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Installing Local Recirculation Air Diffusers during Building Deep Renovation Reduces Energy Consumption of Ventilation Systems

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Abstract

Capital repairs of public buildings and, in particular, insulating external wall increase the proportion of heat consumption by the ventilation system in the total building energy consumption. Surplus internal heat can be observed in rooms with high heat generation values (over 30 W/m^2) even during the heating season. Using surplus internal heat to heat the outdoor air during the heating season can help reduce the heat consumption of the ventilation system.

The probability of excess internal heat occurrence in public buildings during the heating season has been analyzed. To this end, changes in specific thermal losses in buildings of various volumes occurring over the heating season in various Russian regions with different climate conditions have been compared with specific internal heat generation values typical of public buildings. Specific heat losses have been identified on the basis of rated values of the building's specific heat insulation value. The application area of ventilation systems with local recirculation air diffusers is outlined based on the outcomes of the analysis; it is concluded that these systems have a huge energy saving potential, both in case of reconstruction or deep renovation of an existing building, and when new public buildings are designed.

On analysing the characteristics of ventilation systems with local recirculation air diffusers, it has been established that these have an advantage over traditional through-flow ventilation systems, or central recirculation systems.

A local recirculation air diffuser delivering outdoor air inside the building at a low temperature (from +6 °C) has been designed. The supply air is heated to the comfort temperature as it enters the working area by mixing the outdoor air with the internal air, thus assimilating internal surplus heat.

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A design solution for the recirculation air diffuser is proposed. Computer simulation of air flows generated by the recirculation air diffuser has confirmed that comfort parameters of the supply air jet can be reached at the inlet to the work area when outdoor air is supplied at temperatures starting from +6 °C.

1. Introduction

Maintaining a high quality of air in the room, and reducing energy consumption are the two tasks that engineers have to solve in choosing internal ventilation schemes both when they design new buildings [1, 2] and reconstruct or deep renovate existing ones [3, 4]. In view of this, more and more attention is paid to researches into existing schemes of ventilation systems and designing new ones [5-10]. The authors have developed ventilation system with local recirculation diffusers. The proposed system's main functionality is assimilation of surplus internal heat in the cold and transition seasons by means of underheating the outdoor air in the input system. Optimal parameters of the supply air jet flowing into the work area of the room are attained by mixing underheated intake air with the room air (recirculation air) in the local recirculation diffusers.

2. Analysing applicability in office buildings

To identify the application area of ventilation systems with the local recirculation diffuser, the possibility of indoor excessive heat generation was analysed for the existing building and the building undergoing capital repair or deep renovation. To this end, the indoor heat balance was analysed in the heating season in various regions of Russia by comparing indoor heat emissions and heat losses via the building envelope.

Average indoor heat emissions in Russian office buildings are 27.46 W/m^2, including 5.4 W/m^2 from people, 12.8 W/m^2 from lighting, and 9.26 W/m^2 from office equipment.

Heat losses occurring via the building envelope depend primarily on the building's specific heat insulation characteristic k, $W/(m^3 \cdot °C)$. Its standard values, regulated by Russian standard SP 50.13330.2012 [11], are similar for newly built and capitally reconstructed buildings, and are determined according to the following formula:

$$k = \begin{cases} \dfrac{4.74}{0.00013 \cdot GSOP + 0.61} \cdot \dfrac{1}{\sqrt[3]{V_h}} & if\ V_h \leq 960 \\[3mm] \dfrac{0.16 + 10/\sqrt{V_h}}{0.00013 \cdot GSOP + 0.61} & if\ V_h > 960 \end{cases}, \qquad (1)$$

where:
V_h is the heated building volume, m^3;
GSOP is the climatic characteristic of the building construction area, °C·days, derived by the formula:

$$GSOP = (t_{in} - t_{m.out})z, \qquad (2)$$

where:
t_{in} is the indoor air temperature maintained in the building in the heating season, °C;
$t_{m.out}$, z is the average temperature, °C, and length of the heating season, in days; the two values are given for every Russian regions in standard SP 131.13330.2012 [12].

