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## ORIGINAL RESEARCH PAPER



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# Projected parameters of air in the classroom and their impact on the human body

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## ABSTRACT

The air temperature in school buildings significantly affects the ability of students and teachers to focus on the educational process. Students usually begin to feel an increase the temperature in room. The purpose of this study is to find the limit of the temperature rise in the classroom when people no longer feel the temperature rise in the room. For this reason, several experimental measurements of indoor air parameters were carried out: air temperature, relative humidity and carbon dioxide concentration. Measured temperature differences and individual subjective ratings of audiences determined the dependence using mathematical statistics, from which can be determined the critical level of increase in air temperature at which people no longer perceive the change in air temperature.

## KEYWORDS

air temperature, relative humidity, correlation degree, mathematical statistics

## 1. INTRODUCTION

Microclimate conditions in school buildings affect students' ability to concentrate and engage in learning. The most perceived indicator of the internal environment is air temperature. According to statements [1], thermal environment, which causes thermal discomfort, significantly affects the performance of people indoors. Six factors influence on thermal comfort: air temperature, radiation temperature, air velocity, relative humidity, clothing insulation and metabolic heat. Research [2] show that self-efficacy (persistence, concentration, and productivity) improves at individual thermal satisfaction increases. In the study [3] was conducted seven-day experiment in Singapore, in which was carried a portable sensor that recorded air temperature, relative humidity and CO<sub>2</sub> concentration at 1-min intervals. High acceptability was found at indoor, whereas low acceptability was found for outdoor and transport environments.

In the study [4], which analyzed thermal comfort in secondary and elementary schools, scientists have concluded that, as a rule, students prefer “cooler than neutral” sensations, the desired temperature is estimated to be 2–3 K lower than neutrality, predicted for adults under

the same temperature influences of the environment. Thermal discomfort may have a lasting and short-lived effect on the learning process, affecting not only on school work, but also on entry into working life [5]. This has been clearly demonstrated in the studies [6–9], which investigated the effect of thermal conditions on the performance of primary and secondary school students.

The study concerning the students' thermal comfort and perceived air quality in natural ventilated university classrooms in north-west China under prevailing mean outdoor air temperature 10 °C were carried out. Results have shown that the people's acceptability of indoor air quality was mainly affected by thermal sensation [10]. Research [11–13] showed good consistency between the measurement data, and survey data, and thus indicated students' good ability to assess the quality of the air in their classrooms. Improved comfort at elevated room temperature can be achieved by changing the airflow rate [14–17]. However, in this study, the main focus was on investigation the effect of indoor air temperature on humans with natural ventilation of the room without the use of mechanical ventilation and change of air flow rate. The experimental investigations were conducted in terms of how people in the room are able to perceive the temperature rise [18, 19].

## 2. AIM OF RESEARCH

The aim of the study is to find the interval of air temperature between the beginning and the end of stay of the person in room, what a person is capable of perceiving and when the temperature difference no longer perceives.

## 3. CHARACTERISTICS OF THE EXPERIMENTAL ROOM

In order to determine the perception of correspondingly no longer perceiving the temperature rise in the room by humans, an experiment was conducted in a selected class of school building. The selected audience is located in a 5-story building on the fifth floor. The classroom has length 11.12 m, width 5.4 m and height from 1.75 to 4.31 m. There are 12 windows in size: 0.74 m high and 0.76 m wide (Fig. 1). There are six opened windows and six windows do not open. The roof paneling is equipped with 6 window openings with the height 1.1 m and width 0.7 m. The length of the seams to provide ventilation with infiltration air is  $l = 39.6$  m. Internal room volume is 192.00 m<sup>3</sup>, floor area is 60.05 m<sup>2</sup>.

## 4. USED MEASURING EQUIPMENT

During the experiment, the indoor air parameters have been measured: temperature, carbon dioxide concentration, and relative humidity. A Testo 435-4 measuring device with a Testo 0632 sensor was applied for the measurement.

