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Do Gender and Age Group Affect Thermal Sensation? A Field Study in an Office Building

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Abstract

Employees need a comfortable indoor environment since they are working for long hours throughout the day. Thermal comfort forms an important part of this indoor environment, which has an imperative role in the employees' productivity, well-being and satisfaction. Therefore, thermal comfort standards are used to maintain indoor environmental conditions that are acceptable to occupants. However, these standards do not consider the effects of occupants' gender and age group, which might affect the perception of occupants, and, thus, might not predict the actual thermal sensation. This study aims at assessing the effects of gender and age groups on thermal sensation by comparing actual thermal sensations to the predicted thermal sensations which constitutes the basis of the standards. Within this context, a field study was conducted in an office building in France during cooling season. An online questionnaire was distributed via email to obtain actual thermal sensations of participants. Moreover, indoor environmental conditions including indoor air temperature and relative humidity were recorded via sensors to obtain predicted thermal sensations. A total of 100 actual and thermal sensation values were obtained and statistical analyses were conducted for comparing the differences between means of actual and predicted thermal sensation values with respect to gender and age groups. The results show that the differences between means of actual and predicted thermal sensation values are statistically significant for male and (35-44) age group.

Keywords: *age, gender, office building, thermal comfort, thermal sensation.*

Introduction

Thermal comfort forms an important part of indoor environment, which has an imperative role in the employees' productivity, well-being and satisfaction. Subsequently, thermal comfort standards are used to maintain indoor environmental conditions that are acceptable to occupants. However, the recommended values in the standards might not necessarily predict the actual thermal sensation of occupants, and, thus, result in unsatisfactory thermal

conditions in buildings. In particular, studies that are carried out in office buildings focus on investigating the difference between actual thermal sensation of occupants and thermal sensations predicted by the standards (Antoniadou and Papadopoulos 2017, Indraganti and Boussaa 2017, Rupp and Ghisi 2017, Thapa et al. 2018). In these studies, Predicted Mean Vote (PMV) was calculated to obtain predicted thermal sensation whereas surveys were conducted to obtain actual thermal sensation of occupants. Rupp and Ghisi (2017) indicated that the PMV model overestimated the cold sensation of occupants in office buildings, which are located in a temperate and humid climate. Moreover, Indraganti and Boussaa (2017) indicated that the PMV model overestimated the occupants' sensation and the occupants felt cooler in offices in Qatar during summer. On the other hand, Thapa et al. (2018) indicated that the PMV model underestimated thermal comfort in office buildings in Darjeeling, which is located in a cold climatic region of India.

Moreover, occupants' gender and age group are stated to affect the perception of occupants; however, thermal comfort standards do not consider the effects of these parameters. Several researchers indicated that female occupants feel cooler than males (Liu et al. 2011, Schellen et al. 2013). In particular, females are stated to prefer higher room temperatures more often than males and the dissatisfaction ratios are higher compared to males (Indraganti et al. 2015, Ricciardi et al. 2016). Rupp et al. (2018) showed that males are more likely to express thermal discomfort compared to females. In comparison, females were more likely to declare cold discomfort. A recent study showed that thermal sensation of elderly is lower than younger adults (Schellen et al. 2010). On the other hand, Indragandti et al. (2015) indicated that young occupants preferred higher indoor temperatures than older occupants. Moreover, Calis and Kuru (2017) concluded that there is a significant statistical difference between the predicted and actual thermal sensation of participants under 25 years old, 26-45 and over 65 years old people whereas the results of Del Ferraro et al. (2015)'s study showed that the best correlation between the PMV model and the actual thermal sensation values is found in a sample of male medical staff under 65 years of age. It can be concluded that thermal comfort and the effects of gender and age group can vary according to building types and climatic conditions. Therefore, thermal comfort and the effects of gender and age group need to be investigated in different types of buildings to reach a consensus.

This study aims at investigating the effect of gender and age group on the difference between predicted and actual thermal sensation values in an office building in France between July 07, 2017 and August 31, 2017. The following sections describe the test bed and data collection methodology. Then findings and conclusions are presented.

