ASSESSMENT OF THERMAL COMFORT PREFERENCES IN MEDITERRANEAN CLIMATE
A University Office Building Case

by

Cihan TURHAN [a] ***and Gulden GOKCEN AKKURT*** [b*]

[a] Department of Mechanical Engineering, Izmir Institute of Technology, Izmir, Turkey
[b] Department of Energy Systems Engineering, Izmir Institute of Technology, Izmir, Turkey

Original scientific paper
https://doi.org/10.2298/TSCI171231267T

This study aims at evaluating the perceived thermal sensation of occupants with respect to thermal comfort standards, ASHRAE 55 and ISO 7730, for office buildings located in Mediterranean climate. A small office building in Izmir Institute of Technology Campus Area, Izmir, Turkey, was chosen as a case building and equipped with measurement devices to assess thermal comfort of occupants with respect to predicted mean vote and actual mean vote. Both objective and subjective measurements were conducted. The former included indoor and outdoor air temperature, mean radiant temperature, relative humidity and air velocity that were used for evaluating the thermal comfort of occupants. Oxygen concentration which can play an additional role in thermal comfort/discomfort, health and productivity of the office occupants, was also measured. Furthermore, occupants were subjected to a survey via a mobile application to obtain subjective measurements to calculate actual mean vote values. Based on objective and subjective measurements, the relationships among the parameters were derived by using simple regression analysis technique while a new combined mean vote correlation was also derived but this time by using multiple linear regression model. Neutral and comfort temperatures were obtained using indoor air temperature and actual mean vote values which were calculated from subjective measurements. The results showed that neutral temperature in the university office building was 20.9 °C whilst the comfort temperature range was between 19.4 and 22.4 °C for the heating season. By applying new comfort temperatures, energy consumption of the case building located in Mediterranean climate, can be reduced.

Key words: *thermal comfort, human body exergy consumption rate, office buildings*

Introduction

Thermal comfort is defined as the condition of mind in which satisfaction is expressed with thermal environment and depends on whole body sensation which is function of six parameters: indoor air temperature, T_i, relative humidity, RH_i, air velocity, v_a, clothing insulation, *clo*, metabolic rate, *met*, and mean radiant temperature, MRT_i, [1]. A considerable number of studies on thermal comfort have been published over the past 50 years. Fanger [2] developed two thermal comfort indices, predicted mean vote (*PMV*) and predicted percentage

* Corresponding author; e-mail: guldengokcen@iyte.edu.tr

of dissatisfied (*PPD*), which were later standardized in ISO 7730 [3] and ASHRAE 55 [1]. The *PMV* refers to a seven-point thermal sensation scale from −3 to +3 (where −3 is cold, 0 is neutral, +3 is hot). When *PMV* is in the range of ±0.5, 90% of the occupants feel thermally satisfied while 10% is dissatisfied (*PPD*). In this study which was based on the First law of thermodynamics, Fanger [2] conducted tests with a number of subjects at different ages and gender in an air-conditioned environmental test chamber which was monitored for indoor climate parameters like temperature, relative humidity, *etc*. On the other hand, Shukuya [4] suggested that human body exergy balance calculations (based on the Second law) represent thermal comfort more accurately than the First law. The method involves the use of outdoor temperature, T_o, and relative humidity, RH_o, as well as indoor environmental data, to calculate the human body exergy consumption, *HBexC*, rate, and *PMV*. Isawa *et al.* [5] showed the correlations between thermal comfort and *HBexC*. Another finding of their study suggested that the lowest exergy consumption occurred at thermal neutrality. Similarly, Prek [6] found that minimum *HBexC* rates were near neutral thermal sensation votes.

Although *PMV* method is reliable in air-conditioned buildings in cold climates, de Dear *et al*. [7] demonstrated that the acceptance range of *PMV* of the occupants in naturally ventilated buildings in warmer climates is much wider than the standard *PMV* model based on objective (T_i, T_o, RH_i, RH_o, MRT_i and v_a) and subjective measurements. Moreover, Heideri and Sharples [8] showed that the occupants in Iran achieved thermal comfort throughout the year, without the need for air-conditioning and the *PMV* values were much wider than the recommended values by international standards.

Actual mean vote (*AMV*) is the mean value of occupant’s actual thermal sensation votes by using ASHRAE seven-point thermal sensation scale [1]. Subjective measurements are surveys that aim to collect data from occupants about their thermal preferences and *clo* value which will then be used for calculation of *AMV* values [9]. In thermal assessment studies, a number of thermal comfort sensation scales have been proposed for assessment of occupant’s perceptions including ASHRAE thermal sensation scale [1], Bedford comfort scale [10], McIntyre 3-point preference scale [11], and acceptability scale [12]. Neutral temperature is the temperature where *AMV* value is zero while comfort temperatures are temperatures where *AMV* values are between ±0.5. Occupants prefer to be in neutral temperature or in comfort temperature zone [13]. Corgnati *et al.* [9] indicated that the students of an Italian university preferred neutral temperatures while in another study conducted in China, Yao *et al*. [14] showed that the perception of occupants was much lower than the *PMV* values and occupants preferred to be in neutral temperature.

