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Do Thermal Comfort Standards Ensure Occupant Satisfaction? Learning From Occupants' Thermal Complaints

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Abstract

Today, buildings are operated according to the standards (i.e. thermal), however; the recommended values in the standards might not necessarily address occupants' needs, and, thus, occupant complaints might arise. This study aims at assessing the performance of the predicted mean vote (PMV) model to detect occupant thermal dissatisfaction. The case study was conducted in a commercial building located in Paris, France between January 2017 and May 2018. Indoor environmental conditions were monitored via sensors and an online tool was used to collect occupant thermal complaints. A total of 53 thermal complaints were analyzed and the corresponding measurements were checked against the reference values suggested by the ISO 7730 Thermal Comfort Standard. The results show that all of the operative temperature measurements both in the heating and cooling seasons were within the thresholds suggested by the standards. In addition, the PMV method suggested that only 4% of the occupants were dissatisfied with the indoor environment. However; the actual dissatisfaction ratio of occupants was 100% under these indoor environmental conditions. The findings of this study show that predefined comfort ranges, and, thus thermal comfort standards are not able to predict occupant thermal dissatisfaction.

Keywords: Thermal complaint; PMV-PPD model; thermal comfort; ISO 7730

1. Introduction

Thermal comfort is stated as an important part of the built environment that affects not only health and wellbeing but also productivity of occupants. Therefore, maintaining a comfortable and satisfactory thermal environment for occupants is one of the main concerns of facility managers. Today, buildings are generally operated according to the thermal comfort standards such as American Society of Heating, Air conditioning & Refrigeration Engineers, US [1] and ISO Standard 7730 [2]. Both standards use the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) indices to assess thermal comfort conditions in indoor environments. Since the PMV-PPD model recommends that a narrow temperature range be applied equally across all building types, climatic zones and population, the prediction accuracy of PMV and PPD indices has been questioned by many researchers. Studies conducted in hot and humid climatic conditions prove that the PMV-PPD model tends to over-predict the perceived warmth in the built environment [3–6]. Furthermore, thermal comfort complaints have been reported in different types of buildings [3,7–11]. However, these studies should also check the compatibility of indoor environmental

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conditions against the standards along with the analysis of thermal complaints. This study aims at investigating the compatibility of indoor environmental conditions against ISO 7730 Thermal Comfort Standard in a commercial building as well as analysing the thermal complaints obtained from the occupants. The following sections introduce the material, present the methodology, provide results and conclusion.

2. Material

The study was conducted between January 2017 and May 2018 in a commercial building located at the West of Paris, France. A total of 17 ambient sensors were used to monitor the indoor air temperature (T) and relative humidity (RH) on the second floor of the building. The data was collected at a 10 mins frequency. The floor consists of two open space offices, one corridor, two small meeting rooms for two persons, one meeting room for 8 persons and two enclosed offices. In addition, a closed-ended survey was used to characterize the kinds of issues occupants complained about in the demonstration zone and the prevalence of these complaints in relation to building systems. The survey data contains (i) timestamp of the demand, (ii) the type of location (i.e. open space office) of occupants, (iii) the domain of the building system (i.e. HVAC, lighting) and (iv) the type of complaint. A total of 53 complaints in relation to HVAC system are analyzed. Since thermal comfort standards recommend different ranges for the heating and cooling seasons, complaints were analyzed separately. A total 29 (~55%) and 24 (~45%) out of 53 thermal complaints were analyzed for the heating and cooling seasons, respectively. It should be noted that on some particular dates more than one occupant has filed a thermal complaint. Accordingly, the timestamp of the filed complaints was taken into account to find the corresponding operative temperature and relative humidity ratios.

