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Analyzing and modeling thermal complaints in a commercial building in France

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Abstract: Buildings are interactive environments in which their operations and occupants are linked. Although buildings are operated according to the standards, occupant complaints may arise when there is a mismatch between indoor environmental conditions and actual user needs. Therefore, the accuracy of thermal comfort prediction models suggested by the standards and alternative prediction models need to be investigated. This study aims at assessing the performance of the predicted mean vote (PMV) model suggested by the ISO 7730 Standard to detect occupant thermal dissatisfaction. In addition, a multivariate logistic regression model was developed to predict thermal complaints with respect to "too warm" and "too cold." This 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. The results showed that all the operative temperature measurements in both the heating and cooling seasons were within the thresholds suggested by the standards. The PMV method suggested that only 4% of the occupants were dissatisfied with the indoor environment whereas the actual dissatisfaction ratio was 100% under these indoor environmental conditions. In addition, the multivariate logistic regression model showed that operative temperature and season have a significant effect on thermal complaints. Furthermore, the accuracy of the developed model was 90.6%.

Keywords: thermal dissatisfaction, thermal complaint, PMV–PPD model, logistic regression

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1 Introduction

Buildings are interactive environments in which their operations, performance, and occupants are linked. At present, buildings are operated according to the standards such as ISO 7730 (International Standardisation Organisation 2005) and ASHRAE Standard 55 (American Society of Heating Refrigerating and Air-Conditioning Engineers 2010) for thermal comfort and ISO 16817 (International Organization for Standardization 2012) for visual comfort. However, these standards might not reflect the preference of occupants. Shooshtarian and Rajagopalan (2017) found that the assumption of equality between thermal neutrality and thermal satisfaction stated in comfort standards is not valid. Similar finding was supported by Calis and Kuru (2017), who pointed out that the standards do not reflect the preferred neutral temperatures. Furthermore, it was noted that thermal comfort temperature was lower than the temperature suggested by the standards (Trebilcock et al., 2017). Therefore, it can be concluded that the standards do not ensure occupant satisfaction. Subsequently, occupants might either interact with building systems which result in poor building performance in real situations or state their dissatisfaction to facility managers who need to take corrective actions. Therefore, occupant complaints can arise when there is a mismatch between indoor environmental conditions and actual user needs. These complaints might provide insights toward solutions and opportunities for improving building performance and increased occupant satisfaction. Accordingly, many researchers focused on understanding occupant comfort and the solutions that address the complaints of occupants (Panas and Pantouvakis 2010; Júlio et al. 2013).

In literature, a significant number of research can be found on thermal complaints since 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. To assess thermal comfort conditions in indoor environments, both ASHRAE 55 and ISO 7730 Standards use the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) indices. However, the prediction accuracy of PMV and PPD indices has been questioned by many researchers since the PMV–PPD model recommends that a narrow temperature range to be applied equally across all building types, climatic zones, and population. The studies conducted in hot and humid climatic conditions proved that the PMV–PPD model tends to overpredict the perceived warmth in the built environment (Appah-Dankyi and Koranteng 2012; Dias et al., 2014; Calis et al. 2015; Calis and Kuru 2017). Furthermore, it is stated that the PMV–PPD model cannot predict thermal complaints in every building typology. Deuble and de Dear (2014) found that the actual thermal dissatisfaction of occupants in office buildings was greater than or equal to the predicted one by the PMV–PPD model. The studies conducted in educational buildings suggested that the dissatisfaction envisaged with the PMV–PPD model and the real dissatisfaction of students were inconsistent (Corgnati et al., 2007; Calis and Kuru 2017). In addition, Azizpour et al. (2013) indicated that the actual thermal dissatisfaction of occupants in a hospital was greater than the predicted dissatisfaction obtained via the PMV–PPD model. Apart from building and climate-related characteristics, some research indicated that occupant-related parameters such as gender and age also have a correlation with thermal complaints (Ceria and De Dear 2001; Choi et al. 2010; Calis et al. 2018). It can be concluded that predicting thermal complaints is not an easy task. Subsequently, alternative methodologies have been proposed in the literature. In particular, regression models are widely adopted and they have a potential to predict occupants' dissatisfaction. Daum et al. (2011) used logistic regression for converting thermal sensation votes of occupants (i.e., too hot, comfortable, and too cold) to a probability of comfort. Gunay et al. (2018) analyzed the manual temperature set point change request data for predicting the reason for the action. The authors developed logistic regression models to predict the set point changes due to hot and cold thermal complaints. The results of a study, which focused on finding the appropriate indoor air temperature in winter, showed that the logistic regression model was able to estimate whether people felt "cool" or not and "warm" or not (Ji and Wang 2019). It can be concluded that logistic regression models have potential to be used for predicting thermal complaints of occupants in indoor environments.

