RELATIONSHIP BETWEEN THERMAL COMFORT SENSATION AND PREDICTED PERCENTAGE OF DISSATISFIED AT CLIMATIZED AUDITORIUM

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Abstract. *In this paper, the PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) indexes, introduced in international standard ISO - 7730 (1994) and based on the Fanger's studies (1972) about thermal comfort, are calculated for an conditioned auditorium placed in the Campus of the Federal University of Pará (UFPA), Belém, Brazil. The environmental parameters (Air Temperature, Relative Humidity, Air Velocity and Mean Radiant Temperature) are measured and the personal parameters (Activity Level and Clothing Insulation) are estimated. The results are compared and analyzed in order to verifying whether the calculated indexes express the thermal response really manifested by the occupants of the conditioned environment, obtained with base in the ASHRAE thermal sensations scale through questionnaire applied in-loco.*

Keywords: *thermal comfort, conditioning environment, PMV and PPD indexes.*

1. INTRODUCTION

The thermal comfort in conditioning environment is associated with the rate of energy production of the body, the physiological mechanisms and the heat transfer adjustments between body and environment to keep the body temperature. The metabolic rate is related with type and the level of activity. Environmental factors such as air temperature, air velocity, relative humidity, mean radiant temperature and personal factors related with the activities and clothes used by occupants are associated directly with the heat transfer.

The thermal discomfort can be felt in all the parts of the body (general discomfort) or just in some parts of it (located discomfort). The individual differences don't leave to establish thermal conditions that eliminate the discomfort general and located. For this reason, the standards specify conditions that attend a criterion maximum of 10% of general discomfort and 10% of located discomfort. In this way, 80% of the occupants of an environment that obey the requirements of the standard will feel satisfied with the thermal environment.

2. EVALUATION OF THERMAL COMFORT

The standard ISO-7730 (1994) establishes parameters of evaluation of thermal comfort in terms of PMV (Predicted Mean Vote) and PPD (Percentage Predicted of Dissatisfied) indexes calculated through the environment and personal comfort parameters. Fanger (1972) related these parameters to the physiological variables. If the heat came from total metabolic rate M (W/m²) is transferred to the environment without that the control mechanisms of the body temperature, the skin temperature and the sweat rate to take strongly account the only physiological variables affected by the thermal balance between the body and the environment. This occurs if the internal heat production is the same to its release for the environment, without consider the used energy for the body to realize useful work. However, this fact is not only enough to establish thermal comfort conditions, because in the environment conditions where this occurs only in a small part it will have comfort sensation. When the metabolic rate increases, the biggest sweat production motive the increase of the heat release for evaporation and the skin temperature falls. The two agreed effect increase the body's heat transfer for the environment. Empirical relations between these variables involve the physiological equations and the heat flow to the sensations of thermal comfort. This way, index PMV is calculated by:

$$PMV = \left[0,303\,\exp\left(-0,036\,M\right)+0,028\right]L \tag{1}$$

where, L (W/m²) the internal heat production and the environment heat rejected difference for a occupant feeling itself comfortable. The Equation (1) was gotten by regression statistics considering the presented votes of thermal sensations scale in the Table (1). The people that didn't vote – 1, 0 or + 1 are considered unsatisfied. The PPD in the same condition is calculated by (Fanger, 1972):

$$PPD = 100 - 95\exp\left[-\left(0{,}03353\,PMV^4 + 0{,}2179\,PMV^2\right)\right] \qquad (2)$$

The relation between the PMV and the PPD is presented in the Figure 1. A PPD of 10 % corresponds to the band of PMV between – 0,5 and + 0,5. With PMV = 0 about 5 % of the occupants will be unsatisfied. Therefore, a situation doesn't exist where all the occupants of a conditioning environment will be satisfied with the thermal environment. It's recommend to use these indices only for PMV values between – 2 and + 2.

Table 1. Thermal sensations scale (ASHRAE, 2005)

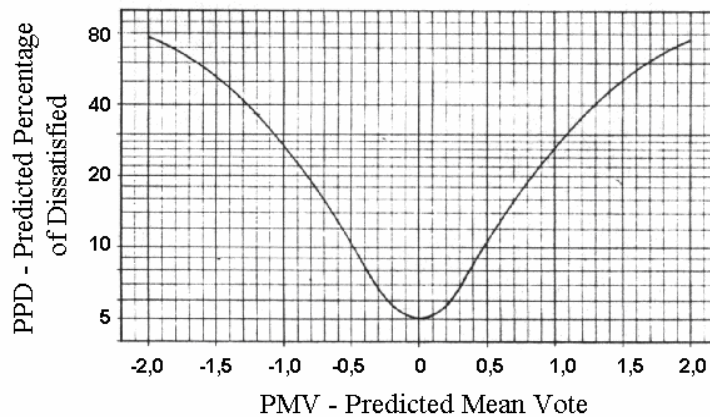| +3	hot
+2	warm
+1	slightly warm
0	neutral
−1	slightly cool
−2	cool
−3	cold

Figure 1. PPD as function of PMV.

