Assessing the indoor thermal comfort of a toll station

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Abstract. The importance of a good indoor environment for peoples' health and wellbeing is nowadays clearly established. Besides enhancing the wellbeing of building occupants and helping decrease the occurrence of building related illness, a good indoor environment can also lead to a decrease in worker complaints and absenteeism. This paper presents the results of a three-month monitoring campaign where the thermal comfort of a toll station was evaluated, including the main room and the cabins. The physical parameters required for the assessment of both global and local thermal comfort were measured and the results were compared with the thermal perception of the occupants, which was collected through questionnaires. The indoor environmental quality in the main room was better than in the cabins and a mismatch between the PMV index and the occupants thermal sensation was identified.

1 Introduction

The importance of a good indoor environment for peoples' health and wellbeing is nowadays clearly established. The indoor building environment is complex and there are varieties of factors that can influence its quality, such as thermal comfort. Besides enhancing the wellbeing of building occupants and helping decrease the occurrence of building related illness, a good indoor environment can also lead to a decrease in worker complaints and absenteeism.

Some studies concerning the indoor environment in toll stations were already published, but the focus is commonly only on the indoor air quality due to the atmospheric pollutants from traffic exhausts [1-3]. The importance of thermal comfort is, thus, sometimes neglected. This paper presents the results of a large fieldwork where the thermal comfort of a toll station was evaluated both by using the methodology proposed by ISO 7730 and by questionnaires. The applicability of the PMV (Predicted Mean Vote) model to this kind of spaces is evaluated and discussed.

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2 Framework

2.1 Case study

The case study selected for this research is the toll station of the main entrance of Leixões Harbour in Porto, Portugal. The station includes 4 cabins and a main room (Figure 1). The toll cabins have 6 m² of net floor area. The floor covering is a rubber mat that laid on a wood structure, and the façades have a sandwich panel in the first 1.10 m height and the rest is a colourless tempered glass. Just one person occupies each cabin. The main room has a net floor area of 30 m². The façades include a concrete wall in the first 1.00m height and the rest is a colourless tempered glass. This room has a HVAC system that has an intermittent operation according to the setpoints defined by the users.

Fig. 1. Case study: a) aerial view; b) the 4 cabins and the main room.

2.2 Equipment and methodology

The thermal comfort evaluation was carried out between March and May and both overall comfort (30 minutes) and local discomfort (30 minutes) were assessed. The measurements were made inside the 4 cabins and in the main room. During the measurement, the users were asked to fill an objective individual questionnaire to assess their perception of the thermal environment. A total of 60 thermal comfort surveys were carried out (35 in the cabins and 25 in the main room) and 153 questionnaires were collected.

Relevant parameters to assess global thermal comfort - air temperature, relative humidity, mean radiant temperature and air velocity - and local thermal discomfort - draught rate, floor temperature and temperature at different body heights - were measured in accordance with ISO 7730 and ASHRAE 55 specifications. The equipment used in the field campaign follows the ISO 7726 guidelines. Exterior air temperature and relative humidity were recorded throughout the whole fieldwork duration. Figure 2 shows the position of the equipment in a cabin and inside the main room.

Fig. 2. Location of the equipment: a) cabin; b) main room.

3 Results

3.1 Questionnaire

During the fieldwork, a total of 153 questionnaires were collected: 118 were cabins’ workers and 35 were occupants of the main room. By analysing the sample (Figure 3), it can be seen that the respondents in the main room were almost entirely males (98%), whereas in the cabins, on the other hand, the highest percentage of respondents were female (74%). Regarding the age group of the sample, in the main room the ages vary from 25 years to 56 years, and the age group from 40 to 45 years represents almost half of the respondents (40%). In the cabins, respondents are in a narrower age group, corresponding to younger ages, mostly between 30 and 40 years.

Fig. 3. Sample characterization: a) cabins; b) main room.

The individual thermal sensation, TS, was assessed through the well-known Fanger’s scale ranging from -3 (cold) to 3 (hot). Figure 4 shows the results. In the cabins, the thermal sensation (TS) of neutrality (TS = 0) is the prevailing one (44% for the morning and 58% for the afternoon). The discomfort due to the heat is more important in the afternoon, in contrast to the cold perception. In the main room, most respondents also indicated a thermal sensation of neutrality (TS = 0), especially in the morning (71% for the morning and 56% for the afternoon).

