TITLE: THERMAL COMFORT FACTORS IN HOT AND HUMID REGION: MALAYSIA

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Abstract

The importance of the parameters influencing the thermal comfort varies with the climate of the countries. In many cases, the air temperature has been considered the major influencing factor to the thermal comfort and many of the indexes produced are mainly focusing to the determination of the comfort temperature. Recent studies have found that the International standard for indoor climate based on Fanger's predicted mean vote equation is inappropriate to be based on in calculating the thermal comfort level for the hot and humid regions.

This paper presents the results of the investigation to determine the crucial factor in influencing the outcome of the comfort level for this area. The two important parameters studied are the air temperature and relative humidity which have become the biggest constraints in providing passively comfortable indoor environment for this region. The study reveals that the relative humidity, in contrast with the results of many thermal comfort studies conducted in different climate regions, is more influential in the comfort level assessment compared to the air temperature. The range of percentage at which relative humidity starts influencing the comfort level is also determined and other significant factors such as the air movement, air velocity and clothing are also studied as the contributing factors to the thermal comfort. A new method of interpreting the thermal comfort level for the region is also suggested based on the findings of the study.

1.0 Introduction

The thermal comfort has been considered by many as the major influencing factors in the indoor comfort level. The International Standards such as ASHRAE ISO 7730 Standard 55(deDear et al) is often used to determine the thermal comfort condition in a building by the architects and professionals. Unfortunately, current researches have obtained evidences that the standards are irrelevant in predicting the comfort level in the tropical countries especially in the countries with hot and humid climate (Mallick, Feriadi, Karyono). Due to this discrepancy, many upcoming researches about thermal comfort in this region have been conducted aiming to establish a more relevant index or range of comfortable temperature for the tropics.

There are five parameters that are important in influencing the indoor thermal comfort of a building. The physical parameters which are the air temperature, air movement, and relative humidity and the external parameters which are the clothing and activity are known as the major factors in the issue. Little is known on how these parameters act in the hot and humid area since many related studies are conducted in the temperate climate regions where the constraints are different. An investigation of the physical parameters was conducted in two small size mosques in Malaysia to find out the importance of these parameters in influencing the thermal comfort level in the hot and humid country such as Malaysia.

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2.0 Standards in the Thermal Comfort Assessment for Tropics

Many of the International Standards produced are found to be inadequate for describing the comfort condition in the tropical climate. The majority of the field studies conducted discovered that the international set up is either overestimating or underestimating the comfort condition in this climate (Nicol). This is partly due to the derivation of the standards that are mainly based on the studies conducted in the moderate environmental condition.

One of the international standards frequently used for indoor climate condition is ISO7730 based on Fanger's predicted mean vote (PMV/PPD) equation. The equation of the formula is applied to derive a numerical value depicting the comfort conditions based on the ASHRAE scale. One of the reasons stated by Nicol to the inaccuracy of the standard's prediction is because the small range of the limitation set in the formula. In many case studies conducted in the tropical countries, the measurements recorded, especially in air temperature and velocity are frequently beyond the limitations. The air temperature of 30^0 Celsius is considered normal for this climate and the air movement of more than 1 m/s is desirable to relieve the heat. These two figures are set up as the upper limits in the formula. Another reason that may have an effect to the result is the conducting method of the experiment. Most of the measurement is based on the close-lab environment. In reality, such environment is rarely available and in many field studies, a factor of adaptability is part of the factor which is not in the environment that is fully controlled. In addition to this, the outside climate plays a very influential role in thermal comfort perception for a free-running building. The study by Humphreys and Humphreys and Nicol discovered that the comfort temperatures are linearly related to the mean outdoor temperature. The relationship derived is:

$$T_c = 0.534T_o + 12.9$$

where T_c is comfort temperature and T_o is mean outdoor temperature

Another standard that is frequently referred in evaluating comfort condition is ASHRAE Std 55. A revised version of ASHRAE Std 55, known as Adaptive Comfort Standard (ACS), has been produced to be applied for naturally ventilated buildings since the original version is found to be irrelevant for naturally ventilated buildings. In the revised version, allowance for the warmer indoor temperature is given and to be applied during summer time for the naturally ventilated (NV) buildings. A wider range of indoor temperature was given based on the findings from the occupants in the NV buildings. The wider range is mostly influenced by the outdoor climate patterns (Nicol) which led to the derivation of the optimum comfort temperature, T_{comf} , that is based on the mean outdoor dry bulb temperature, $T_{a,out}$:

$$T_{comf} = 0.31T_{a,out} + 17.8$$

The range of the temperature with the 90% acceptability is 5^0 and 7^0 Celsius for 80% acceptability, both centered on the optimum temperature, T_{comf}, aiming to discover the temperature or combination of thermal variables (temperature, humidity and air velocity) which subjects consider 'neutral' or 'comfortable'. Nicol and Humphreys had also suggested that in evaluating thermal comfort using adaptive principle, there are three main contextual variables that need to be considered which are the climate, building and time.

3.0 Existing research on thermal comfort in the hot and humid areas

The hot and humid areas are generally located close to the equator. Among the countries that are included in the criteria are located in the Southeast region which includes Malaysia, Singapore, Indonesia and Thailand. The earliest investigation was conducted by Webb in 1949 which led to the derivation of the Equatorial Climate Index (ECI). Based on the index, the ideal air velocity is 0.2 m/s with the relative humidity of 70% and the ideal temperature of 28.86^0 Celsius. However, the prediction is only based on the dry and wet bulb temperature and wind speed but excluded activity level and clothing value in the derivation. These two factors are important parameters since they are closely related to social and cultural influence. Mallick in his investigation had also discovered that people are highly adaptive to the surrounding environment by changing the behavioural patterns and lifestyle preferences. The process of acclimatization also had a strong influence in the comfort preferences study. In his 1996 study involving a group of architectural students living in urban housing in Dhaka, Bangladesh, Mallick discovered that the participants were able to tolerate high relative humidity and temperature for comfort mainly due to the adaptation to the specific climate. The study also found that the estimated comfort temperature was between the range of 24^0Celsius and 33^0 Celsius under still-air condition and with the movement of air at 0.3 m/s, the range increased by 2.4 ^{0}C for the lower count and 2.2^0C for the upper limit. The air movement was a contributing factor in providing thermal comfort environment, however, according to this study, despite a wide range of recorded relative humidity which ranged from 50% to 95%, the humidity had little influence to the thermal comfort level due to the long term conditioning (Mallick).

Singapore is one of the countries in this region that is actively conducting research on the thermal comfort on the naturally ventilated building. In 2003, Wong and Khoo conducted a thermal comfort study in naturally ventilated classrooms in Singapore. The study discovered that the neutral temperature derived from the TSV is 28.8^0Celsius. Earlier studies conducted by Busch in Thailand and deDear et al in Singapore have also found that 28.5^0 Celsius is the neutral temperature for a naturally ventilated building. The readings obtained are quite close for the neutral temperature in the similar climate region. On the other hand, the PMV based on Fanger's equation and the ASHRAE standard 55-92 were found to be inapplicable in the study of thermal comfort for the area of hot-humid climate. ASHRAE Standard 55 predicted comfort temperature is far lower than the actual comfort temperature based on the field study. The Fanger's PMV model similarly shows discrepancy by being higher at lower temperature(Wong et al). The study by Wong et al in 2002 in naturally ventilated public housing in Singapore also revealed that thermal perception of +2 and +3 is still considered comfortable. Similar to the finding by Mallick's, the study also found that there is a strong correlation between the thermal comfort perception and wind sensation.

