

SESSION E: THERMAL TECHNIQUE AND ENVIRONMENTAL PROTECTION

Assessment of the microclimate and subjective perception of the thermal environment in school

Valentina Zochinova^{1*}, Mihaela Ivanova¹, Tsvetelina Shalamanova¹

¹ National Centre of Public Health and Analyses, Physical Factors Department, Sofia, Bulgaria

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* Correspondence: zochinova@abv.bg

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ABSTRACT

The report presents results of a study of thermal comfort as a criterion for ensuring a favorable learning environment in school buildings. By combining objective measurements of the physical factors of the environment, PMV/PPD indices and subjective surveys, the influence of the microclimate on students in high school are analyzed. The study includes objective measurement and assessment of the microclimate by the classical method and indices for thermal comfort and assessment of the subjective thermal sensation of students during the measurement. It is performed during the “cold” period of the year, which is characterized by an average twenty-four-hour temperature below 10°C and covers 300 male students (14–16 years old) in schools in Sofia. Specialized equipment is used to measure microclimate parameters: temperature, relative humidity, air velocity, radiation temperature and PMV/PPD indices. Tools for visualizing comfort data of the PMV and PPD indices were used as well. To assess the subjective thermal sensation of the environment an anonymous survey among students of the mentioned age group was conducted with a non-representative sample. Conclusions have been drawn concerning the connection between the data from the two types of research, which provides information about the relationship between the values of the studied parameters of the microclimate in the classrooms and the ability of students to concentrate at the temperatures causing discomfort. Over 70% of respondents indicate that thermal conditions affect in moderate to very strong degree affects their attention and concentration. The existing limit values for microclimate could be used as a starting point for development a new legislation for schools environment, but other approach is needed for assessment and control thermal environment.

KEYWORDS

Microclimate, Thermal comfort, School hygiene, High school students, PMV and PPD indices.

1. INTRODUCTION

Ensuring an thermal comfort in schools is a key factor for the health and performance of students. Thermal comfort significantly affects the concentration and performance of students in an educational environment. Scientific research shows that optimal thermal conditions of the learning environment consistent with thermal comfort conditions improve students' ability to concentrate, especially on tasks that require sustained attention and cognitive effort [1] and perform well academically, while discomfort can negatively affect these abilities. The impact of microclimate on learning outcomes can be observed in various aspects of student performance, including academic achievement, emotional well-being, and social development. This relationship is especially important in environments where students spend long periods, such as classrooms in schools. The present study is focused on the dynamics of thermal sensation during different seasons of the year. The aim is to establish to what extent the objective assessment of the physical parameters of the environment corresponds to the results of a study of the subjective thermal sensation of students.

2. MATERIAL AND METHOD

The study includes objective measurement and assessment of the microclimate using classical and exposure indices and assessment of the students' subjective thermal sensation during the measurements.

The applied method takes into account the specifics of microclimate in classrooms, to determine the conditions of thermal comfort in schools, both for students and for characterizing the working environment of teachers.

The present research covers 14 classrooms. The studied premises are in a five-story building with the same geographical orientation east/southeast. They are centrally heated and naturally ventilated.

A preliminary survey and analysis of the learning environment is carried out to identify the sources of heat and humidity, and the air movement. The conditions and parameters of the external environment are taken into account: external temperature and, sunlight. These data make it possible to make an accurate assessment of the parameters of the microclimate in the classroom and to search for the possible connection between the registered environmental parameters values and the subjective sensation among the students during the measurements.

A multidisciplinary approach was applied in the study, which was structured in three stages as follows:

- Objective measurements of temperature, humidity and air velocity.
- Measurements of exposure indices PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) according to ISO 7730 [2].
- Assessment of subjective heat perception by conducting an anonymous survey among 300 students (14-16 years old) using the 7-point Fanger scale [3].

2.1. Characterization of the Studied Group

The study was conducted among high school students aged 14 to 16. They were characterized by level of education, age, gender, thermal insulation of the clothing worn and metabolism. Thermal insulation was determined according to BNS EN ISO 7933 [2] for the thermal characteristics of clothing, and metabolic rate according to BNS EN ISO 8996 [4].

2.2. Objective Study of Microclimate Parameters in Classrooms

The measurements of temperature, humidity, air velocity and radiation temperature at the predetermined points was carried out at regular intervals of time depending on the learning process or the characteristics of the classroom. The interval between the first and last measurements for the day was not less than half of the established duration of the students' shift in the classroom, and their number was at least 3 to determine the dynamics of the environment.