3. Methodology

In this study, thermal comfort standards were assessed according to the ISO Standard 7730. This standard suggests the Fanger's model [12] in which the PMV and PPD indices are used for assessing and predicting thermal comfort in indoor environments including buildings [11,13–17]. The CBE Thermal Comfort tool [18] was used to calculate the PMV and PPD indices, in which the input parameters are indoor air temperatures (°C), relative humidity (%), mean radiant temperature (°C), air velocities (m/s), clothing insulation values (clo) and metabolic rate of the users (met). Indoor air temperature and relative humidity ratios corresponding to the complaints in relation to HVAC system were obtained from ambient sensor data. Mean radiant temperatures were calculated by using the formula (Equation 1) proposed by Nagano [19].

$$T_r = 0.99 \times T_a - 0.01,\ R^2 = 0.99 \tag{1}$$

where T_r represents the mean radiant temperature and T_a represents the indoor air temperature. Air velocity was assumed to be 0.15 m/s, which is below the maximum allowable air velocity in offices according to ISO7730 Standard. Metabolic rates and clothing insulation values of occupants were calculated by using the corresponding tables in ISO7730 Standard. Subsequently, the metabolic rate was determined as 1.2 met, which corresponds to office sedentary activities. The checklist of clothing in the ISO7730 Standard was used to obtain the clothing insulation (clo) values, which were determined according to the most likely garments to be worn. Subsequently, the clo values were determined as 0.57 clo and 1.1 clo for cooling and heating seasons, respectively. Moreover, the operative temperature was calculated to check the compatibility of this parameter with the recommended values in the ISO7730 Standard. Equation 2 which is given in the ASHRAE55-2010, is used to calculate the operative temperatures.

$$T_o = A \times T_a + (1-A) \times T_r \tag{2}$$

In the Equation 1, T_o represents operative temperature and A is weighting factor that depends on air velocity (v_r) and was determined as 0.5 according to the ASHRAE55-2010.

4. Results

4.1. Analysis of indoor environmental conditions

This section presents the assessment of indoor environmental conditions against ISO 7730 Standard per heating and cooling seasons. Operative temperature (°C) and relative humidity (%) were taken into account in the analysis. The maximum and minimum allowable operative temperatures recommended by ISO 7730 are 20 °C and 24 °C for heating season, respectively. Fig. 1 shows the distribution of operative temperatures corresponding to the date of the complaints as well as the recommended maximum and minimum allowable values for the heating season. It should be noted that each dot in the following figures represent the measurement of indoor environmental parameter that corresponds to an occupant’s thermal complaint.

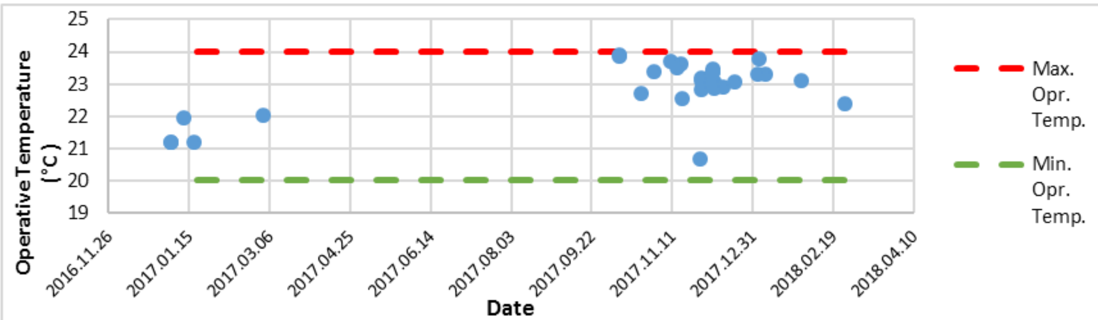

Fig. 1. Distribution of operative temperatures in the heating season

The complaints were collected between January 2017 and May 2018, and, thus, the period covers 2 heating seasons starting from October until the end of March. A total of 24 and 5 thermal complaints out of 29 were collected in the heating seasons of 2017 and 2018, respectively. As can be seen from the figure, all operative temperatures were within the recommended values. The maximum operative temperature was observed on October 9th, 2017 with a value of 23.9°C, which is almost at the maximum allowable operative temperature recommended by ISO 7730 Standard. The minimum operative temperature was observed on November 28th, 2017 with a value of 20.8 °C. Fig. 2 shows the distribution of relative humidity measurements as well as the recommended maximum and minimum allowable values for the heating season. It should be noted that the minimum and maximum allowable relative humidity ratios are 30% and 70% for the heating season, respectively.

