Assessment of Thermal Comfort in a Building Heated with a Tiled Fireplace with the Function of Heat Accumulation

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Assessment of Thermal Comfort in a Building Heated with a Tiled Fireplace with the Function of Heat Accumulation

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Abstract. Thermal comfort determines the state of satisfaction of a person or group of people with thermal conditions of the environment in which the person or group of persons is staying. This state of satisfaction depends on the balance between the amount of heat generated by the body's metabolism, and the dissipation of heat from the body to the surrounding environment. Due to differences in body build, metabolism, clothing etc. individuals may feel the parameters of the environment in which they are staying differently. Therefore, it is impossible to ensure the thermal comfort of all users of the room. However, properly designed building systems (heating, ventilation, air conditioning) allow for creating optimal thermal conditions that will evaluated positively by the vast majority of users. Due to the fact that currently we spend even 100% of the day indoors, the subject becomes extremely important.

The article presents the evaluation of thermal comfort in rooms heated with a tiled fireplace with the function of accumulation of heat using the PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) indices. It also presents the results of studies, on the quality of the micro-climate in such spaces. The system of heating premises described in the article is not a standard solution, but is now more and more commonly used as a supplement to the heating system, or even as a primary heating system in small objects, e.g. single-family houses, seasonal homes, etc. The studies comprised the measurements and analysis of typical internal micro-climate parameters: temperature, relative humidity and CO_2 concentration. The results obtained did not raise any major reservations. In order to fully assess the conditions of use, the evaluation of thermal comfort of the analyzed rooms was made. Therefore, additionally the temperature of radiation of the surrounding areas, and the insulation of the users' clothing was determined. Based on the data obtained, the PPD and PMV indices were determined according to EN ISO 7730: 2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria [1]. The obtained PMV values did not fit within the limits of thermal comfort, and the percentage of people dissatisfied reached almost 20%.

1. Introduction

One of the most important problems of modern construction industry is not the fact of isolating users from external conditions, but how to shape and maintain the internal environment in which users will feel comfortable all the time when using the premises. The complex of such internal conditions is called the indoor climate or the internal microclimate. It constitutes a number of parameters, and the feeling of them is associated with a large number of immeasurable factors. Research conducted for many years on the linking between subjective feelings of the users with the values traditionally

considered to be descriptive of indoor climate allowed to determine five groups of factors that describe the internal microclimate. They are: thermal comfort, quality (purity) of air, lighting, noise and other (factors associated with the sense of smell, visual, etc.). [2, 3, 4, 5, 6]. Because of the subject matter undertaken during the research described in this article the attention has been focused on the parameters of microclimate included in the first two groups.
A sense of comfort or lack thereof depends on:

1. Environmental factors:
    - air temperature in the room,
    - flow rate of the air through the room,
    - relative humidity of the indoor air,
    - Temperature of the surface radiation,
    - asymmetry of the temperature distribution in the room.
2. Individual factors:
    - metabolism,
    - acclimatization,
    - thermal insulation of clothing.

The basic parameter of the internal environment affecting the feeling of comfort is air temperature. For a lightly dressed idle man the comfort temperature ranges from 23 to 26 °C [7]. At temperatures exceeding 26 °C decreased attention and deterioration of perception and reflexes of room users was found. Another important factor of the feeling of temperature is the flow rate of air in the room [7,8]. As the authors' own research has shown, in most facilities in Poland equipped with gravitational ventilation the air flow rate does not exceed 0.1 m/s. [9, 10]. However, an occurrence of a local speed increase is possible, which is perceived as a draft. This feeling is dependent on the air temperature, and the area of body surface exposed to the draft, and the degree of turbulence. The air flow can be assessed as pleasant if the person staying in the room will assess the environment as warm. However, the same air speed can be judged negatively if the person will evaluate the thermal environment as cold.

The impact of relative humidity (RH) on thermal comfort in living areas and commercial premises is usually small. This is connected with the usually RH low value in such areas. Only a combination of high relative humidity (above 70%) with a temperature higher than comfortable brings disadvantages sensations. For health reasons, in most of the objects analyzed by the authors, the RH values ranged from 40% to 70% [7, 8].

The vertical temperature gradient can result in a feeling of cold at the level of head or foot, while for the remaining parts of body the room conditions are comfortable. It is understood that the degree of asymmetry of thermal radiation should not exceed 10 °C, the floor temperature 24 °C. The higher temperature of the floor can cause disturbances in the operation of the thermoregulatory system of the body characterized by alternating chills and sweating [8].

