Analysis of the results of empirical research and surveys of perceived indoor temperature depending on gender and seasons

Maria Jolanta Sulewska¹ · Katarzyna Gładyszewska-Fiedoruk² · Piotr Sztulc³

Received: 24 May 2018 / Accepted: 20 August 2018 / Published online: 6 September 2018
© The Author(s) 2018

Abstract

The indoor thermal condition tests were conducted as real and declared by the respondents. The tests were carried out in the laboratory room in Białystok. The object is a detached, two-storey building with a cellar. The tests were carried out from February to May 2015. In 1 week, on average, ten measurement series were carried out. During one experiment series, there were between 10 and 15 students present in the room. The aim of the publication is to analyze the results of declared perceived temperature tests in the room depending on the gender, the season and indoor and outdoor temperature conditions. On the basis of statistical analysis of the test results, it was found that in the analyzed age group, the perceived temperature declared in the room is not affected by the respondent's gender. The conclusion is that the temperature sensations of young (and probably healthy) people who do not do physical work are similar, regardless of gender. Differences between the average perceived temperature in the room, declared by all respondents in winter and declared in spring are statistically significant. The indoor perceived temperature declared in the winter is almost constant and does not depend on the temperature of the perceived temperature of outdoor air.

Keywords Perceived temperature · Survey research · Statistical analysis · Regression models

Nomenclature

M	Men
N	Number of cases
R^2	Determination coefficient
r	Correlation coefficient
S	Spring
t_a	Air temperature in room
t_{fc}	Calculated perceived temperature
t_f	Declared perceived temperature
t_R	Temperature of partitions
t_z	Outdoor air temperature
t_{zc}	Outdoor perceived air temperature

W	Women
W_i	Winter

Introduction

In recent years, due to the increasing awareness of people, a healthy lifestyle is promoted. Many people who want to lead such a lifestyle, try to nourish well, play sports, and forgetting about the right conditions to exist in their own home or workplace. According to the medical experts from human health organizations, inadequate temperature in the rooms where people are staying can lead to deterioration of health and well-being (Dziubanek et al. 2017).

The air temperature is a parameter of indoor environment most perceived and recognized by people (Frasca et al. 2017; Teleszewski and Gładyszewska-Fiedoruk 2018; Lin and Deng 2008; Wang 2006). The air temperature is determined as one of the basic and most important factors conditioning perception of comfort in the room. The American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE) defined it as a “state of mind” in which satisfaction with the thermal environment is expressed. This is influenced by mood, culture and

Responsible editor: Philippe Garrigues

✉ Katarzyna Gładyszewska-Fiedoruk
k.gladyszewska@pb.edu.pl

¹ Department of Geotechnics and Structural Mechanics, Białystok University of Technology, Białystok, Poland

² Department of HVAC Engineering, Białystok University of Technology, Białystok, Poland

³ Design Studio Jacek Zagórecki, Białystok, Poland

other individuals, and organizational and social factors (ASHRAE 2001, 2013).

On the basis of the above definitions, it can be assumed that thermal comfort is not a state of physical condition of a person, but a state of mind (Toy and Kántor 2017). The definition of thermal comfort remains open to what constitutes a state of mind or satisfaction but emphasizes that the assessment of comfort is a cognitive process involving many aspects arising from physical, physiological, psychological, and other factors (Lin and Deng 2008).

Research on the different sensation of indoor temperature in women and men has so far been conducted by Wang (2006). Wang made research on thermal conditions and thermal comfort in residential buildings in Harbin, northeast of China, carried out on 120 people in winter, showed that men have a slightly different sensation of temperature in the room than women. Men are also less sensitive to temperature variations in the room than women. According to Wang (2006), the most appropriate and comfortable and neutral operative temperature for men was lower by 1.1 °C than for women.

Due to the fact that there are very few similar results of the research depending on gender and seasons presented in the literature (we only got to one scientific publication by Wang (2006), an experiment was carried out, the results of which are presented in this publication. The presented in the current study results concern young people performing intellectual work.

The aim of the publication is to analyze the results of declared perceived temperature tests in the room depending on the gender, the season and indoor and outdoor temperature conditions.

This work analyzes the results of tests conducted on a sample of 396 students. The research was conducted in winter and spring, in northeastern Poland in a temperate climate.

The perceived temperature calculation (t_{fc}) defines what thermal sensation will occur in people in given weather conditions.

The perceived temperature outside the building is calculated depending on the adopted model, based on such parameters as air temperature, wind speed and direction, relative humidity of air, and the amount of atmospheric precipitation.

