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The research of supplied air flow parameters in air heated buildings

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1. Introduction

People spend 80 – 90% of their lifetime indoors [1-3]. In order to ensure their good health, comfort, satisfaction and productivity, it is necessary to maintain the microclimate parameters in the premises [3-5]. In Lithuania, the indoor microclimate of residential buildings is defined as a combination of the following parameters: air temperature, vertical air temperature differences, air velocity and relative air humidity. The combination of these parameters influences the indoor thermal comfort, but the indoor air quality is also an important factor affecting people's well-being. Chemical compounds, odours, combustion products and other harmful products are continuously released into the premises; as a result, the indoor air can be more polluted than the outdoor air [6]. The indoor air quality can be improved by supplying the premises with fresh air. In Lithuania, the amount of supplied air is regulated by Technical Construction Regulation – STR 2.09.02:2005 "Heating, ventilation and air conditioning" [7].

Air exchange in the building is ensured by a ventilation system, which can be natural or mechanical. In buildings with natural ventilation systems, uncontrolled air flow enters the premises through the building envelope leaks. A high level of thermal insulation and air tightness is a solution to reduce the consumption of thermal energy in buildings, but in such buildings, natural air exchange decreases or absolutely disappears; consequently, natural ventilation systems should be replaced with the mechanical ones [8]. Such systems maintain the amount of the supplied and exhausted air, control the temperature of the supplied air and the level of air purification. The mechanical ventilation system supplies the air with temperature the same as that of the premises, or colder in cold season. The air heating system supplies preheated air because it is necessary to compensate for the most part of heat losses of the building [9]. This system can be effectively used as an air heating system and in this way, eliminate the need for other heating sources [10, 11]. The air heating system will be effective only if heat losses of the building are compensated by supplying the minimum amount of fresh air required for building ventilation, and the temperature of the supplied air is not higher than 50°C. The temperature of the supplied air cannot exceed 50°C [11]; otherwise, dust combustion process begins in the air ducts and the supplied air no longer satisfies the hygiene requirements [12]. In order to reduce the amount of energy consumed for the heating of the supplied fresh air, heat recovery units must be installed.

When the premises are air-heated, the amount and temperature of the supplied air have to be balanced to cover the heat losses of the building and ensure the microclimate parameters in the operating area. This area is a 2.0 m space above the floor in the premises. When air is supplied to the premises, it is important to ensure a gradual air flow in all the volume of the premises. Due to insufficient air flow, harmful gases may accumulate near the ceiling, and due to the property of the hot air to move up, significant temperature differences are felt in the premises. However, the increased air flow in the premises causes negative effects, such as draught, moving dust and increased energy consumption. In order to avoid these problems, it is important to appropriately set the amount of the supplied air and chose the places for its supply and exhaustion. In Lithuania, the air for the ventilation of premises is usually supplied through diffusers installed in the ceiling, but using this scheme for the heating of premises, the trajectories of cold and hot air flows are different because gravitational and inertial powers affect the air flow in different directions. When hot air is supplied down the diffusers installed in the ceiling, gravitational powers are several times stronger than the inertial powers; therefore, hot air accumulates near the ceiling. When the inertial powers are increased, i.e. the velocity of the supplied air is increased, the air flow cannot disperse; therefore, the air velocity in the operating area is too high.

In order to determine the efficiency of air heating system in respect of the energy characteristics of the building and to analyse the parameters of hot air flow in the premises, theoretical and experimental researches were carried out.

2. Theoretical research

2.1. The description of modeled building energy performance

Theoretical research was carried out in the building modelled according to the recommendations for a low energy building. The building was modelled in consideration of its shape, orientation regarding the cardinal directions, the area of glazed envelopes, the level of thermal insulation of envelopes and other qualities.