A significant impact on thermal comfort has the insulation of clothing. The unit of clothing insulation is clo 1 and corresponds to the conduction resistance of 0.155 m^2K / W. 1 clo is the thermal insulation of clothing, which provides a standard person of thermal comfort in a room at 21 °C and 50% relative humidity and air velocity of 0.01 m/s. In Poland, a big problem is improper adjustment of clothing to the season. According to the observation of the authors of the article of clothing insulation of Poles working in offices is approx. 0.5 ÷ 1.0 clo.

2. Subject matter and scope of research

The research was carried out in premises which are a separate entity and located on the ground floor of two-storey building. The building had a three-layer outer walls with a layer of thermal insulation of polystyrene and new tight window frames. The object has gravitational ventilation. The rooms in which the research was carried out had a total surface area of approx. 90 m^2. They act as a showroom, a sales showroom and a small design office.

The main source of heat was a tiled fireplace with heat accumulation. It was situated in the central part of the building, and accumulation channels were led inside interior wall in such a way that in each room they constituted a source of heat. An additional source of heat was a combi gas boiler, which was launched only in the case of very low external temperatures and fed the standard steel panel radiators placed on the exterior walls of the rooms. During the research a gas boiler was switched on only at weekends when the tiled fireplace was not operated and the internal air temperature dropped below 18 °C. Diagram of the building and the distribution of research positions are shown in figure 1.

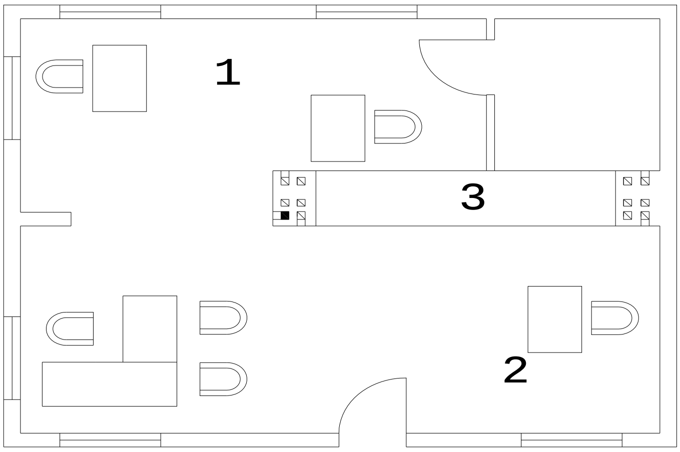

Figure 1. Diagram of the rooms in which research was carried out (1, 2 - measurement stations, 3 - tiled fireplace with accumulation channels)

The research included the registration of course of change of the basic parameters describing the microclimate of the premises, i.e. air temperature, relative humidity and air velocity. Measured was also the radiation temperature of the partitions, and the equipment of the room, the partial pressure of water vapour and the temperature of the blackened sphere were also determined. In addition, recorded was the value of the CO_2 concentration as an indicator of indoor air quality. Four measurement cycles were carried out each lasting seven days. Two cycles were carried out in the autumn, the other two in the winter.

3. Measurement results

A common characteristic of both rooms was the nature of the course of microclimate parameter variability. The values of all measured parameters increased from the beginning of the use of rooms and in a short time reached maximum values. After leaving the premises completely the values slowly decreased to finally reach the minimum values (figure 2).

The results of measurements of basic parameters of microclimate do not raise major objections, and indicate very good quality of indoor air. In the whole period of analysis the concentration of CO_2 in principle did not exceed of the ordered 1000 ppm [11]. The cases of exceedance shown in figure 2 were temporary and occurred sporadically. Taking into account the CO_2 concentration, the air quality in the building could be qualified for category 2 by IDA [12]. The lowest values of carbon dioxide concentration was observed at night or early in the morning. They were from 214 ppm to 349 ppm, which roughly corresponded to the values in the outside air. During the day, the CO_2 concentration increased at a rapid pace. Characteristic slight declines in the value of the concentration of carbon dioxide during the day (figure 2) were the result of short-term ventilation of rooms.

The air temperatures recorded during the use also did not raise major objections, and for most of the day's operation ranged 20 to 25 °C. Only during the weekend when the heating was not working for a period of approx. 36 hours the air temperature dropped to approx. 18 ° C. At that time the alternative heating with gas boiler launched with the set point of minimum temperature at 18 ° C. Relative humidity throughout the period of measurements fluctuated between 36.2 ÷ 51.1%.