Test Bed Description and Data Collection

The study was conducted in 'Challenger' site, an office building with 68000 m^2 and the headquarters of Bouygues Construction located in Guyancourt, to the West of Paris, France (Figure 1). Regarding the climatic conditions, summers are warm and mild with no dry season. It receives approximately equal rainfall every month during the year and the average temperature of all months is lower than 22°C. The hottest month is July, when the maximum temperature is about 24°C whereas the coldest month is January, when the minimum temperature is 1°C in average.

Figure 1: Bird view of Challenger building.

Data collection was carried out between July 07, 2017 and August 31, 2017 in the demonstration zone which is presented in Figure 2. The floor has open space shared offices occupied by employees. The type of occupation in the building is non-permanent and is generally occupied between 8:00 am and 7:00 pm during the weekdays. A set of 17 BuildAx sensors (Figure 3) were installed on the second floor of the South Triangle to measure the distribution of the indoor air temperature, relative humidity and luminosity of the area. The sensors are set to send data at a 10 mins frequency and they communicate wirelessly with a router installed at the centre of the zone that 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.

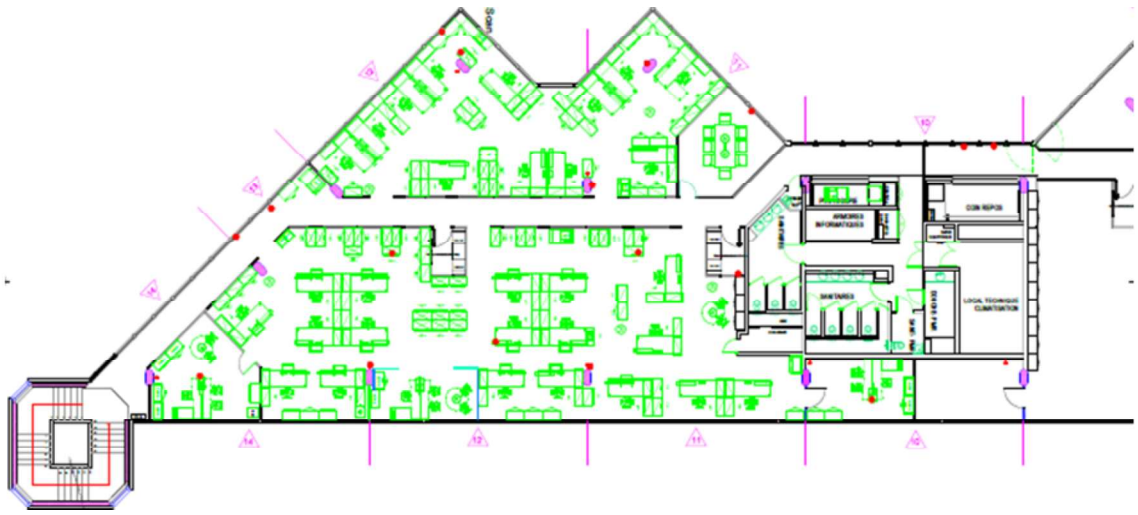

Figure 2: Installation plan of BuildAX sensors (the locations of the sensors are marked with a red dot).

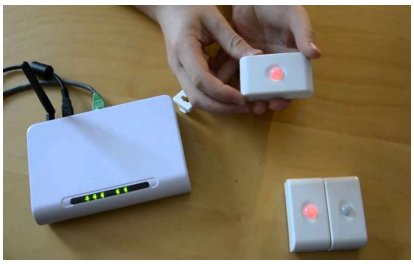

Figure 3: BuildAx sensors and router.

Mean radiant temperatures were calculated by using the formula proposed by Nagano (Nagano and Mochida 2004). $T_r = 0.99 \times T_a\text{-}0.01$, $R^2 = 0.99$ 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. It should be noted that the maximum allowable air velocity is stated as 0.19 m/s in the cooling season. Then, PMV indices were calculated by using values of indoor air temperature, mean radiant temperature, relative humidity and air velocity. It should be noted that PMV is used to obtain predicted thermal sensation of participants by using Fanger's 7 point scale (Table 1).