The demand for heat energy depends on the shape and orientation of the building [13]. The smaller is the proportion between the area of envelopes and the area of floor, the smaller are the heat losses through the envelopes. The modelled two-storey building is nearly cube-shaped. The external dimensions of the building are the following: length − 10.66 m, width − 9.81 m, height − 6.88 m. The total area of the building equals to 179.90 m^2, the volume equals to 719.47 m^3. The heat balance of the building is significantly influenced by solar heat gains through the glazed envelopes [14, 15]; therefore, the largest area of glazed envelopes is on the southern side of the building: 14.80 m^2. On the western side, glazed area is 10.05 m^2, and on the eastern – 7.80 m^2, whereas 5.38 m^2 of glazed area was designed on the northern side following the requirements for natural lighting given in Technical Construction Regulation – STR 2.02.01:2004 [16]. The total glazed area of the building amounts to 38.03 m^2. Considering the orientation of the building regarding the cardinal directions, bedrooms, kitchen and sitting room are oriented to southern and western sides, and the premises that are not frequently used are oriented to eastern and northern sides. Energy characteristics of the building are the following: the value of heat transfer coefficient of envelopes, tightness, the coefficient of linear thermal bridges, the efficiency of heat recovery unit according to the requirements for the buildings of A, A+, A++ energy efficiency classes [17]. The values of heat transfer coefficient of the envelopes are indicated in Table. The air exchange in the building due to the infiltration of the outdoor air is not higher than 0.6 times per hour at the pressure difference of 50 Pa, which corresponds to 0.05 times per hour under natural conditions [7]. Linear thermal bridges are allowed only through window and door reveals, and their value is not higher than 0.05 W/mK [17]. For the ventilation of the premises, a mechanical ventilation system with a heat recovery unit was installed; the efficiency of the unit is 65% for A class buildings, 80% for A^+ and 90% for A^{++} class buildings.

Table

Modeled building energy performance

Building energy performance class	Thermal transmittance U_N, W/m^{2}K				
	Walls	Floor	Roof	Windows	Doors
A	0.12	0.14	0.10	1.00	1.00
A+	0.11	0.12	0.09	0.85	0.85
A++	0.10	0.10	0.08	0.70	0.70

2.2. Heat demand for heating the building

In accordance to the characteristics of the building indicated in Table and following the requirements of the Technical Construction Regulation – STR 2.09.04:2008 “Heating load of the building. The need for heat for heating” [18], heat transfer coefficient of the building was calculated; it consists of heat transfer coefficient of the envelopes and heat losses due to ventilation (Fig. 1). Also, the proportion of heat transfer coefficient of each kind of building envelopes was analysed (Fig. 2).

