

Physical conditions influence to the thermal comfort

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Thermal comfort in buildings can be ensured through four microclimate parameters (air temperature, air humidity, air speed and thermal radiation) and two personal factors (metabolic rate and clothing insulation). A review of the literature in the field of research shows that there are other influential physical parameters that, in laboratory conditions, can cause change in thermal sensitivity of an individual. Noise and illumination intensity as a physical parameters of the working environment can affect thermal sensitivity and thermal comfort of a person. This paper analyses the influence of a microclimate parameters: air temperature, relative humidity, air speed and thermal radiation, as well as the influence of noise and illumination intensity to the thermal comfort of an individual in the indoor environment, with no direct solar radiation.

Key words: thermal comfort, microclimate parameters, noise intensity, illumination intensity

INTRODUCTION

Thermal comfort is defined as a psychophysiological state of a person, not a state of the environment. [1] According to the international standard (ISO 7730 2005), which is accepted as the Serbian standard, thermal comfort is defined as a state of mind, i.e. human consciousness, which expresses satisfaction with the thermal environment. In a stable thermal environment, thermal comfort can be considered a disadvantage of inconvenience. [2]

Researches of microclimatic parameters influence on human thermal comfort has been performed around the world in the last hundred years, both in laboratory conditions, i.e. climate chambers, as well as in a real environment. In buildings, thermal comfort can be provided with four microclimate parameters (air temperature, humidity, air flow rate and heat radiation, i.e. average radiation temperature) and two personal human parameters (metabolic intensity and clothing insulation).

The main goal of this paper is to determine the influence of air temperature, relative humidity, air flow rate and thermal radiation on thermal comfort in the working environment, as well as the relationship between noise and light, and thermal comfort in the working environment indoors, in conditions without direct sunlight radiation, out of the heating season and outside air temperatures in the range from 5°C to 28°C.

1. MICROCLIMATE PARAMETERS AND THERMAL COMFOR

Microclimatic conditions affect people's health, subjective feelings of comfort and work ability a lot. Taken together, or separately, they affect the course of thermoregulatory processes in humans and in some cases can cause people diseases exposed to these conditions. Unfavorable microclimatic conditions have a negative effect on psycho-physical condition and labor productivity. However, it has been proven that a person can still adjust and live in conditions with very large temperature differences, differences in relative humidity, air flow rate and other physical - climatic changes, but it takes some time to get used to, i.e. for acclimatization. As it is known, the temperature of the human body is approximately 37°C. Although people live in areas where the outside temperature is up to + 53°C (Sahara) and down to -72°C (Siberia), they keep their body temperature constant. Even small changes in temperature indicate that the condition of the organism is not normal, i.e. that the person is ill. Maintaining a human body constant temperature is performed either when the produced heat is transferred to the environment or the body is protected from excessive heat release. In order to achieve satisfactory thermal comfort, two conditions must be carry out.

- the first is that the combination of skin temperature and body temperature provides a feeling of thermal comfort - neutrality.

- the second is the fulfillment of the energy balance of the human body in a given environment. This means that the energy obtained by metabolism must be equal to the energy losses from the body due to conduction, convection, radiation, evaporation and respiration. These two conditions are built into the equation of thermal equilibrium of the body, which is called the thermal comfort equation:

$$M - W = H + E_c + C_{res} + E_{res} \quad (1)$$

where are:

M and W - respectively, the level of metabolism and effective mechanical work of the individual,

X - loss of body energy due to conduction, convection and radiation (dry energy losses).

E_c - energy exchange due to evaporation from the skin, and

C_{res} and E_{res} - energy exchange during respiration by convection and evaporation.

The Rulebook on general measures and norms of safety at work for construction facilities intended for working and auxiliary premises (Sl. list SFRJ broj 27/1967.god.) provides a table of norms for temperature, relative humidity and air flow rate in working premises. Table 1 shows the optimal and allowed values for the winter and transition period - outdoor air temperature up to 10°C, as well as for the summer period - outdoor air temperature above 10°C.