The measurements were carried out during the cold period of the year which is characterized by an average twenty-four-hour temperature below 10 °C and the day interval is chosen to cover the period of the classes. They were performed three times a day, at three levels above the ground – at the level of ankles, abdomen and head of students at sitting position. Measurement duration is determined by the time constant of the measuring equipment.

The points are indicated in a schematic field and in a study protocol, where all measured values of the microclimate components are reflected in the time range determined according to the methodology.

Due to the lack of a specific regulatory document on the requirements for the microclimate in schools for children and adolescents, a work environment regulation was used [5]. It determines the limit values of the parameters air temperature, air velocity and humidity for two periods of the year: "warm" and "cold". For this case limit values for the "cold" period on the year, and "light physical work" (sitting without systematic physical exertion or lifting and carrying of weights). The limit values are as follows: air temperature from 18 to 25 °C, air velocity up to 0.2 m/s and relative humidity in the interval from 30% to 75%.

The results of the measurements of the microclimate parameters are calculated separately for each room determined for measurement. The results for the values of temperature (t), relative humidity (Φ) and air velocity (v) used for assessment are determined by the formulas:

$$\begin{aligned} X_{\min} &= X_{\varphi} - S; \\ X_{\max} &= X_{\varphi} + S; \\ X_{\varphi} &= \frac{X_1 + X_2 + X_3 + \dots + X_n}{n}; \\ S &= \sqrt{\frac{1}{n-1} \left[(X_1 - X_{\varphi})^2 + (X_2 - X_{\varphi})^2 + \dots + (X_n - X_{\varphi})^2 \right]}, \end{aligned}$$

where $X_1, X_2, \dots, X_n$ are the measured values of the respective parameter; $X_{\min}$ – the minimum value of the parameter X ; $X_{\max}$ – the maximum value of the parameter X ; n – the total number of measurements of the respective parameter (temperature, relative humidity and air velocity) carried out at the workplace designated for measurement for the respective period of the year; S – the standard deviation of the respective parameter. The resulting intervals ($t_{\min}$; $t_{\max}$), ($\Phi_{\min}$; $\Phi_{\max}$) and ($v_{\min}$; $v_{\max}$) are the final results for the comparison with limit values.

2.3. Microclimate Assessment with Thermal Comfort Indices PMV /PPD

The measurement of thermal comfort indices is in parallel to the measurement of microclimate components. Two main parameters are defined for calculating the heat balance:

- Metabolism (Met): Determined based on BNS EN ISO 8996 Ergonomics of thermal environment. Determination of metabolic rate [4]

For the study period, a value of 1.2 met (corresponding to 70 Wm²) was adopted, corresponding to light sedentary activity (studying).

- Thermal insulation of the worn clothing (Clo): Determined according to BNS EN ISO 7730 [2] Table C.2 - Thermal insulation for clothing and changes in optimal working temperature

An average value of 0.7 clo (winter everyday clothing) was adopted for the study period.

For the purposes of the study, the following measuring equipment and auxiliary tools are used:

- Testo 400 combined device
- Thermal comfort meter type 1212 Bruel and Kjaer
- PC software testo Data Control;
- Software tool for calculating and visualizing thermal comfort CBE Thermal Comfort Tool - <https://comfort.cbe.berkeley.edu/>

Aiming to objectively characterizing the solar heating of the premises, measurements of the radiation temperature were also carried out with a spherical thermometer during the measurements.

2.4. Study of the Subjective Perception of Thermal Comfort Among High School Students

Subjective thermal sensation was investigated using a questionnaire method. The developed questionnaire for the study uses Fanger scale [3] and ISO 7730 [2] to assess thermal sensation. The questionnaire is applied during the measurements of the physical parameters characterizing the microclimate, so that the answers to the questions reflect the environmental conditions as much as possible. The questionnaire is used to study the sensitivity to various environmental stressors. The questions refer to the specific individual reactions of the person to environmental factors such as air temperature, air velocity; air humidity. To check the understandability of the questions, a pilot study was conducted on 75 students before the final study. Before the start of the study, written informed consent was obtained from the parents/guardians of the students, as well as the consent of the participants themselves. Participation in the survey is voluntary. No personal data (names, personal identification numbers) were collected that could identify a specific student. The data were processed in aggregate form and are used solely for the purposes of the study. In online surveys, unique codes are used to prevent repeated completion and guarantee objectivity. The results obtained are compared with the data obtained from measurements of environmental parameters and thermal comfort indices. The questionnaire study was approved by the Medical Ethics Committee of the National Center for Public Health and Analysis.

