Checking the parameters of the internal environment by calculated simulation of measurements with a ball thermometer

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Abstract. According to the regulatory documents in force in the Russian Federation, the measurement of the normalized indoor environment indicators should be carried out with a ball thermometer. These norms also apply to the premises of the transport infrastructure buildings. In this paper, the values of the radiation temperature *tr* and the local asymmetry of the radiation temperature *dtr* as to the ball thermometer have been estimated by calculation. An ordinary room of an intermediate floor with a window in the outer wall with a width of 3.8 m and a height of 1.8 m, the bottom of which is located at a height of 1 m from the floor, in Belgorod, has been subject to consideration. The room is provided by an air heating. The values of the asymmetry of the radiation temperature at the boundary of the serviced area of the room, that is, at a distance of 0.5 m from the outer wall, at a height of 1.7 m and 1.1 m from the floor in the calculated winter conditions exceed the optimal ranges limited by norms. It is shown that with an increase in the resulting room temperature, the values of the radiation temperature asymmetry also increase. The presented distributions of the radiation temperature over the volume of the room indicate that in the calculated winter conditions, the optimal requirements for *tr* values are not met at the same heights of 1.7 m and 1.1 m from the floor. Acceptable conditions meet the requirements of the norms. Keywords: calculated winter conditions, radiation temperature, local asymmetry of radiation temperature, resulting temperature, calculation, boundary of the serviced zone.

1 Introduction

Compliance with the thermal microclimate norms in the premises, including those related to the transport infrastructure, is given increased attention all over the world. Microclimate parameters are determined both by numerical modeling [1, 2, 3] and experimentally [4]. At the same time, among the parameters of the microclimate, an important place is given to the room radiation temperature and the local asymmetry of the radiation temperature [5-10]. In addition, the room radiation microclimate is fairly linked to the heating or cooling systems of the room [11 -20].

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At the same time, in the Russian professional construction literature, the authors did not find articles that would draw attention to the presence in paragraph 6.3 of the Russian State standard GOST 30494-2011 "Residential and public buildings. Indoor microclimate parameters" (hereinafter GOST) the normalized maintenance "in the center of the serviced area and at a distance of 0.5 m from the inner surface of the exterior walls and stationary heaters" of the resulting temperature *tr* and local asymmetry of the resulting room temperature *dtr*.

Let us explain the GOST terminology used in the text of our article: the radiation temperature of a room is the area-averaged temperature of the internal surfaces of the room enclosing sdtructures and heating appliances; the resulting room temperature is defined as a complex indicator of the radiation temperature of the room and the room air temperature. Moreover, with an air rate of 0.2 m / s or less, the resulting temperature is equal to the half-sum of these components, and with a higher air rate, 60% is allocated to the convective part, and 40% to the radiation part. The temperature of a ball thermometer is the temperature in the center of a thin-walled hollow sphere that characterizes the combined effect of the air temperature, the radiation temperature and the air rate.

A ball thermometer for determining the resulting temperature is a hollow sphere blackened from the outside (the degree of blackness of the surface is not lower than 0.95), inside which the thermometer is placed. The local asymmetry of the resulting temperature is the difference of the resulting temperatures at the point of the room, determined by a ball thermometer for two opposite directions. A ball thermometer for determining the local asymmetry of the resulting temperature is a hollow sphere in which one half of the ball has a mirror surface (the degree of blackness of the surface is not higher than 0.05), and the other half has a blackened surface (the degree of blackness of the surface is not lower than 0.95). The temperature of the ball thermometer measured in the center of the ball is the equilibrium temperature from the radiation and convective heat exchange between the ball and the environment.

These standards should be checked at different heights from the floor, depending on the preferred position of people: sitting or standing in the room. In addition, these heights are different for the premises of preschool educational institutions and the rooms for adult people.

However, in the Table 7 of GOST it is indicated that "the centers of the planes spaced from the inner surface of the outer wall and the heater by 0.5 m" should be the places of measurement of microclimate parameters at the boundaries of the serviced zone. That is, the authors of GOST treated the boundaries of the serviced zone not as an air space, but as the surface of the enclosing structure. Such an attitude does not make sense, since the center of the above-mentioned border of the serviced area, for example, in a children's institution with a height of 3.6 m in the cleanliness of the premises, is 1.8 m away from the floor, which is not relevant for kindergarten children. Therefore, in the article, all estimates of the resulting and radiation temperature refer to the heights specified in clause 6.3 of GOST.