The perceived calculated temperature in the room does not consider the force of wind, precipitation, and humidity. The computable perceived temperature is calculated using the formula (Szargut 1968):

$$t_{fc} = \frac{(t_R + t_a)}{2} [^{\circ}\text{C}] \quad (1)$$

The calculated indoor perceived temperature depends on the partitions temperature and the air temperature in room.

The aim of the publication is to analyze the results of perceived temperature tests declared in the room depending on

the gender, the season, and the indoor and outdoor temperature conditions using statistics.

Experimental research

Measuring equipment and the experiment room

The paper presents an analysis of the actual and declared thermal conditions test results in the room. The measurements were made using measuring equipment and a questionnaire (Sztulc 2017).

The air parameters were tested using a Testo 435-4 meter, with an IAQ probe and a probe for measuring wall surface temperature in the room. The ranges and the accuracy of measuring instruments were described in detail in previous scientific papers (Teleszewski and Gładyszewska-Fiedoruk 2018; Gładyszewska-Fiedoruk and Nieciecki 2016).

The research was carried out in the laboratory room (Fig. 1), located in the building of the Faculty of Building and Environmental Engineering at the Białystok University of Technology, in Białystok, northeastern Poland. The building is a detached, two-storey construction with a full basement. In recent years, it has undergone total thermal modernization. During the experiment, the computers were not turned on. Operating computers are a source of heat, which may disturb the room temperature. There is a gravity ventilation system in the room; central heating radiators are located under the window sill.

The room is located on the first floor of the building and has the following dimensions: 11.8 m × 5.57 m and a height of 3.0 m. The room has nine windows facing the south side with a height of 2.0 m and a width of 1.2 m, mounted at a height of 0.8 m from the floor of this room. The room is used at various times of the day, with a variable number of persons present during the experiment, from 10 to 15.

The tests were carried out from February to May 2015 (Sztulc 2017). The experiment was carried out in the winter and spring season. In 1 week, on average, ten measurement series were carried out in which 10 to 15 students took part, during their laboratory classes. The same students responded to the same set of questions after 1 week in changed indoor thermal condition, depending on indoor condition (weather condition). In total, such repeated tests were carried out on 80 people.

Measurements of air temperature were carried out at a height of about 1.0 to 1.1 m from the floor (as recommended ASHRAE 2013) and at a distance of about 2 m from people in the room.

Measurements of partitions temperature were carried out at a height of about 0.2 and 0.7 m from the floor (as recommended ASHRAE 2013).

Fig. 1 Didactic laboratory room in which the perceived temperature was examined [authors' own collection]

Respondents entered the room under examination from the corridor. During measurements, they were dressed in their everyday clothes without outerwear (without coats, jackets), wearing winter or spring boots. People participating in the survey completed surveys about 10–15 min after entering the room. The time between entering the laboratory room and performing the test allowed acclimatization of the examined people to the temperature condition prevailing in the room. Participants filling out the questionnaires made a small physical effort and remained in a sitting position.

The error account of the measured values was carried out in accordance with the recommendations contained in publication (Moffat 1988). Temperature measurement error (relative error) ranged from 1.8 to 5.2%.

The questionnaire was prepared by the authors for the purposes of their own experimental research. The objective of the survey was to define the thermal sensations of people in the same room, at different indoor and outdoor air temperatures. The respondents completed information in the following questionnaire form:

Date of survey:

Gender: ☐ Women ☐ Men

Perceived temperature declared in the room:°C

Real indoor temperature – taken:°C

Partitions temperature – taken:°C

The results of temperature measurements outside the building and the perceived outdoor temperature were obtained from the meteorological institute (Web-1 2018).

The group of people on whom the tests were performed was aged in the period of psychologically early adulthood,

i.e., in the age range 23–34 (here 23 years). This age is also referred to as the peak of physical development. It should be noted that the development process cannot be treated in a “rigid” way, because it is a continuous process (Heathcote and Berne's's 2010; Wolański 2012).

The measurement results

The experiment was carried out at the indoor air temperature specified in Fig. 2. Indoor air temperature and temperature of partitions during the relevant measurement series are presented in Fig. 3 for the winter and Fig. 4 for the spring.

During all the series of the experiment, the temperature ranged from 21 to 23 °C. The HVAC system was helpful in maintaining approximately constant condition in the room. In the winter, the air temperature in the room was always 1 to 2 °C higher than the temperature of the partitions. In the spring, the air temperature in the room was very close to the temperature of the walls.