3. RESULTS AND DISCUSSION

3.1. Objective Study of Microclimate Parameters

Air temperature

- The calculated air temperatures in the studied premises are in the range from 15,6 to 26,1°C, with temperature amplitudes during the working day being within 3 – 5 °C, which is the result of sunlight.
- No vertical temperature gradient between ankle level (0.1 m) and head level (1.1 m when sitting) was detected. This prevents the feeling of discomfort in the lower extremities, which is a common problem with poorly designed heating.
- No local cooling was observed from the window surfaces, which indicates good thermal insulation of the window frames used.

Air velocity

- The air velocity in the students' living area ranges between 0.00 m/s to 0.05 m/s.
- During the cold period, strong air flow contributes to the cooling of the human body, but the established values are significantly below the limit values.

Air humidity

- The relative humidity of the air is in the range of 30% to 55%.
- The lower calculated values are close to limit values, which is typical for the winter period due to the operation of heating appliances.
- Humidity remains within limit values, preventing excessive drying of the air and mucous membranes of inhabitants.

Spatial model of a studied room

To visualize the distribution of parameters, a spatial model of the room was prepared with average values plotted by zone: next to a window, next to a door, in the middle of the studied room.

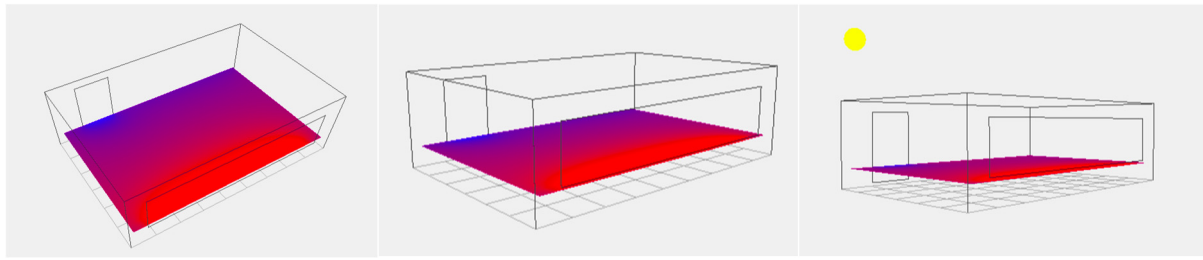


Figure 1: Spatial model

3.2. Results of PPD and PMV Indices Measurements

The use of the PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) indices according to BNS EN ISO 7730 [2] is critically important for the winter period, as it takes into account the subjective thermal sensation of the person, influenced by clothing and metabolism.

As a result of the measurements, the following average values were obtained:

- PMV index: -1.1 to 0.6
- PPD index: 30% to 5%

The minimum value of the measured/calculated PMV values (-1.1) is found near the windows and external walls. The value indicates a feeling of “cool” and is outside the thermal comfort zone according to ISO 7730 (from -0.5 to +0.5). The maximum value (0.6) is observed near the heating appliances. This value corresponds to a feeling of “slightly warm”, which is slightly above the comfort limit. There is a pronounced thermal heterogeneity in the rooms (temperature imbalance between all measurement points), such as registered on sunny days.

The PPD index values from 30% to 5% indicate maximum dissatisfaction (30%), registered in the areas with PMV = -1.1 (around the windows). Nearly a third of the students in these places experience thermal discomfort. Comfort conditions (PPD = 5%) are registered in the central areas of the room. The reasons for the high number of dissatisfied students are cold perception due to the windows, which are the reason for low PMV values (-1.1) and a high percentage of dissatisfied students (30%). Heating devices create peaks up to 0.6 PMV, which also leads to dissatisfaction. The dynamics are due to the low morning temperature in the room and afternoon sunlight.

3.3. Results of the Subjective Study of Thermal Comfort in a Learning Environment

The present research covers 300 respondents, predominant age group is 15 years old (54.5%), followed by 16-year-olds (33.8%) and 14-year-olds (11.7%). The sample is homogeneous, as prevail men (99.1%). The participants are relatively evenly distributed between 8th and 9th grade, and almost all respondents (99.6%) are found in classrooms type of the premises, which does the results representative basically for this one type of educational environment.