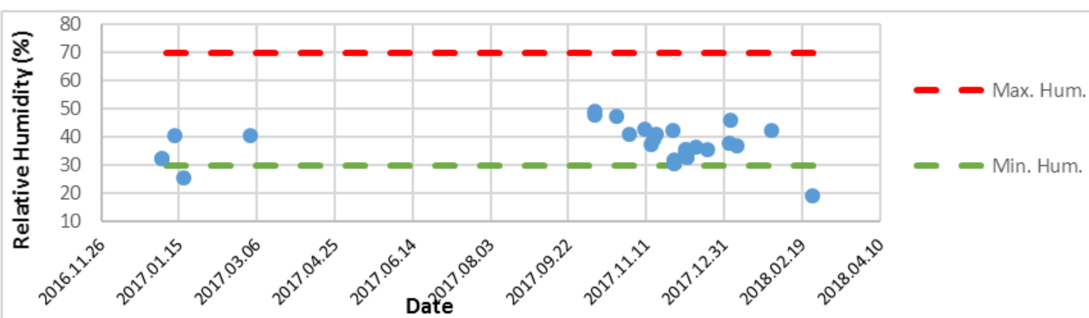

Fig. 2. Distribution of relative humidity ratios in the heating season

As can be seen, 2 out of 29 measurements were below the recommended minimum relative humidity ratios. The minimum relative humidity was observed on January 26th, 2018 with a value of 19.3% whereas the maximum relative humidity was observed on October 9th, 2017 with a value of 49.1%.

Regarding the cooling season, ISO 7730 Standard recommends 23 °C and 26 °C as the maximum and minimum allowable operative temperature, respectively. The complaints were collected between January 2017 and May 2018, and, thus, the period covers 2 cooling seasons starting from April until the end of September. It should be noted that the experimental campaign covered only the months of April and May in the cooling season of 2018. A total of 11 and 13 thermal complaints out of 24 were collected in the cooling seasons of 2017 and 2018, respectively. Fig. 3 shows the distribution of operative temperatures as well as the recommended maximum and minimum allowable values for the cooling season.

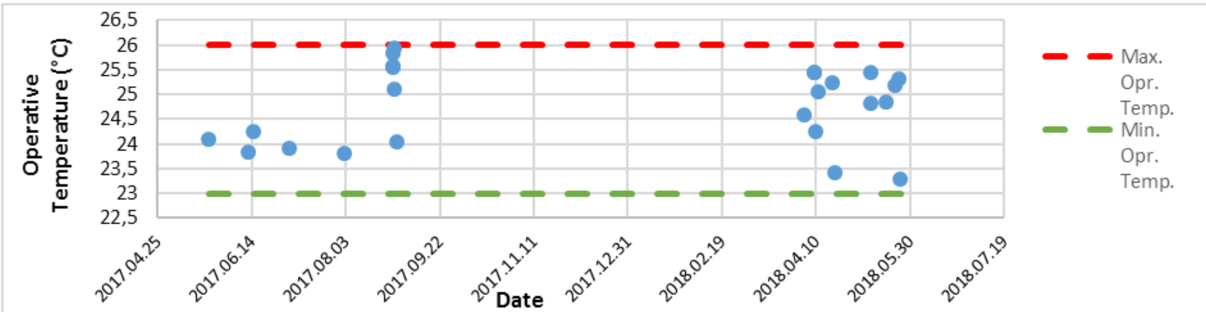

Fig. 3. Distribution of operative temperatures in the cooling season

As can be seen from the figure, all operative temperatures were within the recommended values. The maximum operative temperature was observed on August 28th, 2017 with a value of 25.9°C, which is close to the maximum allowable operative temperature. The minimum operative temperature was observed on May 25th, 2018 with a value of 23.2 °C. Fig. 4 shows the distribution of relative humidity measurements as well as the recommended maximum and minimum allowable values for the cooling season. It should be noted that the minimum and maximum allowable relative humidity ratios are 30% and 70% for the cooling season, respectively.