Fig. 2 Indoor air temperatures during different series of the experiment

Fig. 3 Indoor air and wall temperatures during the relevant measurement series in the winter

Dataset description

The dataset consists of $N=396$ cases, described with 12 variables X1–X12. In this work, the following 10 variables were analyzed (variables X2 and X3 were not analyzed here):

- X1—perceived temperature declared in the room (t_f), $t_f=15.0$ – 26.5 [°C]
- X4—gender, symbols: women = W , $N_W=239$; men = M , $N_M=157$
- X5—gender code, codes: women, $W=0$, $N_W=239$; men, $M=1$, $N_M=157$
- X6—actual (real) indoor temperature (t_a), $t_a=20.3$ – 25.7 [°C]
- X7—partitions temperature (t_R), $t_R=19.1$ – 25.7 [°C]
- X8—season, season codes: winter = W_i , $N_{W_i}=63$; spring, S ; $N_S=306$; where the winter runs from December 22 to March 20, and the spring runs from March 21 to June 21
- X9—season code, season codes: winter = 0 , $N_{W_i}=63$; spring = 1 , $N_S=306$
- X10—indoor perceived calculated temperature, calculated on the basis of actual air temperatures taken in the

room and partitions, (t_{fc}) according formula (1): $t_{fc}=20.0$ – 25.75 [°C]

X11—outdoor air temperature (t_z), $t_z=2$ – 16.67 [°C]

X12—outdoor perceived air temperature (t_{zc}), $t_{zc}=(-1.67)$ – 16.67 [°C]

Statistical analysis of data

Statistical data analysis was performed using the STATISTICA version 13 computer software (STATISTICA 2002).

The following questions were analyzed:

- 1). Does perceived temperature declared in the room (X1) differ from the perceived design temperature in the room (X10)?
- 2). Should the declared perceived temperature (X1) be considered in the entire dataset, or individually in subsets separated due to the grouping factor, which are as follows:
 - a. Participant's gender
 - b. Season of the year
- 3). Does the perceived temperature declared in the room (X1) depend on the perceived design temperature in the room (X10)?
- 4). Does the perceived temperature declared in the room (X1) depend on the outdoor perceived temperature (X12):
 - a. In women
 - b. In men

Checking the normality of X1 and X10 variable distributions

At the outset, it was checked whether the dependent variables X1 and X10 had normal distributions, in order to check the assumptions for statistical analysis and to select appropriate tests for the significance of medium differences:

- In the entire dataset
 - In two subsets separated from the entire dataset in respect of gender of the respondent (variable grouping X4 (or X5)) by code: 0—women, 1—men
- In two subsets separated from the entire dataset in respect of the time of year (variable grouping X8 or X9) by code: W_i , winter (season code = 0); S , spring (season code = 1)
- In four subsets separated by gender and season (grouping variables X4 or X5 and X8 or X9)

Fig. 4 Indoor air and wall temperatures during the relevant measurement series in the spring

Table 1 Normality test results W Shapiro-Wilk of X1 and X10 variables

No.	Subset	Subset size N	Variable X1	Variable X10
1	Dataset	396	$p = 0.00 < 0.05$ NN	$p = 0.00001 < 0.05$ NN
2	Women	239	$p = 0.00012 < 0.05$ NN	$p = 0.0011 < 0.05$ NN
3	Men	157	$p = 0.0011 < 0.05$ NN	$p = 0.0035 < 0.05$ NN
4	Winter (women + men)	63	$p = 0.09 > 0.05$ N	$p = 0.00 < 0.05$ NN
5	Spring (women + men)	333	$p = 0.00001 < 0.05$ NN	$p = 0.00001 < 0.05$ NN
6	Winter (women)	40	$p = 0.24 > 0.05$ N	$p = 0.00028 < 0.05$ NN
7	Spring (women)	199	$p = 0.00014 < 0.05$ NN	$p = 0.00043 < 0.05$ NN
8	Winter (men)	23	$p = 0.19 > 0.05$ N	$p = 0.0016 < 0.05$ NN
9	Spring (men)	134	$p = 0.0034 < 0.05$ NN	$p = 0.0049 < 0.05$ NN

N normal distribution, NN not corresponding to normal distribution, p computer calculated probability level

The size of individual subsets of data is listed in Table 1.