Table 1. The parameter values reported for the measuring station 1 and 2

Parameter	Room no. 1			Room no. 2		
	Minimum	Maximum	Medium	Minimum	Maximum	Medium
Temperature [°C]	18.5	23.1	22.6	19.9	25.4	23.0
RH [%]	30.3	46.6	37.0	32.1	45.5	38.0
CO_2 [ppm]	409	1029	467	423	1342	641

The results of measurements indicate, however, a very high lability of the parameters measured at various measuring stations. This applies particularly to air temperature and CO2 concentration. Additionally, registered in the same time instantaneous values of the air temperature in the two areas differed by up to approx. 3 ° C, and the difference in carbon dioxide concentration reached up to 350 ppm. However, the determined daily and weekly average values of air temperature did not differ significantly. This difference was more than 0.5 ° C. Daily and weekly average value of the CO2 concentration differ however from each other strongly. The maximum difference in mean daily concentrations of carbon dioxide at various measuring stations was even 270 ppm. In the case of both relative humidity the difference in instantaneous and average daily values amounted to a few percent. RH mean weekly values differed by no more than about 2.5%.

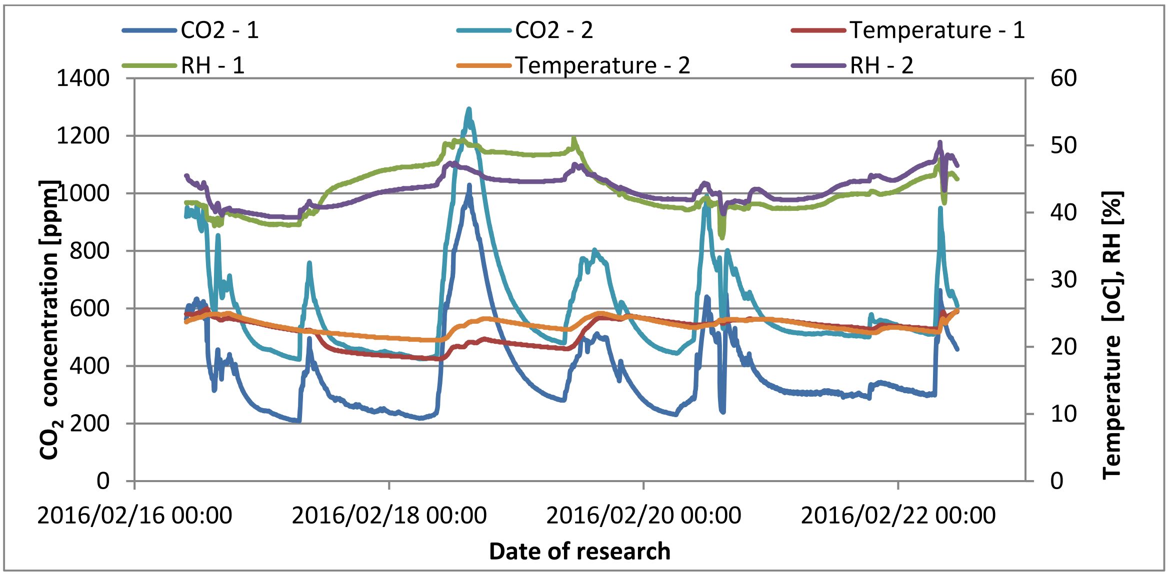

Figure 2. Weekly chart of the course of variability of microclimate in room 1 and 2 for the selected measurement period

These differences arise from the fact of placing in room 2 a fireplace equipped with a window through which a substantial amount of heat was reflected, and a larger surface of the wall with the accumulation channels in room 2. Undoubtedly it influenced a higher air temperature and lower relative humidity in the room.

4. Determination of PMV and PPD indices

The basis for the assessment of the thermal environment in rooms is EN ISO 7730: 2005 [1]. The parameter values of the microclimate of the environment for the determination of PMV and PPD indices were adopted in accordance with the above measurements. At the same time the measurements of the temperature of radiation of partitions and equipment of the premises were carried out. On the basis of Table B1 norm [1], the level of metabolic heat production of the room users was determined. It was assumed that all employees are performing office work, and therefore their energy expenditure is 70 W/m^2. According to Table C1 of this norm was determined the mean value of thermal insulation of clothing of the premises users, which averaged 0.92 CLO (0.144 m^{2}K/W). In addition, it was assumed that the velocity distribution of the air flow in the room was uniform. Based on the above findings, and bearing in mind the differences in the basic parameters of microclimate (Table 2 and 3) it was decided to perform measurements and determine the size of PMV and PPD for each room separately. Determination of the value these indices were conducted in accordance with the procedure set out in the standard [1].