Indoor air quality (*IAQ*) along with the perception of thermal comfort has a substantial impact on the health and productivity of occupants. The type and the amount of contaminants such as CO, CO_2, NO_2, radon (Rn), and SO_2 affect *IAQ*. Elevated CO_2 concentration stimulates human respiratory system and increases met values. The O_2 and CO_2 are both present in the atmosphere and when CO_2 concentration increases, O_2 concentration decreases. Gauthier *et al*. [15] claimed that the gap between *PMV* and *AMV* could be because of the *IAQ* parameters. Based on their measured CO_2 concentrations in an office building and calculated *AMV* values, they concluded that there was no significant relationship between CO_2 and *AMV* due possibly to the limited number of participation in the experiment. Hence, they recommended further experiments to be done with increased participation.

Regression analysis is a common data analysis approach in thermal comfort studies. Nicol and Humphreys [16] used regression analysis to determine the comfort temperatures in the UK. Singh *et al.* [17] derived a regression formula for indoor climate and thermal comfort in residential buildings of Liege, Belgium. Heideri and Sharples [8] correlated *AMV* and *PMV* values in Iran. Van der Linden *et al.* [18] used regression analysis for evaluation of thermal indoor climate with T_o values. The aim of the regression analysis is to investigate relationships among parameters used in thermal comfort models. Hence, the model minimizes sum of squares of the differences between observed and estimated values of a parameter by the least squares method [19]. The most frequently used regression analysis techniques are simple (SLR) and multiple linear regression (MLR) methods. McCartney and Nichol [20] applied SLR techniques on thermal comfort with one independent parameter, T_o. Fanger [2] used T_i values to find an SLR equation for thermal comfort. Similarly, Singh *et al.* [17] correlated *PMV* values with T_i. In spite of the fact that T_i is known to be the strongest factor affecting thermal comfort, inclusion of factors like RH_i, MRT_i, v_a, and even *IAQ* in the regression model should be expected to improve the fit.

The main purpose of this study was to assess thermal comfort preferences of occupants in a university office building, in Izmir, Turkey, which is located in Mediterranean climate. Another aim was to improve the correlation between *PMV* and *AMV* by introducing O_2 concentration in the regression model for *PMV*.

The case building

The case building is located at Izmir Institute of Technology Campus, Izmir, Turkey (at 38.3 °N and 26.6 °E), fig. 1, which is in Mediterranean climate (a. k. a Csa type climate zone under the Koppen-Geiger climate classification [21]). The minimum and maximum average annual temperatures are 5.7 °C and 33.1 °C, respectively with a mean temperature of 17.8 °C [22].

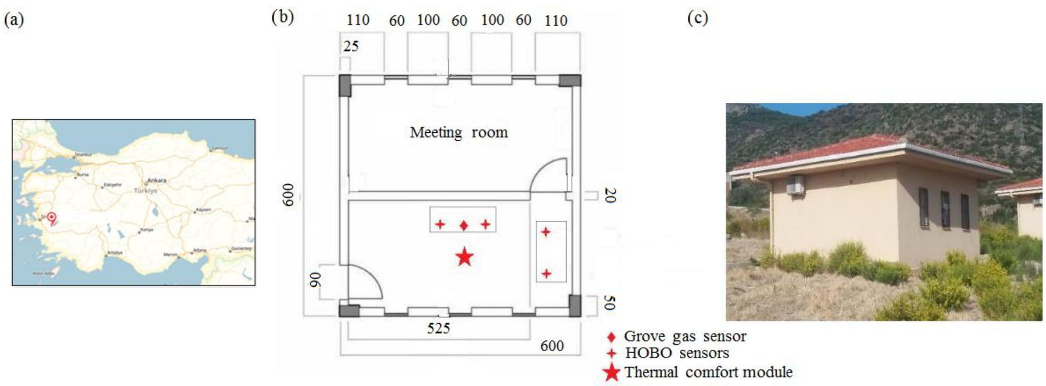

Figure 1. The case building; (a) location, (b) plan, and (c) outer view

Dimensions of the square shaped case building are 6 m (width) × 6 m (depth) × × 2.8 m (height). There are four external walls with six windows and two equally sized rooms in the building. The indoor environment is controlled by an air-conditioner to keep T_i at 22 °C from 09:00 to 12:30 and 13:30 to 17:00 during weekdays in heating/cooling seasons. The air-conditioner is operated at high fan speed in the morning and at low fan speed in the afternoon. In order to prevent air velocity disturbances on the occupants, the fan is fixed to blow straight up. External walls of the building consist of cement plastering, pumice concrete and cement screed. The innermost layers of the floor are cast concrete, floor screed and limestone. Layers of the roof consist of plasterboard, air-gap, glass wool and asphalt and all the window frames are PVC with double glazing (13 mm air-gap). Similarly, the external door has PVC frame. The airtightness of the building is assumed as 0.5 air changes per hour which is a moderate rate for naturally ventilated office buildings [23].

