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Investigation of Thermal Environments in Humid Tropical Classroom in Indonesia

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Abstract

Thermal comfort is one of the influencing factors in increasing concentration in teaching and learning process. This study has assessed the comfort level and differences in thermal sensations and preferences between male and female college students in a classroom in the humid tropical climate of Indonesia. The classroom was designed to operate to the extent possible using natural ventilation and daylight as passive techniques. The study was conducted by distributing questionnaires for 182 students to ascertain the thermal perceptions and preferences at different times and under varying conditions (including whether a ceiling fan was used) and by measuring air temperature, relative humidity and wind velocity in the classroom. The results suggest that noon and afternoon are both critical times that tend to have lower thermal comfort levels. At these times when a fan was not used, there were over 70% of students expressed discomfort; more males reported feeling uncomfortable than females. However, at noon with quite a high temperature, the effects of using ceiling fan are not able to increase significantly level of thermal comfort, but in the afternoon the use of the fan was instrumental in increasing the percentage of people feel comfortable. The PMV and PPD indices have been compared to the results of students' thermal perception analysis and noted that these indices are very sensitive to airflow parameter.

Keywords: thermal comfort; classroom; airflow velocity; ceiling fan; humid tropical climate; gender

1. Introduction

The productivity is commonly defined as the resultant of the individual intrinsic abilities and the external conditions. It is known that the productivity can achieve the expected level if the living conditions meet the minimum standards such as for continuing the work efficiently and comfortably, as reported in the European Project ThermCo (2009). External conditions, including thermal comfort conditions, which correspond to air temperature, air movement, humidity and body heat radiation (affected by metabolic rate and clothing), combine with contributing factors such as acclimatization, food and drink, body shape, subcutaneous fat, age and gender, and the state of one's health (Auliciems et. al., 2007). The classroom is an important facility in the learning process. Thermal comfort in the classroom should improve the learning process and student performance. An uncomfortable classroom, especially a hot one, can cause students to swelter, resulting in reduced concentration and disruptions in learning.

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Humid tropical climates with high average annual temperatures and relative humidity can induce sweltering and sweating. Givoni (1978) stated that there is a very close relationship between humans and climate and vice versa; even Olgyay (1976) stated that the typical climate determine largely the existing architecture in the area of climate. This adaptation process is essential to achieve a balance and to mankind itself with its environment to achieve comfort or neutral conditions. According to ISO 7730 (1985) that thermal comfort is a condition of mind which expresses satisfaction with the thermal environment. Thermal comfort is maintained only when the heat produced by the body's metabolism is equal to the heat lost from the body and signals from the body's heat and cold sensors are neutral. Furthermore, in order to simplify the definition, it is stated that thermal environment not only temperature as the only main parameters, but the role of other parameters is crucial. The human body has an automatic mechanism when confronted with the environment. In a cold environment will occur heating mechanisms: reduction of blood flow and shivering. While, in a hot environment will occur cooling mechanism by increasing blood flow and sweating (evaporation).

A classroom in the Faculty of Engineering at the University of Sam Ratulangi (USR) was originally designed to use natural ventilation and natural lighting, but whether this classroom meets standard thermal comfort levels has never been examined. The room was designed to provide comfort to its students with cross ventilation, intended to provide airflow with adequate distribution, evacuating the old, dirty air with new, fresh air. Nevertheless, it is necessary to ascertain whether the level of intended thermal comfort has been achieved.

Fanger (1970) observed that some experiments showed no substantial difference in comfort conditions between males and females, either among college-age persons or among elderly persons. In those instances, if any differences do exist, they are small and of no engineering significance. However, this research has been limited by age group and nationality (Danish and American). Nicol et al. (2012) stated that Andamon et al. found that in the warm climates of Southeast Asia, the preferred conditions correspond to 'cool', rather than 'neutral', on the ASHRAE scale. Therefore, we must be careful with the meaning of thermal preferences of respondents.

Other studies have been conducted on thermal comfort by Mochida et. al. (2005), who found that comfortable conditions can be obtained by increasing the flow of air in the chamber. Additionally, the work led to the use of air flow and distribution, which can increase thermal comfort (Kindangen, 1997, 2006). Mochida et. al. (1994) examined characteristics of humidity and comfort for the average dressed person with a constant skin temperature. They found that there was a substantial relationship between skin temperature and discomfort. Clement-Croome (1997) carried on research on the indoor environment to define design criteria. The guarantee of thermal comfort in office buildings that are climate-controlled (air-conditioned) has been investigated by Kajtar et. al. (2000), who found that thermal comfort can only be achieved for expected conditions if in accordance with design criteria. While reports about thermal comfort in academic buildings have been written by various researchers (Auliciems (1972), Wong et. al. (2003), Zang et al. (2007)) found that in general, appropriate treatments will define comfort conditions for occupants in the classroom.