Table 1. Fanger 7-point scale.

-3	**-2**	**-1**	**0**	**1**	**2**	**3**
cold	cool	Slightly cool	neutral	Slightly warm	warm	hot

In addition, metabolic rates and clothing insulation values of participants are 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 ISO 7730 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 for females and males. Moreover, an online questionnaire was designed and distributed via email to building occupants in order to obtain actual thermal sensation of the participants as well as to extract information about participant profiles with respect to gender and age group. The questionnaire was distributed 2 times once every two weeks. A total of 54 occupants participated and a total of 100 responses were included in the study. The analyses were conducted with respect to gender as well as 4 age groups (25-34; 35-44, 45-54 and 55-64). The majority of responses (36%) were in the age range of 45-54 and the percentage of the female subjects was 67% (Figure 4).

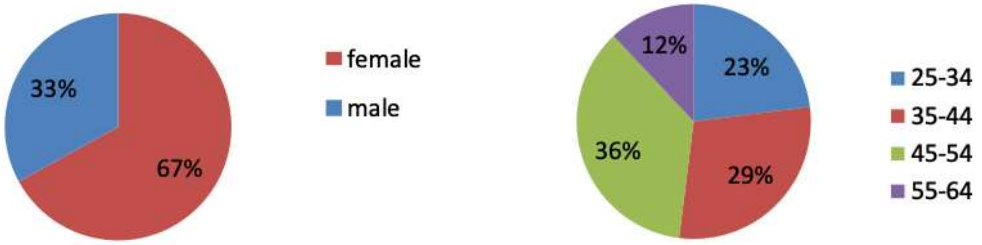

Figure 4: Distribution of participants with respect to (a) gender (b) age group.

Methodology

Statistical analyses were carried out to understand whether or not the difference between the actual thermal sensation of participants and predicted thermal sensations are statistically significant for male, female and different age groups. The analyses were conducted by using SPSS (version 22.0 for Windows) software.

In order to determine the applicable significance test for two independent variables (gender and age group), normality and homogeneity tests are conducted at the confidence level of 0.05. It should be noted that if the sample size is between 7 and less than or equal to 2000, Shapiro-Wilk test can be used to check the normality whereas the Levene's test can be used to check the homogeneity. In addition, if there are two independent variables and the population from each group is normally distributed and the homogeneity of variances can be assumed equal, then t-test is carried out to understand the statistical significance. On the other hand, if there are two independent variables and the population from each group is not normally distributed and the homogeneity of variances cannot be assumed equal, non-parametric Mann-Whitney U test is carried out. If the variable is not normally distributed, then non-parametric tests have to be carried out to investigate the statistical significance.

Findings

Since all data sample sizes were larger than 7, Shapiro-Wilk normality tests were conducted. The results of normality tests show that all predicted thermal sensation values for males and females are not normally distributed since their p-values are smaller than the significance level (0.05) (Table 2). On the other hand, actual thermal sensation values are not normally distributed except for the (25-34) age group.

Table 2. Shapiro-Wilk normality tests results.

		Statistic	df	*p*-value
GENDER				
Male	Actual Thermal Sensation	0.921	33	*0.020*
	Predicted Thermal Sensation	0.505	33	*0.000*
Female	Actual Thermal Sensation	0.917	67	*0.000*
	Predicted Thermal Sensation	0.500	67	*0.000*
AGE GROUP				
25-34	Actual Thermal Sensation	0.916	23	0.054
	Predicted Thermal Sensation	0.463	23	*0.000*
35-44	Actual Thermal Sensation	0.913	29	*0.020*
	Predicted Thermal Sensation	0.533	29	*0.000*
45-54	Actual Thermal Sensation	0.920	36	*0.013*
	Predicted Thermal Sensation	0.540	36	*0.000*
55-64	Actual Thermal Sensation	0.854	12	*0.041*
	Predicted Thermal Sensation	0.327	12	*0.000*

The non-parametric Mann-Whitney U test was used to test whether or not the mean values of actual and predicted thermal sensation are equal. The mean values of actual and predicted

thermal sensation per gender and age group are shown in Figure 5 and 6, respectively. As can be seen from the figures, all mean values of actual thermal sensation are higher than those of the predicted thermal sensation. The difference between the mean values of actual and predicted thermal sensation for males (0.69) is higher than females' (0.34). Moreover, the biggest difference (1.03) is observed at (35-44) age group.