Fig. 1 shows the graph of behaviour of the normalized value of the building's specific heat insulation characteristic depending on the building volume (from 6,000 to 200,000 m^3) for three Russian cities, Archangelsk, Moscow, and Samara.
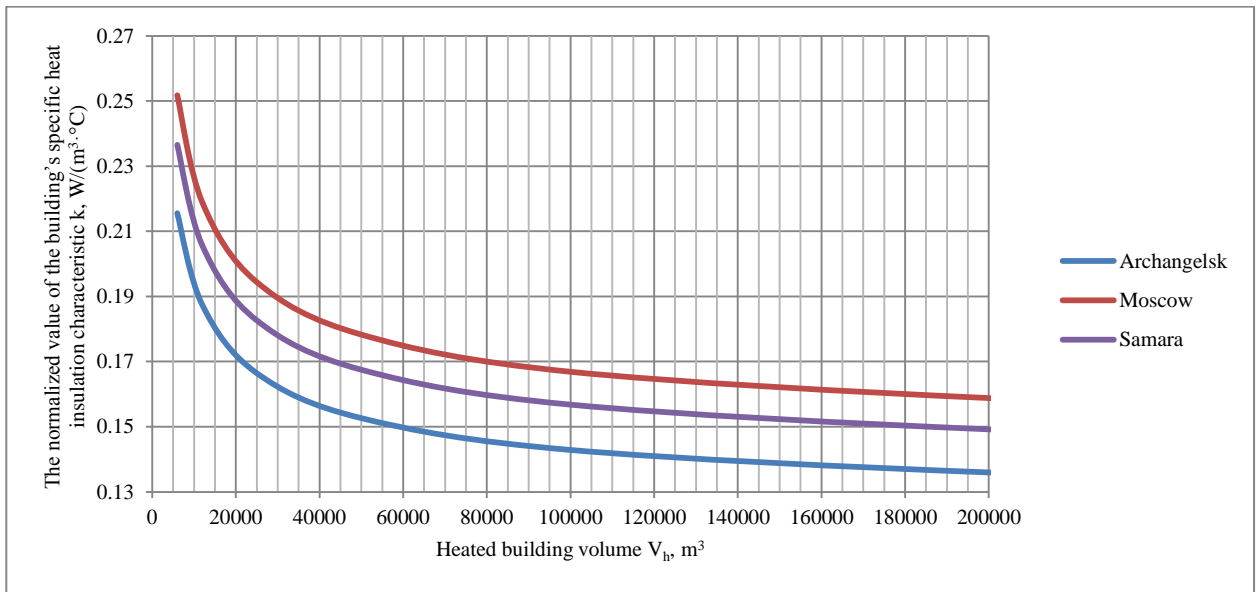
Fig. 1. The graph of behavior of the normalized value of the building's specific heat insulation characteristic depending on the building volume

The values of specific heat insulation characteristics were established for buildings of 6,000 m³ and 40,000 m³ according to Formula 2. Then, the values were used to find specific indoor heat losses occurring after the outdoor temperature was increased from the baseline in the respective city (Archangelsk, Moscow, Samara) to +18°C, which is the indoor temperature maintained in office spaces during the heating season (according to standard GOST 30494-2011 [13] (Fig. 2)). The point where the graph reflecting changes in heat losses crosses the indoor heat emissions graph was determined, and using Fig. 2 the temperature was found whereat surplus internal heat is generated.

Fig. 3, 4 and 5 show the graphs of outdoor air temperature change t_{out}, °C during the year (source of data: energy.plus.net [14]) in Archangelsk, Moscow and Samara. Additionally, the figures show the lines depicting the following temperatures:

- Polynomial is the line of the averaged polynomial temperature of outdoor air, °C;

- $t_{in} = +18$ °C – indoor air temperature;

- t_{out6} is the outdoor air temperature whereat specific internal heat emissions in a building with the volume of 6,000 m3 equals specific heat losses occurring through the building envelope, °C;

- t_{out40} is the outdoor air temperature whereat specific internal heat emissions in a building with the volume of 40,000 m3 equals specific heat losses occurring through the building envelope, °C.