Table 2. The values of microclimate parameters adopted for estimating the indices of thermal comfort - room No. 1.

Parameter	t_a [°C]	t_r [°C]	t_g [°C]	RH [%]	v_a [m/s]	p_a [Kpa]
Mean value	22.25	21.83	22.16	43.61	0.05	0.91
Standard deviation	2.04	0.71	1.64	3.58	0.01	0.17

Table 3. The values of microclimate parameters adopted for estimating the indices of thermal comfort - room No. 2.

Parameter	t_a [°C]	t_r [°C]	t_g [°C]	RH [%]	v_a [m/s]	p_a [Kpa]
Mean value	23.15	32.18	22.91	43.39	0.05	0.90
Standard deviation	1.06	2.92	1.96	2.20	0.01	0.17

Table 4. Estimation results of PMV and PPD indices for the average values of microclimate parameters

Measuring position	PMV	PPD [%]
Room 1	0.68	14.8
Room 2	0.79	18.2

A characteristic feature of the tested rooms were large fluctuations in room temperature within 8 hours of work. In the early hours of the morning the temperature in both rooms was approx. 20 °C. After starting the fireplace temperature increased quite rapidly (approx. 1 ÷ 2 hours) up to 24 to 25 °C. However, in case of low outside temperatures the air temperature registered in the rooms in the morning was approx. 18 °C. This was due to the holding of a minimum internal temperature during the night. Obtaining a temperature of 20 °C in this case varied between 0.5 to up to 1.5 hours from start of the fireplace. Due to the relatively long exposure time of premises users to such extreme temperatures it was decided to estimate the values of PMV and PPD also for the obtained minimum and maximum values accepting for the calculation the registered corresponding values of the other parameters. In the case of maximum temperatures, the average insulation of clothing was estimated at 0.74 clo, for the minimum value it remained unchanged.

Table 5. The estimated results of PMV and PPD indices for the obtained maximal values of temperature

Measuring position	PMV	PPD[%]
Room 1	0.85	20.36
Room 2	0.49	10.18

Table 6. The estimated results of PMV and PPD indices for the obtained minimal values of temperature

Measuring position	PMV	PPD[%]
Room 1	-0.78	17.94
Room 2	-0.79	18.13

5. Conclusions

In the central European climate the most difficult period in terms of ensuring conditions for thermal comfort for the users of premises is winter. This is mainly due to the provision of a sufficiently high temperature in the rooms. In addition to well-proven ways of heating buildings, alternative solutions are introduced. In the discussed building an unusual heating system was used. As the main source of heat a tiled fireplace with heat accumulation was used. The measurements of basic parameters of microclimate did not raise major objections remaining usually within the recommended standards. They were characterized by large fluctuations throughout the day. A more thorough analysis involving the determination of the indicators thermal comfort did not give positive results. The designated values of PMV index, determined on the basis the measurements of the average values of microclimate parameters, are not within the limits of thermal comfort, i.e. -0.5 <PMV <0.5. They amount to 0.68 in room 1 and 0.79 in room 2. The percentage of people dissatisfied with the conditions of the thermal environment amounted to 14.8% and 18.2% respectively. The resulting differences are due to having placed in the second room a glazed fireplace combustion chamber, and a larger area of the accumulating channels. It affected the differences of the air temperature and the relative humidity in the rooms. The analysis of the values of the measured parameters showed their high lability and quite a long time of exposure of the users to registered extreme values. The defined values of PMV and PPD for the minimum and maximum values also do not fall within the limits of thermal comfort. This is consistent with the observations of users. In the morning they complained about they too low air temperature and judged the environment as "cool" in a seven scale of subjective feelings. At the end of the day, they assessed the temperature being too high and the environment as "warm". At the same time, attention needs to be paid to the obtained mean values of RH, which amounted to 37 ÷ 38%. Such low values of relative humidity expose users to drying of mucous membranes of the nose and mouth.

On the basis of the obtained values of PPD and PMV it should be stated that the use of the fireplace with the function of heat accumulation is not a good way of heating and does not provide thermal comfort for users of such spaces. It seems reasonable to use this source of heat only as a supplement to the heating system of the building or to develop a more effective way to distribute the heat indoors.

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