environment and personal variables produced different values in comparison with the TSV and TCV. The comparison of the means between TSV and TCV showed a high "sig. (two-tailed)" value of more than 0.05 and also a Pearson's correlation value (r) of 0.729. This indicated that the TSV shows good agreement with the TCV.

Analyses of neutral temperature

To predict the neutral temperature (T_n), regression analyses were carried out. Figure 6 shows scatterplot analyses with line-fit regression of PMV and TSV against the operative temperature (T_o). The regression analysis from SPSS version 16 shows that the "sig." was very small $0.000 < 0.05$, which confirmed a linear regression between the two variables. For the statistical test of regression coefficients, both coefficients had very small "sig." values of $0.000 < 0.05$. The coefficient determinant r^2 0.935 indicates that the regression is very good. Using a regression equation, the neutral temperature can be calculated according to Equation (1), which results in 25.3°C T_o. This meant that the PMV model predicts the respondents to feel neutral (neither warm nor cold) at the

Table IV. Comparison of means of pairs PMV-TSV, PMV-TCV, and TSV-TCV

	Paired differences							
				95% CI on the difference				
	Mean	SD	MSE	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1								
Predicted mean vote-thermal sensation vote	0.84	1.05	0.0967	0.65	1.04	8.739	117	0.000
Pair 2								
Predicted mean vote-thermal comfort vote	0.88	0.87	0.0798	0.72	1.04	11.015	117	0.000
Pair 3								
Thermal sensation vote-thermal comfort vote	0.03	0.70	0.0650	-0.09	0.16	0.524	117	0.602

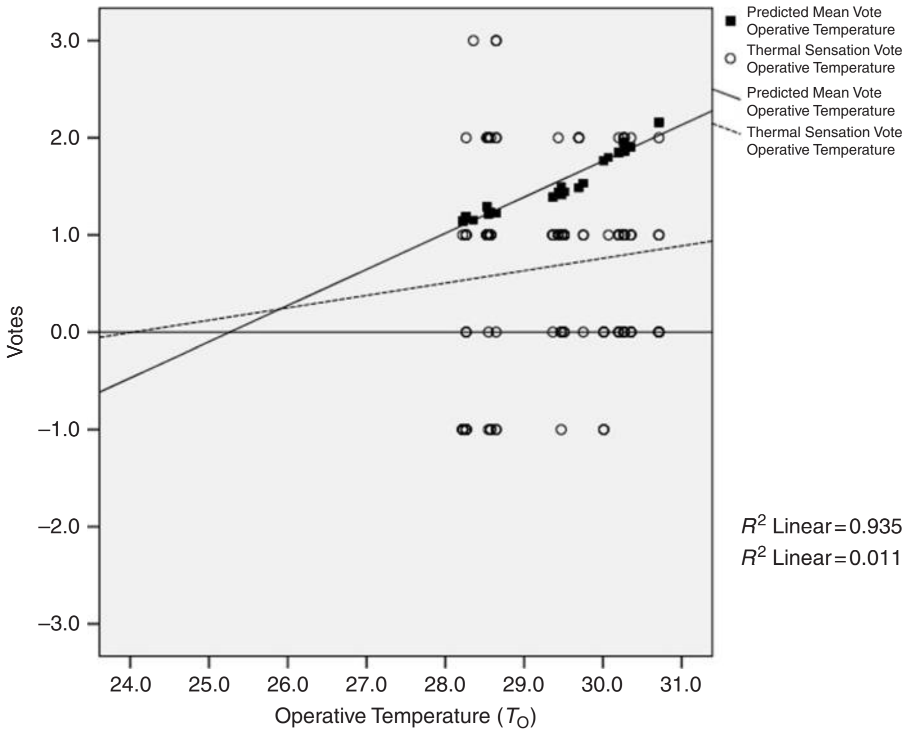


Figure 6. The regression analyses between the PMV and operative temperature and the TSV and operative temperature

temperature around 25.3°C T_o. Respondents will begin to feel warm if the temperature is more than 25.3°C T_o and will feel cold if the temperature is lower than this. This neutral temperature predicted by PMV model is quite low:

$$PMV = 0.372\ T_o – 9.394 \quad (1)$$

The regression analyses of statistical tests for TSV and T_o showed a week linear regression. The test parameters for linearity "sig." value 0.258 > 0.05 and also the "sig." for both equation coefficients were more than 0.05, with r^2 0.011, which shows that the regression equation is not statistically significant. This regression analysis yields an equation as shown in Equation (2). The equation produces a neutral temperature even lower at 24.1°C T_o. One reason for this is could be the calculated T_o were quite low. Low calculated T_o values were a result of the low MRT recorded during the survey. The MRT values were in the range of 25 to 30°C, although the value of indoor air temperature ranges from 30 to 32°C:

$$TSV = 0.172\ T_o – 3.064 \quad (2)$$

The neutral temperature of TSV based on the operative temperature is lower than the finding of research carried out in Jakarta by Karyono (2000) for AC buildings and for natural ventilation buildings located in the sub-tropical area of Hwang *et al.* (2006). Karyono (2000) found a neutral temperature of 26.7°C (T_o). This value is also lower than the result obtained by Busch (1990), de Dear *et al.* (1991), and Kwok (1998). In this case, the neutral temperature may not be correct if it is approximated on the basis of the operative temperature.