Upon the results of the normality test W Shapiro-Wilk, at the significance level $\alpha = 0.05$, histograms and normality graphs (Mac Berthouex and Brown 2002; Rencher 2000), it can be concluded that distributions of variables X1 and X10 in the entire dataset and in groups, separated in respect of accepted grouping variables, do not correspond to the normal distribution, except for three instances marked in italics in Table 1.

It was assumed that the analyzed measurable variables X1 and X10 in two populations (subsets of 2–5) do not have normal distributions and constitute large samples (with the amounts $N > 50$). The subsets of numbers 6–9 also do not have normal distributions and two subsets (numbers 6 and 8) do not constitute a large sample ($N < 50$).

Analysis of whether the perceived temperature declared in the room differs from the perceived designed temperature in the room

The significance of differences in mean X1 and X10 variables was tested. Obtaining a result indicating the significance of differences in mean variables will mean that the variables X1 and X10 differ from each other in a statistically significant manner.

The t tests for two independent samples (X1 and X10 variables in the entire dataset) were selected with independent estimation of variance (because the subsets of data were large: $N_{X1} = N_{X10} = 396$, and their distributions did not correspond to the normal distribution).

The choice of the Student's t test for independent groups depends on (Estrada-Vidal and Tójar-Hurtado 2017; Grafem and Hals 2002) the nature of the distribution of the variable in groups (whether the distribution is normal N or not the normal NN):

- Amounts in groups (small sets—when $N < 50$, large sets—when $N > 50$)
- Variance in individual groups (homogeneous or heterogeneous)

The assumption of equality of variances in groups was tested using the Levene and Brown and Forsyth tests, and it was found that the hypothesis of equality of variances in groups (at $p = 0.00 < 0.05$) can be rejected, so the Cochran-Cox test was used, which in turn showed that the differences between the average perceived temperature declared in the room and the average designed temperature in the room are statistically significant (with double-sided $p = 0.00 < 0.05$). This is illustrated in Fig. 5, in which the diagrams of the mean variables X1 and X10 are clearly different and disjoint.

The average perceived temperature declared in the room in the examined period is lower by about 1.1 °C than the average perceived designed temperature in the room. The average perceived temperature declared in the room was 21.3 ± 2.1 °C, and the average perceived designed temperature in the room was 22.4 ± 1.3 °C.

Analysis of whether the perceived temperatures declared in the room differ from each other depending on the respondent's gender

Another test referred to the significance of the mean differences of the variable X1 in two groups separated by the grouping variable, which was the respondent's gender. T tests for two independent samples with independent estimation of variance were selected.

On the basis of the Levene test (at $p = 0.44 > 0.05$) and the Brown and Forsyth test (at $p = 0.49 > 0.05$, the hypothesis of equality of variances in groups was confirmed, so the t test was chosen based on which can be inferred (at $p = 0.084 > 0.05$) that the differences between the average temperature perceived in the room, declared by men and women are statistically insignificant (the diagrams on Fig. 6 partially have the same range). Average perceived temperature declared in the room by women was 21.2 ± 2.1 °C, by men 21.5 ± 2.2 °C, the difference between the averages was about 0.4 °C. The value of the perceived temperature in the room is declared regardless of the respondent's gender.

Fig. 5 Average perceived temperature declared in the room (X1) and the average perceived designed temperature in the room (X10) with histograms

Analysis of whether the perceived temperatures declared in the room differ from each other depending on the season

The significance of the mean differences of the variable X1 was tested in two groups separated in respect of the grouping variable, which was the calendar season of the year.

The *t* tests for two unrelated tests with independent estimation of variance (large $N_{W1} = 63$ and $N_S = 333$ tests were selected, the samples differ significantly and the distributions of variables in the groups are not normal).

The hypothesis of equality of variances in groups was rejected upon Levene's test (at $p = 0.025 < 0.05$) and Brown and Forsythe test (at $p = 0.034 < 0.05$); therefore,

Fig. 6 Mean values of perceived indoor temperatures (Y1) declared by women (W) and by men (M) with histograms

Fig. 7 Mean values of perceived temperature declared in the room (X1) in winter (Wi) and in spring (S) with histograms

the Cochran-Cox test was selected upon which an assumption can be made (at $p = 0.00 < 0.05$) that the difference between the average temperature sensed in the room declared by all respondents in winter and spring is statistically significant. This is illustrated in Fig. 7, where the X1 medium variable diagrams in winter and in the spring, they are separable.

The average perceived temperature in the room declared in winter is lower by about 1.3 °C than the average temperature perceived in the room declared in spring. The average perceived temperature in the room declared in winter was 20.2 ± 1.7 °C, and in the spring was 21.5 ± 2.1 °C.