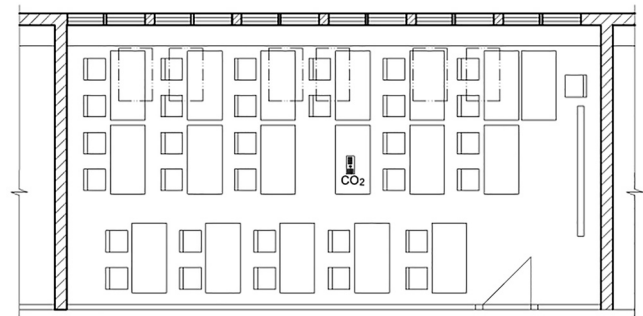


Fig. 1. Plan of the classroom with the presence of the Testo 0632 sensor

The technical parameters of the measuring instrument are as follows: temperature measurement range—from 0 °C to +50 °C, sensitivity of the device –0.1 °C, and accuracy of the device –0.3 °C. The relative humidity diapazon is 0–100%, the sensitivity of the device is  $\pm 0.1\%$  relative humidity, and the accuracy of the device is  $\pm 1.8\%$ . CO<sub>2</sub> concentration measurement range is from 0 ppm to +10,000 ppm, the sensitivity of the device is 1 ppm, and its accuracy is  $\pm 3\%$ . The operating temperature of the measuring instrument ranges from –20 °C to +50 °C. The unit was located near the center of the occupied territory at the height of the head of a sitting person about 1.05 m. People were evenly distributed throughout the room. This approach is consistent with the results that have been published [20–22].

In order to allow a mathematical description of the course on the experimental results, it is significantly to maintain stable boundary conditions in measurement [23–25]. Besides the measured internal characteristics, hourly data on ambient air parameters, for example, air temperature and wind velocity were recorded. The displayed data affects the rate of ventilation caused by infiltration.

## 5. MATERIALS AND METHODS

The experimental measurements were taken in the winter months of January and February during the written preparation for the exam in the same subject. During the study, 28 experimental measurements were performed. Other students with different numbers always participated in the experiment. There were a total of 304 students, including 212 men and 92 women. The average age was 23 years. Data on subjects participating in the experiment are shown in Table 1. All students performed the same activity during the experimental measurement - written preparation for the exam in the same subject.

Each experimental measurement began in the afternoon, the day before the students arrived in the room. The experimental room was initially ventilated by natural ventilation, opening the windows to a carbon dioxide concentration of approximately 420 ppm. The room was cooled during this ventilation. After ventilation, all windows and

Table 1. Quantity of experiment participants

| Measurement number | Quantity of men (–) | Quantity of women (–) | Quantity of people (–) |
|--------------------|---------------------|-----------------------|------------------------|
| 1                  | 10                  | 1                     | 11                     |
| 2                  | 13                  | 4                     | 17                     |
| 3                  | 14                  | 3                     | 17                     |
| 4                  | 12                  | 8                     | 20                     |
| 5                  | 9                   | 4                     | 13                     |
| 6                  | 12                  | 4                     | 16                     |
| 7                  | 5                   | 1                     | 6                      |
| 8                  | 4                   | 1                     | 5                      |
| 9                  | 9                   | 5                     | 14                     |
| 10                 | 10                  | 3                     | 13                     |
| 11                 | 5                   | 0                     | 5                      |
| 12                 | 4                   | 1                     | 5                      |
| 13                 | 3                   | 0                     | 3                      |
| 14                 | 10                  | 10                    | 20                     |
| 15                 | 12                  | 6                     | 18                     |
| 16                 | 6                   | 5                     | 11                     |
| 17                 | 9                   | 2                     | 11                     |
| 18                 | 3                   | 4                     | 7                      |
| 19                 | 3                   | 2                     | 5                      |
| 20                 | 1                   | 1                     | 2                      |
| 21                 | 6                   | 5                     | 11                     |
| 22                 | 5                   | 1                     | 6                      |
| 23                 | 4                   | 5                     | 9                      |
| 24                 | 7                   | 5                     | 12                     |
| 25                 | 12                  | 5                     | 17                     |
| 26                 | 10                  | 5                     | 15                     |
| 27                 | 10                  | 1                     | 11                     |
| 28                 | 4                   | 0                     | 4                      |

doors were closed indoors, and in the day and night the room air was heated to the desired temperature with hot water system, the average value of which was 22.4 °C. At the time of preparation, no one was in the room. Between 7:55 and 8:00, the doors were opened for students to enter the room.