Indonesia is another country in the Southeast Asia region that is currently active conducting research pertaining to the comfort level in the hot and humid climate. In 2004, for examples, Feriadi and Wong conducted an investigation regarding the thermal comfort perception, evaluation of the thermal comfort prediction and the behavioural action that influence thermal comfort perception in naturally ventilated houses in Indonesia. The study concluded that the prediction using the ASHRAE and Bedford Scale is irrelevant in predicting the thermal comfort condition for tropical climate. The finding also suggested that adaptive behaviour may influence the neutral temperature to be higher than it was supposed to, however, cooler temperature is still preferable, if possible. Earlier, Karyono conducted a field study on the thermal comfort, which samples are divided into various categories and groups, for a multi storey office building in Jakarta, Indonesia. The groups are categorized by gender, age, ethnic background and physical characteristics. The study concluded that it is statistically insignificant between the neutral temperature between male and female, subjects under 40 and over 40 years old and between different ethnic backgrounds as well as between thin and normal subjects. The study also revealed that the neutral temperature is increased in the late afternoon compared to the early morning by 3^0 Celsius.

4.0 Commons characteristics of the hot-humid climate

In many cases, the outdoor condition of a building especially the climate influences the indoor climate of the building. For the outdoor condition, normally, when the air temperature rises, the relative humidity will decreases. This condition is evidenced in the experiment and the result is shown in Figure 1.

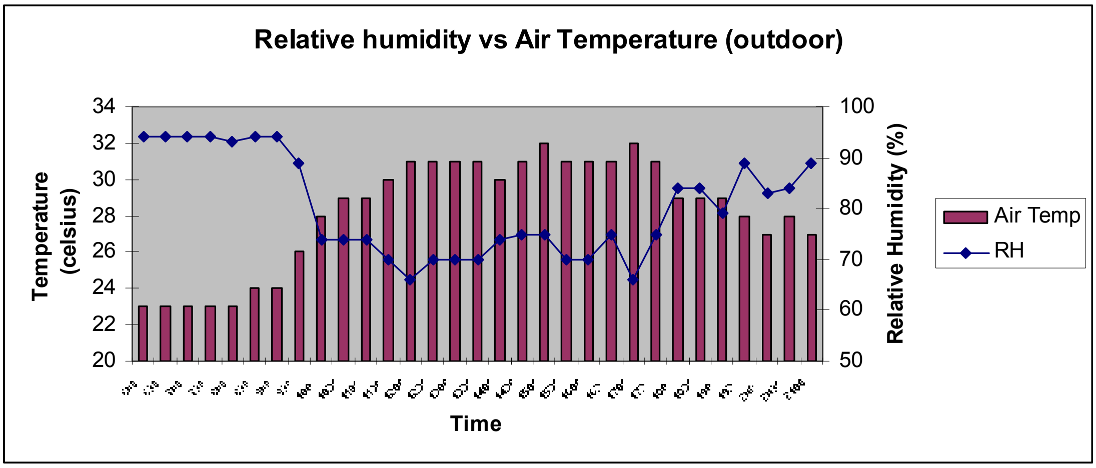

Figure 1:Outdoor relative humidity vs. air temperature

The air temperature and relative humidity are the important factors in determining the comfort level in the hot and humid country. The typical climate of the hot and humid country is the high air temperature at an average of 28 Celsius with an average of 80% of relative humidity. These factors have become the biggest challenge for the architects in designing a passive cooling building. The hot air and high relative humidity have become very problematic in designing naturally ventilated buildings among other contributing factors such as privacy, etc. Due to these extreme conditions, many of the buildings in this country are air conditioned in order to meet the required comfort level due to the little available knowledge on the effect of these variables to the thermal comfort condition. A field study has been conducted to investigate how each of these parameters influences the comfort condition.