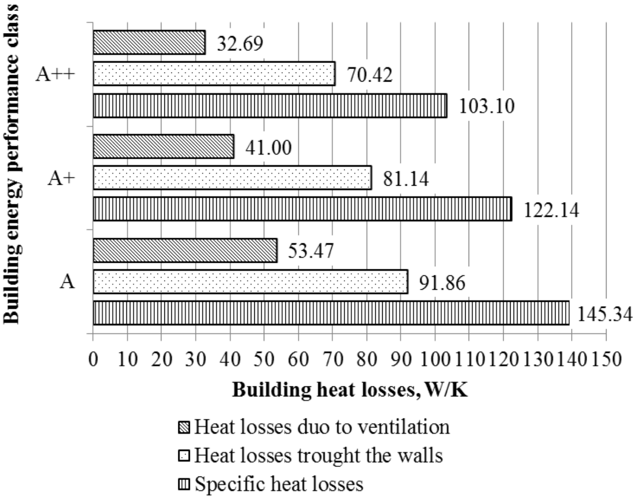


Fig. 1 Heat transfer coefficient of the building

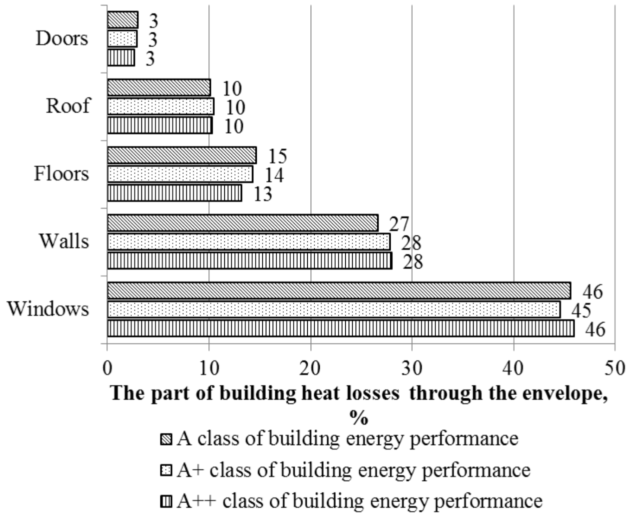


Fig. 2 The proportion of heat transfer coefficient of the building envelopes

The biggest part of building heat losses through the envelope are through windows at about 46%, through the walls 30%, through the floors and roof 10 – 15%. The lowest part of building heat losses are through the doors at about 3% in all three energy performance classes of buildings.

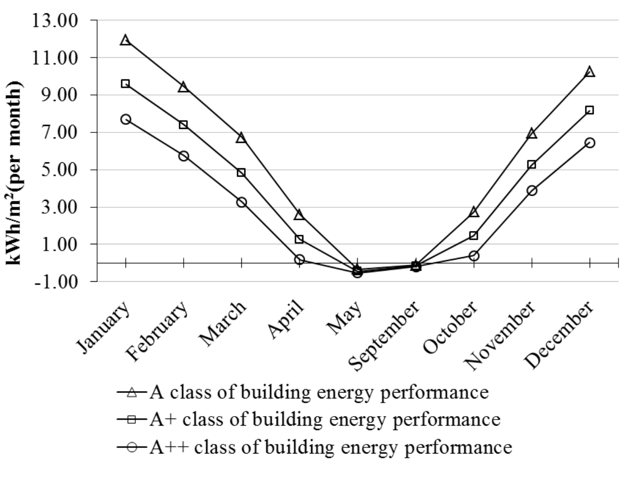


Fig. 3 Monthly heat demand for heating the building

Monthly heat demand for heating the building is calculated by assessing the difference between the monthly average outdoor temperature and the temperature of the premises (Fig. 3). The data of the heating season in Kaunas city were used for the calculations [19]. Depending on the energy efficiency class of the building, heating season begins in September or October, and ends in April or May.

The greatest heat demand was in January, when 8 – 12 kWh heating load was required for covering heat losses of 1 m^2 of the premises. Due to solar radiation and the influence of internal heat sources, heat inflows to the premises in May and September exceed heat losses; therefore, the premises do not have to be heated during these months.

2.3. The effectiveness of air heating system

As it was mentioned, the air heating system will be effective if heat losses of the building are covered by supplying the premises with the least amount of fresh air necessary for ventilation, and the temperature of the supplied air is not higher than 50º C. In the modelled building, the amount of the supplied air varied from 0.008 to 0.017 m^3/s, depending on the area and purpose of the premises. Fig. 4 shows the temperature of the supplied air that ensures thermal comfort of the premises by supplying the premises with the least amount of fresh outdoor air.