The area in Figures 3, 4 and 5, which is limited by the lines of outdoor air temperature t_{out}, indoor air temperature t_{in}, and the outdoor air temperature at which indoor specific heat emissions equals specific heat losses through the building envelope t_{out6} and t_{out40}, reflects the energy saving potential of the ventilation system with the local recirculation diffuser in an office building. During this period, surplus internal heat occur in the building, while the outdoor air has the free cooling potential. It follows from the figures that both in new buildings and in those that undergo capital repair (deep renovation), the proposed system has a very high energy saving potential: surplus indoor heat occur in building with volumes over 40,000 m³ practically all year round, and according to the international consultancy Colliers [15], the volume of buildings currently erected in Russia generally exceeds 40,000 m³.
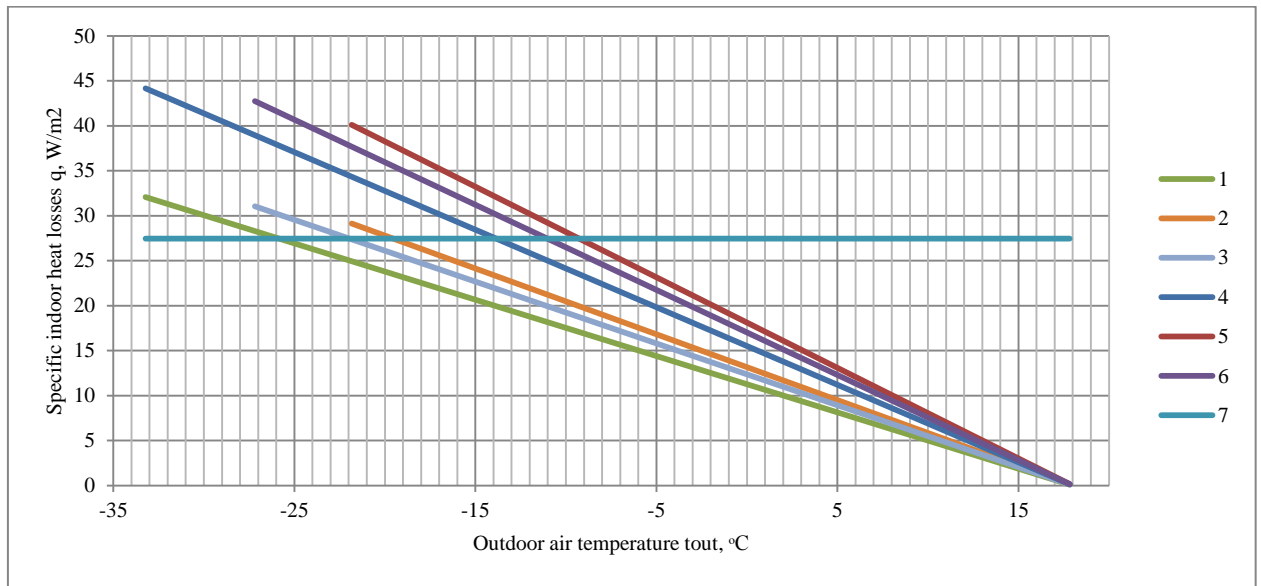
Fig. 2. The graph of behavior of specific indoor heat losses depending on outdoor air temperature for a building:

1 – in Archangelsk with the volume of 40,000 m3; 2 – in Moscow with the volume of 40,000 m3; 3 – in Samara with the volume of 40,000 m3; 4 – in Archangelsk with the volume of 6,000 m3; 5 – in Moscow with the volume of 6,000 m3; 6 – in Samara with the volume of 6,000 m3; 7 – the indoor heat emissions graph
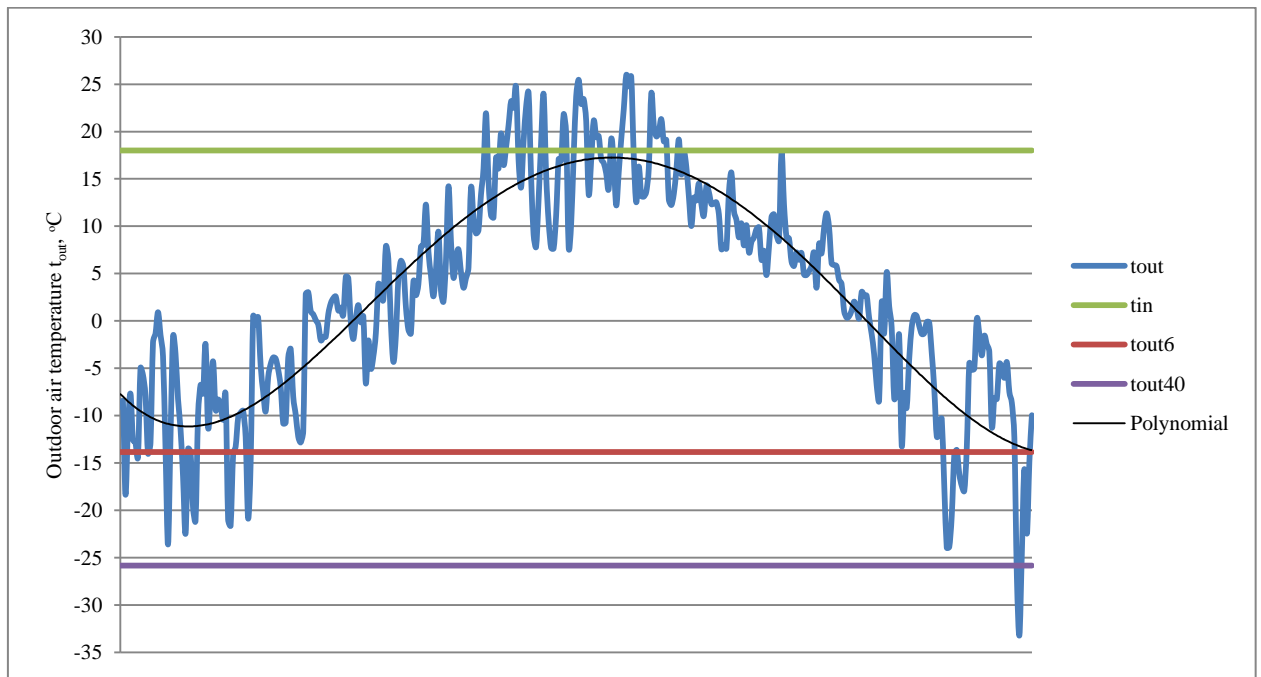