It is concluded that the perceived temperature values declared in the room differ significantly from one another statistically depending on the calendar season.

Analogous conclusions were obtained from the analysis of the perceived design temperature values. The average perceived design temperature in the room in winter is lower by about 1.6 °C than the average perceived design temperature in the spring. The average indoor perceived design temperature in the winter was 21.1 ± 0.7 °C, and in the spring 22.7 ± 1.2 °C.

Analysis of the relationship between the perceived temperature declared in the room and the perceived design temperature in the room, for women and men in winter and spring

Linear regression models (Draper and Smith 1998; Mosteller and Tukey 1997) of the perceived temperature declared in the

room (X1) from the perceived design temperature in the room (X10) were developed depending on gender and season (Fig. 8).

Figure 8 shows graphs of the following dependencies:

$$\text{Women, winter} : y = 18.7 + 0.1x \pm 1.8; r = 0.03; R^2 = 0.001 \quad (2)$$

$$\text{Women, spring} : y = 4.2 + 0.8x \pm 1.9; r = 0.40; R^2 = 0.16 \quad (3)$$

$$\text{Men, winter} : y = 23.6 - 0.2x \pm 1.6; r = 0.08; R^2 = 0.01 \quad (4)$$

$$\text{Men, spring} : y = -0.2 + 1.0x \pm 1.8; r = 0.57; R^2 = 0.33 \quad (5)$$

The predictive quality of models can be assessed on the basis of the value of the correlation coefficient r and the determination coefficient R^2 (Grafem and Hals 2002; Krzanowski 1998). Models (2) and (4) have very low correlation coefficients (respectively: $r = 0.03$ and $r = 0.08$) and explain a negligible part of the variability of the dependent variable ($R^2 = 0.001$ and $R^2 = 0.01$, respectively).

The conclusion is that in winter the perceived temperature declared in the room is almost constant and does not depend on the perceived design temperature in the room. This is probably affected by the HVAC installation, which maintains approximately constant temperature conditions in the room.

Fig. 8 Correlation of the perceived temperature declared in the room with the perceived design temperature in the room depending on the gender and the calendar season

Models (3) and (5) for men and women in spring have a fairly low predictive quality. The linear correlation coefficients are respectively $r=0.4$ and $r=0.57$ and do not explain much of the variability of the dependent variable (respectively $R^2=0.16$ and $R^2=0.33$). This means that the perceived indoor temperature declared in the spring by both genders depends also on other factors, not included in Eqs. (3) and (5).

More specifically, the issue of perception of the temperature declared in the spring and winter, by both women and men is shown separately in Figs. 9 and 10.

Figure 9 shows that there are some linear relationships between variables X1 and X12, but they are not very clear, and the spread of points around the lines is quite significant. The relationship charts for women and men almost coincide with each other, which confirm the conclusion that gender does not affect the perceived temperature declared in the room in the spring.

Both graphs are almost parallel to the x -axis and almost coincide with each other, which confirm the previous conclusions about the almost constant perceived indoor temperature declared in the winter. In view of the above,

Fig. 9 Dependence of the perceived temperature declared in the room on the perceived design temperature in the room in the spring

Fig. 10 Dependencies of the perceived temperature declared in the room on the perceived design temperature in the room in winter

further analysis will be carried out only for the results of tests conducted in the spring period.

Analysis of the relationship between the perceived temperature declared in the room and the outdoor perceived temperature of air declared by women in the spring

The relationship between the perceived temperature declared in the room (X1) and the perceived temperature of the external air (X12) declared by women in the spring is as follows (Fig. 11):

$$y = 20.2 + 0.1x \pm 2.0; r = 0.31; R^2 = 0.1 \quad (6)$$

Model (6) has a low correlation coefficient ($r=0.31$) and explains only about 10% of the variability of Y1 ($R^2=0.1$). The comparison of the temperature value declared in the room by women in spring and calculated on the basis of the model (6) with the values from the tests is shown in Fig. 12. Relative error RE (accuracy of prediction) is over 25%.

Analysis of the relationship between perceived temperature declared in the room and perceived outdoor temperature of the air declared by men in spring

The relationship between perceived temperature declared in the room (X1) and perceived outdoor temperature of the air (X12) declared by men in spring is as follows (Fig. 13):

$$y = 20.2 + 0.2x \pm 2.0; r = 0.41; R^2 = 0.17 \quad (7)$$

Model (7) has a fairly low correlation coefficient ($r=0.41$) and explains only about 17% of the variability of Y1 ($R^2=0.17$). The comparison of perceived indoor temperature values declared by men in the spring calculated on the basis of the model (7) with the values from the tests is shown in Fig. 14. Relative error RE (accuracy of prediction) is around 20%.