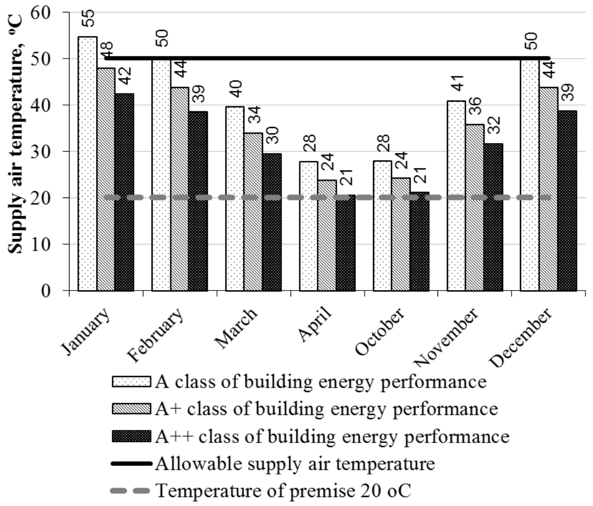
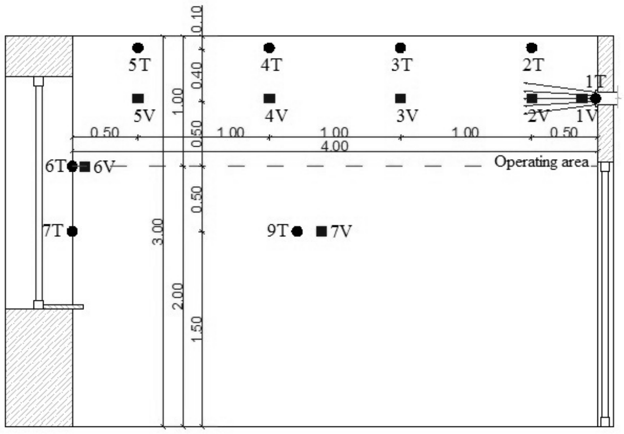


Fig. 4 The temperature of the supplied air necessary for covering heat losses of the building by supplying the premises with the least amount of air necessary for ventilation

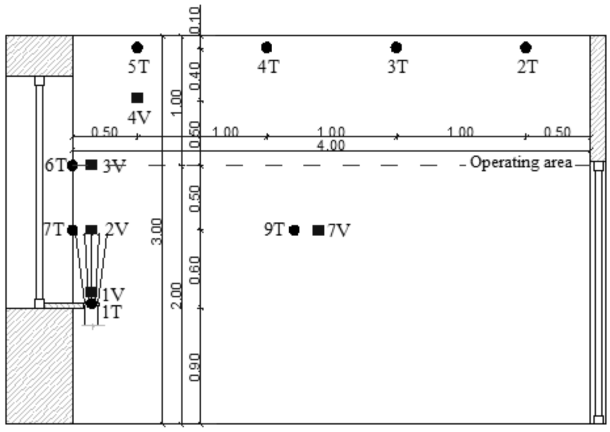
In order to maintain a constant temperature of 20º C in the building during the coldest months of the heating season by supplying the premises with the least amount of air necessary for ventilation, the temperature of the supplied air in the building of A energy efficiency class exceeds the allowed limit by 5º C. In the buildings of A+ and A+ + energy efficiency classes, the air heating system will work efficiently through all seasons. The temperature of the supplied air in January would be 42 – 48ºC.

3. Methods of experimental research

The experimental research was carried out in the premises of the following dimensions: width − 2.87 m, length − 4.00 m, height − 3.00 m. The heat losses of the premises were covered by supplying the premises with preheated air. The heating system consisted of an air heater, ventilator, air duct and air supply grille. The amount of air supplied to the premises was regulated using a manually controlled bolt. The effective area of air supply grille was 0.009 m^2.



a



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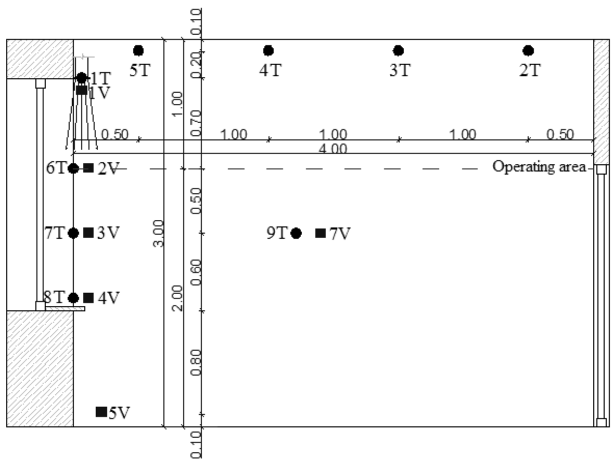

c

Fig. 5 Schemes of air supply and places of temperature and air velocity measurement: a) air is supplied horizontally, through the grilles installed in the wall above the operating area; b) air is supplied vertically from the bottom to the top, through the grilles insta lled under the windowsill; c) air is supplied vertically from the top to the bottom through the grilles installed above the window