Fig. 3. The graph of outdoor air temperature change during the year in Archangelsk
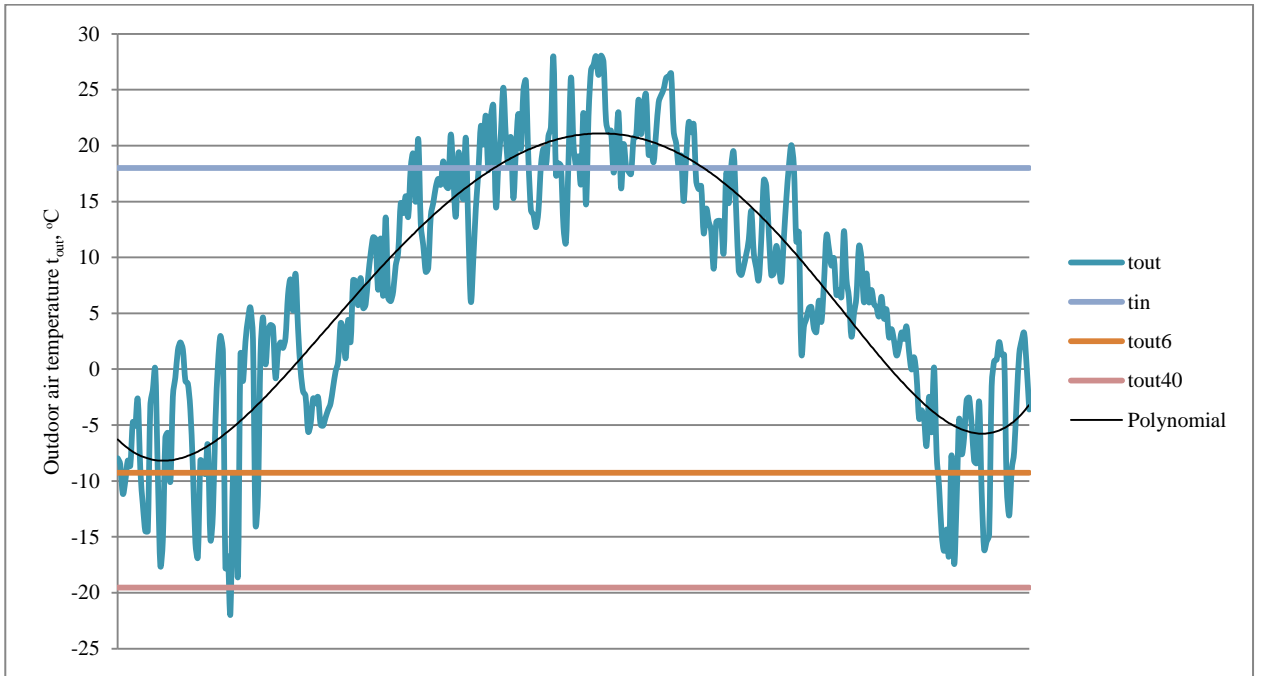
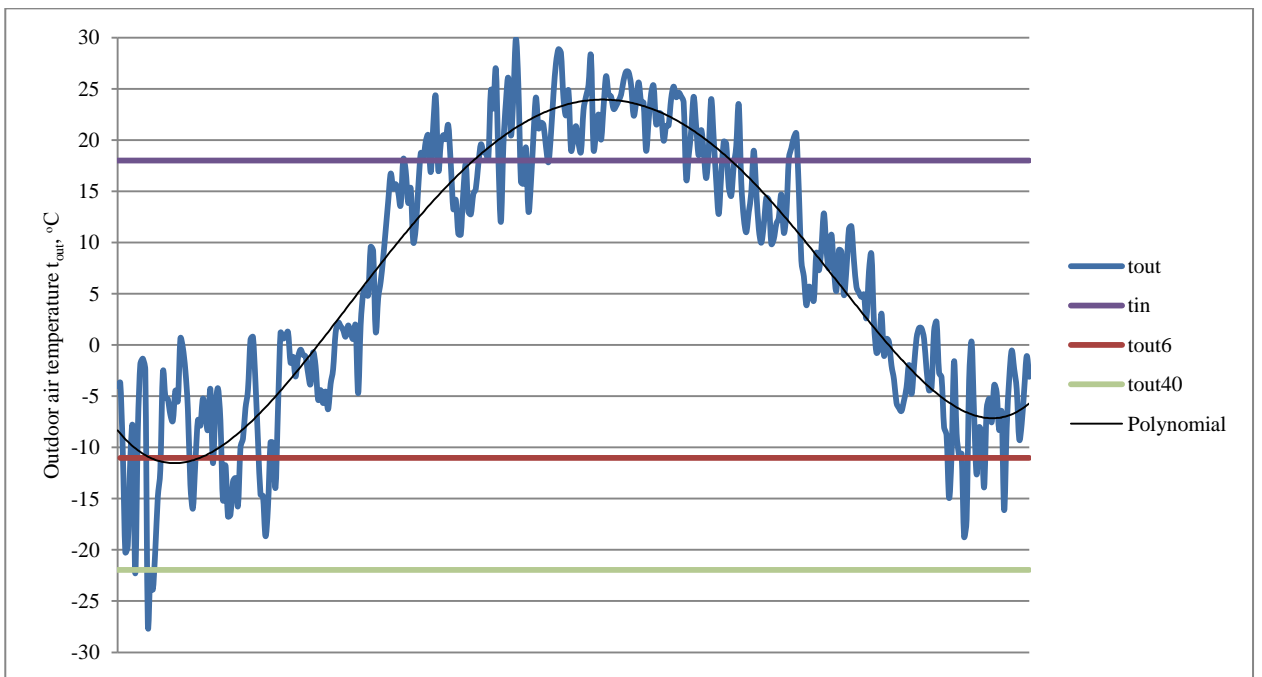Fig. 4. The graph of outdoor air temperature change during the year in Moscow