With the normalized values of the air rate, air temperature and the resulting temperature set in GOST, the radiation temperature norm can be calculated. Since the air temperature can be considered constant in the volume of the room, and the radiation temperature has its own value at each local location, it is convenient to operate with the radiation temperature *tr* so forth.

2 Methods

In this paper, the values of the radiation temperature *tr* and the local asymmetry of the radiation temperature *dtr* with respect to the ball thermometer were estimated by calculation. The calculation applied the formula, which is known from spherical geometry, of the coefficient of irradiance from a flat elementary platform to a sphere of known diameter [21].

It is clear that the radiation temperature *tr* and the local asymmetry of the radiation temperature *dtr* depend on the temperature of the inner surfaces of the enclosing structures and especially the outer ones. Moreover, the temperature of the inner surface of the window, as an external fence with the lowest resistance to heat transfer, has the greatest influence on these parameters. The calculation of the internal surface temperature of all enclosing structures of the room at a given resulting temperature of 20 ° C has been provided according to the PC program [17]. The calculation uses the solution of a system of equations of stationary thermal balances of the air and the internal surfaces of all room enclosing structures, where the air temperature and the temperature of each surface facing the room are unknown.

The air thermal balance takes into account the air convective heat exchange with each inner surface of all enclosing structures (external and internal) and the convective heat of the air heating system. The thermal balance of each internal surface takes into account the radiant heat exchange with each other surface of the room. The radiant heat exchange of surfaces facing the room with each other is carried out taking into account compliance with the law of closure of radiant flows, which consists in the fact that the sum of the irradiance coefficients from each surface to all the others is equal to 1.

In the latest edition of the code of rules "Thermal protection of buildings" SP 50.13330.2012 with amendment No. 1, put into effect on 12/14/2018, the norms of increased resistance to heat transfer of windows of residential and public buildings from 0.49 to 0.8 $m^{2}\cdot{}^{o}C$ /W were introduced, depending on the number of degree-days of the heating period (DDHP). But for medical and preventive, preschool educational and general educational organizations and boarding schools, the minimum values of heat transfer resistances are left at the same level from 0.3 to 0.8 $m^{2}\cdot{}^{o}C$ /W. It should be mentioned that the norms of heat transfer resistance for windows were previously increased for all buildings. However, since the mentioned standards of thermal protection of windows, left at a low level, relate to buildings with the most health vulnerable contingent of people, the below verification of compliance with GOST standards will be performed for these very buildings.

The city of Belgorod, which does not belong to the northern cold zone, was chosen for verification. In this city, the design temperature of the coldest five days with 0.92 availability makes -24 °C. For a large number of rooms of these buildings, the design temperature has been accepted equal to +20 °C. The internal temperature is maintained by an air heating system. The geometry of an intermediate floor room for this study has been taken from a real project. The length of the outer wall between the axes of the side partitions is 6 m, and the depth of the room from the inner face of the outer wall to the axis of the opposite partition is 5.4 m. The height of the room in cleanliness is 3.3 m. Symmetrically along the width of the room there is a window in the outer wall measuring 3.8 x 1.8 m with a height of the bottom of the window from the floor of 1 m. The window area is 35% of the total area of the vertical external enclosure of the room.

Using the norms of indoor air temperature and the resulting temperature according to GOST, it is possible to determine the optimal ranges of the radiation temperature for nursery and junior groups of 20.5 - 22.5 °C, for middle age kindergarten groups of 18.5 - 20.5 °C, for hospital wards of 18.5 - 21 °C, the permissible ranges for these three cases are, respectively: 19.5 - 23.5 °C; 17.5 - 24.5 °C; 17.5 - 23.5 °C.

Taking the air temperature constant in the volume of the room, we can consider the norms of asymmetry of the radiation temperature of the premises equal to double norms of the resulting temperature: for optimal values no more than 5 °C, and for permissible ones no more than 7 °C.