The analysis of the theoretical research shows that the largest heat losses are found through the glazed envelopes. In order to cover these losses, three schemes of preheated air supply to the window area were chosen:

- air is supplied horizontally, through the grilles installed in the wall above the operating area (Fig. 5, a);
- air is supplied vertically from the bottom to the top, through the grilles installed under the windowsill (Fig. 5, b);
- air is supplied vertically from the top to the bottom through the grilles installed above the window (Fig. 5, c).

During the experiment, hot air flow velocity in the premises was analysed in respect of the amount and temperature of the supplied air. For each air supply scheme, four measurements were taken, changing the amount of the supplied air from the least amount of fresh air necessary for ventilation of the premises to the maximum possible, considering the capacity of the modelled air heating system. During the experiment, the temperature of the supplied air and the air in the premises, as well as air velocity, were measured (Fig. 5, a-c). The highest air velocity was in the centre of the air flow; therefore, the points for measurement were chosen at 0.5 – 1.0 m from the grille, where the axis velocity of the hot air flow becomes equal to the velocity of the surrounding air flow. The temperature was measured at four points in 0.10 m distance from the ceiling, in the axis of the hot air flow near the exhaust grille, and in the operating area. The temperature of the premises and the air flow velocity were measured in the centre of the premises at points 9T and 7V (Fig. 5, a-c). Air temperature in the premises was measured using copper-constantan thermocouples every second. The obtained data were used for calculating the average of 1 min, which was recorded in the data accumulator. Air flow velocity was measured using a multifunctional meter of temperature and air velocity. The results of each point were calculated by taking the average of 1 min.

4. Results of experimental research

In order to ensure the accuracy of the experimental data of each air supply scheme, the experiments were carried out three times under the constant temperature of 18ºC in the premises. The measurements were taken in November and December 2012; during this period, the outdoor temperature varied from -3 to -10ºC. If outside air temperature drops to -22°C, i.e. up to the coldest five days mean temperature in Kaunas city, the inside surface temperature of enclosures would change negligible due to the low values of their thermal transmittance U_N. The heat losses would rise considerably only through windows, therefore they should be compensated by increasing of supplied air rate for heating.

In accordance to Technical Construction Regulation – STR 2.09.02:2005 “Heating, ventilation and air conditioning” [20], the minimum amount of air supplied to the experimental premises was 0.006 – 0.008 m³/s, depending on the purpose of the premises. During the experiments, the largest and the smallest amount of the supplied air was 0.021 m^3/s and 0.008 m^3/s respectively. The results obtained during the experiment (the temperature and velocity of hot air flow) are presented in Figs. 6-8.