Table 1. Norms for temperature, relative humidity and air flow rate in working premises, for the summer and winter period

Type of work	Temperature of outside air								
	to +5°C			from +5 to +15°C			more than +15 °C		
	Temperature [°C]	Rel. humidity [%]	Air fow rate [m/s]	Temperature [°C]	Rel. humidity [%]	Air fow rate [m/s]	Temperature [°C]	Rel. humidity [%] ¹	Air fow rate [m/s]
easy physical work	18-28	max 75	max 0,3	18-28	max 75	max 0,6	max 28	28 °C→55 26 °C→60 24 °C→65 < 24 °C→73	max 0,5
medium physical work	15-28	max 75	max 0,5	15-28	max 75	max 0,6	max 28	28 °C→55 26 °C→60 24 °C→65 < 24 °C→73	max 0,7
hard physical work	15-28	max 75	max 0,5	15-28	max 75	max 0,6	max 28	28 °C→55 26 °C→60 24 °C→65 < 24 °C→73	max 1,0

Note: The floor temperature must not exceed 25°C, and the ceiling temperature of 35°C.

2. CLOTHING INSULATION AND THERMAL COMFORT

The thermal sensation of a person is under the influence of microclimatic factors, which can be inhomogeneous in the human body, i.e. air temperature, air humidity, air flow rate and radiation temperature of the surrounding surfaces are always different at different altitudes. In most cases, the microclimate parameters, especially in the working

environment, are not homogeneous throughout the human body. Certain parts of the body, such as the head and legs, are exposed to different ambient environments, which causes different heat sensations. [2,3]

The way of clothing significantly affects the feeling of temperature comfort, so the thermal clothing insulation coefficient, CLO, is defined by the standard ISO9920. Some basic types of clothing and the corresponding values of thermal clothing insulation coefficient are shown in Table 2.

Table 2. Clothing insulation coefficient

Clothing	Clothing insulation coefficient	
	m ² K/W	CLO
No clothes	0,00	0,0
Summer clothes (shorts, T-shirt, sandals)	0,05	0,3
Summer clothes (pants, T-shirt, shoes)	0,08	0,5
Spring clothes (pants, shirt, shoes)	0,11	0,7
Winter clothes (pants, sweater, jacket, shoes)	0,20	1,3

The feeling of heat mainly refers to the thermal balance of human body and it is realized if the internal generation of thermal energy is equal to the amount of thermal energy that is transferred to the environment. If the heat balance is disturbed, the person will feel discomfort, i.e. thermal discomfort and mechanisms for regulating body temperature will be triggered. [2,4] According to Fanger, person expressed thermal comfort on a seven-point scale used to assess thermal sensation, and is shown in Figure 1, (ISO 7730 2005).

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot warm
- 3	- 2	- 1	0	1	2	3

Figure 1. Image of human heat sensation [1]

3. METABOLIC INTENSITY AND THERMAL COMFORT

Estimation of metabolic intensity is determined on the basis of an international standard (ISO 8996 2004). During the assessment, the mean value of metabolic intensity in the last one hour is adopted, because the organism may be under the influence of previous metabolic activity (ISO 8996 2004). [5] Unit (*met*) is used during calculating and estimating metabolism intensity, which represents the ratio of the current metabolism intensity and the metabolism intensity in the sitting position of a man. The value is: 1 met = 58.15W/m² of human body surface. For a person with a body surface area of 1,73m², in the state of thermal comfort, the heat output will be about 100W or 1 meter (ISO 7730 2005). If any of the factors affects the increase in the metabolism intensity in the human body, it means a greater generation of thermal energy and an increase in internal body temperature. In that case, the mechanisms for the transfer of thermal energy from the organism to the environment are activated. [4] For thermal comfort conditions, the metabolic rate (M) should be in the range of 46W/m² to 232W/m² or 0.8 met to 4.0 met (ISO 7730 2005).

