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TESTING OF THERMAL COMFORT AT WESTERN SERBIA ACADEMY OF APPLIED STUDIES

Abstract: *The paper analyzes thermal comfort conditions of Western Serbia Academy of Applied Studies' (hereinafter ASSZS) premises, using the Fanger method. Influence of individual parameters: air temperature, relative humidity, air flow rate, mean radiation temperature, noise and illumination level, as well as influence of thermal insulation of clothing and metabolism intensity assessment on the thermal comfort of employees in ASSZS has been tested. PMV and PPD indexes were measured using these data. A linear correlation between the calculated values of the PMV index and the respondent's statement about the thermal sensation has been determined, too. Statistical processing of the collected data was used to rank the facilities.*

***Key words*:** influence microclimatic parameters, personal parameters on the thermal comfort, thermal comfort assessment, PMV/PPD Fanger*'s* index

INTRODUCTION

Thermal comfort is defined as such a state of mind, i.e. human consciousness, which expresses satisfaction with the thermal environment, ISO 7730, 2005, [1].
A person's thermal sensation is influenced by microclimatic factors, but air temperature, air humidity, air flow rate and mean radiant temperature of the surrounding surfaces are always different at different altitudes, [2,3].

The Rulebook on preventive measures for safe and healthy work at the workplace ("Official Gazette of the RS", number 21/09 and 1/19, hereinafter Rulebook) defines the permissible values of microclimate parameters in the working premises. The requirements for indoor illumination are defined by the standard SRPS EN 12464-1:2012 Light and lighting - Lighting of workplaces, while the quality of illumination as a consequence of daylight and electrical lighting is defined by the SRPS U.C9.100:1963. The limit value of noise exposure is determined by the Rulebook on preventive measures for safe and healthy work when exposed to noise, (Official Gazette of the RS, no. 96/11, 78/15 and 93/19) and the standard SRPS EN ISO 9612:2016 Acoustics - Determination of noise exposure in the working environment - Engineering method. The thermal insulation coefficient of clothing (CLO) is defined by the ISO 9920 standard, while the assessment of metabolic intensity is defined by the ISO 8996 2004 standard.

Table 1. shows the thermal comfort expressed on Fanger's scale (very cold, cold, slightly cool, neutrally pleasant, slightly warm, warm, very warm).

Table 1. *Human thermal sensation (ISO 7730 2005),* [1]

VC	C	SC	NP	SW	W	VW
-3	-2	-1	0	1	2	3

According to the ISO 7730 2005 standard, the thermal environment is considered acceptable if at least 80% of respondents are satisfied with it.

RESEARCH METHOD

Thermal comfort parameters: air temperature, relative air humidity, air flow speed, mean radiant temperature, noise and illumination level, as well as thermal insulation of clothing and assessment of metabolic intensity were measured. Using these data, PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) indices were obtained. The PPD index has been introduced in order to anticipate the percentage of unsatisfied persons in a given thermal environment [1].
Two techniques were employed to gather the data: one involved the use of a questionnaire, while the other involved the use of measuring instruments to measure the microclimatic parameters of noise and illumination in the workplaces of the employees.

Questionnaire

The questionnaire was modified, in accordance with international standard ISO 10551 1995. It consists of sections related to demographic data, workplace data, light perception, noise perception and thermal comfort. At the same time, the evaluation of the intensity of metabolism and the thermal insulation of the clothing was carried out, in accordance with international standards, ISO 7730 2005, ISO 8996 2004 and ISO 9920 2007. While filling out the questionnaire, the respondents did not have the opportunity to see the measured values on the measuring instruments.

Examining the physical conditions of the working environment

The tests were carried out during the month of March 2022, under different external meteorological conditions, in a closed, combination of naturally - artificially ventilated facilities.

The respondents performed their work while standing, sitting on chairs or walking slowly around the workplace. Measurements of the working environment's internal conditions, such as: air temperature, ^{0}C, relative air

humidity, %, air flow speed, m/s, thermal radiation, ^{0}C, noise level, dB(A) and illumination, lux, were carried out during the day, at two different heights: 1.1 m and 1.7 m, in the period from 08:00 to 14:00, and it lasted 5 minutes at each workplace. The measurement results were read on the measuring instruments and the mean value for both heights was taken into account.