Methods

A measurement campaign was conducted from February 6th, 2017 to April 7th, 2017, in the case building during office hours. Objective measurements (T_o, RH_i, RH_o, T_i, v_a, O_2) were recorded with 5-min intervals while subjective measurements (surveys) were conducted twice a day. Objective and subjective measurements were used to calculate *PMV*, *HBexC*, and *AMV*. Then, *AMV* values were compared with *PMV* values. Neutral and comfort temperatures were obtained using T_i and *AMV* values which were calculated from subjective measurements. A new combined mean vote (*CMV*) correlation was derived by regression analysis techniques based on objective and subjective measurements. The *CMV* was proposed in this study as a means of improving the correlation between *PMV* and *AMV*. Finally, sensitivity analysis was applied to the regression model of *CMV* to evaluate the influence of parameters on the dependent parameter.

Measurements

The data were collected by four mini dataloggers which record T_i, T_o, RH_i, and RH_o data [24] and a thermal comfort module (TCM) [25] which contains T_i, v_a, RH_i, and operative temperature (OT_i) sensors. The case building was occupied by two male occupants during office hours. All the windows and doors were kept close during the measurements. All sensors were deployed close to the occupants positioned at 1.1 m height from the ground level. The *OT* sensor was installed in inclining position with 30° to the vertical direction to simulate a person in sitting position, fig. 2(a). Concentration of O_2 was measured by a Grove-Gas Sensor, figs. 1(b) and 2(a) [26]. The normal O_2 concentration in the air is 20.9% whilst the acceptable upper and lower bounds of O_2 concentration in a room is 23.5% and 19.5%, respectively [27].

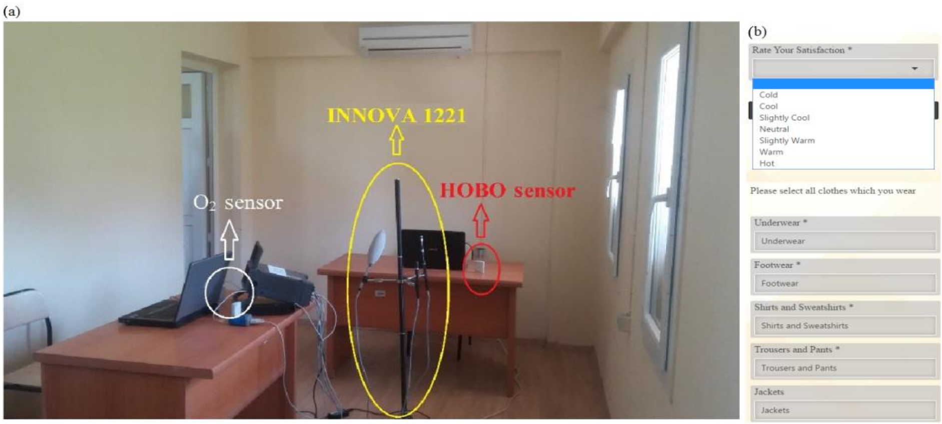

Figure 2. (a) Location of the sensors and (b) screenshots of mobile application interface

Subjective measurements were conducted via a mobile application which was designed as an occupant sensing application for smartphones according to ISO 10551 [28]. The mobile application adopts preferences of occupants regarding thermal comfort by inherently incorporating the sensor data and the feedbacks of the occupant with ambient conditions. The interface of the mobile application was originally designed using ASHRAE sensation scale which gives the *AMV* values of the occupants. Moreover, the application enquires the name and garments of the occupant and easily calculates the *clo* value of each occupant according to ASHRAE 55 [1]. The mobile application was developed exclusively for Android-based smartphones and helped store the data in a web server, fig. 2(b).

Data analysis

The OT_i is a simplified measure of thermal comfort derived from T_i, MRT_i, and v_a. The T_i is commonly accepted as the most effective factor on thermal comfort but MRT_i has impact as high as T_i [17]. Since OT_i was measured by TCM, MRT_i could be extracted from eq. (1) as given in ASHRAE 55 [1]:

$$OT_i = A \cdot T_i + A \cdot MRT_i \tag{1}$$

where A is the weighting factor for various v_a.

If $v_a < 0.2$ then $A = 0.5$, if $0.2 < v_a < 0.6$ then $A = 0.6$ and if $0.6 < v_a$ then $A = 0.7$ [1].

