Thermal comfort evaluation in workplaces in Brazil: the case of furniture industry

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SUMMARY

The main objective of this work is to create subsidies for an analysis of Predicted Mean Vote (PMV) from ISO 7730 (1994) and from the new version of the norm, from 2005, for thermal comfort evaluation in Brazilian workplaces. The furniture industry in the city of Itatiba, São Paulo State, in Brazil, was chosen for the study. A survey among the workers was carried out through questionnaires, collecting data about thermal sensation, clothing and worker’s activities. Dry and wet bulb temperatures, as well as globe temperatures were measured, simultaneously to the questionnaires. The Software Conforto 2.03 was used to estimate thermal resistance of the clothes, metabolic rates, mean radiant temperature, relative humidity and the correspondent PMV for the set of environmental and personal variables. The declared votes were compared with those obtained by calculating the PMV. The obtained results were compared to the patterns specified by the standards ISO 7730, 1994 and only 4.3% of the answers are in the limits of PMV recommended for thermal comfort. An analysis is performed about the work conditions in this industry, considering the workplace conditions, especially the poor ventilation.

INTRODUCTION

The growth of industrial processes and the diversification of the economic activities show that most of urban population lives for a great number of hours in the working environments. In hot climates, like in Brazil, there is an increasing interest about the possibility of mechanical air conditioning. But this technique for achieving comfortable thermal environments is very expensive and energy consuming. The artificial climates for human occupation are designed with the objective to provide comfortable environments and also that the thermal ambient can be adapted so that each individual will be in a condition of thermal comfort.

Thermal comfort studies are based in the thermal balance of the body. With the objective of establishing optimum comfort criteria for the greatest of people Ole Fanger [1] performed studies in controlled chambers in Denmark. Fanger’s model was adopted as the basis for the international standard ISO 7730 (1984), and updated in 1994 [2]. This standard establishes the determination of the PMV and PPD indices and specification of the conditions for thermal comfort in moderate thermal environments.

With the advancement of thermal comfort evaluation studies, many researches have been accomplished in different regions around the world. Some of these researches question the defined limits established by ISO 7730 in regions with tropical climate. Most of the
accomplished studies evaluate ambient where the occupants sedentary activities, like offices and schools.

Thermal discomfort is a common feature in the Brazilian work environments and that certainly affects the efficiency and the workers' productivity. Most of the complaints refer to discomfort due to heat, but there are also complaints due to cold environments. These occur mainly in places where cold or frozen products are kept or manipulated. Designers of buildings and ventilation systems, as well as those responsible for work safety and health can find few practical tools available for thermal comfort evaluation in the built environments.

In Brazil, there are not available standards for thermal comfort evaluation adequate for the work conditions in the country, and especially, for no sedentary activities, as those developed in most industrial workplaces. In the national context, there is only a norm by the Ministry of Labour that regulates the exposition to extreme temperatures.

Due to this lack of information, in the last years some researchers are trying to overcome this problem, and carrying out some field studies about thermal comfort evaluation in the different climate conditions of the country.

With the aim of finding the PPD of students in school rooms, in the process of development of their normal activities, Xavier & Lamberts [3], have measured the environmental variables, simultaneously to the survey among the users with questionnaires about their thermal sensation. The study was carried out in a Technical School in the State of Santa Catarina, south region of the country, from April to July, in the morning and afternoon, with 25 sets of measurements. The authors adopted a constant metabolic rate of 70 W/m² (1,2 met). It was obtained the following equation relating the percentage of dissatisfied (PI) with the operative temperature (T₀):

\[ PI = 1,4151 \cdot T₀^2 - 65,772 \cdot T₀ + 784,22 \]  

(1)

The obtained temperature of neutrality was 23,24°C, corresponding to a minimum percentage of dissatisfied equal to 19,96%.

Gonçalves [4] carried out a study in the city of Belo Horizonte, State of Minas Gerais, in the Southeast Region of the country. His object of study was to find the intervals of comfort temperatures for undergraduate students and compare the results with those of International Standards. In the survey 570 people were interviewed. In his conclusions, the author states that Fanger’s model [1] can be applied to this population, although the obtained PPD for neutrality condition – about 27%, is much higher than Fanger’s result of 5%.

