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May We Obtain Thermal Comfort with Passive and Low Energy Building? Study of Thermal Comfort in Humid Tropical Classroom

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Abstract
Thermal comfort is one of determinant factors in increasing concentration in teaching and learning process. This study has assessed the comfort level in classroom at the Engineering Faculty of Sam Ratulangi University Manado. The classroom was designed to operate as long as possible by using passive techniques and having Intensity of Consumption Energy at below of 70 kWh/m^2/year. The study was conducted by spreading questionnaires to find out how the thermal comfort responses on several conditions, using ceiling fan or not, and by measuring air temperature, relative humidity and wind speed. We found that the noon and the afternoon is a critical time which tends to lower the comfort level. There is over 70% of respondents expressed discomfort at the noon and the afternoon without using ceiling fan. However, at the noon with quite high temperature, the effects of using ceiling fan are not able to increase significantly level of thermal comfort, but at the afternoon the use of fan was instrumental in increasing the percentage of people feel comfortable. PMV and PPD indices from Fanger's comfort equation have been compared to the results of respondents' thermal perception analysis; we noted that these indices are very sensitive to airspeed parameter.

Keywords – thermal comfort; classroom; passive and low energy building; ceiling fan

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 effectively and comfortably [1]. External conditions including thermal comfort conditions which being correspondence to air temperature, air movement, humidity and radiation with the condition of the body's heat (metabolic rate and clothing) and contributing factors such follows acclimatization, food and drink, body shape, subcutaneous fat, age and gender, and state of health [2]. Thermal comfort in the classroom is intended to improve the performance of the teaching and learning process as well as continuing with the current lecture. Uncomfortable conditions that can lead students swelter in the heat even when lecturing so that the concentration is reduced even disrupt the learning process. The climatic condition in Indonesia which is a humid tropical climate has always been a major problem of thermal inconvenience. In the hot environment and coupled with high humidity will cause someone to feel swelter and will definitely sweating. In such conditions, it is necessary airflow psychologically and physiologically able to evaporate the sweat on the skin and gives the impression of a cool. Classroom at the Faculty of Engineering, University of Sam Ratulangi, which was originally designed to use natural ventilation and natural lighting has never been studied whether it meets the standard thermal comfort level. The room was designed with cross ventilation, of course, was expected to provide air flow and adequate distribution in the room to give the impression of comfort or to evacuate the old or dirty air with the new or cooler air. However, it is necessary to find the answer about the level of thermal comfort happened.

2. Methodology

Givoni [3] stated that there is a very close relationship between humans and climate and vice versa; even Olgyay [4] stated that the typical climate determine largely the existing architecture in the area of climate. This adaptation process is essentially to achieve a balance and to mankind itself with its environment to achieve comfort or neutral conditions. According to ISO 7730 [5] that thermal comfort is condition of mind which expresses satisfaction with the thermal environment. 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).

Thermal environmental perception is basically influenced by the interplay of impulse signals whether the impulses from the sensor hot or cold signals. Heat sensors send impulses to the hypothalamus when the temperature exceeds 37°C. Cold sensors send impulses to the hypothalamus when the skin temperature is below 34°C. The bigger temperature difference the more impulses. If impulses are of same magnitude, we feel thermally neutral, if not, we feel cold or warm. Energy balance is a prerequisite for the achievement of thermal neutrality, thermal comfort can be maintained only when the heat produced by metabolism of the body equal to the heat lost from the body and the signal from the sensors of heat and cold should be neutral to each others [6].

Other studies have been conducted on thermal comfort by Akashi Mochida et al [7] stated that comfortable conditions can be obtained by increasing the flow of air in the chamber. Likewise, the study contributed to the role of air velocity and distribution which can increase the thermal comfort [8, 9]. T. Mochida et al [10] examined characteristics of wettability and comfort for the average dressed in skin temperature constant. He found that there was a strong relationship between skin temperature and discomfort. Clement-Croome [11] conducted research on indoor environment and determine the design criteria. Guarantee thermal comfort in office buildings that acclimatized (air-conditioned) has been investigated by L. Kajtar et al [12], who found that thermal comfort only be achieved at the expected conditions in accordance with design criteria. While the study on the level of thermal comfort in education buildings has been conducted by several researchers [13,14,15], which found the average of the traits define comfort conditions for occupants in classroom.