The HT–3007SD and TESTO 480 devices were used to measure air temperature, relative air humidity and air flow rate in the working environment. The black globe thermometer for measuring thermal radiation is placed at a height of 1.1 m and 1.7 m. The mean radiant temperature (t_{mr}), was calculated, according to equation 1. and the recommendations of the ISO 7726 1998 standard [3]:

$$t_{mr} = \left[(t_g + 273)^4 + 2{,}5\ 10^8\ v_a^{0,6}(t_g - t_a)\right]^{\frac{1}{4}} - 273 \quad (1)$$

where are:

t_g – temperature of the black globe thermometer, ^{0}C,
t_a – air temperature, ^{0}C,
v_a – air flow velocity, m/s.
A standard globe thermometer has a diameter D = 0.15m, and an emissivity ε_g = 0.95.

The Bruel&Kjaer phonometer, type 2260, and indoor microphone type 4189 were used for noise level measurement. The instrument was placed at a height of 1.7 m, i.e. in the area of the head height of an average person. The sound level meters, microphone and associated cables, have met the requirements specified in IEC 61672-1:2002, first class 1 or class 2 instruments.

The device HD450 was used for illumination level measurement and it was placed at a height of 0.85 m, in the area of the average height of a desk [4].

For the level of metabolism, a value of 1.2 met was taken, which corresponds to moderate work in a sitting position (1 met = 58.15 of the human body surface), i.e. 70 W/m^2. Using a program PMV_cal_tanabe6.xls (live.com), the prediction of the thermal comfort as well as a comparison between these results and the results of the respondents' expression of thermal comfort on the Fanger scale were performed.
Statistical data processing such as the determination of parameters: standard deviation (S), coefficient of variation (Cv), covariance (Sxy) and Pearson's linear correlation coefficient (r) was performed in the paper [5].

RESULTS AND DISCUSSION

Description sample research
Teaching and non-teaching staff at ASSZS, working in different positions, a total of 120 respondents participated in the research. Measurements were made at 15 measuring points. The structure of employees, gender, time interval of work, time spent at the workplace, and declaration of work activities are shown. in Figures 1, 2, 3, 4 and 5.

The mean age value in the Užice Department is 48.18 years, while in the Valjevo Department it is 46.2 years. All respondents stated that there is a glass window at a distance of less than 2m from the respondent's workplace.

