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THERMAL COMFORT ASSESSMENT OF A FLOOD – AFFECTED BUILDING MICROCLIMATE

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ABSTRACT: In 2010, Plock Country, which is located in Poland, was affected by two flood waves that covered approx. 7 hectares of land located in two communes. This paper presents one of the single-family homes affected by the flooding. The aim of the work is to evaluate the building's microclimate, in terms of its thermal comfort, on the basis of a conducted survey. The studies involved measurements of the basic microclimate parameters, including temperature, relative air humidity and temperature on the internal surface of the partition walls. On the basis of the survey results, analyses were made of the variability of the microclimate parameters as well as of the dependencies between these parameters inside the building.

KEY WORDS: flood, microclimate, thermal comfort

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Introduction

A flood is a temporal hydrological phenomenon which can be occur by the swelling of river waters in reservoirs. The subsequent occurrence of the water bank overflow leads to flooding of coastal or depressed areas and river valleys (Hu et al., 2018).

In May and June 2010, Płock County (Masovian Voivodship) was affected by two flood waves caused by the swelling of the Vistula River. This paper presents one of the single-family homes affected by both floodings. It also describes results of a survey conducted inside the building aimed at assessing its microclimate in terms of thermal comfort. The survey included the measurement of basic microclimate parameters:

- air temperature,
- relative humidity,
- temperature on the inside surface of the partition walls.

Furthermore, this study identified the factors affecting the microclimate prevailing in the rooms. This paper also presents the optimal conditions for each room to ensure thermal comfort and the reduced occurrence of negative impact on the well-being and health of the inhabitants (Małkowska, 2012).

An overview of literature

The microclimate is understood as a number of meteorological factors that determine directly the living conditions of an organism or a group of organisms. The main parameters that determine the prevailing microclimate are the following:

- air temperature,
- relative humidity,
- air movement,
- surface temperature of the partition walls.

Each of these factors has a significant impact on the well-being, physical and mental efficiency, work efficiency and the overall health of the inhabitants (Żenczykowski, 1987).

One of the main issues involved in building design is thermal comfort. Thermal comfort involves the attainment of optimal temperature of the indoor air as well as of the partition walls that form the rooms. The factors describing the microclimate are, at the same time, the thermal properties of the room; it should be noted, however, that they are independent to the parameters of the human body and, depending on the values of the factors such as temperature, relative humidity, air movement and temperature of the surrounding walls, can take up various amounts of internal body heat. Moreover, we also distinguish personal factors related to thermal comfort which include the level of individual activity and the thermal insulation of clothing.

The perception of thermal comfort of the environment depends on the extent to which the apparent temperature differs from the comfort temperature associated with the type of job performed and clothing worn by given individuals. The absence of thermal comfort for extended periods of time may underlie functional dysfunction of internal body organs which, in turn, lead to serious threats to life.

The key factor that contributes to thermal comfort is building structure. The habitation zone that it creates is the result of its thermal properties and the devices contained therein which are used for heating, i.e. heating, ventilation and air-conditioning devices. In order to achieve the required thermal comfort in a building or room, it is essential to take into account both its thermal and physical properties (Andjulovic, Georgescu, 1971; Fanger, 1974; Krygier et al., 1991; Małkowska, 2012; Żenczykowski, 1987).

Poland belongs to the temperate climate zone. In this climate zone, the biggest challenge from the point of view of thermal comfort maintenance is the winter period. Not only is this due to the necessity of protecting against atmospheric factors, but primarily of maintaining the appropriate and constant temperature within the building.

In the climate zones in which the temperature of outdoor air varies significantly during the year, such dramatic changes affect the indoor air temperature variation which goes beyond the limits required to ensure thermal comfort. For this reason, during winter heating devices are used to maintain the indoor air temperature within the limits necessary to achieve thermal comfort. This, on the other hand, is not the case during the summer period. In summer, an increased heat transfer is achieved by means of natural (room ventilation) or mechanical (fan) ventilation. The occurrence of the so-called comfortable conditions inside the building requires, apart from maintaining a given air temperature, balancing the temperature vertically and horizontally (Anjulovici, Georgescu, 1971; Małkowska, 2012).