Analysis of the relationship between perceived temperature declared in the room and perceived outdoor temperature of the air declared by women and men in winter and spring

The correlation of perceived temperature declared in the room (X1) and the perceived outdoor temperature of the air (X12) was developed depending on the gender and the season as follows (Fig. 15):

$$\text{Women, winter} : y = 20.2 - 0.1x \pm 1.8; r = 0.13; R^2 = 0.02 \quad (8)$$

$$\text{Women, spring} : y = 20.2 + 0.1x \pm 2.0; r = 0.31; R^2 = 0.1 \quad (9)$$

$$\begin{aligned} \text{Men, winter} : y &= 20.4 + 0.01x \pm 1.6; r = 0.02; R^2 \\ &= 0.0003 \end{aligned} \quad (10)$$

$$\begin{aligned} \text{Men, spring} : y &= 20.2 + 0.2x \pm 2.0; r = 0.41; R^2 \\ &= 0.17 \end{aligned} \quad (11)$$

In models (8) and (10) terms with variable x are statistically insignificant; models have very low correlation coefficients (respectively: $r=0.13$ and $r=0.02$) and explain a negligible part of the variability of the dependent variable ($R^2=0.02$ and

Fig. 11 Dependence of the perceived temperature declared in the room on the perceived temperature of the outside air (women, spring)

$R^2 = 0.0003$ respectively). It follows the conclusion that in winter the perceived temperature declared in the room is almost constant and does not depend on perceived temperature of outdoor air.

Models (9) and (11) for men and women in spring have low predictive quality and are of no practical significance.

Multiple regression equations

As the perceived indoor temperature (X_1) in the spring declared by both genders may depend still on other factors not included in the simple regression equations, the simultaneous

action of other factors studied was analyzed based on a linear correlation matrix (Mac Berthouex and Brown 2002), prepared for both genders for data from the spring (Table 2).

Based on the above correlation matrix, it can be concluded that all variables are mutually correlated, so that a multiple regression model with more than one independent variable cannot be developed. Possible multiple regression models were considered (Rencher 2000; Draper and Smith 1998):

- 1). Model $X_1 = f(X_{10}, X_{12})$ cannot be considered because $X_{10} = f(X_{12})$, i.e., X_{10} and X_{12} variables are linearly correlated with each other, where $r = 0.62$ (Table 2 in

Fig. 12 Comparison of observed values and predicted values by the Eq. (6) for women in spring; RE, relative error of prediction using the model (6)

Fig. 13 Relationship between perceived temperature declared in the room and perceived temperature of the outside air (men, spring)

italics) (that is, they are more correlated with each other than each of them with variable X1).

- 2). Model $X1 = f(X10, X11)$ cannot be considered because $X10 = f(X11)$, i.e., variables X10 and X11 are correlated linearly with each other, where $r = 0.6$ (i.e., they are more correlated with each other than each of them with variable X1).
- 3). Model $X1 = f(X6, X11)$ cannot be considered because $X6 = f(X11)$, i.e., variables X6 and X11 are correlated linearly with each other, where $r = 0.57$ (i.e., they are more correlated with each other than each of them with variable X1).

Therefore, only simple linear regression equations can be developed between individual variables, the most interesting of which are shown in this article.

Discussion of research

Scientific publications describe measurements of indoor air quality. They were conducted in didactic rooms (Asif et al. 2018; Chmura et al. 2017; Hwang et al. 2017; Kviesis et al. 2017; Marć et al. 2018; Śmiełowska et al. 2017). In most publications, the evaluation of the results was based on a

Fig. 14 Comparison of the values observed and predicted by the Eq. (7) for men in the spring

Fig. 15 Correlation of the perceived temperature declared in the room and the perceived temperature of the outdoor air depending on the gender and the calendar season

simple error calculation. In only a few publications, a wider statistical analysis of measurement results was carried out (Skowron et al. 2018; Sulewska 2012). Few publications address the issue of differences in the perception of indoor ambient conditions depending on gender.