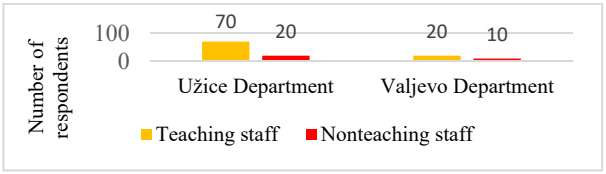

Figure 1. *Structure of employees in ASSZS*

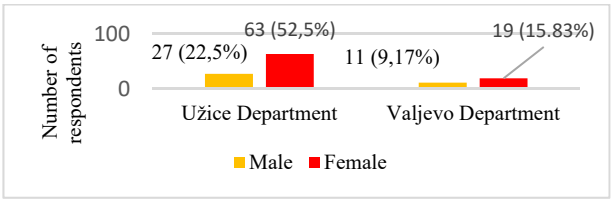

Figure 2. *Gender structure*

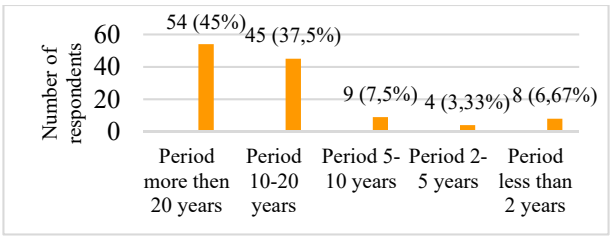

Figure 3. *Years of service*

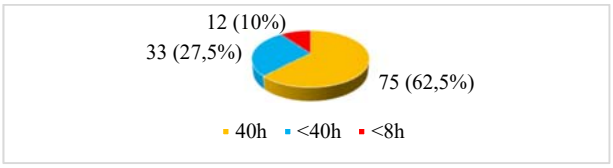

Figure 4. *Working time*

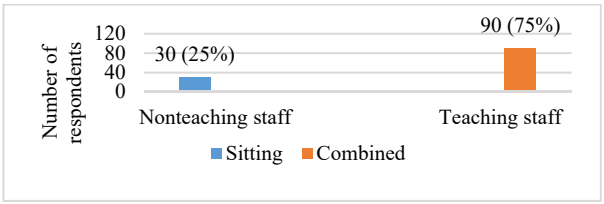

Figure 5. *Work methods of respondents*

Microclimate parameters, illumination and noise level
Information about microclimate parameters was obtained based on respondents' answers at the workplace. Of the teaching staff, only two respondents (2.66%) said that the air is excessively dry and that the humidity level should be higher. Both teachers are male and belong to the younger generation, Figure 6.

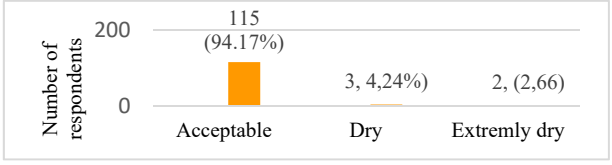

Figure 6. *Air quality*

The results of statements about the sources and illumination level at the workplace are shown in Figure 7.

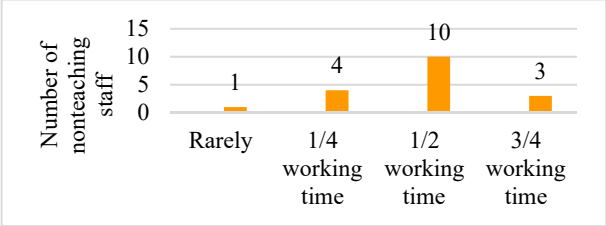

Figure 7. *Sources and illumination level*

Considering the noise level in the workplace, only 3 respondents, 2.5% of the total number of 120 respondents, who worked in the Student Service of the Užice and Valjevo Departments, stated that during ¾ of the working time they should raise their voice in conversation with colleagues.

The results of the microclimate parameters measured values show that the air temperature increases with the increase of the building floors and with the measuring height (1.1m and 1.7m), while the relative humidity values are lower Since there were no observed deviations, the mean values of air flow rate and relative air humidity were determined for both heights in this paper. The highest mean values of relative air humidity and air flow rate were measured in the amphitheaters, in the Užice Department (the largest amphitheater is located on the ground floor) and in the Valjevo Department. This is understandable given that the majority of students remain in those classrooms during lectures and they are constantly getting ventilated.

The mean value of relative humidity in the Student Service, Užice Department, is slightly lower compared to other classrooms in both Departments, which coincides with the statement of the employees of the Student Service, that they would be more comfortable if the relative humidity was higher. The lowest mean value of relative air humidity was measured in the Carpentry Workshop, which is located in the basement of the Užice Department, at 36.8%. That fact and the highest measured air temperature of 24.5^{0}C gives a sense of comfort to the employees.

When the results of the microclimate parameters obtained through the questionnaire and measurements are compared, they almost match.

The results of illumination level measuring and uniformity show that the mean illumination values and uniformity (> 0.85 in all workplaces) are higher than the permitted values, SRPS EN 12464-1:2012. Respondents who belong to non-teaching staff, 18 of them (15%) declared that they experienced eye strain during work which could be due to the previous fact or to spending more time in front of the computer due to a greater volume of work, Figure 8. In this case, there is no complete agreement between the results obtained through the questionnaire and the measurement. According to the Rulebook on preventive measures for safe and healthy work when exposed to noise (Official Gazette of RS No. 96/2011, 78/2015 and 93/2019), the results of noise level measurements show that the measured values are not above the permitted level in both Departments. It is fairly uniform, namely 63dB in the Užice Department and 62dB in the Valjevo Department, which indicates the fact that almost all respondents are exposed to approximately the same noise level in the working environment. Slightly higher noise levels were measured in the Student Services, at 12:00, 70dB, compared to the measurements at 8:00 and 14:00, considering a larger number of students staying in the Student Services at that time. Finally, the percentage of respondents who feel minor consequences due to the increased noise level at that time is small, which does not significantly affect the thermal comfort of employees.