The TCM calculates PMV_{TCM} values based on the measured parameters, *clo* and *met* values (as inputs) [25]. Daily average *clo* and *AMV* values were obtained from the surveys whilst met values were taken from ASHRAE 55 [1] for regular work when sitting in an office. RH_i, T_i, *clo* and *met* values were used to calculate a secondary PMV_{CBE} value using Centre of Building Environment (CBE) thermal comfort tool [29]. The CBE thermal comfort tool uses ASHRAE 55 calculation steps and allows users to calculate *PMV* values. The third PMV_E value was calculated with a human body exergy balance contour calculation tool developed by Iwamatsu and Asada [30]. The tool uses T_o, RH_o, T_i, MRT_i, RH_i, v_a, *clo* and *met* values as well as room dimensions. The outputs of the tool are *HBexC* rate and PMV_E. Further information about the calculation method can be found in [30]. Lastly, three *PMV* values were compared with *AMV* values. To be able to determine the effect of O_2 concentration on *AMV* values, objective parameters were set constant for one day (April 3rd, 2017) and O_2 concentration and *AMV* change over time was observed. The relationship between thermal comfort and O_2 concentration was investigated by deriving a new correlation called *CMV*, based on objective and subjective measurements using SLR and MLR analysis techniques in MATLAB [31]. The SLR is a statistical method that allows us to obtain the relationships between two quantitative parameters [32]. An SLR equation is given:

$$y = \alpha x + \beta \tag{2}$$

The MLR is used to explain the relationship between one dependent variable and two or more independent parameters [32]. A general expression for a regression equation involving multiple parameters can be expressed:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_i x_i + \in \tag{3}$$

where y is dependent (output) variable, x_i are independent (input) parameters, b_i are linear regression-model coefficients, and $\in$ is error term. The commonly used statistical criterion, coefficient of determination, R^2, can be used to evaluate the performance of the regression models, eq. (4), [32]:

$$R^2 = \frac{\sum_j |t_j - o_j|^2}{\sum_j (o_j)^2} \tag{4}$$

Sensitivity analysis is applied to the regression model to evaluate the influence of parameters on the dependent variable. Regarding the impact size of the main variables in regression model, response of the dependent variable to one standard deviation (*SD*) increase in the explanatory variables is investigated. Further information about the sensitivity analysis can be found in [33]. The neutral and comfort temperatures were defined as T_i corresponding to 0 and ±0.5 *AMV* values, respectively. Both temperatures could be calculated according to the Griffiths [34] method since the method is quite useful with small data sets, eq. (5):

$$S = \alpha T_i + \beta \tag{5}$$

Table 1. Summary of the objective measurements

Parameter	Unit	Minimum	Maximum	Mean	*SD*
T_i	°C	18.2	21.4	20.7	0.844
RH_i	%	43.1	61.3	51.8	5.42
RH_o	%	45.2	65.4	53.8	5.37
T_o	°C	17.1	19.3	19.1	0.867
MRT_i	°C	18.5	22.2	21.1	0.856
v_a	$\mathrm{ms^{-1}}$	0.01	0.07	0.02	0.014
O_2	%	16.9	20.7	18.1	0.475
HBexC	$\mathrm{Wm^{-2}}$	2.6	2.9	2.8	0.08
PMV_TCM	–	−1.15	−0.07	−0.56	0.303
PMV_CBE	–	−1.12	−0.15	−0.61	0.259
PMV_E	–	−1.2	0.24	−0.29	0.357

Results and discussion

A total number of 3780 data (from February 6th, 2017, to April 7th, 2017) were recorded during the measurement campaign. The minimum, average, maximum and *SD* values of measured (T_i, RH_i, RH_o, T_o, v_a, O_2) and calculated data (MRT_i, *HBexC*, PMV_TCM, PMV_E, PMV_CBE) are shown in tab. 1.

The developed mobile application was performed to the occupants to obtain their names, garments and thermal comfort preferences, twice a day at 10:45 and 15:15, fig. 3.

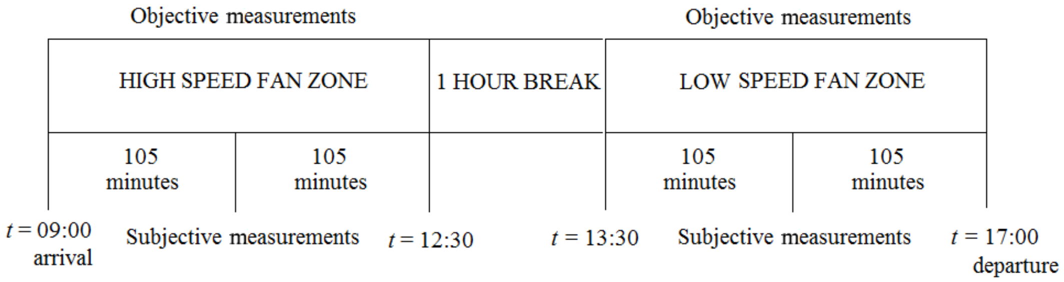

Figure 3. Timeline of the measurements in a day

The metabolic rate of each occupant was chosen as 1.2 met (M = 70 W/m^2) corresponding to regular work when sitting in an office [1]. The thermal insulation effect of wooden stools for occupants seated on chairs (0.01 *clo*) was added according to ISO 7730 [3] since the study was conducted during the heating season. Figure 4 presents the comparison of *AMV* with PMV_TCM, PMV_E, and PMV_CBE values with respect to time. The figure indicates that the ranges of thermal comfort acceptance of occupants (*AMV*) are higher than the *PMV* values.