This study aims at developing a multivariate logistic regression model for predicting thermal complaints in buildings. This article is based on and is an extended version of a study presented at the Creative Construction Conference (Kocaman et al. 2019). In this context, the compatibility of indoor environmental conditions against ISO 7730 Thermal Comfort Standard in a commercial building was investigated. In addition, thermal comfort in indoor environments was assessed via the PMV model. The following sections explain data collection, present the methodology, and provide results and conclusion.

2 Data collection

This study was conducted between January 2017 and May 2018 on the second floor of the commercial building located at the West of Paris, France. The floor consists of two open space offices, one corridor, two small meeting rooms for two persons, one meeting room for eight persons, and two enclosed offices. Heating and cooling of the offices and meeting rooms are supplied from the interior units via the split system located in the ceiling of units double regulating valve (DRV). All room temperatures are maintained between 21 and 25°C except for the corridors leading to the parking lot where the temperature is maintained between 19 and 27°C. The operating of the DRV is programmable with current program working from 5 a.m. to 8 p.m. The internal units start up and condition the spaces depending on the ambient interior temperature of the spaces, before occupancy, as shown in Table 1.

A total of 17 ambient sensors were used to monitor the indoor air temperature (*T*) and relative humidity (RH) in the second floor of the building. The data were collected at a 10-min frequency. In addition, a closed-ended survey was used to characterize the types of issues occupants complained about in the demonstration zone and the prevalence of these complaints in relation to building systems. The survey data contained (i) time stamp of the demand, (ii) the type of location (i.e., open space office) of occupants, (iii) the domain of the building system [i.e., heating, ventilation, and air conditioning (HVAC), lighting], and (iv) the type of complaint. A total of 53 complaints were submitted by 53 individuals. All the

Tab. 1: Operating principles of DRV

	Ambient *T* (°C)	Start-up (a.m.)—programmable
Heating mode	<16	05:00
	16–18	06:00
	18–20	07:00
	≥20	08:00
Cooling mode	≤26	08:00
	26–27	07:00
	27–28	06:00
	>28	05:00

complaints in relation to the HVAC system were 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 time stamp of the filed complaints was taken into account to find the corresponding operative temperature and RH ratios.

3 Methodology

3.1 Calculation of PMV values

In this section, the thermal comfort standards were assessed according to the ISO Standard 7730. This standard suggests the Fanger's model (Fanger 1982) in which the PMV and PPD indices are used for assessing and predicting thermal comfort in indoor environments including buildings (Katafygiotou and Serghides 2014; Soutullo et al. 2014; Trebilcock et al. 2014; Dudzińska and Kotowicz 2015; Gilani et al. 2015; Natarajan et al. 2015; Cheung et al. 2019). The CBE Thermal Comfort tool (Hoyt et al. 2017) was used to calculate the PMV and PPD indices, in which the input parameters were indoor air temperature (C), RH (%), mean radiant temperature (C), air velocity (m/s), clothing insulation value (clo), and metabolic rate of the users (met). Indoor air temperature and RH ratios corresponding to the complaints in relation to HVAC system were obtained from the ambient sensor data. Mean radiant temperatures were calculated using the formula (Equation 1) proposed by Nagano and Mochida (2004).

$$T_r = 0.99 \times T_a - 0.01, R^2 = 0.99 \quad (1)$$

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 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.

$$T_o = A \times T_a + (1 - A) \times T_r \quad (2)$$

where 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.

3.2 Logistic regression

Regression models investigate the relationship between independent variables and an outcome (dependent) variable. If the dependent variable is a categorical variable, discriminant analysis, probit analysis, logarithmic linear regression, and logistic regression can be used for data analysis. In particular, logistic regression is widely used since it enables to use continuous explanatory variables and it is easier to handle more than two explanatory variables simultaneously (Fagerland and Hosmer 2012).