3 Results

First of all, the dependence of the radiation temperature *tr* and the asymmetry of the radiation temperature *dtr* on the resulting temperature maintained in the room was checked. Table 1 shows the results of calculations. The range of the resulting temperature is adopted taking into account the designing standards for medical and preventive buildings. It can be seen from the Table that the optimal norms at the border of the serviced zone are not met at a height of 1.7 m from the floor at any temperature, but at a height of 1.1 m at all considered room temperatures are 20 ° C and above. As for the permissible conditions, they are being met at the limit. If we talk about the radiation temperature *tr* at points on the border of the serviced zone, then according to GOST, the difference between the resulting temperature and the radiation temperature should not exceed 1 ºC. The calculation results indicate a much greater difference in these temperatures. Therefore, it can be stated that the requirements for the radiation temperature *tr* are not met at any of the considered resulting temperatures at all normalized heights from the floor at the boundary of the serviced zone.

In addition, the Table 1 allows, at constant outdoor air temperature and heat transfer resistance of external enclosing structures, to give a numerical estimate of the effect of an increase in the resulting temperature on the local asymmetry of the radiation temperature *dtr*. With an increase in the average resulting room temperature by 9 ºC, the local asymmetry of the radiation temperature *dtr* due to the increased temperature difference between the window surface and the room air increased by 0.9 ºC. At the same time, the values of the radiation temperature *tr* at the boundary of the serviced zone practically follow the change in the resulting temperature.

Table 1. Values of radiation temperature *tr* and local asymmetry of radiation temperature *dtr* at the border of the serviced zone opposite the middle of the window in an ordinary room during the design winter period.

Average resulting room temperature, ºC	**Maximum value of local asymmetry of radiation temperature, ºC at heights from the floor, m**					**Minimum value of local asymmetry of radiation temperature, ºC at heights from the floor , m**				
	1.7	**1.1**	**0.6**	**0.4**	**0.1**	**1.7**	**1.1**	**0.6**	**0.4**	**0.1**
1	2	3	4	5	6	7	8	9	10	11
18	6.07	4.93	3.40	2.89	2.47	14.97	15.55	16.34	16.61	16.99
20	6.28	5.10	3.52	2.98	2.56	16.84	17.45	18.26	18.55	18.92
22	6.48	5.26	3.63	3.08	2.64	18.74	19.36	20.20	20.5	20.88
24	6.69	5.42	3.74	3.17	2.71	20.62	21.27	22.14	22.44	22.84
27	6.98	5.66	3.89	3.30	2.82	23.48	24.16	25.06	25.38	25.79

Figures 1, 2, 3 show the distributions of the radiation temperature *tr* and the local asymmetry of the radiation temperature *dtr* according to the plan and sections of an ordinary room in the form of isolines.

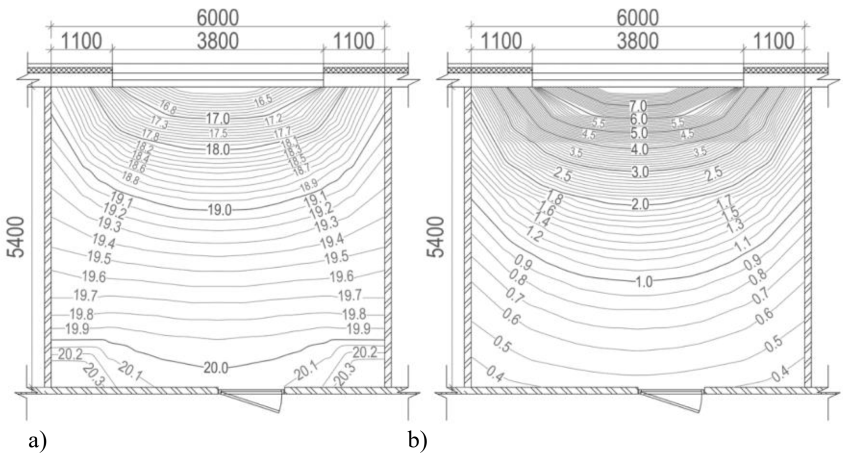

Fig. 1. Distribution of radiation temperature (Fig. 1 a) and local asymmetry of radiation temperature (Fig. 1b) according to the plan of an ordinary room at a height of 1.7 m, in the design winter period.