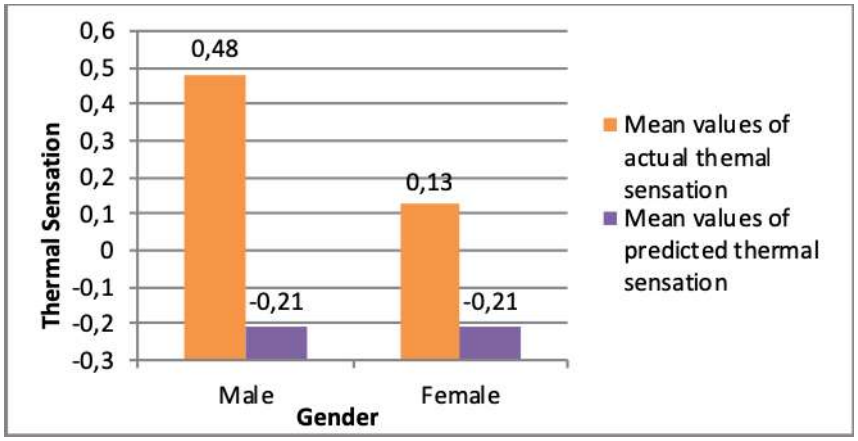

Figure 5: Mean values of actual and predicted thermal sensation per gender.

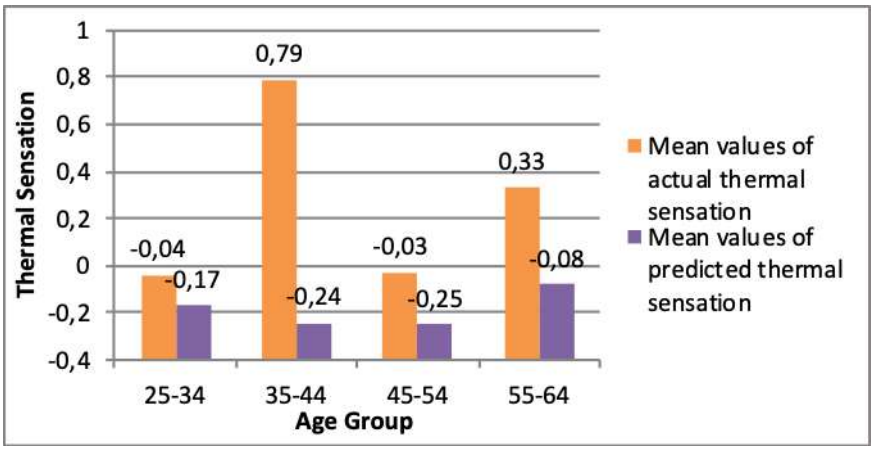

Figure 6: Mean values of actual and predicted thermal sensation per age group.

The results of the Mann-Whitney U tests are presented in Table 3 and Table 4. The results indicate that the difference between the mean values of actual and predicted thermal sensation is statistically significant for male and (35-44) age group since their p-values are lower than the 0.05 significance level. Accordingly, it can be said that the standards, which rely on predicted thermal sensation, might not necessarily predict the thermal sensations of males and the persons who are in (35-44) age group in the cooling season whereas they can predict correctly the thermal sensations of females and other age groups in the cooling season.

Table 3. The results of Mann-Whitney U tests for gender.

	Mann-Whitney U	***p*-value**
GENDER		
Male	356.50	***0.007***
Female	2001.00	0.231

Table 4. The results of Mann-Whitney U tests for age group.