Logistic regression models can be considered as a type of multiple regression models. Logistic regression models are not linear, and thus they are more complex compared with the multiple regression models (Tabachnick and Fidell 2007). Logistic regression function can be formalized as follows:

$$\pi(x) = \frac{e^{\beta_0 + \beta_1 \cdot X}}{1 + e^{\beta_0 + \beta_1 \cdot X}} \quad (3)$$

in which $\pi(x) = E(y/x)$ value is a conditional probability, which must be transformed to linearize $\beta_0 + \beta_1 \cdot X$ in the model. This transformation is a logit transformation and is expressed as follows:

$$g(x) = \ln\left(\frac{\pi_x}{1 - \pi_x}\right) = \beta_0 + \beta_1 \cdot X \quad (4)$$

Transformation variable $g(x)$ is linear to the parameter in the model and is continuous (Hosmer and Lemeshow 2005).

If the number of independent variables is more than 1, then logistic regression model is generalized and called multivariate logistic regression (Chen and Dey 2003). Considering that there are P sets of independent variables, the logit of the multivariate logistic regression model is obtained from the following equation:

$$g(x) = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \cdots + \beta_p \cdot X_p \quad (5)$$

In such cases, the multivariate logistic regression function is formulized as follows:

$$\pi(x) = \frac{e^{\beta_0+\beta_1 \cdot X_1+\beta_2 \cdot X_2+\cdots+\beta_p \cdot X_p}}{1+e^{\beta_0+\beta_1 \cdot X_1+\beta_2 \cdot X_2+\cdots+\beta_p \cdot X_p}} \tag{6}$$

In this study, a multivariate logistic regression model was developed since the number of independent variables in the data set is more than 1. The independent variables were identified as the operative temperature (°C), RH (%), and seasons. Thermal complaints were identified as the dependent variable. A multivariate logistic regression model was established to understand the relationship between the independent variables and the dependent variable. The analysis was performed by using the SPSS program.

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 RH (%) were taken into account in the analysis. The maximum and minimum allowable operative temperatures recommended by ISO 7730 are 20 and 24°C for heating season, respectively. Figure 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 represents the measurement of indoor environmental parameter that corresponds to an occupant's thermal complaint.

The complaints were collected between January 2017 and May 2018, and thus the period covers two 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 9, 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 28, 2017 with a value of 20.8°C. Figure 2 shows the distribution of RH 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 RH ratios are 30 and 70% for the heating season, respectively.

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

Regarding the cooling season, ISO 7730 Standard recommends 23 and 26°C as the maximum and minimum allowable operative temperatures, respectively. The complaints were collected between January 2017 and May 2018, and thus the period covers two 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. Figure 3 shows the distribution of operative temperatures

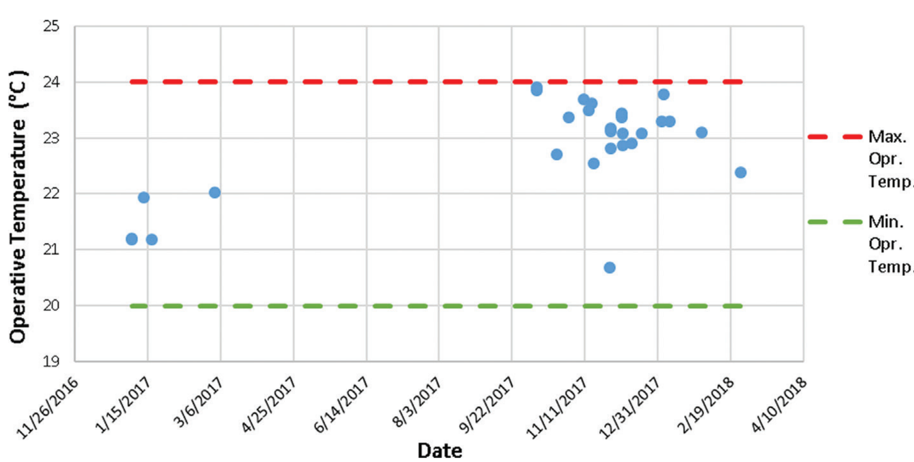

Fig. 1: Distribution of operative temperatures in the heating season.