Table 3. shows the values of metabolic intensity used in the research for different human physical activities. When assessing the metabolism intensity according to the international standard (ISO 8996 2004), it is necessary to take into account the age of the person, because people in older age have a lower value of metabolic intensity (ISO 7730 2005). [4]

Table 3. Metabolic intensity for different physical activities (ISO 7730 2005)

Human physical activity	W/m ²	Metabolic intensity (met)
Half lying position	46	0,8
Sitting, resting	58	1,0

Sitting activity (office, place of residence)	70	1,2
Standing, light activity (laboratory, light industry)	93	1,6
Standing, medium activity (seller)	116	2,0
Walking on a flat surface:		
2 km/h	110	1,9
3 km/h	140	2,4
4 km/h	165	2,8

In addition to the microclimate parameters, the metabolism intensity and thermal clothing insulation, there are other individual factors that determine or affect a person's thermal sensation and the most important are: gender, age, race, health, body composition, adaptation (acclimatization), geographical origin, direct thermal radiation, time of exposure, time of day, season, possibility of regulation of microclimatic factors, etc. [1, 2, 6]

4. RESEARCH ON THE IMPACT OF THERMAL COMFORT

A review of representative publications in the field of thermal comfort that is influenced by microclimatic conditions (air temperature, humidity, air flow rate, heat radiation and atmospheric pressure), noise and brightness, personal parameters (sex, age, clothing, metabolic activity levels) indicates that there are difficulties in defining a unique thermal environment, which will satisfy everyone present in the space.

4.1 Microclimate parameters

A group of authors from Hong Kong examined the influence of microclimatic parameters on thermal comfort by increasing air velocity, temperature and relative humidity in air-conditioned conditions. Analysis of the results indicates that people in Hong Kong, as well as in other Asian cities are more sensitive to changes in air temperature and air flow rate and less to relative humidity. The results indicate that the feeling of thermal comfort in women in Hong Kong is more sensitive to changes in temperature, but less to changes in air velocity, than in men. Compared to men, women want a higher air temperature. The difference in thermal comfort of both sexes narrows at higher air temperatures. [7] The results of experimental research in the climate chamber, conducted on young people in Beijing, where heating is used in winter and in Shanghai, where heating is not usually used in winter (air temperature variations from 12°C to 20°C, cold environment), indicate that respondents who are accustomed to higher indoor temperatures (Beijing) feel colder than respondents who are accustomed to lower indoor temperatures (Shanghai). [8] The results of research on the influence of different sexes on the thermal comfort of Chinese [7, 9] and Dutch authors [10], indicate that women are more sensitive to air temperature (mostly cold) and less sensitive to relative humidity, compared to men. Women have lower skin temperature compared to men [9, 10]. Men want a “slightly cooler” environment, and women prefer a “slightly warmer” environment.

The study of the thermal comfort impact on the worker productivity in five business facilities in Tokyo was conducted during the summer, at an internal constant air temperature of 27°C. The results of the research indicate that workers feel discomfort at an air temperature of 27°C. Worker productivity, compared to the previous year's survey, was examined through self-assessment and resulted in a productivity loss of 6.6%. [11] A group of authors investigated the thermal comfort and productivity of workers in business facilities in Finland during the summer period. The results of self-assessment of work efficiency indicate that work efficiency decreases when the air temperature is above 25°C. [12]

The results of a study by a group of authors [13] showed that an increase in air temperature by 1°C in the interval from 25°C to 26°C affects the reduction of worker performance by 1.9% in the Japanese call center. Increasing the relative humidity at high air temperatures prevents cooling by evaporating water, i.e. sweat in humans, in which case, people want higher speeds of air movement, in order to maintain thermal comfort. [14]. As the atmospheric pressure drops, the feeling of heat in people decreases, people feel colder, and they want lower air speeds. [15]

There are different opinions among some authors that there is no difference in the perception of thermal comfort with age [16], although metabolic activity in older people is lower, people over 67 years of age want higher temperatures compared to the younger population. [17] A study of the influence of microclimate parameters was performed on students in Thailand, and the study examined the influence of air movement in a semi-controlled environment. During the study, the air temperature ranged from 25°C to 28°C and the air flow velocity from 0.2m/s; 0.5m/s; 1m/s; 1.5m/s and 2m/s. During the experiment, the students expressed their feeling of warmth. The results showed that the thermal environment is considered acceptable when the air temperature is up to 28°C and the air velocity in the interval from 0.2m/s to 2m/s. People in Thailand are used to high air temperatures and high air flow speeds. [18]

Some authors have investigated the connection between thermal comfort and human body weight. [19] The study involved 27 lean and obese girls in southern Brazil, who were physically active during and after exercise in warm and heat-neutral conditions. The research results indicate that there are no differences in thermal sensation in both groups in both thermal conditions.