For this study, we carried out by spreading the questionnaire for different times and different treatments. It is intended to obtain a comparison between two conditions at the time specified as turning on and off the ceiling fan in the morning, the noon, and the afternoon. Occupants' comfort perceptions were assessed from the questionnaires with correspondence to average rate thermal condition. Measuring instruments used is a Thermohygrometer 8664 to measure the temperature and an anemometer Meterman TMA 10 and which detects the air speed at certain condition.

The values of climatic parameters from 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 PMV and PPD indices. The comparison is used to draw conclusion the sensitivity of climatic parameter for the calculation of thermal comfort.

Research conducted in a classroom at the Faculty of Engineering Sam Ratulangi University (Unsrat) in end of March to early May 2011, located on the 2nd floor at the North block, which was originally designed to use natural ventilation, natural lighting and having Intensity of Consumption Energy (ICE) below of 70 kWh/m^2/year. The classroom is selected which is located on the second floor. In general, students will respond that the classrooms on the second floor where direct contact with the ceiling and the roof was hotter than the first floor or basement. This is understandable because the heat emission from the roof flows in the space between the ceiling and roof covering to the classroom, especially of metal roofing material that is of zinc aluminum. The type of this roof is *hot roof type*, namely roof construction consists of corrugated zinc-aluminum roofing, ceiling hanger frame close to each other (approximately 50 cm distance) and ceiling lining. Ceiling is made of materials that the unpainted wood triplex is geometrically follow the roof slope to the left or the right. On the right and the left sides there is a window open to accommodate the occurrence of cross-ventilation and to get natural light, as in Fig. 1.

Fig.1 The studied building and classroom conditions

3. Results and Discussion

The research has conducted with measuring and retrieving data within 3 (three) intervals of time such as in the morning (7:00 to 12:00), the noon (12:00 to 13:00) and the afternoon (13:00 to 17:00). The data are only used when the condition of students declared themselves in a healthy condition.

In the morning (7:00-12:00), there are 56% who feel "comfortable" with the climatic conditions, 24% who feel "slightly warm", 16% felt "slightly cool" and 4% felt "cool". We noted that the room condition having interior temperature of 26.3ºC and relative humidity (RH) of 84.6%. Indoor wind speed (v) measured at 0.04 m/s; people will still feel comfortable and not too hot though not turned on the ceiling fan.

Regarding to the respondents' desire what should be changed from the initial climatic conditions, it is noted there are 76% who wanted "to be little cooler", 20% wanted "does not change or remain" with the initial conditions. However, there is 4% who wanted "to be little warmer".

The most respondents used T-shirt with jeans trousers (76%), the other used a shirt and cotton trouser. If we converted into the unit of clothing T-shirts and jeans trousers value 0.47 *clo*, while a shirt with long pants for 0.57 *clo*. Activities undertaken by respondents at the time are sitting the equivalent value of 1 *Met*. Meanwhile, to get a picture of the previous activity, the question of what was done prior to the large activity the most just walked and relax. To more accurately the response of the respondents to the quality of indoor thermal environment then asked whether they are sweating or not. The result is only 12% respondents is sweating and 88% do not sweat, this shows that the condition of the room being not too hot. At the end of the questions in the questionnaire we asked questions that allow respondents to choose one of two choices, namely whether now you feel comfortable or uncomfortable. As predicted, the results of this question noted there were 60% who chose comfort and 40% chose not comfortable.

If compared to the calculation of PMV and PPD indices that incorporated in ISO 7730, we noted that 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 calculation of PPD indices is much lower than the results of the field measurement, where the measurements noted that the average respondents felt uncomfortable was 40%.

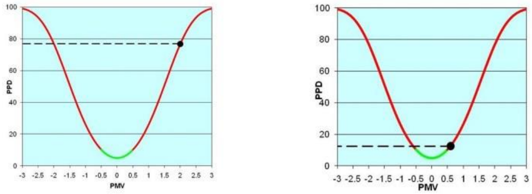
During the noon (12:00-13:00), measurement and deployment of questionnaires carried out with two treatments, when the ceiling fan in the room is executed and not, to be able to know the contribution of air flow velocity of thermal comfort in classroom.