2. Methods

The research was conducted in Manado that is situated in the province of North Sulawesi in Indonesia. Manado is located at latitude 1.4583°N and longitude 124.8260°E and has a humid tropical climate, as shown in Figure 1.

1. **Figure 1. Map of Indonesia, where the research was conducted.**

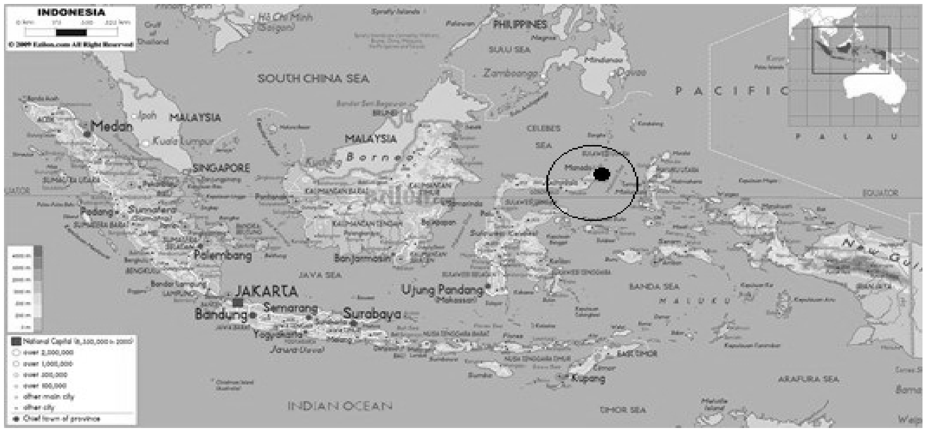
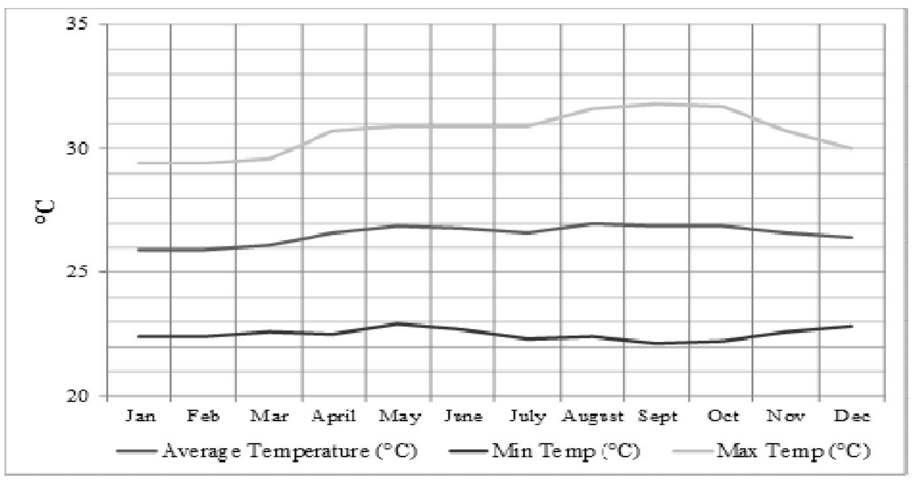


Figure 2. Climatic data for Manado



The hottest month is August with average temperature 27°C and the coldest one is January with average temperature 25.9°C. In general, the temperature difference between the hottest and the coldest month is not too much; their amplitude is small as presented in Figure 2. The rains' period occurs from November to February, being the rainiest month January (452 mm).In this study, we distributed a questionnaire at different times and under different conditions. The aim was to compare two conditions at a determined time, turning on and off the ceiling fan in the forenoon, at noon, and in the afternoon. Occupants' comfort perceptions were assessed from the questionnaires corresponding to the measured indoor climate conditions. To compare the thermal sensation and preference of students, we used a sample of 182 respondents overall. A Thermohygrometer 8664 was used to measure the temperature and an anemometer Meterman TMA 10 to detect the air speed at certain times and conditions. A questionnaire consisting of subjective ratings on scales of thermal sensation, preference and comfort was used in the study to obtain the most important responses of subjects. A 5-point thermal sensation scale (cold, slightly cool, comfortable, slightly warm and warm) was used according to the ASHRAE scale.The values of climatic parameters of measurement were substituted into the calculation of Fanger's comfort equation for finding PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) indices.