At the beginning of their stay, students completed the first indoor air quality questionnaire and began to work separately on their written preparation. In the first questionnaire, participants commented on the perceived room temperature at the beginning of their stay, indicating one of the following options: Coolly, Little coolly, Acceptable temperature, Little heat and Heat.

After completing the written exam and just before leaving the room, the students completed a second questionnaire about the room air quality. In the second questionnaire, people also commented on the perceived room temperature as at the beginning of the room. The total length of stay was approximately 90 min. After completing the written preparation and filling out the questionnaires, the participants of the experiment immediately left the premise.

At the measurement's realization, the temperature, relative humidity and carbon dioxide concentration have been fixed. In addition, ambient air temperature, relative humidity, velocity of wind, carbon dioxide concentration and state of cloudiness have been recorded.

## 6. MEASUREMENT OF AIR PARAMETERS

Internal and external air characteristics have been measured during the experimental studies. In order to obtain comparative values indoors, all measurements were made at the same time of year in the same room, but still with other persons. Similar studies were conducted in [26] within the scope temperature 21–22.6 °C, relative humidity 35–50% and CO<sub>2</sub> concentration 1000–3700 ppm.

Table 2 documents measured ambient average values of air temperature, relative humidity, wind velocity, and cloud cover for people staying in the room. The concentration of CO<sub>2</sub> in the outside air was approximately 420 ppm.

A room was measured with the air temperature, relative humidity and CO<sub>2</sub> concentration. Three mentioned parameters names to set the parameter correction to enable are available: initial and final temperatures, initial and final concentration of CO<sub>2</sub> and length of stay.

Tables 1 and 2 are visually presented on the graph of Fig. 2. The purpose of the graph is to observe the cause of the room air temperature rise. The graph shows the number of persons in the room during each experimental measurement. The individual measurements are arranged in the order from 1 to 28 from left to right.

Table 2. Results of measuring average parameters of ambient air

| Measurement number | Temperature (°C) | Relative humidity (%) | Wind velocity (m s <sup>-1</sup> ) | Cloudiness |
|--------------------|------------------|-----------------------|------------------------------------|------------|
| 1                  | –6.40            | 75                    | 1.0                                | overcast   |
| 2                  | 0.30             | 96                    | 4.0                                | overcast   |
| 3                  | 3.60             | 82                    | 0.5                                | clear      |
| 4                  | 3.00             | 84                    | 1.5                                | overcast   |
| 5                  | 4.90             | 79                    | 0.5                                | overcast   |
| 6                  | 5.20             | 85                    | 2.1                                | overcast   |
| 7                  | 6.70             | 87                    | 2.1                                | overcast   |
| 8                  | 1.40             | 82                    | 3.1                                | overcast   |
| 9                  | 7.20             | 66                    | 1.0                                | overcast   |
| 10                 | –0.70            | 80                    | 2.1                                | clear      |
| 11                 | 0.30             | 80                    | 2.1                                | overcast   |
| 12                 | 0.90             | 82                    | 2.1                                | overcast   |

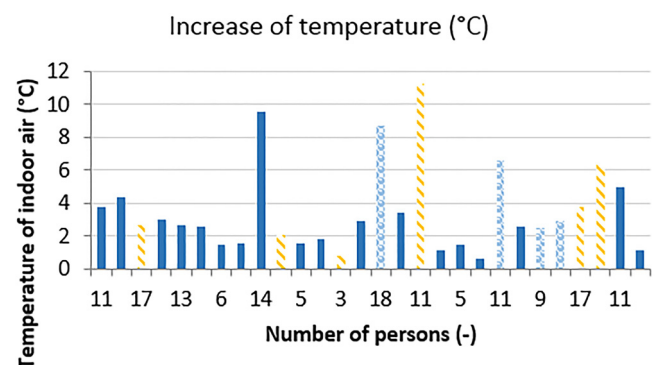
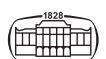


Fig. 2. Increase of temperature in room; // sky is completely clear; ~ cloudy; ■ sky is completely cloudy



During the research, the air temperature in the room varied within the limits at the beginning of the experiment  $t_{in} = [19.4, \dots, 24.6]^\circ\text{C}$  and at the end of the experiment was  $t_{in} = [23.3, \dots, 29.6]^\circ\text{C}$ . The concentration of  $\text{CO}_2$  increased from 437 ppm to 2819 ppm.