Mean radiant temperature

The results of the mean radiant temperature calculation in Užice and Valjevo Departments, according to equation (1), are shown in Table 2.

At workplaces in the office – the 3rd floor and in the Carpentry workshop – the Užice Department, as well as in the teacher's office in the Valjevo Department, there are deviations, i.e. the values are higher at a height of 1.7m than at a height of 1,1m, but they are small. In general, the mean radiant temperatures in the Užice Department increase with the number of floors of the building, while in the Valjevo Department are fairly uniform throughout the building.

Assessment of thermal comfort

The obtained results of the PMV/PPD index, Table 3., were compared with the respondents' statements on the Fanger's scale.

It was taken that the assessment of thermal insulation of clothing for each respondent (spring clothes - pants, shirt, shoes) is 0.7 clo, i.e. 0.11 m^{2}K/W, (*1 clo=0.155 m^2 ºC/W), ISO 9920 2007. For the metabolism level in this work, a value of 1.2 met was taken, which corresponds to moderate work in a sitting position (1 met = 58.15 human body surfaces, i.e. 70 W/m^2).

In the Užice Department, the state of thermal comfort (0 "neutrally pleasant") was expressed by 52.5% of a total of 120 respondents, for "a little warm" (1), 9.17%, and 17.64% of respondents for "warm " (2), and for "a little cool" (- 1) on the thermal sensation scale. The mean value is 0.28, which means it ranges from "neutrally pleasant" (0) to "slightly warm"(1).

In the Valjevo Department, the state of thermal comfort (0 "neutrally pleasant") was reported by 18.33% of respondents, 5% of respondents for "warm" (2) and 1.66% of respondents for "a little cool" (-1), on the thermal sensation scale.

Table 2. *Mean radiant temperature values in Departments*

Užice Department	Mean radiant temperature, t_{mr}	
	1,1m	1,7m
Office – business secretary	22,4624	22,4160
Student service	22,5376	22,5070
Amphitheatre – I floor	22,2226	22,2226
Teacher's office	23,8166	23,6780
Server room – IT service	24,0205	23,9904
Library	23,6588	23,6191
Classroom – II floor	24,2906	24,0582
Laboratory OSH	24,3033	24,1291
Chemical laboratory	24,2452	24,1581
Office – III floor	24,5754	24,6785
Amphitheatar – III floor	24,5045	24,3227
Carpentry workshop - basement	24,4227	24,6454
Valjevo Department	Mean radiation temperature, t_{mr}	
	1,1m	1,7m
Amphitheatre – ground level	22,4026	22,2820
Administrative tasks – II floor	22,3073	22,2766
Teacher's office	22,5351	22,7701

Table 3. *PMV and PPD values in Departments*

Užice Department	PMV	PPD %
Office – business secretary	-0,39	8,2
Student service	-0,40	8,4
Amphitheatre – First floor	-0,49	10,1
Teacher's office	-0,13	5,4
Server room – IT service	0,02	5,0
Library	-0,04	5,0
Classroom – Second floor	0,08	5,1
Laboratory OSH	0,11	5,3
Chemical Laboratory	0,10	5,2
Office – Third floor	0,11	5,3
Amphitheatar – Third floor	0,16	5,5
Carpentry workshop - basement	0,19	5,8
Mean values	*- 0,0567*	*6,19*
Valjevo Department	PMV	PPD %
Amphitheatre – ground level	- 0,48	9,8
Administrative tasks – Second floor	- 0,43	8,8
Teacher's office	- 0,27	6,6
Mean values	*- 0,3933*	*8,4*