The optimal temperature for people in the habitation area provides the heat balance of the body without any effort on its part. In order to ensure the well-being of inhabitants, the air temperature at floor level should be slightly higher than at head level, but the difference should not exceed °C. This is associated with physiological thermal regulation of humans which can be disrupted due to a stronger temperature variation (Andjulovici, Georgescu, 1971; Krajewska, 2005; Małkowska, 2012; Rokiel et al., 2011).

The required internal temperature values depend on the level of physical activity of given individuals. For example, the air temperature in rooms intended for intellectual work or recreation should be 20-22°C in winter and 23-26°C in summer (Krajewska, 2005; Krygier et al., 1991; Małkowska, 2012).

In the design calculations for residential buildings, the average value of relative air humidity for the entire heating period is 55%. The actual relative humidity is different from this adopted value, as it ranges from 30 to 70%. However, its effect on the thermal sensation of inhabitants is insignificant. Changes in relative humidity within these limits can reduce the preferred temperature only by 1°C, which proves to be difficult to detect by the human body in temperatures below 23°C (Janowski, Szulc, 1979; Małkowska, 2012; Rokiel et al., 2011; Śliwowski, 2008).

The relative humidity of the indoor air depends primarily on the parameters of the outdoor air as well as the amount of water vapour inside any given room. Emission of water vapour from the people living inside is a characteristic of residential buildings. As a result of breathing, evaporation from the body surface and simple day-to-day activities (e.g. washing, cleaning) the inhabitants become sources of humidity. Humidity begins to have an impact on human well-being only when it is connected with the need to evaporate water from the skin surface (Małkowska, 2012; Rokiel et al., 2011; Żenczykowski, 1987).

Water vapour in the air may condense on the inner surfaces or inner layers of the partition walls. This phenomenon of condensation is determined by the humidity of indoor air and the thermal insulation of the partition (Małkowska, 2012; Żenczykowski, 1987).

Mould is a result of condensation of water vapour on the surfaces of walls. Generally, it appears in the corners of the inner surface of the walls in rooms located in the building corners. It has a negative impact on human health thus deteriorating the indoor thermal comfort. In addition, it also makes the walls look unaesthetic (Andjulovici, Georgescu, 1971; Małkowska, 2012). A method of preventing the formation of humidity, or at least of its reduction, is room airing. Airing is based on the phenomenon of thermal exchange which is caused by a periodical opening and closing of windows or other openings in the wall partitions (Krygier et al., 1991; Małkowska, 2012).

The speed of the air movement inside a closed room largely influences the well-being of the inhabitants. In the case when the room temperature is low, even slight air movements experienced by a person are unpleasant. Similarly, when the room temperature is high, the air movements felt on the body are perceived as unpleasant.

Nowadays, the greatest challenge in the design of ventilation and air-conditioning devices is the adoption of the right balance of temperature and air speed in order not to cause the sensation of draught in the inhabitants (Rokiel et al., 2011).

Considering the partition walls in terms of their thermal properties, the greatest influence on the thermal comfort in the room is attributed to the floor. This is due to the fact that inhabitants have a direct and almost continuous contact with the floor. While the indoor air temperature is a parameter that can be adjusted using the heating or air-conditioning appliances, this is not the case of the surface temperature of the partition walls. Partition walls are scarcely affected by heating or cooling since these actions do not eliminate the negative effects of cold walls. Raising the air temperature of the room using such devices reduces the heat flux transferred convectively from the entire surface of the human body, while the radiation heat flux remains unchanged (Małkowska, 2012).

In order to maintain the human body in good health condition, it is necessary to ensure constant body temperature. In view of this, the energy obtained from the oxidation of food must be balanced by the heat losses to the environment and the activity-related energy expenditures.