We have presented in our work the results of perceived temperature measurements and a simple error calculation (uncertainty account). The exact mathematical interpretation of the results obtained was possible on the basis of advanced statistical analysis. The significance of differences in the average perceived declared temperature Y1 and perceived calculated temperature Y2 in the room was tested (p. 3.2), testing the significance of differences in mean temperatures Y1 and Y2 depending on gender X4 and X5 (see “[Analysis of whether the perceived temperatures declared in the room differ from each other depending on the respondent’s gender](#)”), testing the significance of differences in mean temperatures Y1 and Y2 depending on the time of year X8, X9 (see “[Analysis of whether the perceived temperatures declared in the room differ from each](#)

[other depending on the season](#)”). On the base of the results of statistical tests, regression models were obtained, and their predictive qualities were determined on the base of the value of Pearson correlation coefficients r and R^2 determination coefficients. Small values of correlation coefficients and determination coefficients indicate inferior quality of models. The best of the obtained statistical models (formula 6) concerns the men’s temperature sensation in spring, $r = 0.57$ and $R^2 = 0.33$. Inferior quality of the models shows that there is no clear difference in temperature sensation by both genders. There is also no clear correlation between people’s internal temperature and the season of the year, because during the experiment, the room temperature was maintained in the range of 21–23 °C.

Conclusions

Calculated values of the design perceived indoor temperature in winter are smaller by about 1.6 °C than the design

Table 2 Linear data correlation matrix for women and men in the spring

Variable	Y1 Perceived indoor temperature	X6 Actual indoor temperature of the air	X7 Walls temperature	X10 Perceived design indoor temperature	X11 Actual outdoor air temperature	X12 Perceived outdoor air temperature
X1	1.0	0.48	0.47	0.48	0.35	0.35
X6	0.48	1.0	0.93	0.98	0.57	0.6
X7	0.47	0.93	1.0	0.98	0.6	0.63
X10	0.48	0.98	0.98	1.0	0.6	0.62
X11	0.35	0.57	0.6	0.6	1.0	0.99
X12	0.35	0.6	0.63	0.62	0.99	1.0

perceived indoor temperature in spring. The average design perceived indoor temperature in winter was 21.1 ± 0.7 °C, and in the spring 22.7 ± 1.2 °C. The difference in computational temperature in the room in spring and winter is statistically significant was 21.1 ± 0.7 °C, and in the spring 22.7 ± 1.2 °C. The difference in the design perceived indoor temperatures in spring and winter is statistically significant.

Differences between the average perceived indoor temperatures, declared by men and women are statistically insignificant. The average perceived temperatures declared in the room by women was 21.2 ± 2.1 °C, by men 21.5 ± 2.2 °C; the difference between the averages was about 0.4 °C. The conclusion is that the temperature sensation of young (and probably healthy) people is not gender dependent.

Differences between average perceived indoor temperature declared by all respondents in winter and in spring are statistically significant. The average perceived indoor temperature declared in winter was lower by about 1.3 °C than the average perceived indoor temperature declared in spring. The average perceived indoor temperature declared in winter was 20.2 ± 1.7 °C, and in spring 21.5 ± 2.1 °C.

The perceived indoor temperature declared in the winter was almost constant and did not depend on the perceived temperature of the outdoor air.

The differences observed when declaring perceived temperatures by women and men in relation to the perceived design temperature indicate that men are more accurately able to determine the temperature.

The abovementioned conclusions apply to people in a specific age group (23 years) performing light-sedentary work.

Research will continue on other age groups of respondents and with other physical activity, because presumably the perceived temperature values of men and women may differ from each other in different test conditions.

Funding information The study has been executed with resources of S/WBiŚ/2/18 and S/WBiŚ/4/14 statutory work financed by the Ministry of Science and Project co-financed by the European Regional Development Fund under the Regional Operational Program of the Podlaskie Province for the years 2007–2013—5.2 and 1.1.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