Because the regression between TSV and T_o is not statistically significant, the use of T_o might not be the correct way to represent the neutral temperature for this case. To increase the accuracy of predicted neutral temperature, we used the air temperature (T_a) as an independent variable instead of the T_o. As shown in Figure 7, a significantly different result was found when the TSV values were correlated to the air temperature. The statistical test shows that the regression was linear ("sig." $0.024 < 0.05$) and the equation coefficients were less than 0.05 for both constant ("sig." $0.033 < 0.05$) and air temperature ("sig." $0.024 < 0.05$). The regression analysis produces an equation presented in the following equation:

$$\text{TSV} = 0.375\ T_a - 11.098 \quad (3)$$

Because the air temperature was much higher than the MRT, the neutral temperature based on the air temperature increased significantly to 29.6°C (T_a). This new neutral temperature is certainly higher than those reported by Busch (1990), de Dear *et al.* (1991), Kwok (1998), and much higher than those reported by Karyono (2000) and Hwang *et al.* (2006). This finding might indicate why a higher percentage of respondents felt comfortable in this high-temperature condition and, therefore, it can be concluded that respondents in NV classrooms in the tropics are more tolerant to a higher temperature.

Conclusion

The analyses show that the indoor thermal environments were high. The average air temperatures (T_a) in the classrooms were about 30.8-32.0°C, while the average humidity varied from 52.6 to 65.2 per cent, with lower air velocity. These were possibly caused by a hotter outdoor thermal environment. However, the majority of respondents' votes laid in the comfortable region (–1 to +1), either in the ASHRAE scale or in the Bedford scale. The percentages of respondents who voted in this central position were 80 and

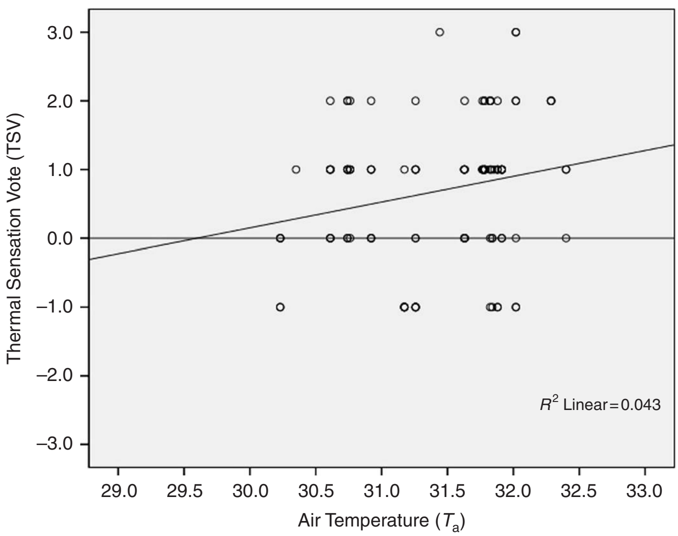


Figure 7.
The regression analyses between the TSV and air temperature

86 per cent for ASHRAE and Bedford, respectively. These were different from the percentage of predicted vote using the PMV method, where all respondents have been predicted to be "slightly warm" (+1) and "warm" (+2). More than 35 per cent of the respondents stated that they were "warm" (+2). Therefore, the use of the PMV method in predicting the thermal comfort of occupants in NV classrooms might produce inaccurate results and, of course, might not be applicable for this tropical region.

The analyses of neutral temperature showed a very different value of neutral temperature (T_n) resulting from the operative temperature (T_o) and air temperature (T_a). The neutral temperature based on T_o is 24.1°C, which is lower than the finding of previous thermal comfort studies carried out in tropical areas. Using the air temperature, the neutral temperature (T_n) increased to 29.59°C (T_a). This value is slightly higher than other results obtained by researchers in this region. To find the most accurate T_n for NV classrooms in this region, it is recommended to collect more data on thermal comfort votes. The survey should include a variation of respondents, time, and seasons.

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References

ASHRAE (2004), *Thermal Environmental Condition for Human Occupancy (ASHRAE Standard 55)*, ASHRAE, Atlanta, GA.

Auliciems, A. and Szokolay, S.V. (2007), *PLEA Notes 3: Thermal Comfort*, Passive Low Energy Architecture (PLEA) in association with Department of Architecture Queensland University, Queensland.