The heat emitted by the human body is the result of its physiological functions. The heat flux emitted by a person consists of:

- the sensible heat emitted by a person as a result of such processes as convection and radiation,
- the latent heat emitted by means of respiration and radiation of water vapour from the body surface (Krajewska, 2005; Krygier et al., 1991; Małkowska, 2012; Rokiel et al., 2011).

One of the available methods for practical assessment of given environments is the thermal sensation index which determines the average evaluation of thermal sensation. The main variable parameters affecting the thermal comfort include:

- energy expenditure (amount of heat generated in the body),
- resistance of heat conduction through the clothing (Clo value),
- air temperature,
- average radiation temperature,
- relative air flow speed,
- partial pressure of water vapour in the surrounding room.

The thermal sensation index can be studied for any combination of the above four variables. The formula for the calculation of the 'Predicted Mean Vote' (PMV) is complicated, which renders it impractical; therefore, tables and diagrams facilitating the determination of PMV are more frequently used. The factors responsible for the thermal sensation of persons inside given rooms can be divided into the elements of microclimate defining the microenvironment and the so-called personal elements describing activities and clothing. In cases when the activity of human body is higher, a lower indoor air temperature is defined as comfortable. It is worth noting that the increased thermal insulation of clothing results in a similar experience (Castaldo et al., 2018; Fanger, 1974; Małkowska, 2012).

One of the most widely used thermal sensation measurement systems is the 7-point ASHRAE scale (from −3 = cold to +3 = hot) (ASHRAE standard, 2013). In the conditions of comfort, thermal load is zero. Conditions different from comfortable will affect the average human skin temperature, but also the amount of sweat generated to maintain the thermal balance of the body.

Table 1 presents the proposed permissible ranges of values of thermal microclimate elements in the heating period (Śliwowski, 2008).

Table 1. Proposed technical standards for the room microclimate elements in the heating period

The elements of microclimate	Limit values
Air temperature, °C	
* in rooms, kitchens, hallways	20–22
* in toilets and bathrooms	above 22
Temperature of partition wall, °C	
*in all spaces below the air temperature accordingly, not more than by	3
Air speed, m/s	
* in all spaces	below 0.15
Relative humidity, %	
* in rooms, kitchens, hallways	40–60
* in toilets and bathrooms	below 70

Source: author's own work based on (Śliwowski, 2008).

In order to ensure the state of thermal comfort, the average temperature of thermal radiation should be close to air temperature. The phenomenon of thermal radiation in rooms is largely determined by the type and location of radiators, the size and thermal quality of windows, the level of thermal insulation of the building envelope as well as the existence of thermal bridges in given rooms.

The necessity to generate appropriately high surface temperatures of the surrounding partition walls, particularly the exterior walls and windows, is caused by the influence of cold surfaces on the thermal sensations of the human body.

The air movement in habitable rooms is the least variable parameter affecting the human thermal comfort. It is widely assumed that air speed up to 0.3 m/s is actually non-detectable for people. This is due to the existence on the skin surface of a static boundary layer of air that is dissipated when air speed exceeds 0.3 m/s (Śliwowski, 2008).

Research methods

In May 2010 in Poland, the amount of precipitation ranged from 123 to 200% of the norm. The highest precipitation totals were observed in the Vistula basin. The flood wave formed on the Vistula River reached the peak of 780 cm. On the 22 May 2010, the stream gauge located in Kępa Polska indicated 738 cm, which meant that the water level was exceeded by 1 metre.

On the 23rd May 2010, the swelled waters of the Vistula River broke the levee located in the town of Świniary in the Płock Country. The flood affected the locations belonging to the Słubice and Gąbin communes.

On the 6th June 2010 came the second flood wave. After the wave, flood water stagnation lasted for about three weeks, with the flood continuing for six weeks. The time between the first and second flood wave was too short to drain the water from the first flooding. Water drainage was additionally slowed down by the temporary flood barrier in the village of Dobrzyków constructed for the purpose of protection from flooding of subsequent locations (Małkowska, 2012; Struzik, Subotowicz, 2010; Zaborowska 2011).