3. DESCRIPTION OF CLIMATIZED ENVIRONMENT

The Figure 2 presents the low plant of the conditioning auditorium with dimensions $12 \times 6 \times 3$ meters. The each one of the 44 seats localization is made by means of rows (A, B..., F) and columns (1, 2..., 8). An air conditioner of split–system type, with power refrigeration of 9,45 kW (36.000 Btu/h), located in the East wall next to the ceiling, carries through the conditioning of environment. Generally, the auditory is intermittent used, and in the periods of occupation the fan speed is the average (selected in the remote control) and the thermostat temperature setpoint is 24°C (in the remote control too). The height of cold air supply if makes 2,00 m of the floor of stage and in the longitudinal auditory axe direction, in way that the air stream reaches of front the seated people. The walls guided to East and to South are dividing with not–conditional internal environments; the others are external walls.

4. METHODOLOGY

The methodology compare the PMV and PPD values gotten through the environment parameters measurement (calculated) gotten with the application of one questionnaire based in the thermal sensation scale presented in Table 1 (questionnaire), in order to verify if results has agreement or not and its possible causes. The air temperature, relative humidity and air velocity measurements had been carried through in the place of each seat with the empty auditory, but with the air conditioner adjustments similar to one busy auditory. The mean radiant temperature was calculated in function of the black globe temperature measurements in three different places in the central corridor of the environment (see Figure 2).

It was admitted the corresponding metabolic rate the one of a seated relaxed person (1,0 met), common condition in occupants of auditory. The clothes thermal isolation was esteem in function of the answers of the questionnaire for each interviewed; in the case of calculated PMV and PPD values, one used 0,5 clo, summer typical clothes, as it is common in our region (hot and humid weather). One hundred four questionnaires for the audience occupants had been answered, distributed at different moments throughout two weeks. A computational program developed in the LABCLIMA of the

Federal University of Pará was used to calculate the PMV and PPD values, from the environment and personal parameters.
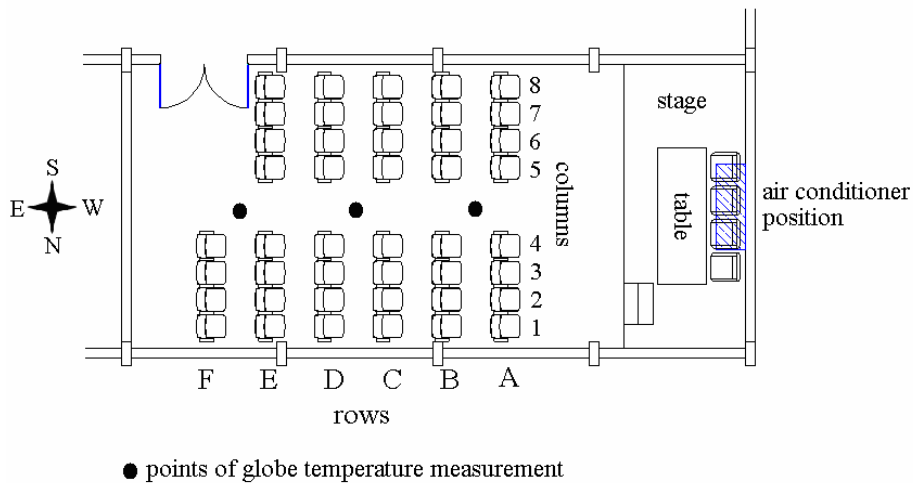

Figure 2. Auditorium low plant.

5. ANALIZES OF RESULTS

Figure 3 presents a comparison between the calculated PMV values and the gotten ones from the questionnaires. The calculated values indicate that the thermal environment would be felt by the occupants as cool or slightly cool, because the majority of the calculated values meet are between – 1 and the – 2. Even so metabolic rates adopted and observed the clothes thermal resistance in the interviewed ones were next to the used to calculate the PMV value, the express thermal sensations in the questionnaires indicate the following distribution: 51% of the occupants feel the slightly cool environment; 21 %, cool; 19 %, neutral 8 %, a slightly warm; and 1 %, warm. In this case, the interviewed ones identified correctly a slightly cool environment even so the calculated values pointed a cool environment still more. This small discrepancy sample that, even so living in hot and humid climate, with average air temperatures of 27,5 °C and relative humidity above of 80 % moderately, the occupants who had answered to the questionnaire prefer slightly cool environments.
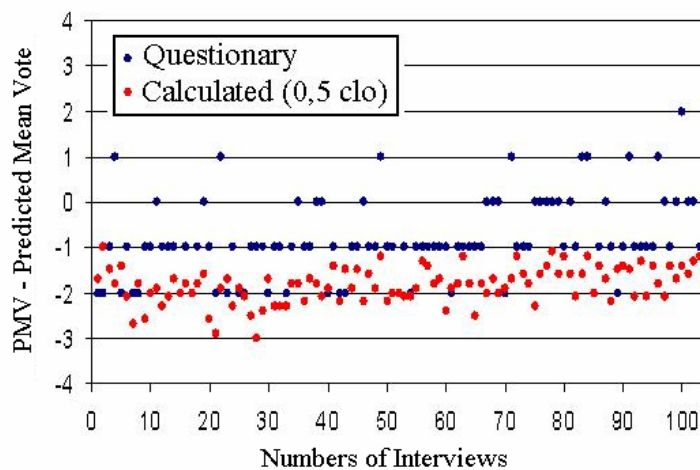

Figure 3. Calculated PMV values compared to that gotten from questionnaire.