Fig. 5. The graph of outdoor air temperature change during the year in Samara

3. Principal diagram and design solutions

3.1. Design solutions for the system with local recirculation diffusers

Fig. 6 shows the principal diagram of a ventilation system with local recirculation diffusers. Outdoor air with the rate of L_{out}, m³/h, and temperature t_{out}, °C, flows into the air handling unit where it is heated by using the exhaust air with the rate of L_{exh}, m³/h and temperature t_{exh}, °C. If the air temperature after heat utilisation exceeds +6 °C (the temperature value is selected so as to rule out condensate formation on the surface of the supply duct [16]), then the air is supplied directly to the local recirculation diffuser without any treatment; otherwise, the air heated (up to +6 °C in the electric heater, and up to +7 °C in the water heater due to particular properties of automatic frost protection) and thereafter fed into the local recirculation diffuser (LRD).

The outdoor air with a temperature of $t_{lrd} \geq +6\,°C$ is mixed in the local recirculation diffuser with the indoor recirculation air with the rate of L_r m³/h and temperature of t_{exh} °C forming a stream of intake air with a temperature of t_s °C. This assimilates surplus internal heat and maintains the indoor air design temperature t_{in} °C.
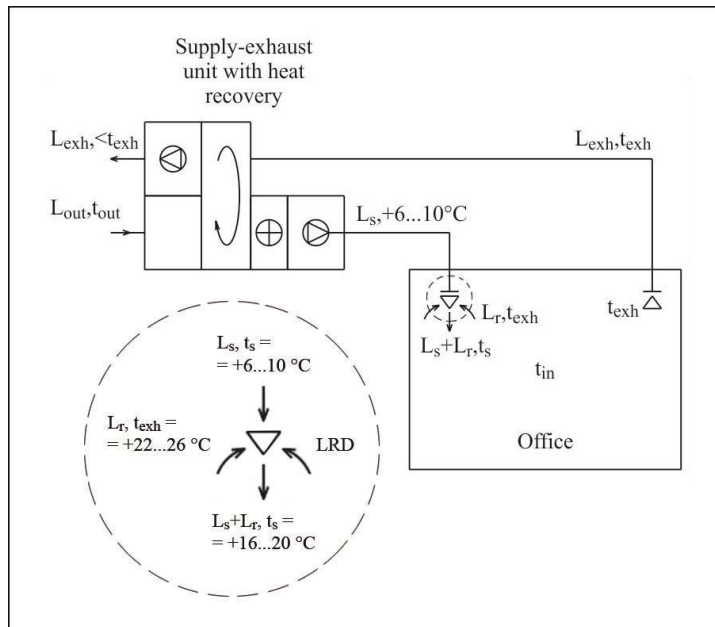

Fig. 6. The principal diagram of a ventilation system with local recirculation diffusers

Ventilation systems with the local recirculation diffusers have the following advantages:

- reduced consumption of heating energy used to heat the outdoor air (as opposed to through-flow ventilation systems);
- reduced consumption of electric power used by the air conditioning system to assimilate internal heat emissions;
- reduced consumption of electric power used to move the ventilation air (as opposed to central recirculation ventilation systems);
- prevention of contaminant spreading from one room to other rooms serviced by one ventilation system (as opposed to central recirculation systems);
- reduction in the design capacity of the air handling unit heater and, therefore, its heat transfer loop.

In the design of the local recirculation diffuser-based ventilation system, outdoor air is fed at a constant rate, and to keep the intake air temperature at the required level, the recirculation air rate has to vary. The latter can be found using the following formula:

$$L_r = \frac{L_{out}(t_s - t_{lrd})}{t_{exh} - t_s} \tag{3}$$

3.2. Design solution for the local recirculation diffuser

A local recirculation diffuser has been designed for the proposed flow diagram. Since consumption of outdoor air must remain stable throughout the ventilation system operation, the main parameter required from a local recirculation diffuser in our research was stability of the air pressure fall in the outdoor air circuit in case of changes in recirculation air use. This is why the local recirculation diffuser was designed where intake air is supplied from above in streams 'clinging' to the ceiling, and the outdoor air is mixed in the room with the recirculation air (Fig. 7).

The local recirculation diffuser works as follows. The outdoor air is supplied at a subambient temperature (≥6°C) from the input system in Pipe 4; Diffuser 5 generates a fan-shaped stream flowing under the ceiling; outdoor air consumption stays stable throughout the system's operation. Fan 7 feeds recirculation air (the air from the serviced room) through Pipe 6 into Static Pressure Chamber 1; the air is cleaned as it passes through Filter 8. Eddying Cells 3 on Surface 2 generate a fan-shaped stream of recirculation air that spreads parallel to the ceiling. This process ensures sufficient mixing of the outdoor air with the recirculation air, which was confirmed by computational modelling.
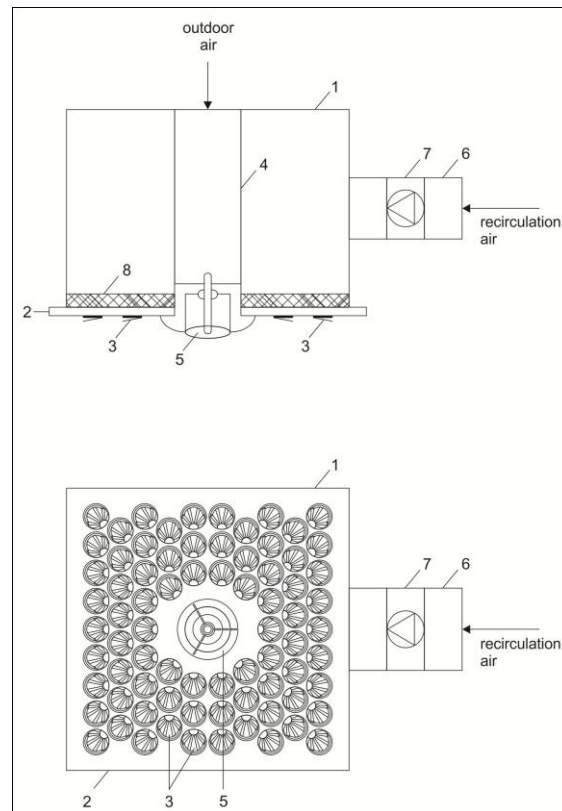