The 2010 flood in the Płock Country affected about 7,000 hectares of land belonging to the Słubice and Gąbin communes inhabited by 3714 persons. Some locations that were completely flooded in this period include:

- Korzeniówka Stara,
- Nowy Troszyn,
- Troszyn Polski,
- Nowy Wiączemin,
- Wiączemin Polski,
- Świaniary,
- Sady,
- Nowosiadło,
- Zysk Polski,
- Rybaki.

Cleanup works in the affected area started in early July 2010. In August and September 2010, drying of the flooded areas using special blowers was performed (Małkowska, 2012; Struzik, Subotowicz, 2010; Zaborowska, 2011).

The subject of the survey was a family home situated in the village of Nowy Wiączemin in the Słubice commune belonging to the Płock Country. The village area was affected by two flood waves in May and June 2010.

After the flood, the building underwent a renovation. The plaster layer inside the building was removed up to the ceiling height and replaced with a new layer. Also, the floor was replaced. On the outer side of the walls up to the height of the flood water, polystyrene insulation was removed and replaced by a new reinforced one with a structure covering. Despite the flooding, the walls of the building remained intact. Analysing the layers of the building partitions, we may conclude that the floor of the surveyed room meets the condition for minimum insulation resistivity ($R_{min.\ of\ insulation}$). The outer wall, however, does not meet the conditions for the maximum thermal transmittance ($U<U_{max}$), but remains close to the permitted limit. The ceiling neither meets the condition (Małkowska, 2012; PL, 2008). The building inspection in one of the rooms discovered an area of mould in the zone of a thermal bridge under the ceiling.

The conducted survey included measurements of some microclimate parameters: indoor air temperature, indoor air relative humidity and temperature of internal surfaces of partition walls. The survey was conducted in the room functioning as the living room. The intended temperature of the room in the design phase was estimated at 20°C (Śliwowski, 2008). The building is heated using a central heating system powered by a solid fuel (coal) boiler. The boiler room is located in the basement the entrance to which is outside the building. The area of the surveyed room is 32.46 m^2.

For the measurements of temperature and relative humidity of indoor air, the LABEL LB 486 converter-logger was used. The device has three sensors: 2533, 2547 and 2625 which were placed in the room at the height of 1.8 m and at a distance of 50 cm from one another.

Surveys were conducted in four series in the following time periods:

- first series: 1-15 November 2011,
- second series: 16-22 January 2011
- third series: 28-29 November 2011,
- fourth series: 5-6 December 2011.

Measurements were read and recorded by the equipment in 20 minute intervals (Małkowska, 2012).

In order to determine the microclimate parameters in the surveyed building, which consisted in measuring the surface temperature of the walls, four TESTO 177-T3 measuring devices were used. Each of the devices is equipped with three probes. One probe is located inside the device and serves to measure air temperature, while the other two measure the surface temperature of partition walls. For the survey purposes, the second probe was situated at the floor level, and the third above it, at the height of 1 meter. Three devices were located by the outer walls and one by an inner wall. The wall surface temperature measurements were taken from 29th October to 6th December 2011. The measurement results were recorded by the devices in five-minute intervals (Małkowska, 2012).

Results of the research

In the surveyed room, air temperature should fit in the range of 20÷22°C (table 1). Table 2 shows the percentage of temperature measurements that meet one of the conditions of thermal comfort (temperature greater than or equal to 20°C), and the percentage of measurements failing to meet the thermal comfort conditions (temperature below 20°C).

The analysis indicates that during most of the surveyed period the temperature was below 20°C, which means that for most of the time the conditions for thermal comfort were unfulfilled.

The analysis of the temperature measurements of indoor air during the first series of studies (1-15.11.2011) found that, as a rule, the temperature of indoor air increased in the afternoon and decreased around 11 p.m. The temperature increase was caused by the firing up of the boiler, while the decrease was the result of the boiler cooling down during the night. Figure 1 shows an example distribution of daily temperatures of indoor air in the surveyed room.