4.2 Noise

Recommendations, i.e. standards for the design and construction of facilities, safety and health at work in facilities, take into account the noise and thermal environment of the working environment separately, as independent parameters that have an impact on the person indoors. The results of the research so far on the influence of noise on human thermal comfort are different. According to some authors, noise cannot cause a disturbance of thermal comfort, i.e. it has no effect on the thermal comfort of a person in his environment. Contrary to these views, there are research results that confirm the thesis that noise in the human environment can affect thermal comfort. In Fanger's [20] studies, in which subjects were exposed to two noise levels (40dB and 85dB) and skin temperature, rectal temperature and evaporation through sweating were measured, the results showed that noise had no effect on thermal comfort. In the research of Japanese authors, the combined effects of noise and temperature on thermal comfort were used and Japanese students were exposed to different levels of operating temperature in the range from 18,9°C to 28,1°C and different noise levels in the range from 58,5dB to 95,5dB. Participants expressed their thermal feeling of discomfort on a numerical scale in the range from (0) cold to (100) hot. The results of the experiment indicate that the noise level has a small effect on thermal comfort in the area of "cold", "neutral" and "warm", but not in the area of "hot". [21]

On the other side, the results of research by some authors have indicated that noise significantly affects the subjective assessment of thermal comfort. [22] In these studies, the effects of temperature and noise on thermal comfort were combined. Subjects were exposed to different noise levels in the range of 35dB(A) to 85dB(A) and air temperature from 14°C to 34°C and reported on numerical scale from 0 to 100, on heat sensation and noise perception. The results of the experiment indicate that women accept a noisier environment compared to men, which indicates that thermal comfort is dominant in women. Noise was assessed as an unpleasant factor, when the initial noise intensity during the experiment was high, while temperature was the biggest disturbing factor when the subjects started the experiment in warm conditions, far from heat-neutral conditions. [23]

The same authors, but in another study [24] investigated the combined effects of noise and air temperature on thermal environment perception and acceptability, in subjects exposed to different noise levels (35dB(A), 60dB(A), 75dB(A) and air temperatures (18°C, 24°C and 30°C), air flow velocities 0.1m/s are under strictly controlled conditions. Experimental results indicate that noise and air temperature may interact in the assessment of thermal comfort. Heat load reduces acoustic perception and thus can reduce acoustic comfort. High noise levels increase thermal discomfort. The results show that acoustic perception decreases when the thermal environment is far from human thermal neutrality, although the combined effects of noise and air temperature did not cause physiological effects during the experiment. The results indicate that regardless of the ambient temperature, thermal discomfort is higher when the noise level increases.

With the combined effect of air temperature and noise research through behavior and performance measurement, researchers [25] indicate that the problem can arise and be complex when it comes to the duration of exposure. Entering the building for a few minutes or staying inside the building for a few hours will certainly cause various effects related to the perception and assessment of the acoustic and thermal environment. Noise and air temperature independently cause physiological reactions, but they affect the assessment of thermal comfort at the same time. In studies performed under strictly controlled laboratory conditions, it has been shown that a deviation of the operating temperature by 1°C from thermal neutrality leads to the same change in thermal sensation as a deviation of noise by 2,6dB(A) in the short term or 2,9dB(A) in the long term. [24] A change in operating temperature by 1°C in the range of 23°C to 29°C, has the same effect on human comfort as a change in noise of 3.9dB(A). [26]