5.0 Methodology

In conducting the investigation, two mosques with the same size but vary in terms of roof and fenestration designs are selected. The building type is chosen to minimize the variation in clothing value since the users of the mosques are strictly specified in terms of the dressing code appropriate to be worn in the place. The activities conducted in the mosques are basically categorized as light activities. Twenty participants, which consist of sixteen males and four females, are stationed at various locations inside the prayer hall of the mosques between the hour of 1300 until 1530. This is the period that the heat gain is at the highest level during the day. The air temperature, relative humidity and wind speed are then recorded using the data logger at the interval time of ten minutes. A set of questionnaires is given to each of the participants to record the thermal sensation they experienced during this period of time.

The measurements are recorded using the hot-wire anemometer, hygrometer and thermometer which are connected to the data logger, Babuc M. The equipment is placed at the height of 600mm from the floor level which is equivalent to the sitting position. The questionnaires are designed to acquire the level of thermal comfort of the users using the 7 point ASHRAE scale with the inclusion of the humidity level they experienced. The data collected is then analyzed and compared using the PMV equation and the actual readings.

6.0 Results and Discussion

6.1 Air Temperature and the Comfort Level

Many previous studies concentrated in finding the range of air temperature that the occupants will feel comfortable. The air temperature has been considered as the main factor among others that influences the thermal comfort level. A change in the air temperature will normally change the level of comfort a person experiencing and this is true in many conducted researches. Recent studies conducted in hot and humid countries discovered that the range of the comfortable temperature established based on the research conducted in moderate climate countries is not applicable or relevant to the hot and humid climate countries. The range for the hot and humid countries is wider and higher than the predicted range. A field study also shows that a change in the air temperature does not affect the comfort condition based on the votes given by the respondents in two mosques in Putrajaya, Malaysia. The results are shown in Figure 2 and Figure 3.

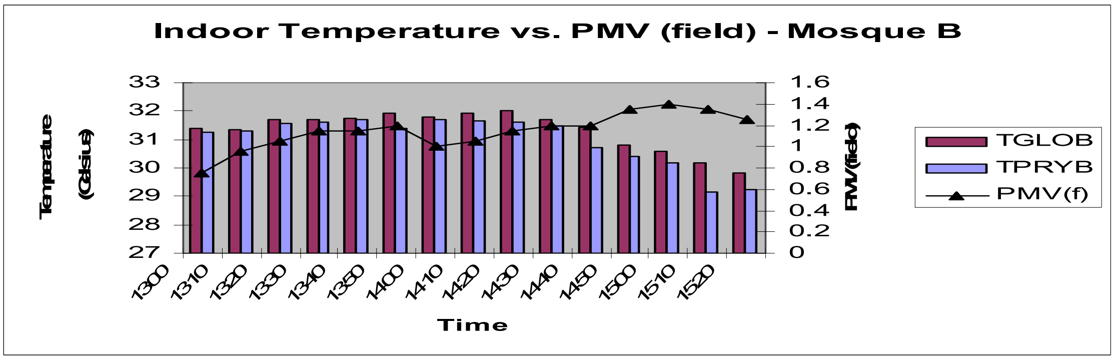

Figure 2: Indoor temperatures. PMV(field)

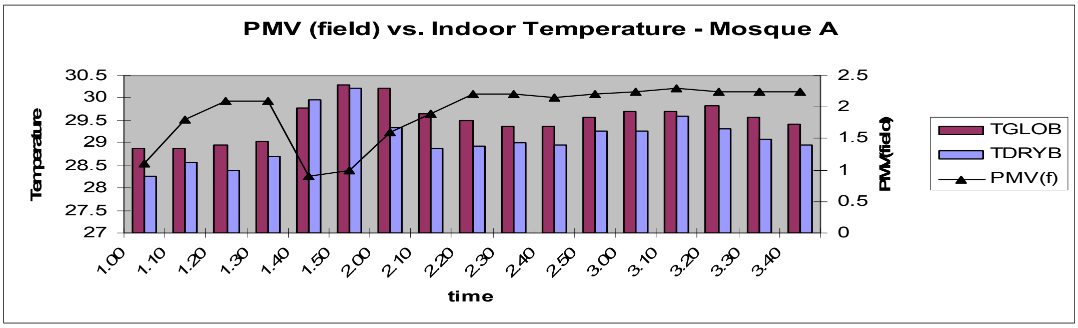

Figure 3: Indoor temperature vs. PMV(field)