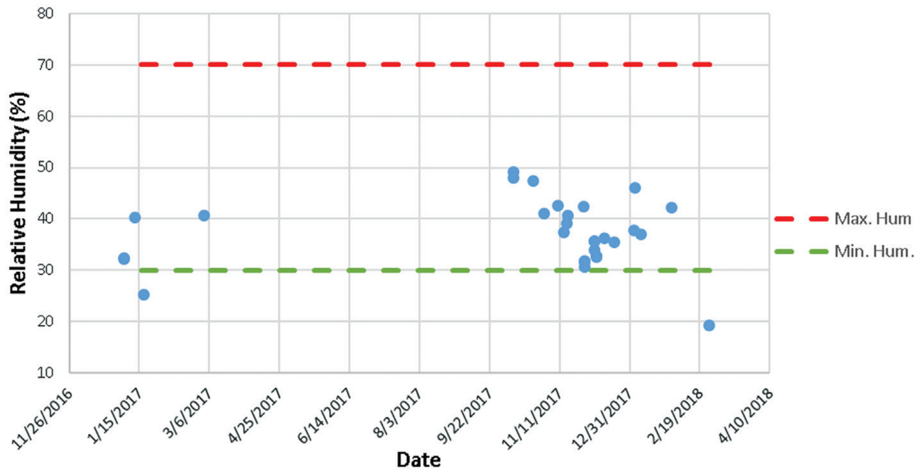

Fig. 2: Distribution of relative humidity ratios in the heating season.

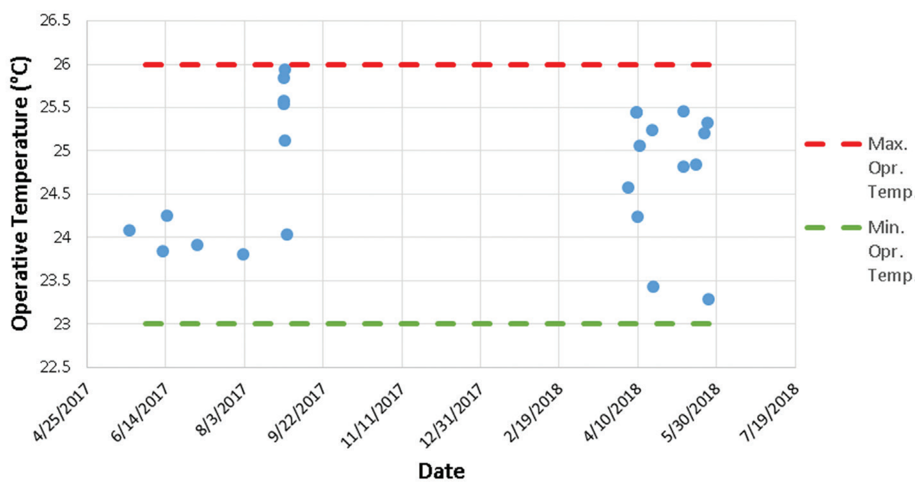

Fig. 3: Distribution of operative temperatures in the cooling season.

as well as the recommended maximum and minimum allowable values for the cooling season.

As can be seen from the figure, all the operative temperatures were within the recommended values. The maximum operative temperature was observed on August 28, 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 25, 2018 with a value of 23.2°C. Figure 4 shows the distribution of RH 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 RH ratios are 30 and 70% for the cooling season, respectively.

As can be seen from the figure, all RH ratios were within the recommended values. The maximum humidity was observed on August 28, 2017 with a value of 52.3%. The minimum humidity was observed on April 11, 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. Figure 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 represents the PMV values calculated according to the measurement of indoor environmental parameter that corresponds to an occupant's thermal complaint.

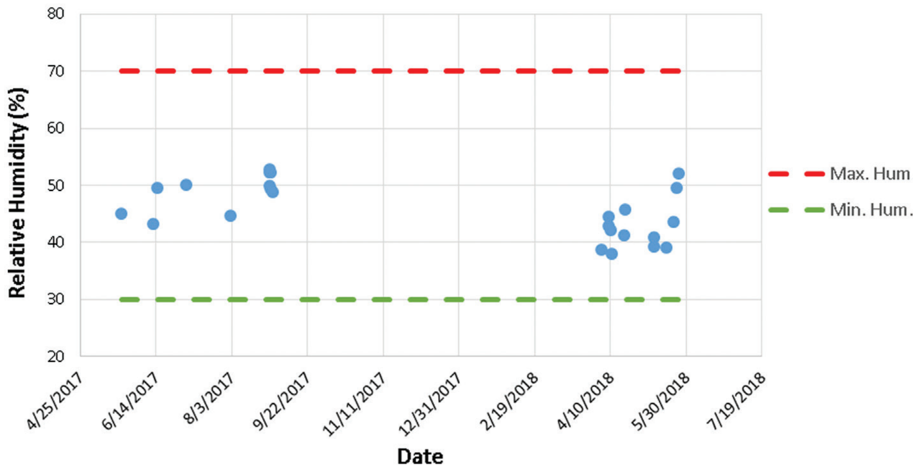

Fig. 4: Distribution of relative humidity ratios in the cooling season.