Figure 5(a) shows the change of O_2 concentration and *AMV* values with time. As it can be seen from the figure, occupants feel warmer when the O_2 concentration decreases while objective parameters are kept constant. As an example, a 3.3% decrease in O_2 concentration, increases the *AMV* value from −0.5 to 0.5. Thus, there would be a significant relationship between *AMV* and O_2 concentration.

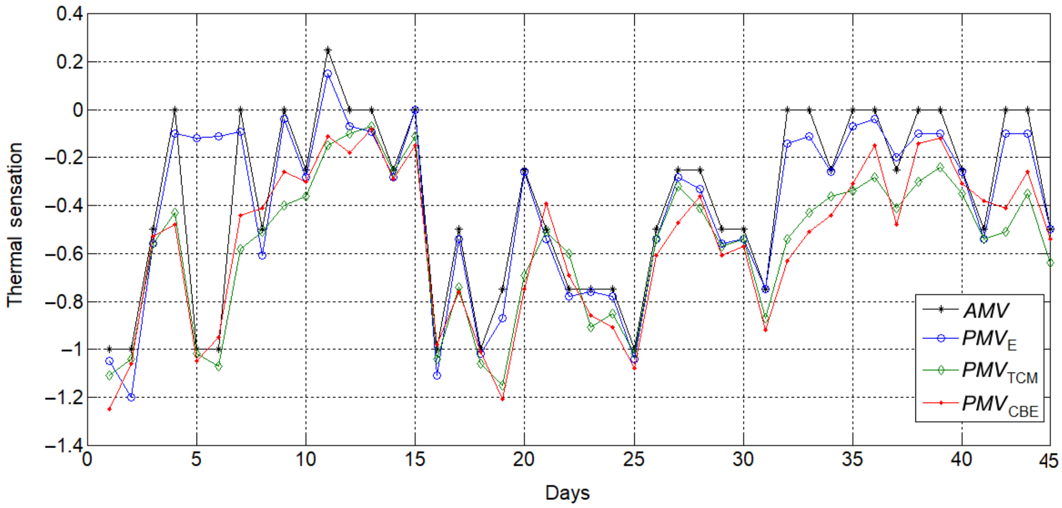

Figure 4. Comparison of AMV, PMV_{CBE}, PMV_{TCM}, and PMV_E

Regression analysis was conducted to predict *AMV* values and according to the results, *AMV* values are highly-correlated with *PMV* values, eqs. (6)-(8):

$$AMV = 1.103\ PMV_{TCM} + 0.2374\ (R^2 = 0.79) \tag{6}$$

$$AMV = 1.012\ PMV_{CBE} + 0.1749\ (R^2 = 0.77) \tag{7}$$

$$AMV = 1.006\ PMV_{E} + 0.1465\ (R^2 = 0.81) \tag{8}$$

Equations (6)-(8) exhibit that the occupants live in Mediterranean climate, perceive the environment at a higher thermal sensation. For instance, in eq. (6), *AMV* is equal to 0.24 when $PMV_{TCM} = 0$, and PMV_{TCM} is equal to −0.21 for $AMV = 0$. These results infer that *PMV* values are higher than perceived *AMV* which can result in unnecessary energy consumption in the case building because of the higher set temperatures. Variation in *AMV* with T_i is shown in fig. 5(b) and their correlation is given:

$$AMV = 0.3356\ T_i - 7.015\ (R^2 = 0.82) \tag{9}$$

The slope in eq. (9) is found as 0.3356 °C. Based on the findings, the neutral temperature of the case building was calculated to be 20.9 °C while the comfort temperature range lied from 19.4 to 22.4 °C. These results are quite in-line with the study for office buildings located in Mediterranean climate in Iran [8]. By applying new comfort temperatures, energy consumption of the case building could be decreased since the set temperature was 22 °C.

Figure 6(a) shows the relationships between *HBexC* [Wm^{-2}], T_i [°C], and *MRT* [°C] which were derived by Shukuya *et al*. [4]. Fine lines with numbers depict *HBexC* rates. The bold line represents a comfortable indoor thermal condition that gives a good thermal comfort for occupants. The neutral *AMV* value is shown with red shaded area on the graph. The neutral temperature, T_i, of 20.9 °C gives the minimum *HBexC* and MRT_i as 2.63 W/m^2 and 22.1 °C, respectively. Calculated MRT_i values were between 18.5 and 22.2 °C which are in a good agreement with fig. 6(a). It is worth to note that for air-conditioned indoor spaces, v_a,