In Figure 2 and Figure 3, the changes in PMV recorded based on the respondents' votes do not directly influenced by the change in air temperature or mean radiant temperature. Theoretically, when the temperature increases more than the comfort temperature (21-23 Celsius), the PMV is expected to increase to reflect that the respondent will feel warm or hot. However, in both Figure 2 and 3, the increase in air temperature does not necessarily increase the PMV value and vice versa. In these cases, the air and mean radiant temperature does not strongly influence the thermal comfort level based on the votes given by the participants. From the results, it can be implied that the air temperature has less significance in influencing the thermal comfort level.

6.2 Relative Humidity and the Comfort Level

Early investigation on the influence of relative humidity to the comfort level had concluded that the change on the relative humidity has little change to the thermal comfort level. For tropical countries especially in the hot and humid regions, high relative humidity is one of the biggest obstacles to tackle besides high air and mean radiant temperature. The average percentage of relative humidity of the day is around 80 -85% and in some cases may reach 100% especially early in the morning. Relative humidity is another important factor in thermal comfort because it determines the ability of air particles to absorb heat and evaporate. In order for this to happen, the relative humidity must be low enough to allow evaporative process to happen. The high percentage of relative humidity may retard the process and cause discomfort. Heavy sweating is one of the common problems that cause extreme discomfort in hot-humid area. When the relative humidity is high, sweat produced by the body may not be able to evaporate to help the body to cool. Figure 4 and Figure 5 show the relationship between the relative humidity and the comfort level measured in two mosques in Malaysia.

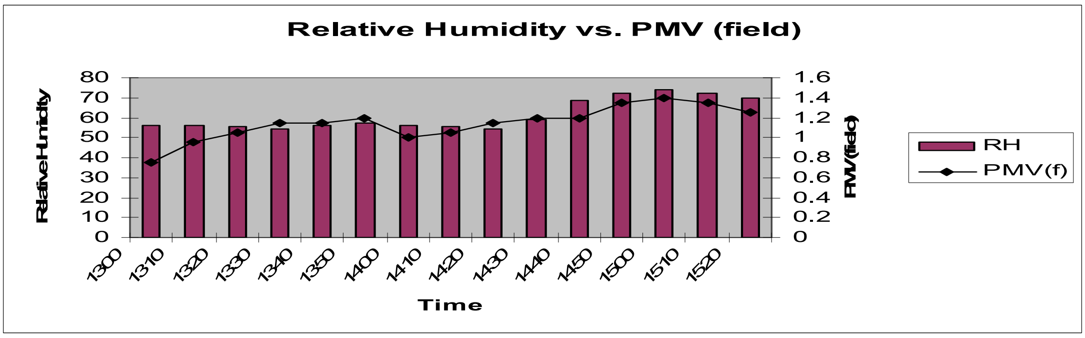

Figure 4: Relative humidity vs. PMV(field)