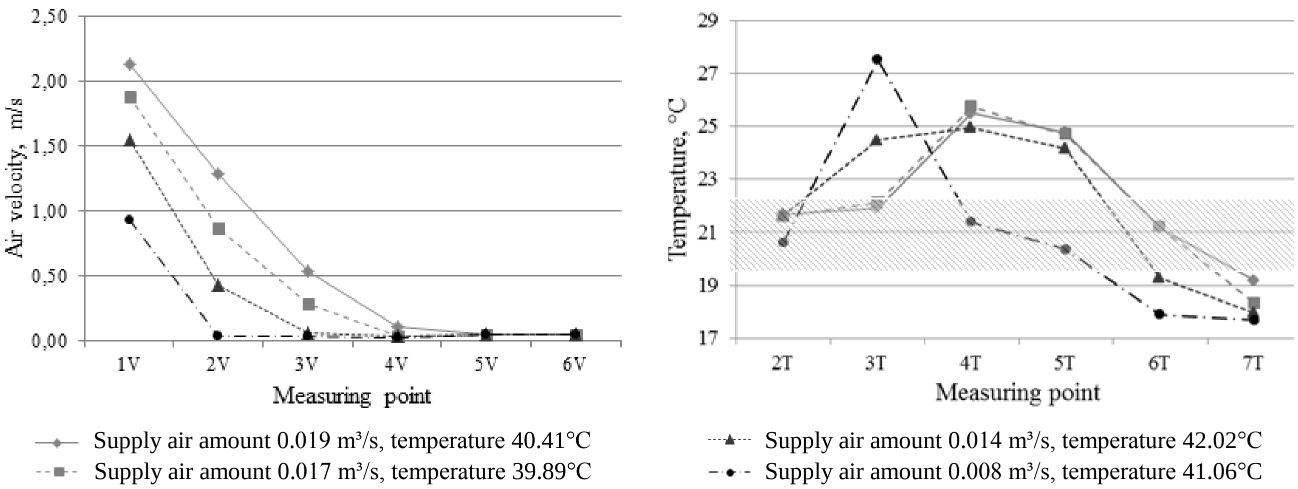

Fig. 6 Parameters of hot air flow, if air is supplied horizontally, through the grilles installed in the wall above the operating area

During the first experiment, when air was supplied horizontally through the grille installed in the wall above the operating area, the parameters of air flow were measured at six points (Fig. 6). Air velocity decreased while going further from the air supply grille and became equal to the air velocity of the premises at points 5V and 6V. According to the air supply scheme given in Fig. 6, a, hot air flow reaches the operating area at point 6V Fig. 6, where air velocity does not exceed the value of 0.15 m/s allowed in the cold season. The temperature was measured at seven points; four of them were in the ceiling area, one next to the grille and two in the operating area. The measurements of the temperature in the ceiling area at points 2T, 3T, 4T, 5T (Fig. 6) revealed that when the amount of the supplied air was decreased, the influence of gravitational powers on hot air was the greatest near the grille. When supplying 0.021 – 0.017 m^3/s of air, the highest temperature was at point 4T (Fig. 6), which is 2.5 m away from the grille. When the minimum amount of air was supplied, the highest temperature was measured at point 3T, which was 1.5 m away from the grille.