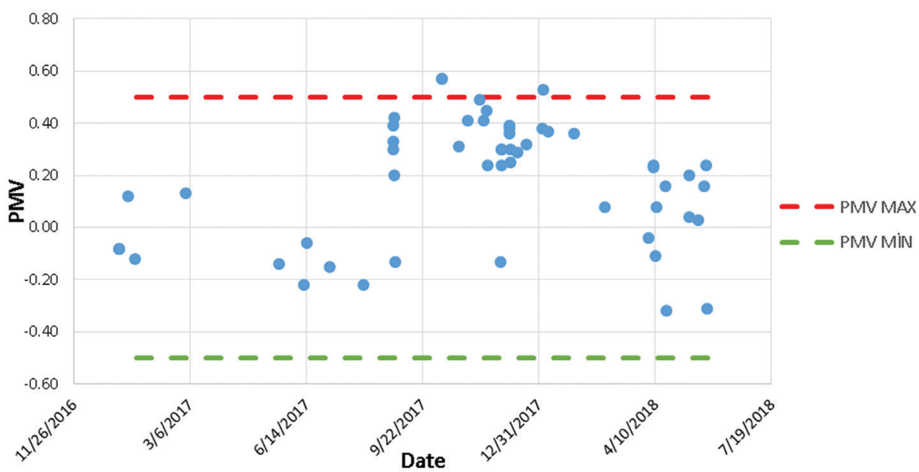

Fig. 5: Distribution of PMV values.

The results showed that 96% of the 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. Figure 6 shows the distribution of PPD values and the recommended allowable values for both seasons.

The PPD values suggested that there are two 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. Figure 7 presents the distribution of thermal complaints filed by the occupants. The results showed 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.

4.3 Logistic regression analysis

In this analysis, thermal complaint is the binary dependent variable with categories, namely too warm and too cold. The season, operative temperature, and RH values are independent variables.

For the binary dependent variable, a total of 28 and 25 responses were obtained for “too warm” and “too cold”, respectively. The base category for thermal complaints is “too warm” (Table 2).

Table 3 shows the descriptive statistics for the numerical independent variables, which are operative temperature and RH.

For the season, which is a categorical independent variable, the performance is evaluated with respect to a base category. The base category for season is “cooling” and Table 4 presents the frequency of season with respect to thermal complaints.

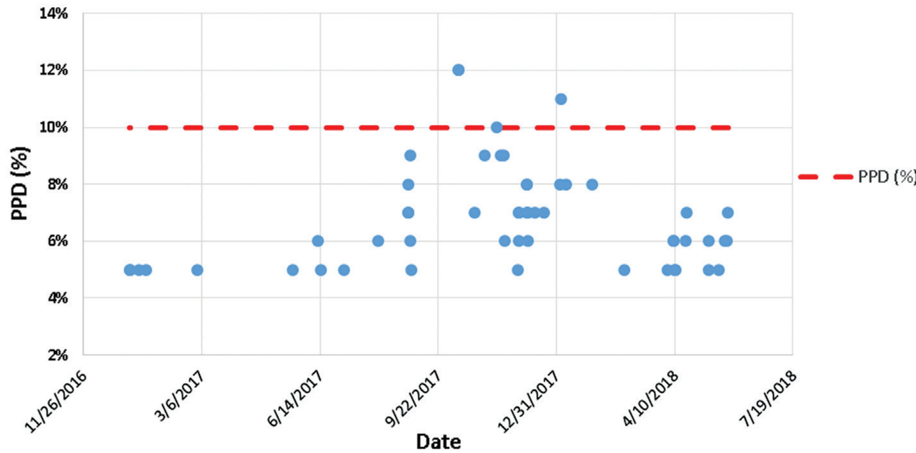

Fig. 6: Distribution of PPD (%) values.