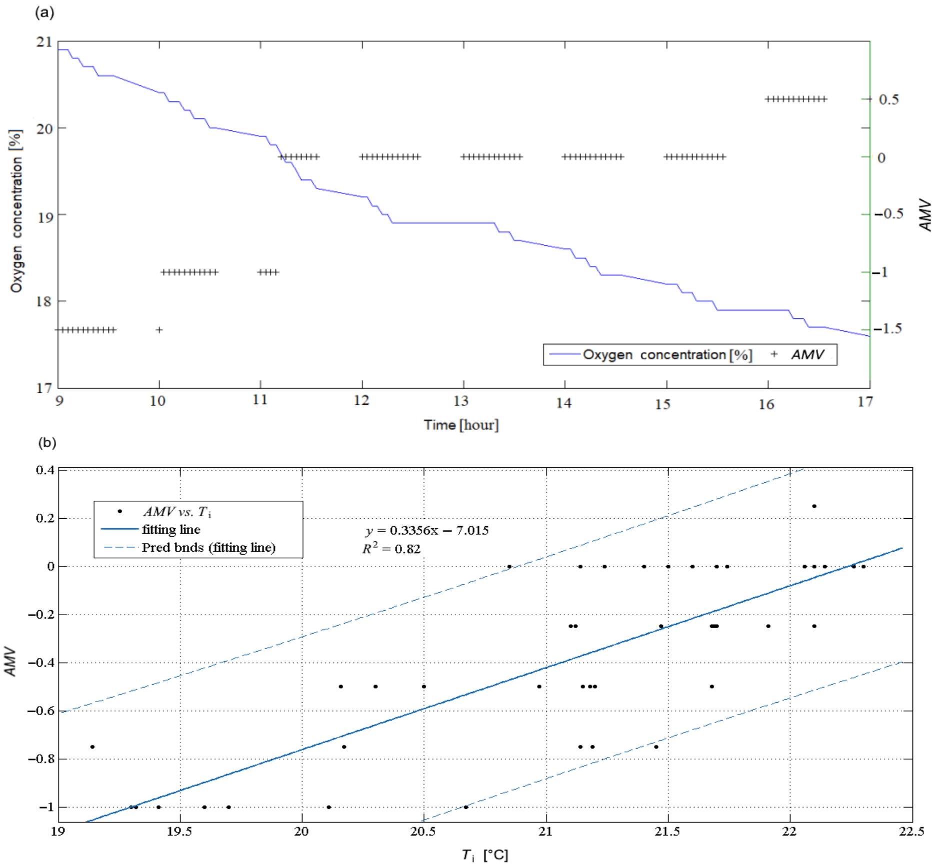

Figure 5. The O_2 concentration and *AMV* (a); *AMV* values *vs.* T_i (b)

values could be higher than the measured values in this study. Since MRT_i was calculated from eq. (1) which mainly depends on v_a values, for higher v_a values, *HBexC* rates could be higher for the same T_i compared with fig. 6(a). A sensitivity analysis on the results was conducted in order to observe the impact of v_a on *HBexC* rates. A 0.1 m/s increase in v_a, increases the *HBexC* rate by 3.3%.

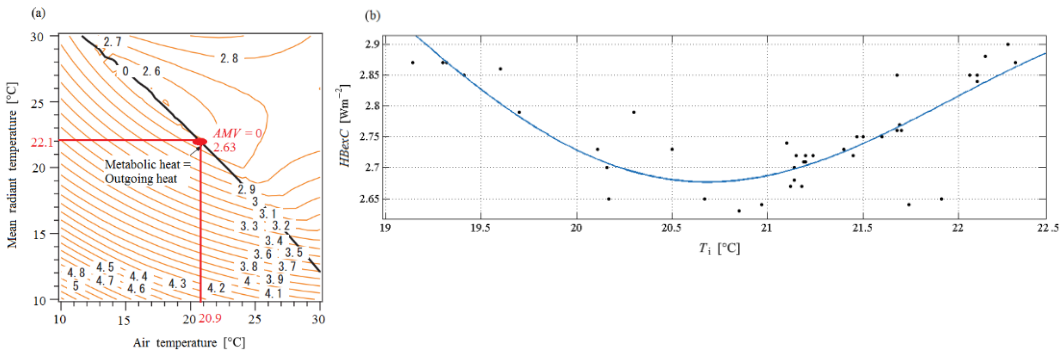

Figure 6. The *HBexC* of an average occupant in winter condition [8] (a) and human body exergy consumption dependent on indoor air temperature (b)

Figure 6(b) represents the T_i change with *HBexC* rate. When T_i increases, *HBexC* rate decreases until T_i reaches the neutral temperature. Then, *HBexC* rate shows an increasing trend similar to the [4].

Regression analysis was carried out to determine the relationship between thermal comfort and O_2 concentration. A total of 3780 data were split into two categories, 80% of the data for calibration and 20% of the data for validation of the model. In addition to O_2 concentration, there were two more independent parameters selected for regression analysis, T_i and RH_i which are known to be the most effective parameters on thermal comfort [2]. Recalling eq. (3), *CMV* can be written as given in eq. (10):

$$CMV = b_0 + b_1 T_i + b_2 RH_i + b_3 O_2 + \in \tag{10}$$

Note that the data set contains measurements for T_i, RH_i, and O_2 concentration whilst the noise component $\in$ is comprised of factors that are unobservable, or at least unobserved. The optimal values of the regression coefficients of both SLR and MLR models were obtained by employing calibration data. Performing the calibration data, the eq. (11) was derived to interpret *CMV* with three independent variables:

$$CMV = 0.241\ T_i + 0.238\ RH_i - 0.112\ O_2 - 5.512\ (R^2 = 0.76) \tag{11}$$

Table 2. Regression table

Dependent parameter		*CMV*		
Parameters	Unit	Regression model	*p*-value	*t*-value
Intercept	–	−5.512 ***	0.005	−3.9
T_i	°C	0.241 ***	0.000	4.94
RH_i	%	0.238 **	0.016	2.49
O_2	%	−0.112 **	0.035	−2.17
R^2	0.76			

Notes: *** significance at 1%, ** significance at 5%

To test the performance of the regression analysis, validation data were fed to the regression model. Table 2 shows the descriptive regression model statistics.