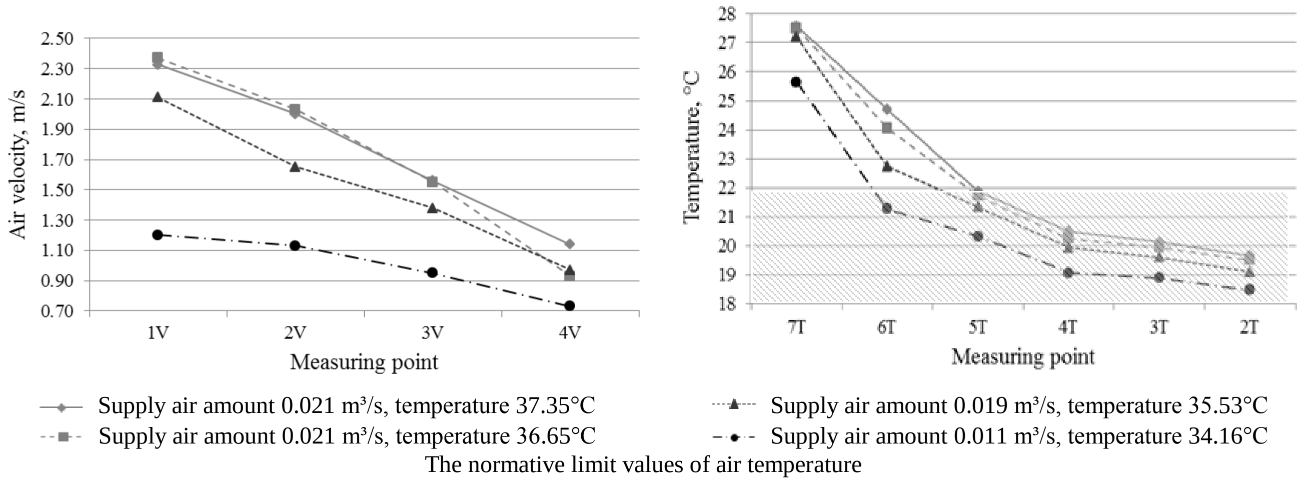

Fig. 7 Parameters of hot air flow, if air is supplied vertically from the bottom to the top, through the grilles installed under the windowsill

During the second experiment, when air was supplied vertically from the bottom to the top through the grille installed under the windowsill, air flow velocity was measured at four points, and the temperature was measured at seven points. Air flow velocity decreased when going further from the air supply grille, but even at point 4V (Fig. 7), the air flow velocity exceeded the limits. When the flow of the supplied hot air reached the ceiling, the air flow disseminated; therefore, in the places that were not in the main trajectory of the air flow, air velocity was in the norm. The supplied air flow did not cool down to the allowed temperature according to the hygiene norms, HN 42:2009, in all points of the operating area. The temperature of the supplied air gradually decreased while going further from grille, but at points 7T and 6T (Fig. 7) it still exceeded the allowed limits. In the ceiling area, the temperature distributed gradually between 22 – 18°C. When preheated air was supplied according to the scheme shown in Fig. 7 and hot air flow directly entered the operating area, air velocity and temperature exceeded the limits.

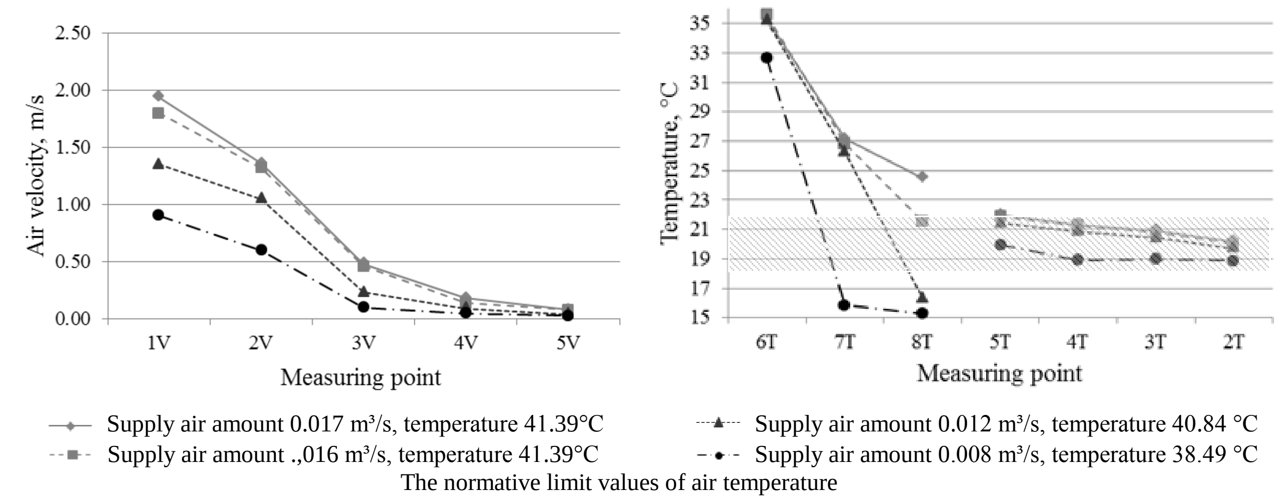

Fig. 8 Parameters of hot air flow, if air is supplied vertically from the top to the bottom through the grilles installed above the window

According to the third air supply scheme, when the air is supplied vertically from the top to the bottom through the air supply grille installed above the window (Fig. 8), the consistent patterns of change in air velocity and temperature were similar to those of the second experiment. When going further from the grille, the supplied air velocity and temperature decreased. However, due to the gravitational powers that work in the opposite direction to the inertial powers, the air flow disseminated faster than during the second experiment; therefore, there were significant differences in air velocity and temperature in the operating area.