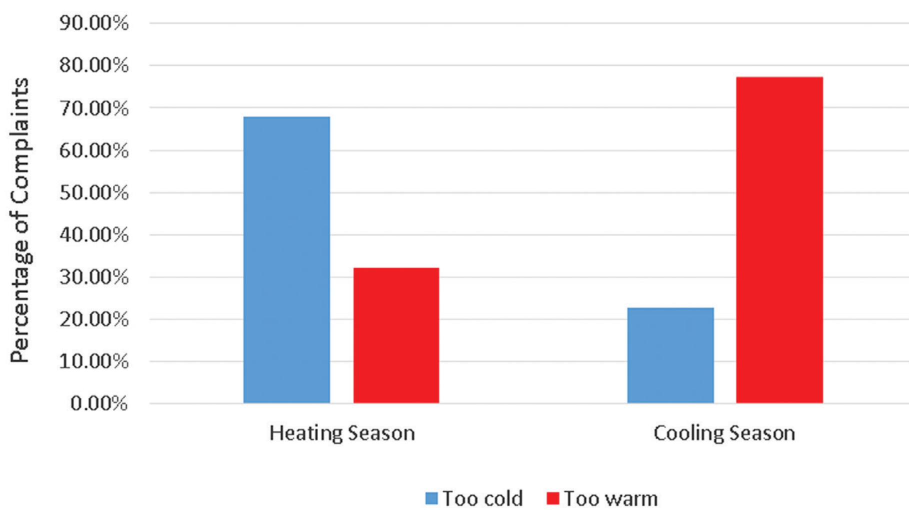

Fig. 7: Distribution of thermal complaints per season.

Tab. 2: Dependent variable encoding

Original value	Internal value
Too warm	0
Too cold	1

Tab. 3: Statistics for numerical independent variable

	Operative temperature	Relative humidity
N	53	53
Mean	23.8383	41.0077
Median	23.7400	41.1000
Mode	23.20	19.32
Standard Deviation	1.27730	7.25820

The first model, a null model (the intercept-only model), was without any predictors. The overall accuracy of the first prediction model was 52.8% as shown in Table 5.

Tab. 4: Categorical variables codings

		Frequency	Parameter coding
			−1
Season	Heating	29	1.000
	Cooling	24	0.000

In the second model, the predictors were included in the model (Step 1) and chi-squared goodness-of-fit test was conducted. Table 6 gives the overall test for the model which includes the predictors. The results showed that all p values are <0.05, and thus the prediction model based on predictors is statistically significant.

Table 7 presents the –2 log likelihood, Cox & Snell R^2, and Nagelkerke R^2 values. R^2 values in this model can be interpreted similar to the R^2 values obtained in the regression analysis. Nagelkerke R^2 value is a standardized value. It should be noted that Nagelkerke R^2 value is always more than Cox & Snell R^2 value. The results showed that 85.4% of the change in the dependent variable can be explained by the developed model.

The results of the second model are given Table 8. The model correctly predicted 26 out of 28 thermal complaints that said "too warm." Besides, it correctly predicted 22 out of 25 thermal complaints that said "too cold." Overall, the accuracy of the model is 90.6%.

The statistical results of the variables are given Table 9. The *p* values indicate whether or not the independent variables are significant. Since the *p* value of RH is more than 0.05, it can be concluded that RH has no effect on the thermal complaints. On the other hand, the operative temperature and the season have a significant effect on the thermal complaints because the *p* values of these variables are <0.05.

Since the *B* value of operative temperature is negative, the probability of a thermal complaint to be "too warm" increases if the operative temperatures increase. In addition, since the *B* value of the season is negative, the probability of a thermal complaint to be "too warm" increases in the cooling season compared with the heating season.

Tab. 5: Results of the first model

Observed			Predicted		
			Thermal complaint		Percentage corrected
			Too warm	Too cold	
Step 0	Thermal complaint	Too warm	28	0	100.0
		Too cold	25	0	0.0
	Overall percentage				52.8

Tab. 6: Omnibus tests of model coefficients

		Chi-squared test	df	*p* value
Step 1	Step	54.108	3	0.000
	Block	54.108	3	0.000
	Model	54.108	3	0.000

5 Conclusion

To predict thermal dissatisfaction, the standards use the PMV/PPD model. However, most of the studies proved that the PMV models cannot accurately predict thermal dissatisfaction, and thus thermal complaints arise in the buildings. Therefore, predicting thermal complaints in indoor environments is a challenging task for facility managers and building owners.