From Fig. 2 it can be seen that the stay of persons caused the greatest influence on the increase in the air temperature in the room. The average temperature increase in the number of persons from 1 to 10 was  $1.52^\circ\text{C}$ . With the number of people in the room from 11 to 20, the temperature increase was  $4.81^\circ\text{C}$ .

When the room air temperature was lower, the room temperature increase was higher. For example, at an air temperature at the beginning of a person's stay from  $19$  to  $21^\circ\text{C}$ , an increase of  $3.76^\circ\text{C}$ , and at an initial temperature of a person's stay from  $22$  to  $24^\circ\text{C}$ , an increase of  $3.36^\circ\text{C}$ .

## 7. RESULTS AND DISCUSSION

The extensive parametric studies of the effect of air temperature and  $\text{CO}_2$  concentration on human perception of temperature and general air condition at the beginning and end of classroom have been carried out. In the process students answered the questions in a test form on how comfortable they feel in the audience.

The input factors that affect people's well-being were selected as follows:

- $X_1$ –Temperature on the start stay ( $^\circ\text{C}$ );
- $X_2$ –Temperature on the end stay ( $^\circ\text{C}$ );
- $X_3$ –Increase of temperature =  $X_2 - X_1$  ( $^\circ\text{C}$ );
- $X_4$ –Concentration of  $\text{CO}_2$  at the start of stay (ppm);
- $X_5$ –Concentration of  $\text{CO}_2$  at the end of stay (ppm);
- $X_6$ –Increase of concentration =  $X_5 - X_4$  (ppm).

The test results were analyzed separately for men and women. Generalization was performed and the evaluation parameters were obtained depending on the number of people in the room.

The evaluation parameters were determined by the formula:

$$Y = \frac{Y_i}{N}, \quad (1)$$

where  $Y_i$  is the measuring parameter;  $i = 1, 2, \dots, 14$ ;  $N$  is the number of men and women interviewed separately.

The survey results were grouped according to students' answers.

Respondents' perception of room temperature at the beginning of the study was determined by the criteria:  $Y_1$  – slightly cold,  $Y_2$  – acceptable temperature,  $Y_3$  – weak heat.

Respondents' perception of the air condition at the beginning of the study was determined by criteria:  $Y_4$  – fresh air,  $Y_5$  – acceptable condition,  $Y_6$  – light odor,  $Y_7$  – heavy air.

At the end of the study, perceptions of room temperature were determined by criteria:  $Y_8$  – slightly cold,  $Y_9$  – acceptable temperature,  $Y_{10}$  – weak heat,  $Y_{11}$  – heat.

At the end of the study, the respondents' perception of air was determined by the criteria:  $Y_{12}$  – acceptable condition,  $Y_{13}$  – light odor,  $Y_{14}$  – heavy air.

As it can be seen, many research criteria were covered during the survey. Therefore, mathematical statistics were used to process the experimental data.

The results of the survey were processed in tabular form separately for men and women. The coefficients shown in the table show the correlation between the input factors and the research criteria. The increased correlation coefficient indicates the increased influence of the input factor on the study criterion.

Table 3 shows the results of the experimental data for men in the classroom.

According to the feelings of men we can conclude, that the elevated temperature and heavy air at the end of the study are affected by the temperature increase. This is evidenced by an increased the correlation degree of  $Y = 0.6$  and above.

Table 4 shows the processing of the experimental data obtained from the questionnaires of women.