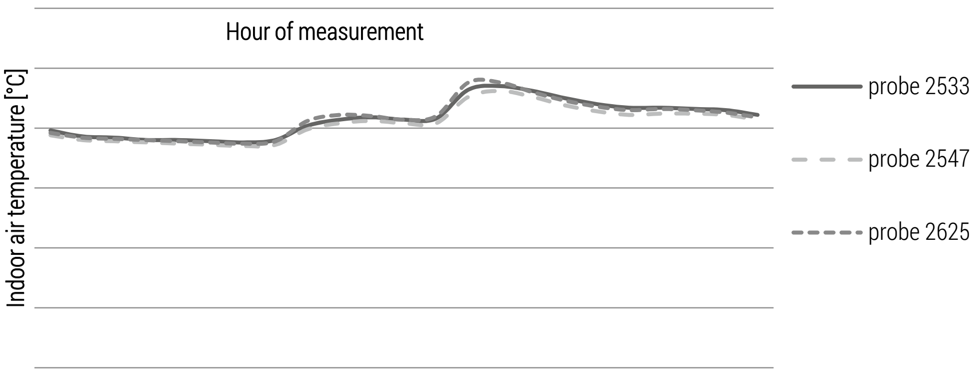

Figure 1. Daily distribution of indoor air temperature on 2.11.2011

Source: author's own work.

Table 2. Percentage of measurements of temperatures that meet/fail to meet the conditions of thermal comfort

Series 1	Survey period		1-15.11.2011	Average Value [%]
	Amount of measurements		1087	
	% measurements below 20°C	probe no. 2533	65.2	74.2
		probe no. 2547	78.7	
		probe no. 2625	78.7	
	% measurements equal or greater than 20°C	probe no. 2533	34.8	25.8
		probe no. 2547	21.3	
		probe no. 2625	21.3	
Series 2	Survey period		16-22.11.2011	
	Amount of measurements		413	
	% measurements below 20°C	probe no. 2533	37.2	50.1
		probe no. 2547	61.5	
		probe no. 2625	51.6	
	% measurements equal or greater than 20°C	probe no. 2533	62.8	49.9
		probe no. 2547	38.5	
		probe no. 2625	48.4	
Series 3	Survey period		28-29.11.2011	
	Amount of measurements		91	
	% measurements below 20°C	probe no. 2533	64.8	70.0
		probe no. 2547	74.7	
		probe no. 2625	70.3	
	% measurements equal or greater than 20°C	probe no. 2533	35.2	30.0
		probe no. 2547	25.3	
		probe no. 2625	29.7	
Series 4	Survey period		5-6. 11 2011	
	Amount of measurements		88	
	% measurements below 20°C	probe no. 2533	29.6	40.9
		probe no. 2547	50.0	
		probe no. 2625	43.2	
	% measurements equal or greater than 20°C	probe no. 2533	70.5	59.1
		probe no. 2547	50.0	
		probe no. 2625	56.8	

Source: author's own work.

The next studied parameter in the room was the relative air humidity. Its value must fit in the range of 40÷60% (table 1) to ensure thermal comfort for the inhabitants. Table 3 presents the percentage of relative air humidity in the room. The table involves the measurements of humidity in the range from 40 to 60%, i.e. those which satisfy the condition of thermal comfort, and the measurements that are outside the limits, thus failing to meet the conditions of thermal comfort.

Based on the above information, we can conclude that high indoor air humidity (above 60%) is present for most of the time in the surveyed room. There are also measurements below 40% (very low-humidity air). These are, however, incidental situations that were not taken into consideration in the further part of the study.

In the case of the surface temperature of partition walls, it should not be lower than the indoor air temperature by no more than three degrees (table 1). In the surveyed room, the air temperature should be in the range of 20÷22°C; therefore, the surface temperature of the walls enclosing the room must be greater than or equal to 17°C. The figures 2 and 3 show the percentage of measurements of the surface temperature of the walls at the height of 1 m and by the floor that meet the condition of thermal comfort for individual measurement points.