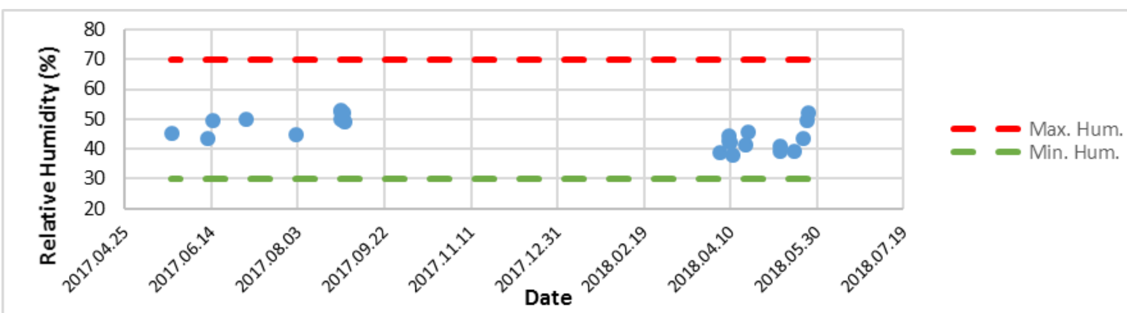

Fig. 4. Distribution of relative humidity ratios in the cooling season

As can be seen from the figure, all relative humidity ratios were within the recommended values. The maximum humidity was observed on August 28th, 2017 with a value of 52.3%. The minimum humidity was observed April 11th, 2018 with a value of 38.0%.

4.2. Comparison of PMV values and thermal complaints

This section investigates the compatibility of PMV and PPD values with ISO 7730 Standard. The maximum and minimum allowable PMV values are -0.5 and +0.5 for both heating and cooling seasons. Fig. 5 shows the distribution of PMV values as well as the recommended maximum and minimum allowable values for both seasons. It should be noted that each dot in Figures 5 and 6 represent the PMV values calculated according the measurement of indoor environmental parameter that corresponds to an occupant’s thermal complaint.

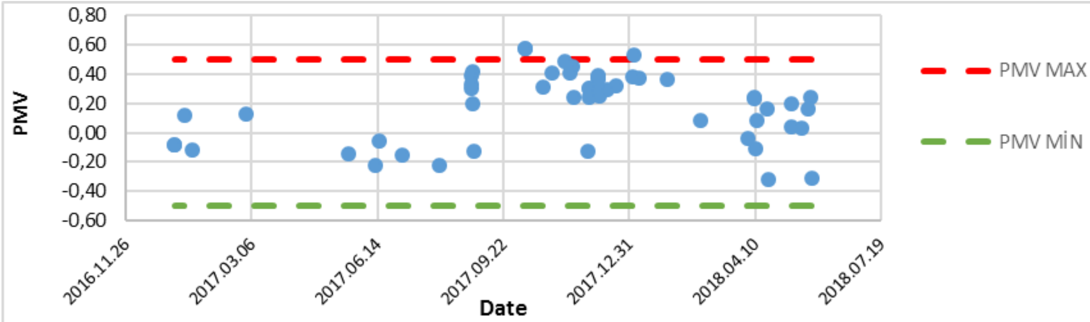

Fig. 5. Distribution of PMV values

The results show that 96% of PMV values comply with ISO 7730 Standard, which means that 96% of indoor environmental conditions are satisfactory for the occupants. In addition, the allowable PPD value is less than %10 for both heating and cooling seasons per ISO 7730 Standard. Fig. 6 shows the distribution of PPD values as well as the recommended allowable values for both seasons.