The model results suggested that there is a relationship between *CMV* and the independent parameters with an R^2 of 0.76. The T_i parameter has a positive and significant coefficient at 1% in regression model which means that higher T_i values result in higher *CMV* values. Similarly, RH_i has a significant and positive coefficient. However, the impact of O_2 concentration is negative and significant at 5% on the *CMV*. In other words, decrease in O_2 concentration caused an increase in *CMV* value similar to those reported in [15]. Sensitivity analysis showed that *CMV* increased by 0.56 and 0.03 when T_i and *RH* were raised by one SD, respectively. The effect of one SD increase in O_2 concentration, however, led to a reduction in *CMV* by 0.001. Another observation from the sensitivity analysis was that the most effective parameter was $T_{i.}$

Conclusion

This study presents thermal comfort preferences of occupants in a university office building located in Mediterranean climate. The office room with two male occupants was assessed by both objective and subjective measurements in order to perceive thermal sensation of the occupants. The objective measurements including T_i, T_o, RH_i, $RH_{o,}$ The O_2 concentration and v_a were used to calculate the *PMV* values by TCM, CBE thermal comfort tool and human body exergy balance contour calculation tool. A mobile application which uses the seven-point scale of ASHRAE 55 was run to obtain *AMV* values of the occupants. The *PMV* values were correlated with *AMV* values. Correlations showed that *PMV* values underestimated the perceived thermal sensation of the occupants in Mediterranean climate. The highest correlation rate was obtained by human body exergy balance contour calculation tool since it considered MRT_i and minimum *HBexC* rate together. In addition, the objective and subjective measurement data were treated through SLR and MLR analysis to derive the new *CMV* values. The values for R^2 and p indicated that *CMV* was correlated/associated with T_i, RH_i and O_2 concentration. If *AMV* values were taken into consideration, the energy consumption in the case building could be reduced. Even though the study was limited to one office building, two male occupants and two-months of measurement campaign, it still gave an idea that in warmer climates *AMV* should be considered for energy saving and *IAQ* parameters should also be included in thermal comfort analysis. In this study, T_i was used in Griffiths method, however, OT_i could be also used in order to define neutral temperatures for larger sample sizes since it is a key parameter which uses indoor surface temperatures, air velocity, clothing, metabolic rates and T_i, together. Larger sample size that accounts for gender should be expected to improve the correlations. Studies on a larger population of occupants with different age and gender, collection of data over longer periods of time and long term surveys are planned to further justify the findings in the future.

Nomenclature

clo – clothing insulation, [–]
MRT – mean radiant temperature, [°C]
met – metabolic rate, [–]
O_2 – oxygen concentration, [%]
OT – operative temperature, [°C]
RH – relative humidity, [%]
S – comfort votes, [–]
T – air temperature, [°C]
x – independent parameter
v – velocity, [ms^{-1}]
y – dependent parameter, [–]

Greek symbols

α – slope
β – constant (intercept)
ϵ – error, [–]

Subscripts

a – air
i – indoor
o – outdoor

Acronyms

AMV – actual mean vote
CBE – center of building environment thermal comfort tool
CMV – combined mean vote
HBexC – human body exergy consumption, [Wm^{-2}]
IAQ – indoor air quality
MLR – multiple linear regression
PMV – predicted mean vote
PPD – predicted percentage of dissatisfied
Rn – radon
SD – standard deviation
SLR – simple linear regression
TCM – thermal comfort module

References

[1] ***, ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy, ASHRAE, Atlanta, Geo., USA, 2004
[2] Fanger, P., *Thermal Comfort*, Danish Technical Press, Copenhagen, 1970
[3] ***, ISO Standard 7730, Moderate Thermal Environments-Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort, International Standards Organization, Geneva, Switzerland, 1994
[4] Shukuya, M., *et al.*, Human-Body Exergy Balance and Thermal Comfort, Working Report of IEA/ECBCS/Annex 49, Paris, 2009
[5] Isawa, K., *et al.*, Human-Body Exergy Consumption Varying with the Combination of Room Air and Mean Radiant Temperatures, *Journal of Environmental Engineering*, *70* (2003), 570, pp. 29-35
[6] Prek, M., Thermodynamic Analysis of Human Heat and Mass Transfer and Their Impact on Thermal Comfort, *International Journal of Heat and Mass Transfer*, *48* (2005), 3-4, pp. 731-739
[7] De Dear, R. J, *et al.*, ASHRAE RP-884 Final Report: Developing an Adaptive Model of Thermal Comfort and Preference, American Society of Heating, Refrigerating and Air Conditioning Engineers, ASHRAE, Atlanta, Geo., USA, 1997