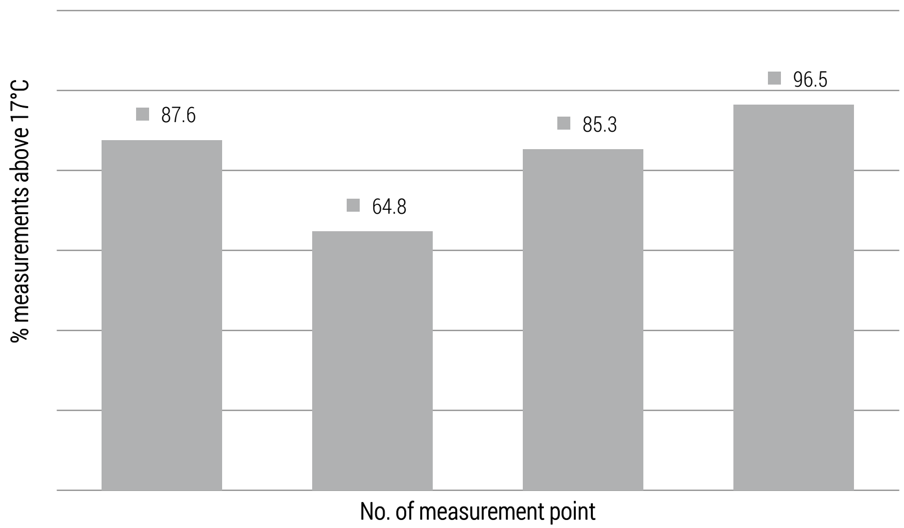

Figure 2. Percentage of measurements of the surface temperature of the partition walls at the height of 1 m that satisfy the condition of thermal comfort

Source: author's own work.

Table 3. Percentage of measurements of relative humidity that meet/ fail to meet the conditions of thermal comfort

series 1	Survey period		1-15.11.2011	Average Value [%]
	Amount of measurements		1087	
	% measurements within 40÷60%	probe no. 2533	68.3	63.3
		probe no. 2547	54.7	
		probe no. 2625	66.9	
	% measurements above 40%	probe no. 2533	0.0	0.2
		probe no. 2547	0.0	
		probe no. 2625	0.6	
	% measurements below 60%	probe no. 2533	31.7	36.6
		probe no. 2547	45.4	
		probe no. 2625	32.6	
series 2	Survey period		16-22.11.2011	
	Amount of measurements		413	
	% measurements within 40÷60%	probe no. 2533	61.3	55.7
		probe no. 2547	50.9	
		probe no. 2625	55.0	
	% measurements below 40%	probe no. 2533	0.0	0.5
		probe no. 2547	0.0	
		probe no. 2625	1.5	
	% measurements above 60%	probe no. 2533	38.7	43.8
		probe no. 2547	49.2	
		probe no. 2625	43.6	
series 3	Survey period		28-29.11.2011	
	Amount of measurements		91	
	% measurements within 40÷60%	probe no. 2533	0.0	2.2
		probe no. 2547	0.0	
		probe no. 2625	6.6	
	% measurements above 40%	probe no. 2533	0.0	0.0
		probe no. 2547	0.0	
		probe no. 2625	0.0	
	% measurements below 60%	probe no. 2533	100.0	97.8
		probe no. 2547	100.0	
		probe no. 2625	93.4	

series 4	Survey period		5-6. 11 2011	
	Amount of measurements		88	
	% measurements within 40÷60%	probe no. 2533	18.2	16.3
		probe no. 2547	6.8	
		probe no. 2625	23.9	
	% measurements above 40%	probe no. 2533	2.3	3.0
		probe no. 2547	3.4	
		probe no. 2625	3.4	
	% measurements below 60%	probe no. 2533	81.8	83.0
		probe no. 2547	92.1	
		probe no. 2625	75.0	

Source: author's own work.