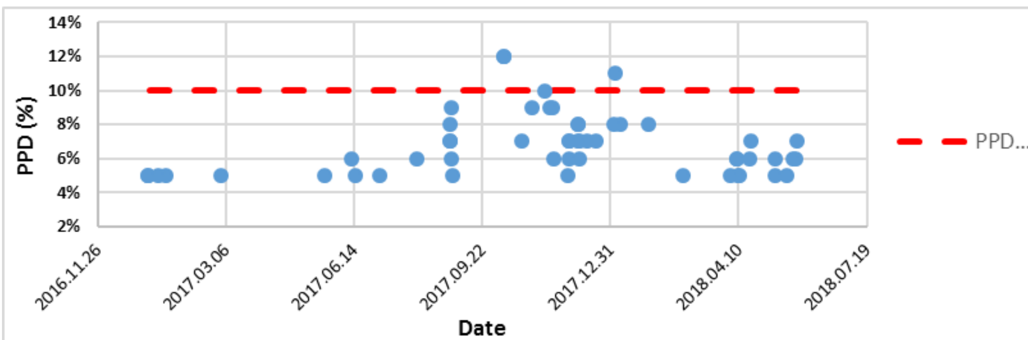

Fig. 6. Distribution of PPD (%) values

The PPD values suggest that there are 2 incidents in which occupants were not satisfied with the indoor conditions. These incidents were observed in the heating season. However, there are 53 thermal complaints filed in these particular conditions. Fig. 7 presents the distribution of thermal complaints filed by the occupants. The results show that occupants have both warm and cold complaints regardless of the season. Therefore, a predefined comfort set point do not ensure occupant thermal satisfaction in the built environment.

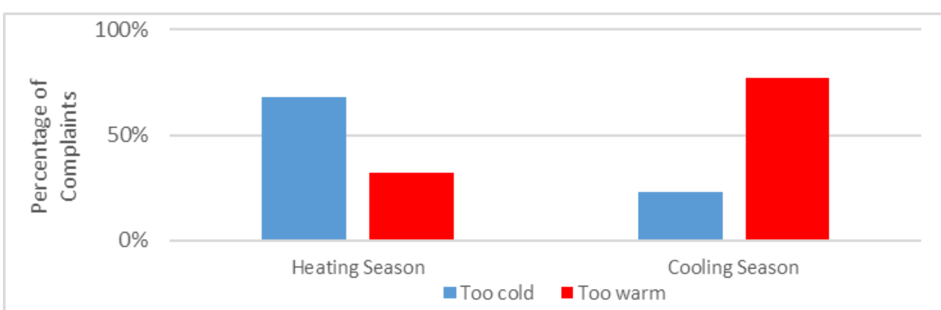

Fig. 7. Distribution of thermal complaints per season

5. Conclusion

In this study, the accuracy of PMV method for predicting occupant thermal satisfaction was checked via assessing thermal complaints of occupants. In addition, the compatibility of indoor environmental conditions against ISO 7730 Thermal Comfort Standard in a commercial building located in Paris, France was investigated. The results show that all of the operative temperature measurements both in the heating and cooling seasons were within the thresholds suggested by the standards. Ninety-three percent and 100% of measurements regarding relative humidity ratios were within the recommended ranges. Furthermore, the PMV values showed that 96% of the occupants felt natural, and, thus, only 4% of the occupants were dissatisfied with the indoor environment. However; the thermal dissatisfaction ratio of occupants under these indoor conditions was 100%. The findings of this study show that predefined comfort ranges do not ensure occupant thermal satisfaction. The limitation of this study is that the findings are based on one building, and, thus, future studies can incorporate more buildings to validate the results of this study.

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