Figure 4 presents a comparison between the calculated PPD values and the gotten ones from the questionnaires. In any auditory seat the unsatisfied of the occupants with the thermal environment is evident. Some seats of A, B and C rows present PPD above 80 %, therefore the cold air stream insufflating, in result of limits/defects not cured in the evaporation unit, is concentrated in these places. In addition, the unit thermostat sensor of evaporation temperature is located in the air return; therefore, the air temperature in the conditioning environment will be always below of 24 °C.

On the other hand, it is observed in Figure 4 that a visible agreement exists between the calculated PPD values using the typical clothes of summer (0,5 clo) and the gotten the answers of the interviewed ones: in the two cases the number of unsatisfied is raised.
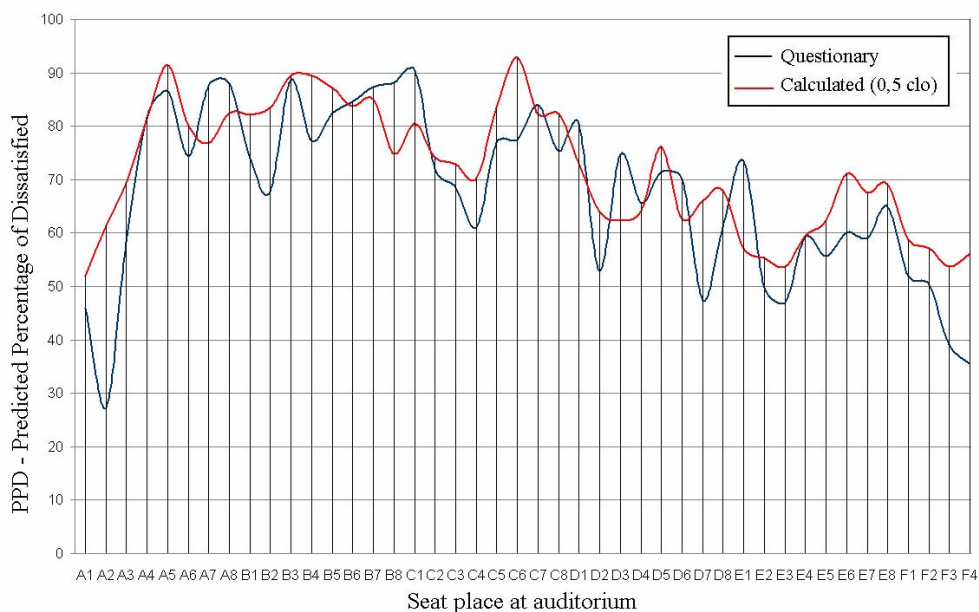

Figure 4. Calculated PPD values compared to that gotten from questionnaire.

6. CONCLUSION

The use of standard ISO 7730 (1994) for evaluation of thermal comfort in conditioning environments requires sufficiently care in the environment parameters measurements (air temperature, relative humidity, air velocity and mean radiant temperature). The personal parameters estimate (activity level and clothes insulation) for a visual inspection has its limitations. For this reason, some wrongs are carried for the calculations of PMV and PPD indices.

Although following the standard, when a field procedure will be made, many of the recommendations can be harmed by limitations imposed for own environment operational characteristics. Thus, considering that the procedures were satisfactory attended, a significant agreement was observed between the PMV and PPD values calculated from measurements and the gotten ones of the interviews with the eventual environment occupants. According with the standard would be between a slightly cool and cool environment; however, according the occupants the thermal sensation was a slightly cool.

To reduce the PPD values, some simple actions and without additional cost, could be taken: (1) to increase the thermostat setpoint for 25°C or 26°C; it's common conditioned environment users speak about the air temperature of conditioning environment using terms as "the equipment are not freezing", without perceiving that thermal comfort doesn't mean "frozen" environment; (2) to reduce the fan speed of conditioner air supply; this trend for cool environment sensation is decurrently of the raised air velocity, that presents measured values between 0,5 and 0,6 m/s, above of the values praised in standard, between 0,10 and 0,25 m/s; (3) to increase the clothes insulation used; inadequate in terms of energy efficiency, therefore would raise the energy consumption.

7. REFERENCES

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5. RESPONSIBILITY NOTICE

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