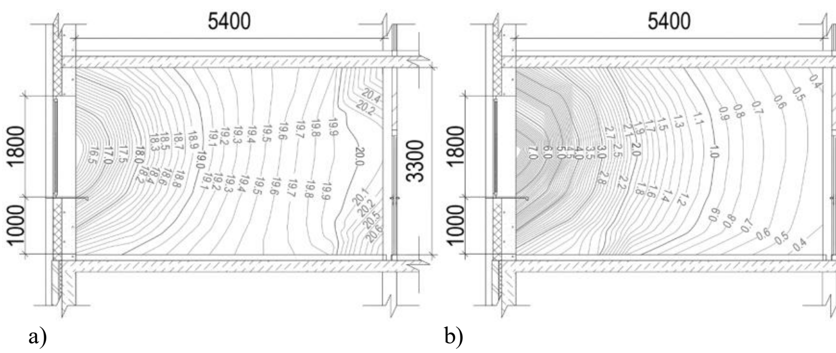

Fig. 2. Distribution of radiation temperature (Fig. 2a) and local asymmetry of radiation temperature (Fig. 2b) along the longitudinal room section the middle of the room in the design winter period.

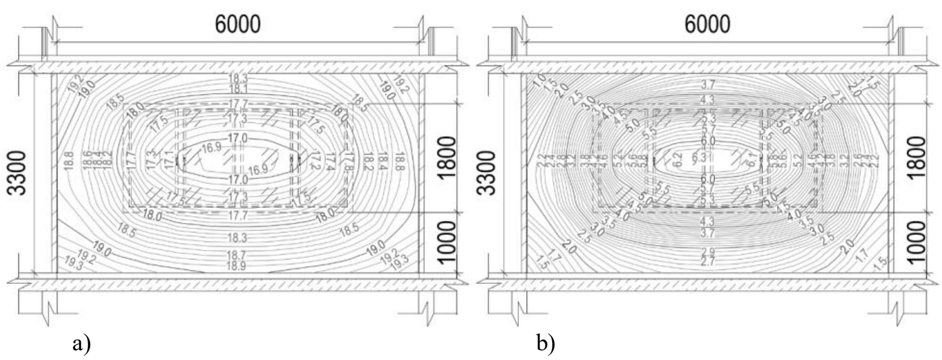

Fig. 3. Distribution of radiation temperature (Fig. 3a) and local asymmetry of radiation temperature (Fig. 3b) along the cross section of the room at the border of the serviced zone in the design winter period.

4 Discussion

The smallest values of the radiation temperature *tr* and the largest values of the local asymmetry of the radiation temperature *dtr* are formed opposite the center of the window.

In the presented work, the middle of the room at a height of 1.7 m according to the room plan is the closest to such a point on the border of the serviced zone. On the plan 1a and the longitudinal section 2a, it can be seen that the radiation temperature takes minimum values opposite the center of the window and increases with moving away from the window. The intensity of this increase decreases as you move deeper into the room. The same can be said about the local asymmetry of radiation temperature, but it does not increase, but decreases. According to the isolines on the longitudinal section, it can be traced that, according to the height of the room, the most extreme values of the radiation temperature and local asymmetry of radiation temperature are formed at a height of 1.9 m from the floor, that is, opposite the center of the window. These results confirmed previous studies [21].

On the plans and sections of the room, it can be seen that near the lateral internal partitions, the radiation temperature rises slightly, and the local asymmetry of the radiation temperature decreases. Moreover, these changes are smoothed out as they approach the end internal partition. This is because the cooling effect of a window with less resistance to heat transfer than that of the outer wall is more pronounced opposite the window itself, and opposite the piers next to the window, the irradiation of this partition, the temperature of the inner surface of which is higher than the windows, is more pronounced.

The longitudinal section clearly shows that the lowest values of the radiation temperature *tr* and the highest values of the local asymmetry of the radiation temperature *dtr* are observed opposite the center of the window, both according to the plan and the height of the room. Near the pier partitions, the *tr* values increase, and the values of the local asymmetry of the radiation temperature *dtr* decrease.

5 Conclusions

The higher the resulting room temperature, the greater the value of the local asymmetry of the radiation (and hence the resulting) temperature at the boundary of the serviced area of the room opposite the window. The closer to the center of the window, the higher these values are. The radiation temperature at the border of the serviced zone increases with the increase in the resulting one, however, the difference between these temperatures increases, which, according to GOST, should fit into 1 °C, and in the calculation performed at a height of 1.7 m from the floor it exceeds 3 °C , and even at a height of 0.1 m from the floor the difference slightly, but exceeds 1 °C.

Even with the corresponding heat transfer resistances of the windows of medical and preventive, preschool educational and general educational organizations and boarding schools, when designing, it is necessary to check the requirements for radiation temperature and local asymmetry of the resulting temperature at the border of the serviced zone, since they are not always observed.

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