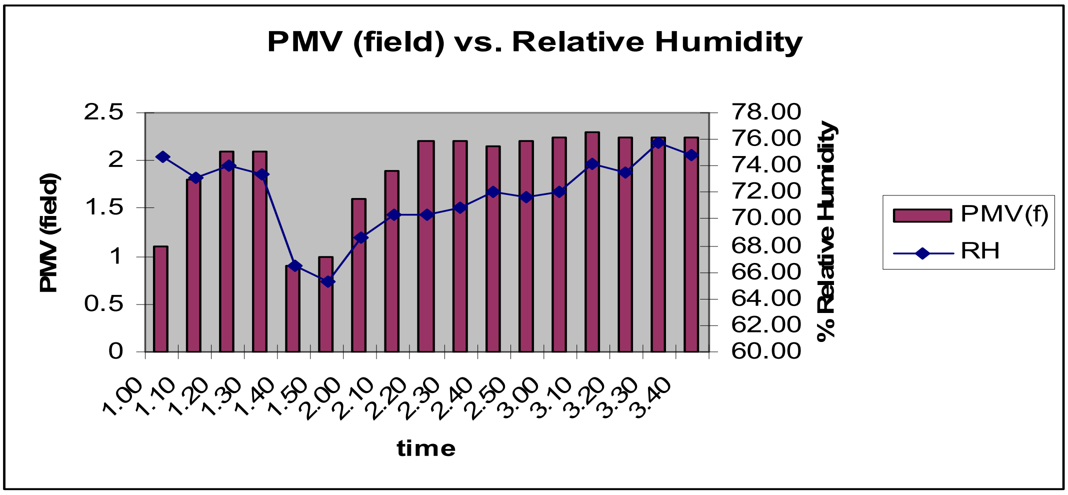

Figure 5:Relative Humidity vs. PMV (field)

In Figure 4, the relative humidity measured is fairly constant and it is followed by the relatively constant result of the PMV based on the votes given by the respondents. It is fairly difficult to predict whether the relative humidity will change the thermal comfort condition of the respondent at this moment. However, the pattern suggests that small changes of the relative humidity percentage can change the comfort level. This is even justified in Figure 5 where it shows quite a huge range of relative humidity measured and PMV votes. It is clearly observed that when there is a reduction in the percentage of the relative humidity, the PMV measured is also reduced which implies that the respondents feel more comfortable in that situation. From the Figure 5, it can also be suggested that with the relative humidity at more than 70%, people will start to experience discomfort after a certain period of time. In Figure 4, however, the comfort votes are fairly low compared to Figure 5 since the percentage of the relative humidity is mostly below 70%.

6.3 Air Movement and the Comfort Level

Figure 6 and Figure 7 show the relationship between the air velocity and the thermal comfort level. Figure 6 indicates that the air velocity is relatively the same throughout the time except at one time where the air velocity reaches more than 4m/s. The measurement is taken with the all the openings closed except the openings on the side of the roof. On the contrary, the measurement in Figure 7 is taken in an open building which allows outside air movement into the interior. It is fully dependent on the cross ventilation aided by the wind speed from the outside which is clearly described by the pattern measured. Inconsistent air flow from the outside through the building can be seen from the readings and therefore it can be suggested that the source of air flow from the outside is fairly unreliable to be used to ensure satisfactory cross ventilation. In an open building, the measured air speed is relatively low with 0.5m/s compared to the closed building with the openings between the roofs which is 1.1m/s.

Figure 6 shows that with the constant air movement the thermal comfort condition is not affected however, with the existence of a very strong air movement, the thermal comfort condition seems to improve tremendously. On the other hand, the constantly changing of the air speed does not improve the thermal comfort condition. This is reflected in Figure 7 where the air velocity is continuously changing throughout the experiment. It is also noted that the air speed is relatively weak and most of the time is unnoticeable. In some cases, the rise in the air velocity causes the votes to increase due to the hot air from the outside.