We have compared the results of respondents' thermal perception with the calculation of the PMV and PPD indices. The comparison is used to draw conclusions the sensitivity of climatic parameter for the calculation of thermal comfort.The research was conducted from the end of April to early July in a classroom at the University of Sam Ratulangi in Manado, located in the North block and on the second floor. The classroom was originally designed to use natural ventilation and lighting. In general, students respond that the classrooms on the second floor are hotter than those on the first floor or basement, due to contact with the ceiling and the roof. This condition is understandable because the heat emitted from the roof flows in the space between the ceiling and roof covering the classroom. This type of the roof is called a hot-roof, and its construction consists of corrugated zinc-aluminium sheets, ceiling hanger frames that are close to each other (approximately 50 cm distance) and ceiling triplex sheets. The ceiling is made of unpainted wood triplex, and geometrically follows the roof slope from left to right. On the right and the left sides are windows that can be opened to accommodate cross-ventilation and to obtain natural light, as in Figure 3.

Figure 3. Classroom building (a), the atmosphere of classrooms in which research was conducted (b).


(a)


(b)

3.Results and Discussion

3.1. The Preferable time and usage of ceiling fan

The research has been conducted by measuring and collecting data within 3 intervals of time: in the morning (7:00 to 12:00), at noon (12:00 to 14:00) and in the afternoon (14:00 to 18:00). Only data collected from students who declared themselves to be in healthy condition were included in the study. Seventy-six percent of the respondents wore a T-shirt with jeans, the remainder wore a shirt and cotton trousers. Converted into a unit of clothing, T-shirts and jeans have a value of 0.47 clo, while a shirt with long pants is 0.57 clo. Activities undertaken by respondents at the time in which they were sitting have a value equivalent to 1 Met. Information was also obtained regarding the activities of the respondents immediately prior to the study, and most reported walking or relaxing.In the morning time interval (7:00-12:00), the room temperature was 26.3ºC and relative humidity (RH) 84.6%.

Indoor wind speeds (v) measured at 0.04 m/s; students felt comfortable and not too hot, even without the ceiling fan. Of all respondents, 56% felt comfortable with the existing conditions, 24% felt slightly warm, 16% felt slightly cool and 4% felt cold. The preferences of total respondents in the initial climatic conditions are measured at 76% who would prefer to be a little cooler, 20% who were satisfied with the initial conditions and 4% who preferred to be a little warmer. To gain more information on the quality of the indoor thermal environment, we asked respondents whether they were sweating. The results showed that only 12% respondents were sweating, indicating that the room was not too hot. At the end of the questionnaire, we asked the respondents to indicate whether they felt comfortable. As predicted, the responses indicated that 60% of the respondents felt comfortable and 40% of the respondents did not feel comfortable.If compared to the PMV and PPD indices that incorporated in ISO 7730, we noted that the PMV is equal to 0.7 indicated a state of neutral to slightly warm. PPD value that describes the percentage of people who do not satisfy with their thermal environment showed just 12%. The PPD index is much lower than the results of the field measurement, where the measurements noted that on average, respondents felt uncomfortable was 40%, as described in Table 1.

Table 1. Thermal environment in the morning no fan.

Time:		**07:00 – 12:00**
Climatic's condition:		
	T int	26.3° C
	RH	84.6 %
	v	0.04 m/s
Thermal sensation (%):		
	Cold	4
	Slightly cool	16
	Comfortable/neutral	56
	Slightly warm	24
	Warm	0
Thermal preference (%):		
	More hotter	0
	More slightly warmer	4
	No change	20
	More slightly cooler	60
	More cooler	16
Sweating or not (%):		
	Sweating	12
	Not sweating	88
Comfortable or no (%):		
	Comfortable	60
	No comfortable	40
PMV and PPD:		
	PMV	0.7
	PPD	12 %

At noon (12:00-14:00), the measurement and distribution of the questionnaires were executed with two treatments, with and without the use of the ceiling fan, which enabled us to determine the contribution of air flow velocity on thermal comfort in the classroom. The climatic conditions during this time without running the ceiling fan were 28.2ºC with a relative humidity of 72.3% and an indoor wind speed of 0.04 m/s.The results of thermal sensation from this time were as follows: no respondents felt cool, only 5% felt slightly cool, 38% felt slightly warm, 35% of respondents felt warm, and only 22% felt neutral or comfortable.