In this study, the compatibility of indoor environmental conditions against ISO 7730 Thermal Comfort Standard in a commercial building was investigated and the accuracy of PMV method for predicting occupant thermal satisfaction was checked via assessing thermal complaints of occupants. Besides, a multivariate logistic regression model was developed for predicting thermal complaints with respect to "too warm" and "too cold." The results showed that all the operative temperature measurements in both the heating and cooling seasons were within the thresholds as suggested by the standards. Of note, 93 and 100% of measurements regarding RH ratios

Tab. 7: Model summary

Step	−2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
1	19.196	0.640	0.854

Tab. 8: Results of the second model

			Predicted complaint		Percentage corrected
			Too warm	Too cold	
Step 1	Thermal complaint	Too warm	26	2	92.9
		Too cold	3	22	88.0
	Overall percentage				90.6

Tab. 9: Variables in the equation

		B	S.E.	Wald	df	*p* value	Exp (*B*)	95% CI for Exp (*B*)	
								Lower	Upper
Step 1	Relative humidity	−0.299	0.190	2.469	1	0.116	0.741	0.511	1.077
	Operative temperature	−9.545	3.550	7.228	1	0.007	0.000	0.000	0.075
	Season	−11.429	4.515	6.407	1	0.011	0.000	0.000	0.076
	Constant	245.670	91.760	7.168	1	0.007	4.933E + 106		

were within the recommended ranges. The PMV values of 96% corresponding to the calculations based on the measured indoor conditions showed that the occupants felt neutral; however, the thermal dissatisfaction ratio of occupants under these indoor conditions was 100%. Furthermore, the developed model showed that the operative temperature and season have a significant effect whereas RH has no significant effect on thermal complaints. The developed model predicts 90.6% of occupants' thermal complaints correctly. The limitation of this study is that the findings are based on one building. Future studies can incorporate more buildings to validate the results of this study. Besides, the test campaigns can be carried out longer periods in other similar type of buildings. Another approach to further expand thermal complaint research could be investigating individualized thermal preferences of occupants.

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References

American Society of Heating Refrigerating and Air-Conditioning Engineers. (2010). ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy is an American National Standard ASHRAE, Atlanta, GA, USA.

Appah-Dankyi, J., & Koranteng, C. (2012). A thermal comfort evaluation of a junior high school building in Accra, Ghana. *Journal of Construction Project Management and Innovation, 2*(2), pp. 403-423.

Azizpour, F., Moghimi, S., Salleh, E., Mat, S., Lim, C.H., & Sopian, K. (2013). Thermal comfort assessment of large-scale hospitals in tropical climates: A case study of University Kebangsaan Malaysia Medical Centre (UKMMC). *Energy and Buildings, 64*, pp. 317-322.

Calis, G., Alt, B., & Kuru, M. (2015). Thermal comfort and occupant satisfaction of a mosque in a hot and humid climate. In: *Congress on Computing in Civil Engineering, Proceedings*, 2015-January, pp. 139-147. doi: 10.1061/9780784479247.018.

Calis, G., Atalay, S. D., Kuru, M., & Mutlu, N. (2018). Forecasting occupancy for demand driven HVAC operations using time series analysis. *Journal of Asian Architecture and Building Engineering, 16*(3), 655-660.

Calis, G., & Kuru, M. (2017). Assessing user thermal sensation in the Aegean region against standards. *Sustainable Cities and Society, 29*, pp. 77-85.

Ceria, K., & De Dear, R. (2001). Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate. *Journal of Thermal Biology, 26*, pp. 409-414.

Chen, M. H., & Dey, D. K. (2003). Variable selection for multivariate logistic regression models. *Journal of Statistical Planning and Inference, 111*(1-2), pp. 37-55.

Cheung, T., Schiavon, S., Parkinson, T., Li, P., & Brager, G. (2019). Analysis of the accuracy on PMV–PPD model using the ASHRAE global thermal comfort database II. *Building and Environment, 153*, pp. 205–217.

Choi, J. H., Aziz, A., & Loftness, V. (2010). Investigation on the impacts of different genders and ages on satisfaction with thermal environments in office buildings. *Building and Environment, 45*(6), pp. 1529-1535.

Corgnati, S. P., Filippi, M., & Viazzo, S. (2007). Perception of the thermal environment in high school and university classrooms: Subjective preferences and thermal comfort. *Building and Environment, 47*(2), 951-959.

Daum, D., Haldi, F., & Morel, N. (2011). A personalized measure of thermal comfort for building controls. *Building and Environment, 46*(1), pp. 3-11.

Deuble, M. P., & de Dear, R. J. (2014). Is it hot in here or is it just me? Validating the post-occupancy evaluation. *Intelligent Buildings International, 6*(2), pp. 112-134.