[8] Heideri, S., Sharples, S., A Comparative Analysis of Short-Term and Long-Term Thermal Comfort Surveys in Iran, *Energy and Buildings*, *34* (2002), 6, pp. 607-614
[9] Corgnati, S. P., *et al*., Perception of the Thermal Environment in High School and University Classrooms: Subjective Preferences and Thermal Comfort, *Building and Environment*, *42* (2007), 2, pp. 951-959
[10] Bedford, R. E., *et al*., Recommended Values of Temperature on the International Temperature Scale of 1990 for a Selected Set of Secondary Reference Points, *Metrologia*, *33* (1996), 2, pp. 133-154
[11] Griffiths, I. D, McIntyre, A. D., Sensitivity to Temporal Variations in Thermal Conditions, *Ergonomics*, *17* (1974), 4, pp. 499-507
[12] Brager, G., *et al*., A Comparison of Methods for Assessing Thermal Sensation and Acceptability in the Field, *Proceedings*, Thermal Comfort: Past, Present and Future, Garston, Liverpool, UK, 1993, pp. 17-39
[13] Humpreys, M. A., Thermal Comfort Temperatures World-Wide-the Current Position, *Renewable Energy*, *8* (1996), 1-4, pp. 139-144
[14] Yao, R., *et al*., A Theoretical Adaptive Model of Thermal Comfort-Adaptive Predicted Mean Vote (aPMV), *Building and Environment*, *44* (2009), 10, pp. 2089-2096
[15] Grathier, S., *et al*., Investigating the Effect of CO_2 Concentration on Reported Thermal Comfort, *Proceedings*, CISBAT 2015, Lausanne, Switzerland, 2015, pp. 315-320
[16] Nicol, J. F., Humphreys, M. A., Adaptive Thermal Comfort and Sustainable Thermal Standards for Buildings, *Energy and Buildings*, *6* (2002), 2, pp. 563-572
[17] Sing, M. K., *et al*., Relation Between Indoor Thermal Environment and Renovation in Liege Residential Buildings, *Thermal Science*, *18* (2014), 3, pp. 889-902
[18] Van der Linden, A. C., *et al.*, Adaptive Temperatures Limits: A New Guideline in the Netherlands: A New Approach for the Assessment of the Building Performance with Respect to Thermal Indoor Climate, *Energy and Buildings*, *38* (2006), 1, pp. 8-17
[19] Kosun, C., *et al*., Soft Computing and Regression Modelling Approaches for Link-Capacity Functions, *Neural Network World*, *9* (2016), Mar., pp. 129-140
[20] McCartney, K. J, Nicol, F. J., Developing an Adaptive Control Algorithm for Europe, *Energy and Buildings*, *34* (2002), 6, pp. 623-635
[21] ***, World Map of Koppen-Geiger Climate Classification, 2006
[22] ***, Turkish State Meteorological Service, https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=IZMIR
[23] ***, EN ISO 13790 (former 832), Thermal Performance of Buildings — Calculation of Energy Use for Heating, 2006
[24] ***, HOBO Temperature/Relative Humidity/Light/External Data Logger, Onset, 2010
[25] ***, INNOVA 1221 Instruction Manual, LumaSense Technologies, 2007
[26] ***, Grove-Gas Sensor, Seed Studio, 2016
[27] ***, Occupational Safety and Health Administration, United States Departments of Labor, 2010
[28] ***, ISO 10551, Ergonomics of the Thermal Environment e Assessment of the Influence of the Thermal Environment Using Subjective Judgement Scales, Geneva: International Standardization Organization, 1995
[29] ***, CBE Thermal Comfort Tool, Center for the Built Environment, Berkeley, California, USA, 2017
[30] Iwamatsu, T., Asada, H., A Calculation Tool for Human Body Exergy Balance, The International Energy Agency, Energy Conservation in Buildings and Community System, Paris, Annex 49, No. 6, pp. 4-5, 2009
[31] ***, MATLAB 6.1, The MathWorks Inc., Natick, Mass., USA, 2000
[32] Turhan, C., *et al*., Comparative Study of a Building Energy Performance Software (KEP-IYTEE-ESS) and ANN-based Heat Load Estimation, *Energy and Buildings*, *85* (2014), Dec., pp. 115-125
[33] Duran, H. E., Short-Run Dynamics of Income Disparities and Regional Cycle Synchronization in the US, *Growth and Change: A Journal of Urban and Regional Policy*, *45* (2014), 2, pp. 292-312
[34] Griffiths, I., Thermal Comfort Studies in Buildings with Passive Solar Features: Field Studies Report to Commission of the European Community, ENS 35909, London, 1990

Paper submitted: December 14, 2017
Paper revised: March 22, 2018
Paper accepted: March 23, 2018