Therefore, there were 73% who felt uncomfortable under these conditions, in the state of slightly warm, slightly cool and even warm. There were striking differences between the sensation of slightly warm and the sensation of warm.The desire to improve climatic conditions is evidenced by 53% who wanted to be cooler, 25% who wanted a little cooler and 20% who did not desire changing the climate conditions. The automatic response of the human body is to sweat if in a hot environment. Sweating is a physiological cooling mechanism; therefore, it can be assumed that most respondents would sweat in the existing thermal environment. During the 12 to 2 p.m. hour, the study recorded that 64% of all respondents were sweating while the remaining 36% were not sweating. To confirm or evaluate the suitability of the classroom environment, the students responded to the question of whether they were comfortable. As expected, 74% of the respondents said it was not comfortable while the remaining 26% expressed that it was comfortable.The temperature and humidity levels during the noon hour (12:00 to 2:00 p.m.) were slightly lower with the use of the ceiling fan running at a speed of 1.5 m/s. The interior temperature decreased to 27.9ºC with a relative humidity of 70.8%.With the ceiling fan running, 25% of respondents felt slightly cool, 24% felt neutral/comfortable and 34% felt slightly warm.

When compared with the results from not using the ceiling fan, it can be concluded that a significant shift occurred in which the percentage of people who felt warm was reduced to 28% but only 2% differences of students felt comfortable. Under this condition, the respondent's perception of air movement can increase their thermal sensation. Additionally, there has been a change in the percentage of respondents' preferences in the categories of wanting to be cooler and neutral or no change to the previous state. It could be observed that there were still 59% of respondents who said it was uncomfortable while the remaining 41% expressed being comfortable as summarized in Table 2.Calculation of PMV and PPD indices showed that during the noon without using of fan gained value PMV = 2, categorized in warm state and PPD by 76%. When compared with field measurements, in such circumstance, the average respondent in the perception of "warm" and 74% in a state of discomfort. The results of the calculation using the PMV and PPD indices and measurements showed no significant differences. However, when the magnitude of the air velocity increased, the calculation showed PMV at 0.6, which is state of the neutral to slightly warm, and PPD showed at 14%. While the measurements recorded 59% of respondents were dissatisfied. This striking difference suggests that the calculation of the PMV and PPD are quite sensitive to the increasing air speed than the reality on the field.

Table 2. Thermal environment at the midday of a room with running ceiling fan and not.

Time:		**12:00 – 14:00**	
		Withouta ceiling fan	With a ceiling fan
Climatic's condition:			
	T int	28.2° C	27.9° C
	RH	72.3 %	70.8 %
	v	0.04 m/s	1.50 m/s
Thermal sensation (%):			
	Cold	0	10
	Slightly cool	5	25
	Comfortable/neutral	22	24
	Slightly warm	38	34
	Warm	35	7
Thermal preference (%):			
	More hotter	0	0
	More slightly warmer	2	14
	No change	20	31
	More slightly cooler	25	31
	More cooler	53	24
Sweating or not (%):			
	Sweating	64	24
	Not sweating	36	76
Comfortable or no (%):			
	Comfortable	26	41
	No comfortable	74	59
PMV and PPD:			
	PMV	2	0.6
	PPD	76 %	14 %

The measurement and distribution of questionnaires were conducted during the afternoon (14:00 to 18:00) with two treatments, with the ceiling fan activated and not. The indoor climatic condition when the ceiling fan did not run was recorded with an air temperature of 27ºC, relative humidity of 86.3% and wind speed measured at 0.04 m/s. This condition caused most respondents to be in the warm sensation (43%) and in little warm sensation (33%) categories, while only 17% felt comfortable, and all respondents declared themselves healthy.The desire to improve climatic conditions is evidenced by 54% who wanted to be cooler, 33% who wanted a little cooler and 10% who did not desire changing the climatic conditions, the rest who wanted a little warmer. We noted that 47% of respondents was sweating and 53% who did not sweat. The proportion of sweating and not one, indicating the contribution of air temperature in the afternoon that was a bit down. As predicted, 73% of respondents said they were uncomfortable while the remaining 27% expressed feeling comfortable.

The indoor climatic condition in the afternoon with the fan running was recorded at 26.5ºC air temperature, 89% relative humidity and 0.7 to 1.2 m/s airflow velocity. These conditions caused 48% of all respondents to feel comfortable, 14% feel slightly warm and 21% feel warm, 10% feel slightly warm and 7% feel cold. If compared with the conditions without the ceiling fan it could be concluded that people who felt comfortable enhanced as much 31%, and those who felt slightly warm and warm respectively reduced approximately 19% and 22%.The percentage of all respondents who wanted to modify the conditions to be a little cooler was 38%, unchanged 34% and to be cooler 21%. It is noted that in this condition, only 31% of respondents reported sweating compared to 69% who did not sweat; 69% of respondents said they were comfortable while the remaining 31% expressed feeling uncomfortable.