Climatic conditions during this time without running ceiling fan air temperature were recorded of 28.2ºC and relative humidity (RH) of 72.3%. Indoor wind speed (v) measured at 0.04 m/s, where no respondents feel "slightly warm", 35% feel "warm", while feeling "neutral or comfortable" only 22.5%. Thus there are about 77.5% who feel uncomfortable in under this condition, in the state of slightly warm even hot.

The desire to improve climatic conditions can be explained where there are 53% wanted "to be cooler," 25% "adding a little cool" and 20% do not want change climatic conditions.

Automatic response of the human body would sweat if they are in a hot environment. This is a physiological cooling mechanism, so it can be ascertained that the most respondents would sweat on existing thermal environment. During hours of 12 to 1 pm, recorded 64% of all respondents are sweating while the remaining 36% is not sweating. As the previous results, to confirm or validate the suitability of the respondent filed a response to a question with a choice between two answers only. As expected there is 74% of respondents said it was not comfortable while the remaining 26% expressed comfort.

In the other hand, this time with running the ceiling fan has recorded that air temperature in the classrooms of 27.9ºC with a relative humidity 70.8%, the interior temperature decrease of 0.3ºC from the previous state as a result of convection forced by using ceiling fan. The condition of classroom during this time with running ceiling fan caused there are 35% of respondents who felt "slightly warm", 24% felt "neutral/comfortable" and 24% felt "slightly cool". When compared with the condition in which not using the ceiling fan, it can be concluded that a significant shift in which people feel "warm" is reduced to 7% only. It is noted there are still 59% of respondents said it was uncomfortable while the remaining 41% expressed comfort.



(a) (b)

Fig. 2 Calculation of PMV and PPD for the noon, (a) without running fan (b) with running fan

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 77.5% 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 PMV and PPD are quite sensitive to the increasing of air speed than the reality on the field.

Measurement and distributing questionnaires conducted during the afternoon (13:00 to 17:00) with two treatments, when the ceiling fan in the room is not executed and the time the ceiling fan runs. The condition climatic without running ceiling fan in the room was recorded that air temperature being 27ºC and relative humidity (RH) of 86.3%. Indoor wind speed (v) measured at 0.04 m/s, which is the most respondent in hot perception (43%), while feeling "neutral" or "comfortable" only 17%, of the 30 respondents who declared himself healthy.

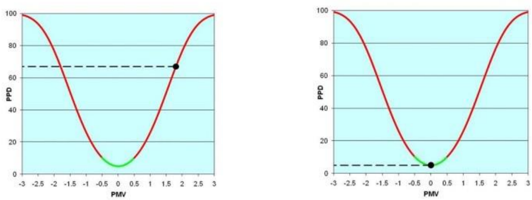
The desire to improve the climatic conditions can be explained from the results, where there are 53% wanted "to be cooler," 34% wanted "to be little cooler" and 10% did not want a change in climatic conditions.

Sweating is a physiological cooling mechanism, we found 47% of respondents was sweating and 53% who did not sweat. The proportion of sweating and not sweating, indicating contribution of air temperature in the afternoon that was a bit down. As predicted there are 73% of respondents said they was uncomfortable while the remaining 27% expressed comfort.

The climatic condition of the afternoon by running fan that recorded air temperature at 26.5ºC with 89% relative humidity and wind velocity of v = 0.68 to 1.2 m/s. This climatic conditions has caused 48% of respondents who were "neutral / comfortable", 14% felt "slightly warm", 21% felt "warm", 10% felt "slightly cool", and 7% felt "cold", from 29 healthy respondents. When compared with the condition in which not using the ceiling fan it can be concluded that a significant shift in which people feel "slightly warm" and "warm" successively reduced about 19% and 22%.

The percentage of respondents wanted to change the condition "being little cooler" is 38%, "unchanged / neutral" by 34% and "to be cooler" by 21%. As noted on this condition there are only 31% of respondents sweating compared to 69% do not sweat; 69% of respondents who say comfortably while the remaining 31% expressed discomfort.

The results of calculation of 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 = 0, 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 calculation of PMV and PPD indices are quite sensitive to changes in airspeed parameters.