According to the subjective feeling of the respondents, results indicate that the mean value of the thermal sensation respondents, in the Valjevo Department is -0.3933 on the thermal sensation scale, i.e. in the interval from "neutrally pleasant" (0) to "a little warm" (1), Table 3. Generally, the PMV index, in Užice and Valjevo Departments predicts lower values on the thermal scale (colder feeling), than the results of respondents' statements. Using the PMV index it is not possible to accurately predict human thermal comfort in these buildings. Women have lower skin temperatures than men, so the thermal sensation in women is more pronounced in the same thermal environment, and women express a desire for higher air temperatures than men in the same thermal environment [6]. As the basal metabolic rate decreases in men and women, older people in the same thermal environment feel colder than younger people [7]. The fact, that 52.5% of women participated in the Užice Department, i.e. 15.83% in the Valjevo Department and the age structure of the respondents, is not supported by this disagreement between the calculated results of the PMV index and the results of the thermal sensation, because the opposite should be expected. According to [1], the differences in the results between the PMV index and the respondent's statement about thermal comfort may arise due to "bad data entry", i.e. the measured microclimatic parameters of the working environment and the estimated personal parameters of the person [1]. The authors [8] state that the cause may arise due to the psychological and cultural differences of the respondents. The presented results do not confirm the results of the author [9], that the respondents feel colder than predicted by the results of the PMV index.

The ranking of the thermal environment in the Užice and Valjevo Departments, according to [1], indicates that they are in the "B" category. The highest values of the PPD index do not exceed 10%, so the thermal environment is acceptable in both the Užice and Valjevo Departments.

Statistical analysis

Table 4. *Results of the measured air temperature statistical analysis in the working environment*

Location of measurement	t_{sr}, ^{0}C	S	Cv
Užice	23,00	1,06	0,04606
Valjevo	21,75	0,64	0,02935

The working places can be described as "light work - without physical strain", which means that the measured air temperature values are in accordance with the recommendations of the Rulebook. The higher value of the standard deviation is in the Užice Department. The values of the variation coefficients, 4.606% and 2.935%, indicate very small oscillations of the air temperature around the mean value, in both Departments, which may have a slight, negative impact on the respondents in terms of thermal feeling and thermal comfort, Table 4.

The mean values of relative air humidity are within the recommended values according to the Rulebook.

Table 5. *Results of the measured relative air humidity statistical analysis in the working environment*

Location of measurement	Rv	S	Cv
Užice	41,6	2,57	0,06188
Valjevo	43,6	1,71	0,03913

The standard deviation and the coefficient of variation of the relative air humidity indicate greater deviations from the mean values in the Užice Department. The higher value of the coefficient of variation, 6.188%, indicates slightly larger oscillations of relative humidity around the mean values in the Užice Department and it can have a smaller effect on thermal sensation and thermal comfort, especially at low and high air temperatures, Table 5.

Table 6. *Results of the measured air flow rate statistical analysis in the working environment*

Location of measurement	V, m/s	S	Cv
Užice	0,029	0,014	0,4728
Valjevo	0,033	0,021	0,6245

The mean values of air flow rate in both Departments are within the recommended intervals according to the Rulebook. However, high correlation coefficient values, 47.28% in the Užice Department and 62.45% in the Valjevo Department, indicate greater deviations from the average values of air flow rate, which can have a negative impact on the local thermal sensation and local thermal comfort, as shown in Table 6. In this regard, attention should be paid to the height at which the measurement was made [10].

Table 7. *Results of the measured illumination level statistical analysis in the working environment*

Location of measurement	Lux	S	Cv
Užice	420,54	131,66	0,3131
Valjevo	426,67	195.02	0.4571

The mean values of the measured illumination level, in both Departments, are slightly higher compared to the prescribed illumination requirements for workplaces in closed spaces. This is confirmed by the higher values of the correlation coefficient, in the Užice Department, 31.31% and the Valjevo Department, 45.71%, which indicates that the illumination level is higher than provided by the standard, which can have a negative impact on the thermal comfort of employees, Table 7.

Table 8. *Results of the calculated mean radiant temperature statistical analysis in the working environment*

Location of measurement		t_{mr}, ^{0}C	S	Cv
Užice	1,1m	23,755	0,8578	0,03611
	1,7m	23,702	0,8585	0,03622
Valjevo	1,1m	22,415	0,1144	0,0051
	1,7m	22,443	0,2833	0,01262

Considering the impact of thermal radiation on the thermal comfort, in accordance with the international standard, it is necessary to take into account the air flow rate, ISO 7726 1998. Deviations depending on the temperature measurement height and the calculated radiant temperature exist, but they are insignificant. The mean value of the air flow rate was taken into account, for both measurement heights and the values of the coefficient of variation differ slightly, which cannot be a true indicator of whether there is an impact on the thermal comfort in the working environment, Table 8.