The results of the PMV and PPD indices in the afternoon without running fan was obtained PMV = 1.6 indicating the condition rather warm and PPD = 67%. When compared with the measurement results it can be concluded that the calculation is lower than the measurements, which were recorded 73% of respondents in the uncomfortable condition. However, the results of the calculations for the afternoon with the running fan recorded PMV = 0 and PPD = 5%, which indicates all the occupants in comfortable circumstances. This result is very different than the measurement, we note that there are 31% of respondents feel uncomfortable. Once again, it was concluded that the PMV and PPD indices are quite sensitive to changes in airflow velocity parameters.

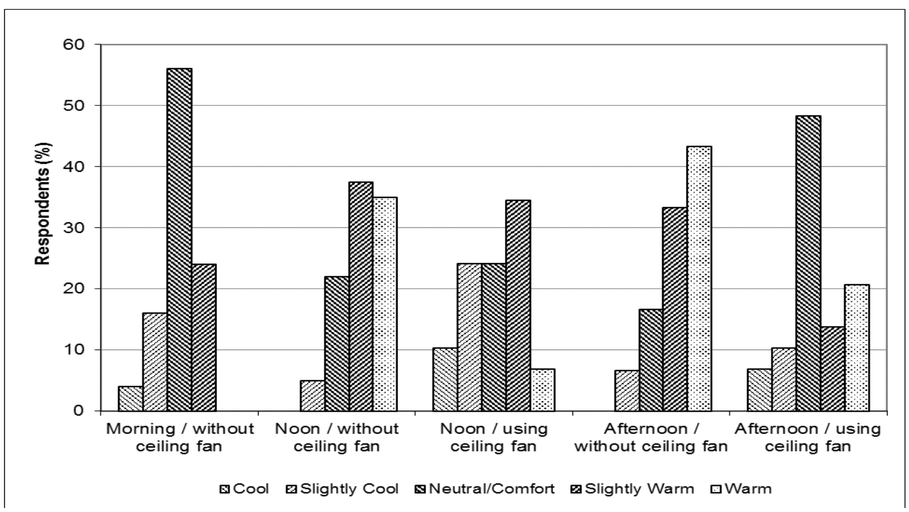
Table 3. Thermal environment in the afternoon for a room with running ceiling fan and not.

Time:		**14:00 – 18:00**	
		Without a ceiling fan	With a ceiling fan
Climatic's condition:			
	T int	27.0° C	26.5° C
	RH	86.3 %	89.0 %
	v	0.04 m/s	0.70 – 1.20 m/s
Thermal sensation (%):			
	Cold	0	7
	Slightly cool	7	10
	Comfortable/neutral	17	48
	Slightly warm	33	14
	Warm	43	21
Thermal preference (%):			
	More hotter	0	0
	More slightly warmer	3	7
	No change	10	34
	More slightly cooler	33	38
	More cooler	54	21
Sweating or not (%):			
	Sweating	47	31
	Not sweating	53	69
Comfortable or no (%):			
	Comfortable	27	69
	No comfortable	73	31
PMV and PPD:			
	PMV	1.6	0
	PPD	67 %	5%

3.2. Role of Air Velocity to Increase Thermal Comfort

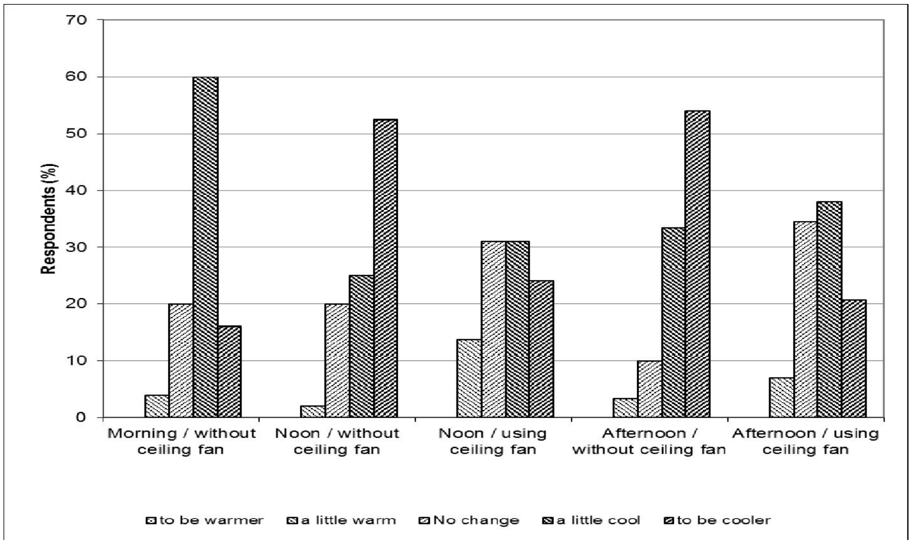
The decreasing of temperature is only able to change the impression of respondents facing a hotter temperature condition. This situation can be explained by considering the percentage of student's preferences to the climatic conditions of the classroom. The desire not changed and to be little cooler becomes greater when running of fan than not using of fan, but the desire to be cooler will be smaller when running ceiling fan. As a function of convection, then by using ceiling fan may decrease the percentage of respondents who sweat. If we pay attention more detail, especially in the afternoon, the using of the fan will only add one respondent who felt more comfortable / neutral than when not using one. This means that the using of the ceiling fan at a relatively high temperature conditions do not significantly alter the response to the conditions of comfort of students in the classroom. The number of students who feel slightly warm only slightly reduced when using a ceiling fan, while the number who felt warm is significantly reduced when using a ceiling fan. Conversely, the number of respondents who felt slightly cool and cold, significantly increase when using a ceiling fan. Impression of slightly warm of the respondents almost does not differ much happened during the noon without the fan, and in the afternoon without it. Impression of warm does not occur in the morning, mostly in the afternoon without running ceiling fan, which was followed by the noon without fan, as in Figure 4.