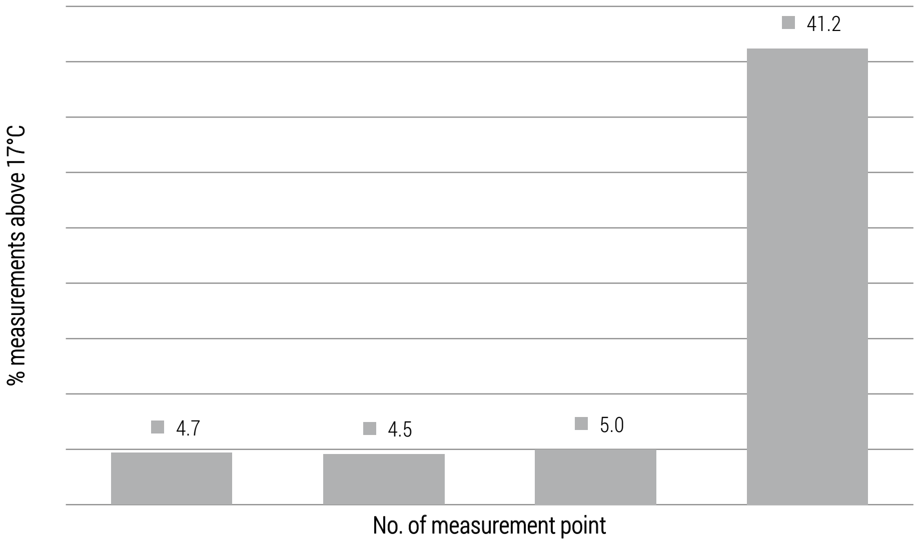

Figure 3. Percentage of measurements of the surface temperature of the partition walls at floor level that satisfy the condition of thermal comfort

Source: author's own work.

Figure 3 shows that, for most of the time, the surface temperature of the partition walls at the height of 1 m exceeded 17°C. The situation is different in the case of the surface temperature of the partitions measured by the floor (table 4). Here, the temperature in most cases is less than 17°C. Particularly noteworthy are the results of the measurement analysis of the device 4. In this case, the measurements involved the inside wall. We observe a large difference in the measurements of this wall and the external walls (other measuring devices). In the case of device 4, the sensors placed at the height of 1 m and at the floor level mostly indicated temperatures equal to or greater than 17°C (from 64,8% to 96.5%, depending on the measurement point) (Małkowska, 2012).

Conclusions

Referring the obtained results to the requirements of thermal comfort outlined by Professor Śliwowski (2008), it turns out that the surveyed room does not meet the conditions of thermal comfort, since the 58.8% of temperature measurements were lower than 20°C, and in 63% of cases the 60% of relative humidity was exceeded. What is more, lower surface temperatures of the outer walls measured by the floor level were observed (95.3% of cases below 17°C), while at the height of 1 metre, the surface temperature of partitions was greater than or equal to 17°C (79.2% of the cases).

After surviving two flood waves and despite the renovation and drying processes, the building does not create comfortable conditions for its inhabitants.

This study demonstrates that the surface temperature of partition walls measured at the floor level changes together with the surface temperature of the partition walls measured at the height of 1 m, but remains permanently lower by 2°C. Moreover, while the room floor satisfies the $R_{min\ of\ insulation}$ condition, the outer wall does not satisfy the condition of U_{max} ($U > U_{max}$), but remains close to the permitted limit. The ceiling neither meets this condition. The study also demonstrates the significance of the influence of heating appliances on the changes of air temperature and humidity in the room (boiler heating).

During building inspection, areas of mould were found in the thermal bridge zone of one of the rooms, which, apart from its unaesthetic appearance, causes negative effects on the health of the family.

Further actions should involve the improvement of the existing conditions in the building towards the achievement of the all-year-round thermal comfort.

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