Fig. 7. Local recirculation diffuser design

Computational modelling of the local recirculation diffuser's capacity to diffuse air was performed on the ANSYS CFX platform - one of the leading CFD (Computational fluid dynamics) software systems; in computational

modelling we used standard turbulence model k-ε. The basis of computational fluid dynamics is to solve a system of nonlinear second order differential equations (Navier-Stokes equations, supplemented by equations for turbulence models, the energy conservation equations, etc.) with the help of their sampling. The ANSYS CFX for sampling and solving equations used finite-volume method (FVM). The system in the computational model was assumed to have a heat-insulated ceiling with a 300x300 mm opening. The distance between the centre of the local recirculation diffuser and the exhaust outlet was 2 m. Open boundary conditions imitating unbounded space were assumed on the other boundaries. Since the problem has a symmetric nature, the model was created for a diffuser half with symmetric boundary conditions. The total number of elements in the mesh amounted to 22 million; the basic elements are tetrahedrons. The computational model was based on the following input data (article [17] gives a detailed description of the simulation performed and the full results of computational modelling):

- volumetric flow rate of intake air $L_{out} = 120$ m^3/h;

- volumetric flow rate of recirculation air flow $L_r = 480$ m^3/h;

- outdoor air temperature $t_{lrd} = 6$°C;

- recirculation air temperature $t_{lrd} = 22$°C.

   In calculating the heat transfer, the authors used the features of a steel air diffuser panel, a plastic diffuser and, and 10 mm thick insulation on the outdoor air duct. The turbulence model k-ε was used in the calculations.

   The purpose of the computation modelling in phase one was to make sure that the supply air jet spreads along the ceiling, outdoor air mixes efficiently with recirculation air at the diffuser outflow, and condensate formation on the surface of the steel air diffuser panel is improbable.

   The computational modelling results (Fig. 8, 9) demonstrate that at the diffuser outflow, outdoor and recirculation air flows mix efficiently and spread along the ceiling. At the same time, air temperature outside the air diffuser panel exceeds 16 °C, which rules out any probability of condensate formation. The temperature of the air diffuser panel (Fig. 10) and on the outside of the air duct heat insulation ∅125 mm also is higher than 16 °C, This rules out the possibility of condensate formation on these surfaces.
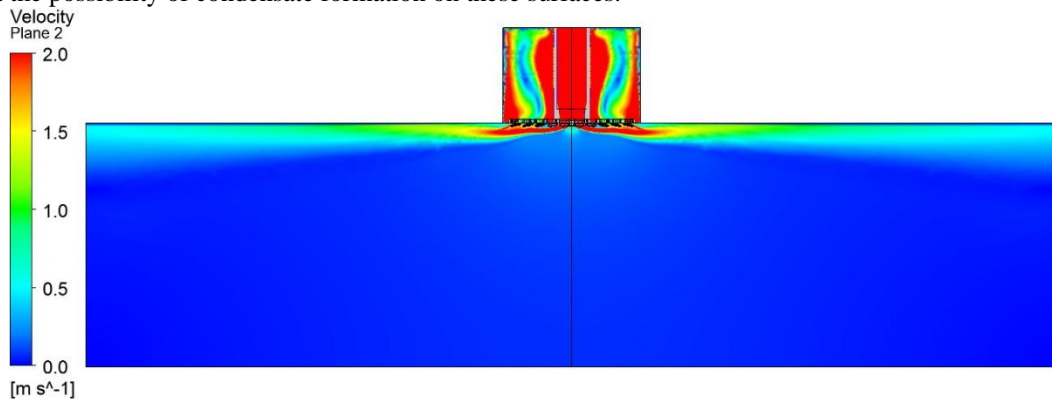