Figure4.Students' thermal sensations.



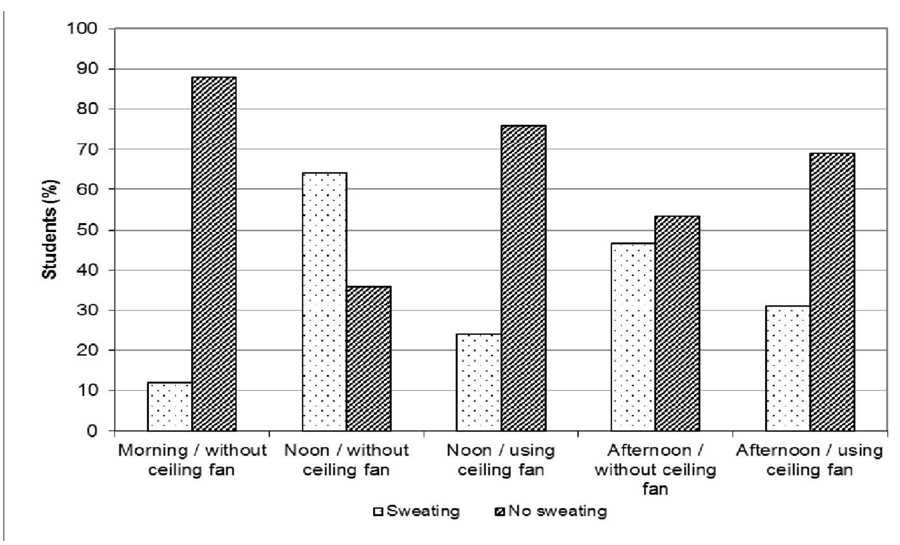
The percentage of respondents who wanted no change from the existing climatic conditions occur most commonly in the afternoon with the ceiling fan, then followed at noon with ceiling fan and the morning without ceiling fan as well as during the noon without ceiling fan. This condition reflects the general impression on the respondents to the climatic conditions in line with the description above. This desire is consistent with the measured temperature parameters for each time and condition. The desire to be cooler dominated at the time of the afternoon without the fan and at noon without ceiling fan, which is not contrary to the calculations at first (Figure 5).

Figure 5. Respondents' thermal preferences.



In accordance with earlier predictions and also in line with existing conditions, where in a warmer environment will trigger a growing number of people who sweat, then the percentage of sweating was dominated during the noon without running fan and the afternoon without fan, as in Figure 6. In contrast the percentage of respondents who do not sweat dominated the morning, and then consecutive at noon with the ceiling fan and the afternoon with ceiling fan.