Dias, L., Raimondo, D., Paolo, S., Manuel, C., da Silva, G. (2014). Assessment of indoor air quality and thermal comfort in Portuguese secondary classrooms: Methodology and results. *Building and Environment, 81*, pp. 69-80.

Dudzińska, A., & Kotowicz, A. (2015). Features of materials versus thermal comfort in a passive building. *Procedia Engineering, 108*, pp. 108-115.

Fagerland, M. W., & Hosmer, D. W. (2012). A generalized Hosmer–Lemeshow goodness-of-fit test for multinomial logistic regression models. *Stata Journal, 12*(3), pp. 447-453.

Fanger, P. O. (1982). *Thermal Comfort*. Robert E. Kriege Publishing Company, Malabar, FL, USA.

Gilani, S. I. U. H., Khan, M. H., & Pao, W. (2015). Thermal comfort analysis of PMV model prediction in air conditioned and naturally ventilated buildings. *Energy Procedia, 75*, pp. 1373-1379.

Gunay, H. B., Shen, W., Newsham, G., & Ashouri, A. (2018). Modelling and analysis of unsolicited temperature setpoint change requests in office buildings. *Building and Environment, 133*(February), pp. 203-212.

Hosmer, D. W., & Lemeshow, S. (2005). Applied logistic regression. *Applied Logistic Regression*. doi: 10.1002/0471722146.

Hoyt, T., Schiavon, S., Piccioli, A., Moon, D., & Steinfeld, K. (2017). *CBE Thermal Comfort Tool*. Center for the Built Environment, University of California, Berkeley.

International Organization for Standardization. (2012). ISO 16817 Building environment design—Indoor environment—Design process for the visual environment.

International Standardisation Organisation. (2005). ISO 7730, ergonomics of the thermal environment-assessment of the influence of the thermal environment using subjective judgment scales.

Ji, Y., & Wang, Z. (2019). Thermal adaptations and logistic regression analysis of thermal comfort in severe cold area based on two case studies. *Energy and Buildings, 205*, p. 109560.

Júlio, J. P., Paiva, A., & Dominguez, C. (2013). Overall aspects for the evaluation of Portuguese dwellings' quality and sustainability. *Organization, Technology & Management in Construction: An International Journal, 5*(1), pp. 702-711.

Katafygiotou, M. C., & Serghides, D. K. (2014). Thermal comfort of a typical secondary school building in Cyprus. *Sustainable Cities and Society, 13*, pp. 303-312.

Kocaman, E., Kuru, M., & Calis, G. (2019). Do thermal comfort standards ensure occupant satisfaction? Learning from occupants' Thermal complaints, In: *Creative Construction Conference 2019*, CCC 2019, 29 June – 2 July 2019, Budapest, Hungary, pp. 7–11.

Nagano, K., & Mochida, T. (2004). Experiments on thermal environmental design of ceiling radiant cooling for supine human subjects. *Building and Environment, 39*(3), pp. 267-275.

Natarajan, S., Rodriguez, J., & Vellei, M. (2015). A field study of indoor thermal comfort in the subtropical highland climate of Bogota, Colombia. *Journal of Building Engineering, 4*, pp. 237-246.

Panas, A., & Pantouvakis, J.-P. (2010). An empirical framework for the performance-based evaluation of health and safety's contribution to sustainable construction. *Organization, Technology & Management in Construction: An International Journal, 2*(2), pp. 173-181.

Shooshtarian, S., & Rajagopalan, P. (2017). Study of thermal satisfaction in an Australian education precinct. *Building and Environment, 123*, pp. 119-132.

Soutullo, S., Enríquez, R., Jiménez, M. J., & Heras, M. R. (2014). Thermal comfort evaluation in a mechanically ventilated office building located in a continental climate. *Energy and Buildings, 81*, pp. 424-429.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using Multivariate Statistics*. Pearson/Allyn & Bacon, Boston.

Trebilcock, M., Soto, J., & Figueroa, R. (2014). Thermal comfort in primary schools : A field study in Chile. In: *Proceedings of 8th Windsor Conference: Counting the Cost of Comfort in A Changing World Cumberland Lodge*, Windsor, UK, 10-13 April 2014, pp. 421-431.

Trebilcock, M., Soto-Muñoz, J., Yañez, M., & Figueroa-San Martin, R. (2017). The right to comfort: A field study on adaptive thermal comfort in free-running primary schools in Chile. *Building and Environment, 114*, pp. 455-469.