In the same year, Xavier, [5] analysed the variables which could influence thermal comfort of people in school and office buildings in three cities of the country: Florianopolis, at the South, Brasilia, with an extremely dry climate, especially in winter, and Recife, at the northeast of the country, located at seaside, with a hot humid climate. Besides the six influence variables (environmental and personal ones) from the PMV model, the author researched also habits like lifestyle, physical activities, stress, age, sex and body form. Results show that, for sedentary activities, metabolic rate is not only function of activity, but also of age and body mass. The author also found a high Percentage of Dissatisfied for neutrality temperature – 25%.
Gouvea and co-authors [6] accomplished a research with the main objective of creating subsidies for an analysis of PMV for thermal comfort evaluation in Brazilian workplaces. The clothing industry in the city of Amparo, São Paulo State, was chosen for the study. A survey among the workers was performed through questionnaires, collecting data about thermal sensation, clothing and worker’s activities. Dry and wet bulb temperatures, globe temperatures and air speed were also measured, simultaneously to the questionnaires. A probit analysis was also performed which allowed to identify the temperature of neutrality. By using the average values of environmental parameters and personal variables of the surveyed population, the neutrality temperature was calculated through the PMV/PPD model. In this case the temperature of neutrality was 22.8 °C, corresponding to 5% dissatisfied people. The probit analysis showed nearly 22.5 °C for this temperature, corresponding to 16% dissatisfied.

The main objective of this work is to create subsidies for an analysis of Predicted Mean Vote (PMV) for thermal comfort evaluation in Brazilian workplaces where moderate activities are performed. In this paper, results of a field research carried out also in the region of Campinas, State of São Paulo, Brazil, are presented. The evaluations followed the ISO Standards – ISO 7730 [2] which establishes the determination of the PMV and PPD indices and specification of the conditions for thermal comfort in moderate thermal environments, the prescriptions of ISO 7726 [7] regarding the instrumentation and methods recommended for the measurement of the environmental variables. Also the standards ISO 8996 [8] and ISO 9920 [9] dealing respectively with Ergonomics-determination of metabolic heat production and Ergonomics-estimation of the thermal insulation and evaporative resistance of a clothing ensemble were adopted.

METHODS

Two furniture industries in the city of Itatiba, State of Sao Paulo, Brazil, were chosen to the study. The city is 23º01’00” South latitude and 46º50’00” West longitude, at an altitude of 760 m. Its climate is temperate, with 20,6º C average annual temperature, oscillating between 18 ºC average minimum and 25 ºC average maximum. Average relative humidity is 72,4%. The city has a population of approximately 100.000 inhabitants, and the main economic activity is the furniture industry.

Two companies were chosen for analysis, here called companies A and B, with different sizes and characteristics. Company A is a modern one, but still maintains some old machines together with those with modern technology. Their production is mainly of special furniture, designed for specifically orders. Production sectors are well organized with defined spaces for each one. All the powder generated is collected through an exhaustion system. The polishing and woodworking sectors were analyzed. Company B is smaller, with old equipment. Sectors are separated in two sheds: one for the production and the second for polishing and painting. Some eolic exhausters are installed, but there are no openings for air renovation. The two sheds were analyzed.

Data were collected through visits to the companies for measurement of the environmental parameters. The questionnaires were applied to all the users of the buildings. For each day of measurement three questionnaires were applied throughout day: one in the morning and two in the afternoon. The daily pre-established schedules for fulfilling of the questionnaires were: 9:00 a.m., 2:00 p.m and at the end of the working period. The fulfilling was carried through by the employees without the interference of the researcher.
The measurements had been carried through in 20 days in the months of March, April, July and August 2003. Through the application of the questionnaires 914 valid answers for comparison with ISO 7730 were collected. (1994), 719 sets of answers in the company A and 195 for the company B. The analyzed population was composed only of male individuals. Four values of thermal insulation of the clothing had been found: 0.55, 0.56, 0.70 and 0.89 clo. Seven activity levels were obtained, according to the description and the interviews: 1.45, 1.71, 2.05, 2.31, 2.48, 2.65 and 3.34 met as shown in Table 1.