5. Conclusions

1. Under the Lithuanian climatic conditions, the air heating system will operate efficiently if heat transmission coefficient does not exceed 0.12 W/m²K and 0.85 W/m²K for non-transparent and transparent envelopes respectively, air exchange in the building is within the limit of 0.05 1/h, linear thermal bridges are allowed only through window and door reveals and do not exceed 0.05 W/mK, and finally, heat recovery efficiency of the mechanical ventilation equipment is no less than 80%.

2. The air supply scheme when air is supplied horizontally through the grille installed in the wall above

the operating area cannot be used for heating the air in premises because the influence of gravitational powers is too strong. Under the influence of these powers, hot air flow stays in the ceiling area and does not mix with the air of the premises. In the window area, the parameters of air velocity and temperature are within the limits, but there are significant temperature differences all over the height of the premises.

3. When air for heating of the premises is supplied vertically from the bottom to the top or from the top to the bottom through the grille installed under the windowsill or above the window, hot air flow works as an air partition, which does not allow the cold air in the operating area. These schemes of air supply cover heat losses of the building, but the microclimate parameters of the premises are not ensured, i.e. air velocity and temperature exceed the limits.

4. According to HN 42:2009 [21] the microclimate parameters of the premises are measured at 0.5 m from the walls and windows. Considering these recommendations, the microclimate parameters of the premises are in the norm when the preheated air is supplied into the premises vertically in the window area.

5. On the basis of the results of the experimental research, for heating the air of the premises it is recommended to use the air supply scheme when air is supplied vertically from the bottom to the top through the grille installed above the window. When air is supplied according to this scheme, the microclimate parameters are ensured all over the volume of the premises, significant temperature differences in the premises are avoided, and the parameters in the window area minimally exceed the allowed limits.

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TIEKIAMO ORO SRAUTO PARAMETRŲ TYRIMAI ORU ŠILDOMUOSE PASTATUOSE

R e z i u m ė

Mažai energijos naudojančių pastatų patalpos gali būti šildomos orinio šildymo sistemomis. Ši sistema veiks efektyviai, jeigu pastato šilumos nuostoliai bus padengiami į patalpas tiekiant ne aukštesnės kaip 50 °C temperatūros mažiausią šviežio oro kiekį, reikalingą patalpoms vėdinti. Kitas svarbus uždavinys – užtikrinti šiluminę aplinką patalpose, neviršijant oro judėjimo greičio ir temperatūros skirtumų žmonių veiklos zonoje normų. Straipsnyje pateikti orinio šildymo efektyvaus naudojimo pastatuose teorinių tyrimų bei oru šildomų patalpų mikroklimato parametrų eksperimentinių tyrimų rezultatai.

J. Poderytė, R. Bliūdžius, K. Banionis, E. Blaževičius, A. Burlingis

THE RESEARCH OF SUPPLIED AIR FLOW PARAMETERS IN AIR HEATED BUILDINGS

S u m m a r y

The premises in low energy buildings can be heated by air-heating systems. However, the heating system will work effectively only if the building heat losses will be compensated by supplying of not higher than 50 °C air temperature and not more than the minimum amount of required fresh air for building ventilation. The other issue is to maintain the indoor comfort by ensuring the correct air velocity and supplied air temperature differences in operating zone of premises. This paper presents the theoretical studies of air heating system effective use and experimental results of indoor climate parameters by supplying the heated air in premises.

Keywords: low energy building, air-heating system, air flow, microclimate, heat losses, air tightness.

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