Including this results, there are large deviations, which is confirmed by the fact that the respondents declared differently about thermal comfort in relation to the measured values of the parameters, Table 9.

Table 9. *Results of the calculated PMV index statistical analysis*

Location of measurement	PMV	S	Cv
Užice	-0,057	0,23	-4,7564
Valjevo	-0,393	0,11	-0,2789

Table 10. *Results of correlation analysis*

		Mean value	S	Sxy	r
Užice	P	- 0,05	0.24	0,238	0,41
	M V	0,28	0.99		
		Mean value	S	Sxy	r
Valjevo	P	- 0,39	0.10	0,097	0,99
	M V	0,33	0.88		

The results of the correlation analysis, Table 10., indicate that in the Užice Department there is a relatively strong correlation, ($0.2 \leq$ lrl < 0.5), between the PMV index and the respondent's statement, the correlation coefficient is r=0.41. In Valjevo Department there is a strong correlation ($0.8 \leq$ lrl < 1), and the correlation coefficient is lrl=0.99. This result shows that only 16.81% (r^2) of the total variation in the thermal sensation of respondents in the Užice Department is explained by the PMV index, and the rest, 83.19%, by the other influences. In the Valjevo Department, as much as 98% (r^2) of the variation in thermal sensation can be explained by the PMV index.

CONCLUSION

The physical conditions of the work environment can have a direct impact on human health, comfort and productivity [11]. The most important personal parameters are the intensity of metabolism and the thermal insulation of clothing.

The test results show that the microclimatic parameters obtained by the questionnaire and by measuring the appropriate devices almost match, that the mean illumination values are higher than the permitted values, that the thermal radiation is higher than the air temperature in the working environment (questionnaire carried out during the heating season), that noise have no a great impact on thermal comfort in the working environment and that there is no agreement between the PMV index and the respondent's statements on the thermal feeling scale when assessing thermal comfort using the PMV index.

The ranking of the thermal environment in the Užice and Valjevo Departments, [1], based on the results of the respondents' statements, indicates that they are in category "B". The highest values of the PPD index do not exceed 10%, so the thermal environment is acceptable in both Departments. However, the results obtained through a questionnaire-based test that measured four microclimate parameters and two personal parameters show that it is not

possible to completely quarantee the thermal comfort of a person in the working environment.

The statistical analysis of the PMV index calculation shows large deviations in the value of the correlation factor and confirms that the respondents made different statements regarding thermal comfort in relation to the measured values of the parameters, which is in agreement with the linear correlation calculation in the Užice Department. The results in the Valjevo Department showed that the respondents felt "colder" compared to the calculated values of the PMV index, it can be seen that there is an agreement, except for 2% of the variations in the thermal sensation which includes an explaination of other factors.

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BIOGRAPHY

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Ispitivanja toplotnog komfora u Akademiji zapadna Srbija

Nataša Ćirović, Ivana Bojović, Nenad Milutinović

Rezime: U radu su analizirani uslovi toplotnog komfora prostorija u Akademiji strukovnih studija Zapadna Srbija (dalje ASSZS), Fangerovom metodom. Izvršeno je ispitivanje uticaja pojedinačnih parametara: temperature vazduha, relativne vlažnosti vazduha, brzine strujanja vazduha, srednje temperature zračenja, nivoa buke i osvetljenosti, kao i toplotne izolacije odeće i procene inteziteta metabolizma na toplotni komfor zaposlenih u ASSZS. Pomoću ovih podataka izmereni su Fangerovi indeksi PMV i PPD. Izvršen je proračun linearne korelacije između proračunatih vrednosti PMV indeksa i izjašnjavanja ispitanika o toplotnom osećaju. Statističkom obradom prikupljenih podataka izvršeno je rangiranje objekata.

Ključne reči: uticaj mikroklimatskih parametara i ličnih parametara na toplotni komfor, procena toplotnog komfora, PMV/PPD Fangerovi indeksi