Table 1. Metabolic rate for the different activities in the two companies A and B

<table>
<thead>
<tr>
<th>Activity</th>
<th>Met</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clerk</td>
<td>1,45</td>
</tr>
<tr>
<td>Production Supervisor</td>
<td></td>
</tr>
<tr>
<td>Electrical fitter</td>
<td>1,71</td>
</tr>
<tr>
<td>Press worker</td>
<td></td>
</tr>
<tr>
<td>Expedition</td>
<td></td>
</tr>
<tr>
<td>Cutting machine operator</td>
<td>2,31</td>
</tr>
<tr>
<td>Hammer worker</td>
<td></td>
</tr>
<tr>
<td>Glass worker</td>
<td></td>
</tr>
<tr>
<td>Machine Polisher</td>
<td>2,05</td>
</tr>
<tr>
<td>Hand working Polisher</td>
<td>2,48</td>
</tr>
<tr>
<td>Machine Woodworker</td>
<td></td>
</tr>
<tr>
<td>Maintenance Mechanician</td>
<td>2,65</td>
</tr>
<tr>
<td>Mounter</td>
<td>3,34</td>
</tr>
</tbody>
</table>

Thermal sensation and preference are presented in Tables 2 and 3. It is observed that for the evaluated interval, 37.96% of the workers consider the environment as thermally neutral (0) and 31.51% consider the environment hot (+2). With regard to the preference, 55.58% consider the environment as thermally neutral (0) and 28.45% manifested the desire that the environment could be little colder. The answers supplied for the workers, with regard to the sensation and preference, do not present a symmetrical distribution. While 529 workers (57.88%) consider the environment between slightly hot (+1) and very hot (+3), 373 workers (40.81%) would only desire that the environment could be between little more cold (+1) and much more cold (+3). It is observed that 288 workers (31.51%) consider the environment hot, approximately the same number - 260 (28.45%) who desired that the environment was little colder (+1) and only 11 workers (1.20%) desired the environment much colder (+3).

Table 2 – Distribution of workers thermal sensation

<table>
<thead>
<tr>
<th>Scale</th>
<th>Sensation</th>
<th>Total occurrences</th>
<th>Occurrence Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 3</td>
<td>Hot</td>
<td>66</td>
<td>7.22</td>
</tr>
<tr>
<td>+ 2</td>
<td>Warm</td>
<td>288</td>
<td>31.51</td>
</tr>
<tr>
<td>+ 1</td>
<td>Slightly warm</td>
<td>175</td>
<td>19.15</td>
</tr>
<tr>
<td>0</td>
<td>Neutral</td>
<td>347</td>
<td>37.96</td>
</tr>
<tr>
<td>- 1</td>
<td>Slightly cool</td>
<td>31</td>
<td>3.39</td>
</tr>
<tr>
<td>- 2</td>
<td>Cool</td>
<td>5</td>
<td>0.55</td>
</tr>
<tr>
<td>- 3</td>
<td>Cold</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No answer</td>
<td>2</td>
<td></td>
<td>0.22</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>914</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Obtained data were compared with the specifications of ISO 7730 [2] which considers and environment comfortable when the PPD is below 10%, corresponding to the PMV between -0.5 and +0.5. Only 39 results are in accordance to these specifications, as shown in Graph 1. Tables 4 and 5 show the distribution of the workers sensation and preference for the interval of PMV between -0.50 and +0.50. It is also observed that with regard to the thermal sensation, 21 workers (53.8%) considered the environment as neutral (0), 6 workers (15.4%) considered the environment hot (+2) and 8 workers (20.5%) considered slightly cold (-1). When asked about the preference in relation to the environment, 24 workers (61.5%) did not desire a change (neutral 0) and 11 workers (28.2%) wished that the environment could be a little colder (+1).

Table 3 – Distribution of workers thermal preferences

<table>
<thead>
<tr>
<th>Scale</th>
<th>Preference</th>
<th>Total occurrences</th>
<th>Occurrence Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>Much hotter</td>
<td>2</td>
<td>0.22</td>
</tr>
<tr>
<td>-2</td>
<td>Hotter</td>
<td>9</td>
<td>0.98</td>
</tr>
<tr>
<td>-1</td>
<td>Warmer</td>
<td>19</td>
<td>2.08</td>
</tr>
<tr>
<td>0</td>
<td>Neutral</td>
<td>508</td>
<td>55.58</td>
</tr>
<tr>
<td>+1</td>
<td>Cooler</td>
<td>260</td>
<td>28.45</td>
</tr>
<tr>
<td>+2</td>
<td>Colder</td>
<td>102</td>
<td>11.16</td>
</tr>
<tr>
<td>+3</td>
<td>Much colder</td>
<td>11</td>
<td>1.20</td>
</tr>
<tr>
<td>No answer</td>
<td></td>
<td>3</td>
<td>0.33</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>914</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Figure 1. PMV, thermal sensation and preferences for PMV between -0.5 and +0.5

Since the measured valued of air speed were very close to zero in the first stage measurements, this parameter was not measured throughout the whole period, since the powder present in the air could damage the sensor. Most of the tasks were performed in standing position, so it was calculated the relative air speed due to the movement of the body in relation to air. This velocity was calculated as a function of the metabolic rate, in accordance with the equation proposed in the standard ISO 7730 [2].

\[
v_{\text{air}} = 0.3 \times (M-1) \quad \text{for } M > 1 \text{ met.} \quad (1)
\]
By doing so, 44 results for PMV between -0,5 and +0,5 were obtained, as it is shown in Graph 2.