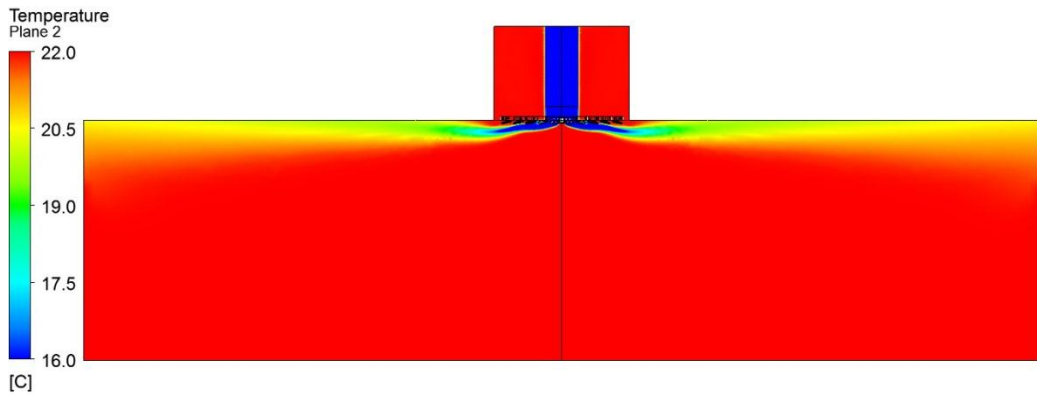Fig. 8. Velocity fields on the vertical plane

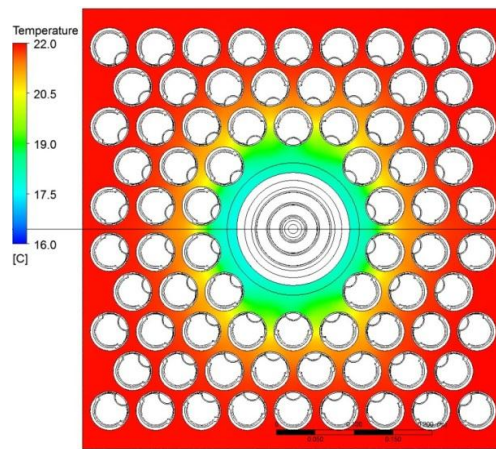Fig. 9. Air temperature fields on the vertical plane

Fig. 10. Temperature field on the air diffuser panel

An experimental prototype of the local recirculation diffuser was made (Fig. 11) with the sizes and parameters as specified in Table 1.
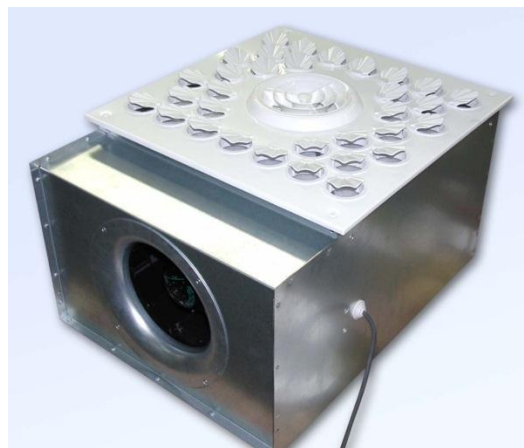

Fig. 11. An experimental prototype of the local recirculation diffuser

Table 1. The main parameters and sizes of experimental prototype of the local recirculation diffuser (LRD)

Names of the main parameters and sizes	Sizes
Capacity range of recirculation air feed fan	0÷480 m3/h
Purity class of recirculation air filter	F5
Maximum electrical capacity of the LRD fan	210 W
Dimensions of the LRD face panel	450 x 450 mm
Dimensions of the LRD plenum chamber (HWD)	301x558x424 mm
Diameter of outdoor air pipe	125 mm
Thickness of the outdoor air pipe in the LRD plenum chamber	10 mm

At the moment, a test bench is being made to test the performance of the experimental prototype of the local recirculation diffuser in an office building. The aim of the test is to:

- research the technical characteristics of the local recirculation diffuser;

- obtain data confirming the main technical characteristics and efficiency of ventilation systems with local recirculation diffusers.

The LRD experimental prototype testing programme includes performing aerodynamic and acoustic tests on special benches, and full-scale test in the office building aiming to find out:

- pressure losses in outdoor and recirculation air loops of the LRD;

- sound power of the LRD;

- LRD fan power consumption in course of system operation;

- the temperature and rate of the air in the work area of the room during system operation;

- the sound pressure in the work area of the room during system operation.

The results of the experiments will be presented in the following publications by the authors.

Acknowledgements

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