- ASHRAE (2001) ASHRAE handbook of fundamentals
- ASHRAE (2013) Thermal Environmental Conditions for Human Occupancy ANSI/ASHRAE Standard 55-2013
- Asif A, Zeeshan M, Jahanzaib M (2018) Indoor temperature, relative humidity and CO₂ levels assessment in academic buildings with different heating, ventilation and air-conditioning systems. *Build Environ* 133:83–90
- Chmura P, Konefał M, Andrzejewski M, Kosowski J, Rokita A, Chmura J (2017) Physical activity profile of 2014 FIFA World Cup players, with regard to different ranges of air temperature and relative humidity. *Int J Biometeorol* 61:677–684
- Draper NR, Smith H (1998) Applied regression analysis, Third edn. Wiley, New York
- Dziubanek G, Spychała A, Marchwińska-Wyrwał E, Rusin M, Hajok I, Ćwieląg-Drabek M, Piekut A (2017) Long-term exposure to urban air pollution and the relationship with life expectancy in cohort of 3.5 million people in Silesia. *Sci Total Environ* 580:1–8
- Estrada-Vidal LE, Tójar-Hurtado J-C (2017) College student knowledge and attitudes related to Sustainability Education and environmental health. *Procedia – Social Behav Scien* 237:386–392
- Frasca F, Siani AM, Casale GR, Pedone M, Bratasz Ł, Strojcecki M, Mleczkowska A (2017) Assessment of indoor climate of Mogiła Abbey in Kraków (Poland) and the application of the analogues method to predict microclimate indoor conditions. *Environ Sci Pollut Res* 24:13895–13907
- Gładyszewska-Fiedoruk K, Nieciecki M (2016) Indoor air quality in a multi-car garage. *Energy Proc* 95:132–139
- Grafem A, Hals R (2002) Modern statistical for the life sciences. Oxford University Press, New York
- Heathcote A, Berne's E (2010) Development of ego state theory: where did it all begin and who influenced him? *Trans Analysis J* 40(3–4): 254–260
- Hwang SH, Lee GB, Kim IS, Park WM (2017) Formaldehyde and carbon dioxide air concentrations and their relationship with indoor environmental factors in daycare centers. *J Air Waste Manage Assoc* 67(3):306–312
- Krzanowski W (1998) An introduction to statistical modeling. Arnold, London
- Kviesis A, Klavina A, Vitols G (2017) Development of classroom microclimate monitoring system. *Eng Rural Devel* 16:719–724
- Lin Z, Deng S (2008) A study on the thermal comfort in sleeping environments in the subtropics—developing a thermal comfort model for sleeping environments. *Build Environ* 43:70–80
- Mac Berthouex P, Brown LC (2002) Statistics for environmental engineers, Second edn. Lewis Publisher, Boca Raton
- Marć M, Śmiełowska M, Namieśnik J, Zabiegała B (2018) Indoor air quality of everyday use spaces dedicated to specific purposes—a review. *Environ Sci Pollut Res* 25:2065–2082
- Moffat RJ (1988) Describing the uncertainties in experimental results. *Exp Thermal Fluid Sci* 1(1):3–17
- Mosteller F, Tukey JW (1997) Data analysis and regression. Addison-Wesley, London
- Rencher AC (2000) Linear models in statistics. Wiley, New York
- Skowron K, Grudlewska K, Kwiecińska-Piróg J, Gryń G, Śrutek M, Gospodarek-Komkowska E (2018) Efficacy of radiant catalytic ionization to reduce bacterial populations in air and on different surfaces. *Sci Total Environ* 610–611:111–120
- Śmiełowska M, Marć M, Zabiegała B (2017) Indoor air quality in public utility environments—a review. *Environ Sci Pollut Res* 24:11166–11176
- STATISTICA (2002) System Reference, Polish Edition, StatSoft Polska Sp. z o.o
- Sulewska MJ (2012) The control of soil compaction degree by means of LFWD. *Baltic J Road Bridge Eng* 7(1):36–41
- Szargut J (1968) Termodynamika techniczna: dla kierunków nieenergetycznych, Wydawnictwa Naukowe Politechniki Śląskiej (In Polish)

- Sztulc P (2017) Badanie temperatury powietrza w pomieszczeniu, Master's Thesis under direction K. Gładyszewska-Fiedoruk, Białystok University of Technology, Poland (In Polish)
- Teleszewski T, Gładyszewska-Fiedoruk K (2018) Changes of carbon dioxide concentration in classrooms - simplified model and experimental verification. *Pol J Environ Stud* 27(5): 2397–2403
- Toy S, Kántor N (2017) Evaluation of human thermal comfort ranges in urban climate of winter cities on the example of Erzurum city. *Environ Sci Pollut Res* 24:1811–1820
- Wang Z (2006) A field study of the thermal comfort in residential buildings in Harbin. *Build Environ* 43:1034–1039
- Web-1 (2018) <https://freemeteo.pl/pogoda/bialystok/historia/codzienna-historia/?gid=776069&station=4155&date=2017-11-26&language=polish&country=poland>. Accessed 27-11-2017
- Wolański N (2012) Rozwój biologiczny człowieka (Human biological development). PWN, Warszawa (**In Polish**)