(a) (b)

Fig. 3 PMV and PPD indices for the afternoon period (a) without running fan and (b) with running fan

4. 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 respondent’s desire to 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" to be smaller when running ceiling fan. As a function of convection, then by using of 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 "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 respondents who feel "slightly warm" only slightly reduced when using ceiling fan, while the number who felt "warm" is significantly reduced when using ceiling fan. Conversely, the number of respondents who felt "slightly cool" and "cool", significantly increase when using of fan. Impression of "slightly warm" of the respondents almost does not differ much happened during the noon without fan, and in the afternoon without it. Impression of "warm" does not occur in the morning, mostly in the afternoon without running of fans, which was followed by the noon without fan, as in Fig. 4.

Percentage of respondents who wanted "no change" from the existing climatic conditions occur most commonly in the afternoon with the ceiling fan, then followed the 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 the noon without ceiling fan, which is not contrary to the calculations at first (Fig. 5). 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 Fig. 6. In contrast the percentage of respondents who do not sweat dominated the morning, and then consecutive the noon with the ceiling fan and the afternoon with ceiling fan.

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 the afternoon with no fan and no fan during the day, in order of 41, 27 and 26%. In other words, during the noon without running fan, in the afternoon without the fan and the afternoon with fan for over 50% of respondents feel uncomfortable, as described in Fig. 7.

It can be concluded that in the classroom at the Faculty of Engineering Unsrat as a passive and low energy building despite using ceiling fan still have not managed to reach comfortable conditions at the noon, and the using of 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 the fan.

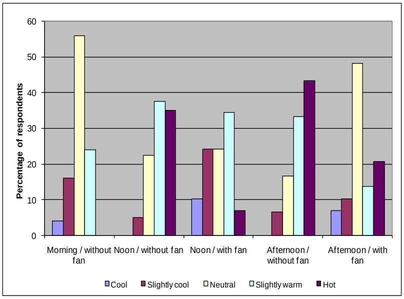


Fig. 4 Respondents' thermal sensation

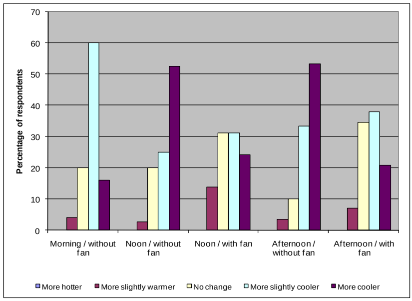


Fig. 5 The desire of respondents

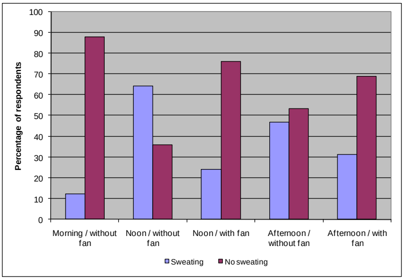


Fig. 6 Sweating and no sweating

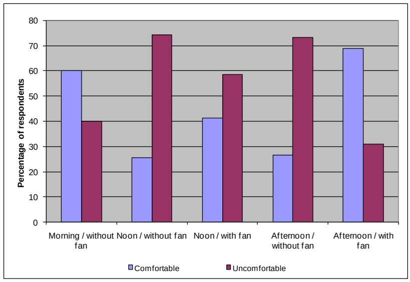


Fig. 7 Feel comfortable or not

5. Conclusions

The study of thermal comfort perceptions in the classroom at the Faculty of Engineering Unsrat as a passsive and low energy building in five conditions have been performed. By differing the treatment between does not use ceiling fan and using it, especially for critical times at the noon and afternoon has given clarity to the role of air flow on the thermal comfort. While the morning condition give the impression of comfort even without using of fan. In accordance with the measurements the noon and afternoon is a critical time which tends to lower the level of thermal comfort. The results indicate that this time there are most respondents said that conditions in the classroom being uncomfortable; there are over 70% of respondents expressed discomfort at the noon without ceiling fan and in the afternoon without ceiling fan. The use of fan can lower the temperature in classroom but in the value of a small and insignificant. The effect of using of fan are physically not able to increase thermal comfort of classroom with quite high temperatures at the noon. But in this condition, the use of fan was instrumental in increasing the percentage of the number of people feel comfortable.

By comparing the results of the calculation of PMV and PPD indices with the results of field measurements obtained that this calculation is quite sensitive to changes in increasing of air speed.

In order to achieve thermal comfort in the classroom we still need to use ceiling fan, especially in the afternoon, while at the noon it is sugested to use air conditioning which can be combined with the fan. The combination in this way would be beneficial especially for energy savings.

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