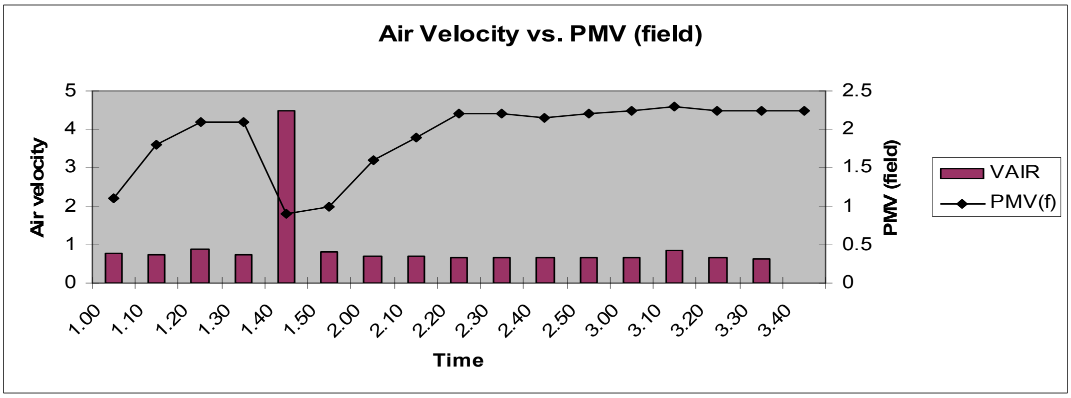

Figure 6: Air velocity vs. PMV(field)

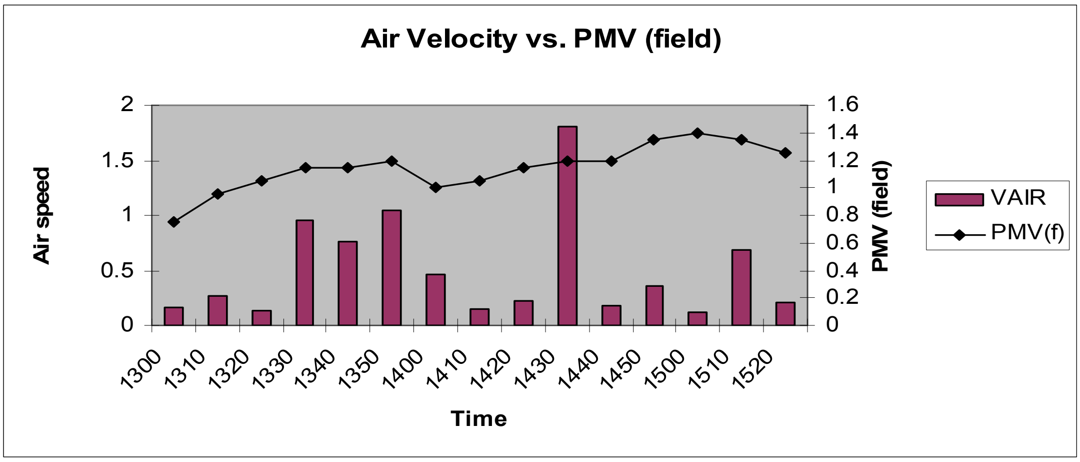

Figure 7: Air velocity vs. PMV (field)

7. Conclusion

Many assumptions can be made from the results above. Looking at the relationship of each parameter with the thermal comfort level may not be appropriate since the votes are mainly focusing on the heat gain or loss experienced. The air temperature is clearly reflected the thermal condition of the space however the thermal comfort condition is also affected strongly by relative humidity and air movement, especially in the hot and humid country where excessive humidity in the air is the biggest obstacle. Based on the investigation, it can be suggested that the range of comfortable air temperature is wider in naturally ventilated buildings in hot and humid countries, in this case, Malaysia. The air temperature of 30 degree Celsius is still considered tolerable. The changes in temperature from lower to higher within this wider range does not affect the comfort vote, however, the small changes in relative humidity have resulted in the changes of comfort vote. The changes in votes are even more substantial if the relative humidity of the indoor space is more than 70%. The air movement, on the other hand, is benefited in the condition where the relative humidity is more than

70% and should be continuous for a period of time rather than just a gust. Higher air velocity compared to the specified by the existing standards is effective in providing comfort to the indoor.

Further investigation is required to inquire how each of these parameters influences each other. These parameters should be studied as a whole rather than separating them in order to understand how each parameter benefiting each other in providing thermal comfort condition in a space. The relationships between these parameters should be established which explain the importance of these parameters in the hot and humid climate.

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