Bedford, T. (1936), "Warmth factor in comfort at work", Report No. 76, Med Res Council, Industry Health Res Board, HMSO, London.

Badan Standarisasi Nasional (BSN) (2011), *Standar Nasional Indonesia (Indonesian National Standardization) – SNI 6390:2011 Konservasi Energi Sistem Tata Udara Bangunan Gedung (Energy Conservation in Building Ventilation System)*, Badan Standarisasi Nasional (BSN), Jakarta.

Buratti, C. and Ricciardi, P. (2009), "Adaptive analysis of thermal comfort in university classrooms: correlation between experimental data and mathematical models", *Building and Environment*, Vol. 44 No. 4, pp. 674-687.

Busch, J.F. (1990), "Thermal responses to the Thai office environment", *ASHRAE Transaction*, Vol. 96 No. 1, pp. 859-872.

Corgnati, S.P., Ansaldi, R. and Filippi, M. (2009), "Thermal comfort in Italian classrooms under free running conditions during mid seasons: assessment through objective and subjective approaches", *Building and Environment*, Vol. 44 No. 4, pp. 785-792.

Corgnati, S.P., Filippi, M. and Viazzo, S. (2007), "Perception of the thermal environment in high school and university classrooms: subjective preferences and thermal comfort", *Building and Environment*, Vol. 42 No. 2, pp. 951-959.

de Dear, R.J., Leow, K.G. and Ameen, A. (1991), "Thermal comfort in the humid tropics. Part I. Climate chamber experiments on temperature preferences in Singapore", *ASHRAE Transaction*, Vol. 97 No. 1, pp. 874-879.

Fanger, P.O. (1970), *Thermal Comfort – Analysis and Applications in Environmental Engineering*, Danish Technical Press, Copenhagen.

Farina, A. (2015), "PMV calculator", available at: www.angelofarina.it/Public/Fisica-Tecnica-Ambientale-2015/Lez-04-05/PMV_cal_tanabe6.xls (accessed 10 December 2015).

Feriadi, H. and Wong, N.H. (2004), "Thermal comfort for naturally ventilated houses in Indonesia", *Energy and Buildings*, Vol. 36 No. 7, pp. 614-626.

Hwang, R.L., Lin, T.P. and Kuo, N.J. (2006), "Field experiments on thermal comfort in campus classrooms in Taiwan", *Energy and Buildings*, Vol. 38 No. 1, pp. 53-62.

ISO (1995), *ISO 7730, Moderate Thermal Environments – Determination of the PMV and PPD Indices and Specifications for Thermal Comfort*, 2nd ed., International Organisation for Standardisation Geneva, Switzerland.

Karyono, T.H. (2000), "Report on thermal comfort and building energy studies in Jakarta – Indonesia", *Building and Environment*, Vol. 35 No. 1, pp. 77-90.

Kwok, A.G. (1998), "Thermal comfort in tropical classrooms", *ASHRAE Transactions*, Vol. 104 No. 1B, pp. 1031-1047.

Kwok, A.G. and Chun, C. (2003), "Thermal comfort in Japanese schools", *Solar Energy*, Vol. 74 No. 3, pp. 245-252.

Mendell, M.J. and Heath, G.A. (2005), "Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature", *Indoor Air*, Vol. 15 No. 1, pp. 27-52.

Mom, C.P., Wiesebron, J.A., Courtice, R. and Kip, C.G. (1947), "The application of the effective temperature scheme to the comfort zone in the Netherlands Indies", *Chronica Naturae*, Vol. 103, p. 19.

Sensharma, N.P., Woods, J.E. and Goodwin, A.K. (1998), "Relationship between the indoor environment and productivity: a literature review", *ASHRAE Transactions*, Vol. 104, Part 1A, pp. 686-701.

Soegijanto (1999), *Bangunan di Indonesia dengan Iklim Tropis Lembab Ditinjau dari Aspek Fisika Bangunan (Buildings in Indonesia with the Humid Tropical Climate Considering Building Physics Aspects*, Direktorat Jenderal Pendidikan Tinggi Departemen Pendidikan dan Kebudayaan, Jakarta.

Teli, D., Jentsch, M.F. and James, P.A.B. (2012), "Naturally ventilated classrooms: an assessment of existing comfort models for predicting the thermal sensation and preference of primary school children", *Energy and Buildings*, Vol. 53 No. 0, pp. 166-182.

USGBC (2009), *LEED 2009 for New Construction and Major Renovation*, US Green Building Council, Washington, DC.

Wong, N.H. and Khoo, S.S. (2003), "Thermal comfort in classrooms in the tropics", *Energy and Buildings*, Vol. 35 No. 4, pp. 337-351.

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