Table 3. Processing of experimental data on feelings of men

| No |       | $Y_1$ | $Y_2$ | $Y_3$ | $Y_4$ | $Y_5$ | $Y_6$ | $Y_7$ | $Y_8$ | $Y_9$ | $Y_{10}$ | $Y_{11}$ | $Y_{12}$ | $Y_{13}$ | $Y_{14}$ |
|----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|----------|----------|----------|----------|
| 1  | $X_1$ | −0.52 | 0.24  | 0.46  | −0.31 | 0.25  | −0.01 | 0.01  | −0.26 | −0.04 | 0.15     | 0.05     | −0.05    | −0.03    | 0.01     |
| 2  | $X_2$ | −0.46 | 0.2   | 0.37  | −0.32 | 0.05  | 0.23  | 0.35  | −0.37 | −0.36 | 0.02     | 0.7      | −0.38    | 0.14     | 0.63     |
| 3  | $X_3$ | −0.19 | 0.08  | 0.12  | −0.16 | −0.01 | 0.26  | 0.32  | −0.25 | −0.37 | −0.07    | 0.72     | −0.39    | 0.17     | 0.62     |
| 4  | $X_4$ | 0.04  | −0.09 | −0.01 | 0.16  | −0.24 | 0.05  | 0.21  | 0.18  | −0.27 | −0.13    | 0.35     | −0.27    | 0.06     | 0.24     |
| 5  | $X_5$ | 0.11  | −0.15 | −0.02 | −0.06 | −0.29 | 0.39  | 0.34  | 0.05  | −0.43 | 0.15     | 0.38     | −0.48    | 0.37     | 0.54     |
| 6  | $X_6$ | 0.11  | −0.15 | −0.02 | −0.07 | −0.28 | 0.39  | 0.34  | 0.04  | −0.43 | 0.15     | 0.37     | −0.47    | 0.38     | 0.54     |

Table 4. Processing of experimental data on feelings of women

| No |       | $Y_1$ | $Y_2$ | $Y_3$ | $Y_4$ | $Y_5$ | $Y_6$ | $Y_7$ | $Y_8$ | $Y_9$ | $Y_{10}$ | $Y_{11}$ | $Y_{12}$ | $Y_{13}$ | $Y_{14}$ |
|----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|----------|----------|----------|----------|
| 1  | $X_1$ | −0.18 | 0.09  | −0.09 | −0.35 | −0.13 | 0.16  | 0.06  | −0.34 | −0.17 | −0.01    | 0.22     | −0.24    | −0.02    | 0.06     |
| 2  | $X_2$ | −0.22 | 0.12  | 0.23  | −0.07 | −0.02 | 0.16  | 0.07  | −0.30 | −0.25 | 0.22     | 0.44     | −0.19    | 0.12     | 0.54     |
| 3  | $X_3$ | −0.14 | 0.08  | 0.30  | 0.13  | 0.05  | 0.07  | 0.04  | −0.13 | −0.17 | 0.30     | 0.34     | −0.07    | 0.14     | 0.54     |
| 4  | $X_4$ | −0.07 | −0.04 | −0.03 | 0.20  | −0.33 | 0.11  | 0.37  | 0.26  | −0.25 | −0.18    | 0.51     | −0.17    | 0.06     | 0.17     |
| 5  | $X_5$ | 0.23  | −0.06 | 0.30  | −0.06 | 0.06  | 0.41  | 0.20  | 0.37  | −0.14 | 0.20     | 0.29     | −0.23    | 0.53     | 0.35     |
| 6  | $X_6$ | 0.23  | −0.06 | 0.30  | −0.07 | 0.07  | 0.41  | 0.19  | 0.36  | −0.13 | 0.21     | 0.28     | −0.22    | 0.53     | 0.35     |



It can be concluded from the feelings of women that despite the fact that the correlation rates are lower than those of men, women are more clearly in the light of the smell at the end of the study, which is affected by the concentration of CO<sub>2</sub>.

## 8. CONCLUSIONS

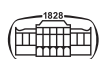
The article presents studies to determine the interval of air temperature between the beginning and the end of stay of the person in room. The difference in temperature, in terms of human perception, was studied.

A correlation analysis was performed when men and women were in the room, respectively. According to the feelings of men it was concluded, that the elevated temperature and heavy air at the end of the study are affected by the temperature increase. This is evidenced by an increased degree of correlation of  $Y = 0.6$  and above. At the same time, women are more clearly in the light of the smell at the end of the study, which is affected by the concentration of CO<sub>2</sub>. At the same time, correlation coefficients in women are somewhat lower than in men, which indicate that women are more sensitive to changes in the environment.

On the basis of correlation analysis, mathematical formulas were derived to simplify the calculation process and bring the results to universality.

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