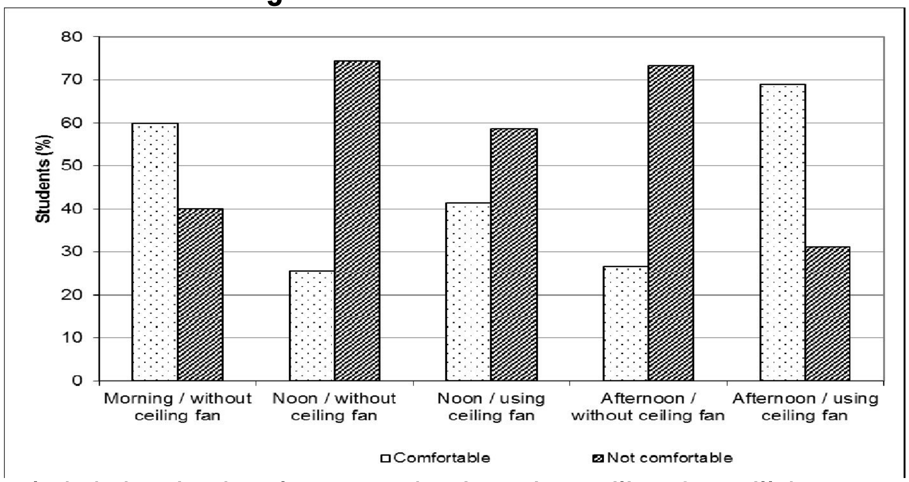
Figure 6. Sweating and no sweating



As described earlier, to validate the respondents' answers to the conditions that existed then at the end of the questionnaire asked the verification questions, the respondents felt comfortable or uncomfortable. The results of this response compared to all the conditions, it was found that the most convenient of which approximately 69% of respondents felt "comfortable" found in the afternoon with ceiling fan. There are 60% of respondents who feel comfortable in the morning without fan, while below 50% of respondents felt comfortable during the noon with fan.

In other words, during the noon either with a running ceiling fan or without using it and in the afternoon without the fan there are over 50% of respondents feel uncomfortable, as described in Figure 7.

Figure7.Feel comfortable or not

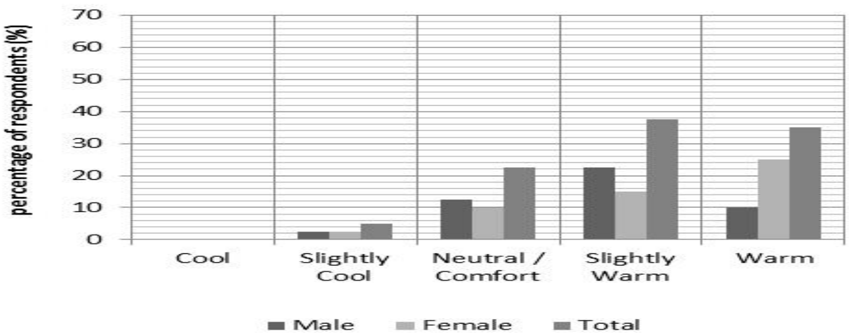


It can be concluded that in the classroom despite using ceiling fan still have not managed to achieve comfortable conditions at noon, and the usage of ceiling fan would be more beneficial in the afternoon. Thus, to create comfortable conditions that can benefit students for every hour is recommended to use air conditioners and used efficiently, especially at the noon that assisted with the use of a ceiling fan.

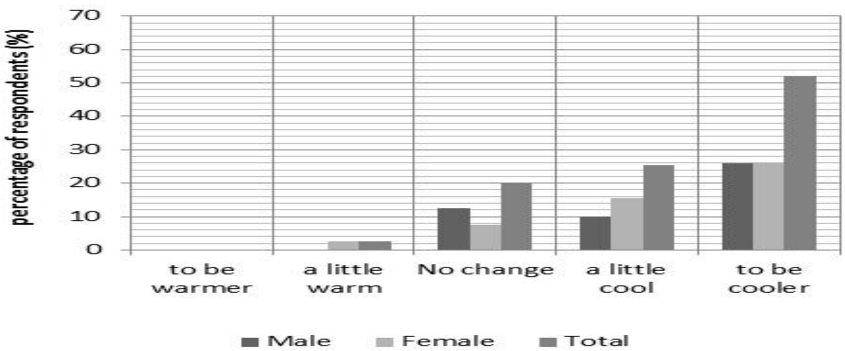
3.3. Gender Differences in Thermal Comfort

To assess the thermal comfort of gender then used the results of measurements and data collection during the day: the hours of 12:00 - 14:00. There were striking differences between the sensation of slightly warm and the sensation of warm; more females felt warm (25% compared with only 10% of males); and more males felt slightly warm (22.5% compared with only 15% of females), as depicted in Figure 8(a). There were no significant differences between females and males in comfort and slightly cool sensations.The preference to be cooler did not differ significantly between females and males. Nevertheless, there were striking differences found between male and female respondents in the preference to remain unchanged or neutral and in the desire to become a little cooler. Where 12.5% of male respondents wanted no change from the initial conditions compared to 7.5% of females, 15% of female respondents wanted a little cool compared to only 10% of males, as shown in Figure 8(b).