Fig. 4. Thermal sensation: a) cabins; b) main room.

3.2 Thermal comfort

Figure 5 shows the mean PMV and the corresponding PPD (Predicted Percentage of Dissatisfied) for each measurement. In the main room, the thermal sensations are between neutrality (PMV = 0) and the slightly cold sensation (PMV = -1), with almost all the tests being within the limits of the three comfort categories defined in ISO 7730 (92% comply the limit of Category III). Regarding the most demanding thermal condition (Category I),

only 36% of the tests are within its limits. In the cabins, the PMV index has a greater variation, with several tests being outside the limits of a desirable thermal environment. In fact, even for the less demanding category, only 63% of the tests fulfilled the requirements. Of the remaining percentage, 11% corresponded to PMV indexes higher than 0.7 (hot sensation) and 26% are linked to cold sensations. Given the greater variation of the thermal sensations in the cabins, the maximum PPD index was approximately 55%, while in the main room this value was only 25%.

Fig. 5. PMV versus PPD: a) cabins; b) main room.

The analysis of the temperature at different body heights is depicted in Figure 6. The $\Delta t_{a,v}$ parameter is the difference between ankle and head temperature. This parameter is the input required to estimate the percent of discomfort PD. The results showed that there is a small percentage of dissatisfied people (maximum 8% approximately) in both locations. With respect to the limits defined by the comfort categories, in the main room all the tests meet the requirements, with 96% of the complying the limits of the most demanding category. In the cabins, all tests revealed an acceptable thermal environment. However, when compared to the main room, only 68% are included in category I.

Fig. 6. Local discomfort due to the temperature at different body heights: a) cabins; b) main room.

Figure 7 presents the relation between the floor temperature and the percent of discomfort PD. The results show that, in both locations, the discomfort occurs only due to cold floor temperature ($t_f < 24^\circ\text{C}$). In the cabins, the maximum percent of discomfort was 32%, while in the main room this value was only 12%. In fact, in the main room, the comfort limits of category III were always complied whereas in the cabins 20% of the tests were above the limit.

Fig. 7. Local discomfort due to the floor temperature: a) cabins; b) main room.

The draught rate DR was calculated assuming a local turbulence intensity of 40%, as recommended in ISO 7730. For each measurement period, two parameters were considered: the mean draught rate, DR_m ; and the maximum draught rate, DR_{max} . Figure 8 shows a box-plot representation of the results. The average values are very low, both for the main room and for the cabins. In the latter, 97% of the tests fulfil the requirements of category I ($DR_m < 10\%$). Regarding the maximum values, the spread of the results is evident. The limit of 30% is exceeded 16% and 17% of the tests in the main room and in the cabins, respectively.

Fig. 8. Local discomfort due to draught: a) cabins; b) main room.

3.3 PMV versus mean thermal sensation

The mean PMV of each test was compared with the mean thermal sensation (TS) of the occupants (Figure 9). In the cabins, a large spread of the results can be observed. Nevertheless, the trend line attained for the cabins follows closely the ideal situation ($PMV = TS$), but the coefficient of determination is only 0.30. In the main room, almost all the tests indicate a warmer thermal sensation than the one predicted by the PMV index. These results pave the way for a discussion regarding the applicability of the PMV model in this kind of environments.

Fig. 9. PMV versus thermal sensation.

4 Conclusions

The main conclusions of this work were:

- The questionnaires applied in the test provided a good understanding of the occupants' perception, indicating a high acceptability of the indoor environment.
- The PMV index presented a greater variation in the cabins, leading to a maximum PPD of 55%.
- The most relevant local discomfort sensation occurred in the cabins due to cold floor.
- The mismatch between PMV and thermal sensation indicate that this index may not be the most appropriated to assess thermal comfort in this kind of environments.

The future works of this research include the assessment of indoor air quality and the definition of strategies to improve the thermal comfort of the workers. The findings are expected to be applicable in other identical infrastructures throughout the country.

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