Tables 4 and 5 show the distribution of the sensation and the preference of the workers for the interval of PMV between -0.50 and +0.50, after the correction for air velocity. One observes that with regard to the thermal sensation, 25 workers (56.8%) considered the environment neutral (0), 6 workers (13.7%) considered the environment hot (+2) and 9 workers (20.5%) considered the slightly cold environment as (-1). When asked about the preference in relation to the environment, 28 workers (63.6%) did not wish any change (neutral 0) and 11 workers (25%) desired a little colder (+1) environment.

Figure 2: PMV, thermal sensation and preferences for PMV between -0.5 and +0.5.

Table 4. Workers thermal sensation for PMV between –0.50 and +0.50, after air-speed correction

<table>
<thead>
<tr>
<th>Scale</th>
<th>Sensation</th>
<th>Total occurrences</th>
<th>Occurrence Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 3</td>
<td>Hot</td>
<td>2</td>
<td>4,5</td>
</tr>
<tr>
<td>+ 2</td>
<td>Warm</td>
<td>6</td>
<td>13,7</td>
</tr>
<tr>
<td>+ 1</td>
<td>Slightly warm</td>
<td>2</td>
<td>4,5</td>
</tr>
<tr>
<td>0</td>
<td>Neutral</td>
<td>25</td>
<td>56,8</td>
</tr>
<tr>
<td>- 1</td>
<td>Slightly cool</td>
<td>9</td>
<td>20,5</td>
</tr>
<tr>
<td>- 2</td>
<td>Cool</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>- 3</td>
<td>Cold</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>44</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4. Workers thermal preference for PMV between –0.50 and +0.50, after air-speed correction

<table>
<thead>
<tr>
<th>Scale</th>
<th>Preference</th>
<th>Total occurrences</th>
<th>Occurrence Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>Much hotter</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-2</td>
<td>Hotter</td>
<td>1</td>
<td>2,3</td>
</tr>
<tr>
<td>-1</td>
<td>Warmer</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>Neutral</td>
<td>28</td>
<td>63,6</td>
</tr>
<tr>
<td>+1</td>
<td>Cooler</td>
<td>11</td>
<td>25,0</td>
</tr>
<tr>
<td>+2</td>
<td>Colder</td>
<td>4</td>
<td>9,1</td>
</tr>
<tr>
<td>+3</td>
<td>Much colder</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>44</td>
<td>100</td>
</tr>
</tbody>
</table>
DISCUSSION

Obtained data in this field research were compared with the standards specified by ISO 7730 [2] and it was verified that, from a total of 914 sets of answers from the survey, only 39 answers (4.3%) are in the limits of PMV recommended for thermal comfort. From the total of 20 days of the survey, only in six days of measurement the recommendations for thermal comfort were reached, in some schedules. Considering the relative air speed caused by the movement of the body, an addition of 0.5% in the amount of answers that in accordance to the recommendations for thermal comfort was observed.

In this research, it was verified that there is little available information for the determination of the metabolism of the Brazilian worker, as well as data on the thermal insulation of the clothing. These values of personal variables are of extreme importance for studies about thermal comfort evaluation; so the estimate of these variables for the attainment of the PMV eventually influenced in the final results. The lack of ventilation and renewal of internal air can be considered as one of the factors that contributed for the discomfort of the users in relation to analyzed environments. Another important factor is that some of the activities performed by the workers were of medium intensity, for which Fanger’s method is not the most indicated.

REFERENCES

2. INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO 7730: Moderate thermal environments: Determination of the PMV and PPD indices and specification of the conditions for thermal comfort, 1994.
5. XAVIER, A.A.P. Condição de conforto térmico para estudantes de 2º grau na região de Florianópolis. Florianópolis, 1999. 198p. (Master Dissertation, Federal University of Santa Catarina Brazil