By attitude to thermal comfort, majority of the students (61.9%) determine the conditions as comfortable. Despite this, significant share reports for deviations – 18.2% feel medium cold, and 13.9% – mild heat. Although the extreme sensations (very cold or very warm) have low relative share, frequency on emergence of uncomfortable conditions is substantial: 43.5% of respondents indicate that sometimes they experience discomfort by the time on educational classes, and about 14% – often or very often. This shows that even at compliance with the limit values, there are dynamic fluctuations that influence on perception on the environment.

Key result from research is the identification of “unstable/unsteady” temperature “as main problem stated from 65.8% of participants. This significantly exceeds the rest factors as too low or too high temperature, stationary air and air flow. Therefore, not so much the absolute values of the temperature, as much as the lack on sustainability and control on the microclimate appears as a leading factor for discomfort.

The results clearly show that deviations from the comfort temperature show essential negatively impact on the students. At high temperature about 78% of respondents report different degree of discomfort, and at low temperature this share is similar. This testimonies for high sensitivity to temperature changes, regardless from the direction of their deviation from the comfort (neutral sensation).

Especially the effect is significant on cognitive processes. Over 70% of respondents indicate that thermal conditions affect in moderate to very strong degree affects their attention and concentration. From this result it is evident that there is connection between the microclimate in the classroom environment and efficiency on the school process.

Concerning the air quality - 61.3% of respondents define air quality as “moderate”, and 17% - as “bad”. Only 9.4 % evaluate it as excellent. This shows existence of potential ventilation problems that can strengthen the feeling for discomfort and influence negatively health and working capacity.

By the attitude on the preferred measures for improvement, greatest share from students (59.9%) supports the use on climatic systems, which reflects aspiration to better control and stability of the premises environmental parameters. The

opening of the windows also is also considered as an effective measure (28.6%), while smaller share supports the use on fans or implementation of specialized ventilation systems.

Interesting result is the lack of clear dominant preference by attitude on temperature range – 54.6% prefer warmer environment, and 45.4% – colder, which emphasizes the necessity from adaptable and flexible solutions.

The results from the study show that although in most cases the school environment is perceived as relatively comfortable, there are essential problems related to instability of temperature conditions and the insufficient ventilation. These factors are shown to have significant influence on concentration and total well-being on the students. The need from improvement of the control of microclimate, including implementation of additional criteria for comfort and methods for measurement and assessment, it is clear expressed and accordingly to be priority in the management of the school environment.

The analysis on spatial distribution of the results shows that the subjective perception is related to the position of the students, finding "to window" (30.6%), more often reported as "unstable" temperature", which could be explained by the influence of the direct heating from the sun and airmovement. Unlikely the students located in the middle on the room (34.1%), more often indicate the problem of "the immovable air" and the lack of fresh air. The lack on flexibility in the system for heating and ventilation is the reason for the high percentage of those experiencing discomfort (43.5%).

The data from the questionnaire also show that 81.3 % of the students' experience declare strong discomfort or unpleasantness sensation during the school process.

It makes an impression that preferences for the environment are almost equally divided (54.6% for warmer against 45.4% for colder.

The data confirm the hypothesis that the microclimate in the classrooms premises often goes out outside the borders on thermal comfort. The high values on radiation temperature (from the sun) additional load thermoregulation of the students. There is a discrepancy between the normative requirements (limit values) and subjective preferences, such as the students show higher tolerance to cool, but fresh air than to warm and steady environment.

4. CONCLUSION

On the basis on the study, following basic conclusions could be made: The research confirms that the microclimate in the classroom room is a factor of the environment that requires permanent monitoring. The comparison of data from the subjective study with the data from the objective measurements allows more precisely definition of the limit values for thermal comfort, specific for the educational infrastructure. The limit values for microclimate parameters according to Regulation No. RD-07-3 [5] could be used as a starting point for development a new legislation for schools environment, but other approach is needed for assessment and control thermal environment.

The rating "Moderate" for freshness of the air (61.3%) shows that the natural ventilation through opening on windows is insufficient for maintenance of high quality on the air at full capacity on the classrooms.

The students demonstrate high readiness for acceptance on contemporary technologies, with 59.9 % preferring climatic systems, which would decide the problem with the individual regulation.

The thermal comfort it is not simple subjective feeling, but a factor for cognitive efficiency, as the large part of respondents consider that temperature discomfort affects in moderate to very strong degree their attention and concentration.

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