Figure 8. Thermal perceptions (a) and preferences (b) between males and females at noon without running ceiling fan



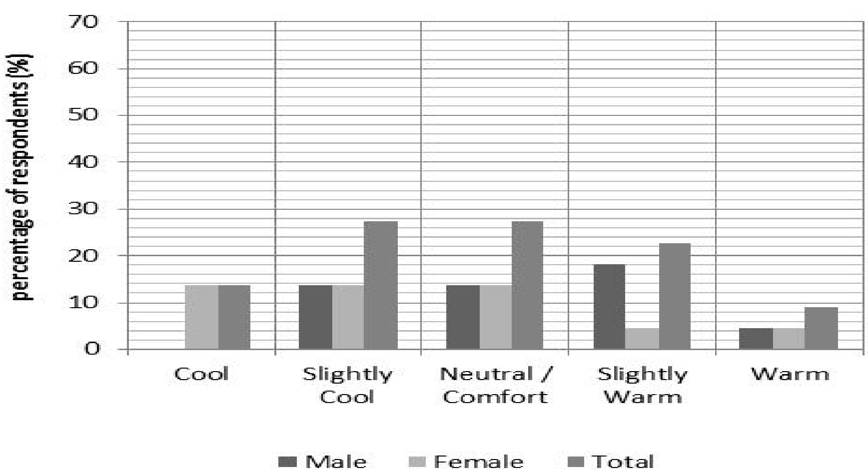
(a)



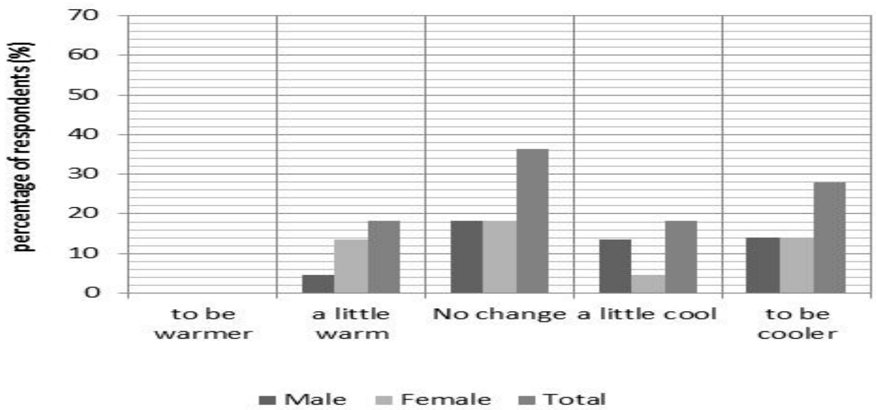
(b)

The respondent's perception of air movement can increase their thermal sensation. The acceptability and preferences reported indicate that females have more sensitivity to the influence of air flow than do males. In the slightly warm category of perception, the percentage of males remained close to the same (18%), compared with a greater decrease for females. The cool sensation was only experienced by female respondents (14%), as shown in Figure 9(a). There is no striking contradiction between the first results and the results of the preference. The preference for a little cool is greater for male respondents, 14% in all; in contrast, 14% of female respondents want to be a little warm, as in Figure 9 (b). It can be concluded that more female respondents feel the immediate benefit with the use of the fan than males.

Figure 9. Thermal perceptions (a) and preferences (b) between males and females at noon with running ceiling fan



(a)



(b)

Statistical analysis using a cross tabulation aims to provide a basic picture of the interrelation between gender and the thermal sensation and preference. The test results indicate that the thermal sensations and preferences for the midday in classrooms that either use a fan or do not use is not significant association. The p-value for thermal sensation on the midday without using a ceiling fan is 0.404915 and for thermal preferences amounted 0.441773; while the p-value for thermal sensation at noon using a ceiling fan is 0.174094 and for thermal preferences is 0.479552. In other words, thermal sensation and preferences is not significantly dependent with the gender: between women and men.

4.Conclusions

This paper reflects the results of a study of thermal sensation and preference in the tropical humid classroom, conducted at the University of Sam Ratulangi in Manado, Indonesia. Observing the different responses to the classroom climate with and without the use of a ceiling fan, particularly during the critical noon and afternoon time intervals have provided clarity on the role of air flow in thermal comfort. The morning condition gave the impression of comfort even without using the fan. It was found noon and the afternoon were both critical times, which tended to lower the comfort level. In such conditions, the number of males who felt uncomfortable was more than the number of females.

In contrast, when a fan was used, thermal comfort was greater for females than for males. The effect of using the fan was limited in increasing thermal comfort in the classroom during quite high temperatures at noon. However, in this condition, using the fan was instrumental in increasing the percentage of people who felt comfortable. By comparing the results of the PMV and PPD indices with the results of field measurements obtained that this calculation is quite sensitive to changes in increasing of air speed. To achieve thermal comfort in the classroom, it is still necessary to use the ceiling fan, especially in the afternoon, while at noon it is suggested that the air conditioning be used, with or without the fan. This combination would be beneficial, especially for energy savings.

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