	Mann-Whitney U	***p*-value**
AGE GROUP		
25-34	263.50	0.980
35-44	233.50	***0.002***
45-54	567.00	0.322
55-64	68.00	0.773

Conclusion

In this study, the effects of gender and age groups on thermal sensation are assessed by comparing actual thermal sensations to the predicted thermal sensations. In-situ measurements as well as an online survey campaign were conducted in an office building in France. Data were analysed to understand whether or not the difference between actual and predicted thermal sensation is statistically significant. The main findings are as follows:

- All of the mean values of actual thermal sensation are higher than those of predicted thermal sensation both for gender and age groups.
- The difference between actual and predicted thermal sensation values of males is higher than those of females'.
- The biggest difference is observed at the age group of 35-44.
- The differences between the mean values of actual and predicted thermal sensation are statistically significant for male and the age group of 35-44.

Future studies should incorporate (18-24) age group and more (55-64) age group subjects to investigate the effects of age group on the difference between actual and predicted thermal sensations. Moreover, additional studies can be conducted during heating season and over a longer period of time to allow monitoring a wider range of environmental conditions.

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References

Antoniadou, P., & Papadopoulos, A.M. (2017). Occupants' thermal comfort: State of the art and the prospects of personalized assessment in office buildings. *Energy and Buildings*, *153*, 136-149.

Calis, G. & Kuru, M. (2017). Statistical significance of gender and age on thermal comfort: a case study in Turkey. In *Proceedings of the Institution of Civil Engineers - Engineering Sustainabilit*y (pp. 1-12).

Del Ferraro, S., Iavicoli, S., Russo, S., & Molinaro, V. (2015). A field study on thermal comfort in an Italian hospital considering differences in gender and age. *Applied Ergonomics*, *50*, 177-184.

Indraganti, M., & Boussaa, D. (2017). Comfort temperature and occupant adaptive behavior in offices in Qatar during summer. *Energy and Buildings*, *150*, 23-36.

Indraganti, M., Ooka, R. & Rijal, H. (2015). Thermal comfort in offices in India: Behavioral adaptation and the effect of age and gender. *Energy and Buildings*, *103*, 284-295.

ISO 7730:2005 (2005). Ergonomics of the Thermal Environment-Assessment of the Influence of the Thermal Environment Using Subjective Judgment Scales. *ISO, Switzerland.*

Liu, W., Lian, Z., Deng, Q. & Liu, Y. (2011). Evaluation of calculation methods of mean skin temperature for use in thermal comfort study. *Building and Environment*, *46*(2), 478-488.

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

Ricciardi, P., Ziletti, A., & Buratti, C. (2016). Evaluation of thermal comfort in an historical Italian opera theatre by the calculation of the neutral comfort temperature. *Building and Environment*, *102*, 116-127.

Rupp, R.F., & Ghisi, E. (2017). Predicting thermal comfort in office buildings in a Brazilian temperate and humid climate. *Energy and Buildings, 144*, 152-166.

Rupp, R.F., Kim, J., de Dear, R., & Ghisi, E. (2018). Associations of occupant demographics, thermal history and obesity variables with their thermal comfort in air-conditioned and mixed-mode ventilation office buildings. *Building and Environment*, *135*, 1-9.

Schellen, L., Loomans, M., de Wit, M. & van Marken Lichtenbelt, W. (2013). The influence of different cooling techniques and gender on thermal perception. *Building Research & Information*, 41(3), 330-341.

Schellen, L., Van Marken Lichtenbelt, W., Loomans, M., Toftum, J., & De Wit, M. (2010). Differences between young adults and elderly in thermal comfort, productivity, and thermal physiology in response to a moderate temperature drift and a steady-state condition. *Indoor Air*, *20*(4), 273-283.

Thapa, S., Bansal, Kr. Bansal, A., & Kr. Panda, G. (2018). Thermal comfort in naturally ventilated office buildings in cold and cloudy climate of Darjeeling, India – An adaptive approach. *Energy and Buildings*, *160*, 44-60.