4.3 Brightness

Research on the influence of light on thermal sensation and thermal comfort is mainly performed experimentally around the world. A study was conducted on the effect of light on body temperature and was conducted by testing subjects on three different illuminances, which are thought to be able to shift the secretion of the hormone melatonin (500, 1000 and 5000lux), and the illuminance level known to does not affect the hormone melatonin (50lux). Subjects were tested during the night hours and the results of the experiment indicate that a brightness of 500lux may be close to the beginning for significant suppression of the hormone melatonin. [27] The authors of the experiment [28] investigated the influence of light on thermal sensation and thermal comfort. The experiment was performed by exposing 10 women to different air temperatures, in the range from 20°C to 31°C. The lighting was adjusted to avoid infrared or thermal radiation and the test was performed in the time period from 09:00 to 13:00. Subjects were exposed to two different illuminances (200lux and 4000lux) and their thermal sensation was assessed on a numerical scale distributed in the interval from (-6) very cold to (+6) very warm. The results of the experimental study showed that the thermal sensation was rated as “warmer”, during exposure to strong light of 4000lux. The study of the influence of "strong" and "low" lighting on clothing and thermal regulatory responses (thermal sensation) was performed in an experiment during the day, in which 5 women of mature age participated and were exposed to two different lighting. Subjects were first exposed to a brightness of 3000lux, strong brightness and then 50lux, low brightness. The air temperature at the beginning of the experiment was 30°C and was lowered to 15°C and the respondents were able to choose a wardrobe in which they would feel comfortable. The declaration of thermal sensation was on a numerical scale from (-3) cold, (0) neutral, to (+3) very warm. The results of the experiment indicated that the subjects wore smaller clothes during high light, when they were exposed to lower air temperature, compared to when they were exposed to low light. During high light, the subjects felt less cold, when the air temperature was lowered and the body temperature measured rectally dropped after exposure to strong light. [29]

A review of the literature that studies the relationship between light, heat sensation and thermal comfort, it can be concluded that there are effects of light on thermophysiological reactions of man and that they can lead to changes in human thermal sensation. Some authors have proven the effects of light on wearing clothes and feeling warm. In most of the analyzed experimental results, the thermal sensation was rated as "warmer", on a numerical scale of thermal sensation, during and after exposure to high light (> 3000lux), compared to low light. [30]

CONCLUSION

According the literature, it can be concluded that the study of thermal comfort is performed worldwide in field studies, which were performed in closed facilities including classical experiments in air-conditioned chambers where the researchers had full control over the conditions.

There are differences in the thermal acceptability of users in buildings with natural ventilation, compared to users in air-conditioned buildings. In buildings with natural ventilation, users are more tolerant of internal thermal conditions.

The results of previous research indicate that the thermal sensation in women is more sensitive to changes in air temperature, but less to changes in air flow rate, than in men. Compared to men, women want a higher air temperature. The difference in thermal comfort of both sexes narrows at higher air temperatures.

People want more air speed in warm conditions. People who are accustomed to adapting to higher indoor air temperatures have a cooler thermal feeling than people who are adapted to lower indoor temperatures. Some authors are of the opinion that there are no differences in the feeling of heat in lean and obese people.

The results of some authors are contradictory and indicate that there is no difference in the perception of thermal comfort with age, although metabolic activity is lower in people in older age.

A review of the literature showed that the combined effects of noise and air temperature in some experimental studies did not cause physiological effects and that noise has no effect on thermal comfort. However, there are results of experimental research which indicate that, regardless of the ambient temperature, the thermal discomfort is higher when the noise level increases. Thermal comfort and thermal discomfort are closely related, although the results of some studies show that noise with air temperature can change thermal comfort and that there is still no solid evidence that noise levels can alter a person's thermal sensation and thermal comfort. Previous research on the combined effects of noise and thermal comfort has been conducted in strictly controlled laboratory and experimental conditions, and some studies have shown that there is a connection, but there is a lack of research in real conditions, i.e. facilities designed to work on a large number of respondents.

A review of the literature shows that light can be the cause of physiological reactions, which are not directly influenced by the visual perception of light and the visual inputs of the environment can change the perception of the thermal environment. So far, some results of experimental research on the visual influence of light on thermal reactions are unconvincing and their influence is very low on thermal comfort and the theoretical framework has not been largely investigated.

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