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Heat transfer under conditions of operation of a gas infrared emitter and an air exchange system

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Abstract. In this work, the processes of heat transfer in a premise heated by a gas infrared emitter (GIE) are studied on the basis of numerical solution of the heat and mass transfer equations in a two-dimensional formulation. Calculations are carried out taking into account the presence of supply and exhaust ventilation in the considered area. Ventilation is required during the operation of high-intensity type GIE. The analysis of the main heat and mass transfer parameters by radiant and convective flows is carried out.

1. Introduction

The issue of forming the thermal comfort in large-sized industrial premises is becoming especially important in recent years [1]. Industrial buildings using a standard heating system with water heaters [2] consume a large amount of thermal energy, which is accumulated closer to the ceiling [3]. Currently, a lot of research is being carried out to improve heating systems for large premises [4, 5]. Thermal comfort is more easily achieved in a radiant heating system [6] compared to a convective one.

In addition, the industrial equipment location also affects the comfortable temperature, since the heat flux from the GIE heats the exposed equipment surfaces. Moreover, convection flows of heated air arise due to the heated surfaces of equipment. Natural circulation (free convection of air masses) can have a strong effect on the comfort temperature. It is necessary to take into account various air parameters, as well as ventilation system influence, to control the indicator of the comfortable air temperature [7]. Nowadays there is a need to simulate heat transfer processes before implementing an expensive heating system. Mathematical (numerical) modeling of heated or cooled objects is gaining more and more popularity [8, 9].

The aim of the work is to establish the influence of the air exchange system intensity in a premise with equipment and an infrared heating system.

2. Mathematical modelling of heat transfer processes

A two-dimensional formulation is used for the flow region to simplify the analysis of heat and mass transfer processes, schematically shown in Figure 1.

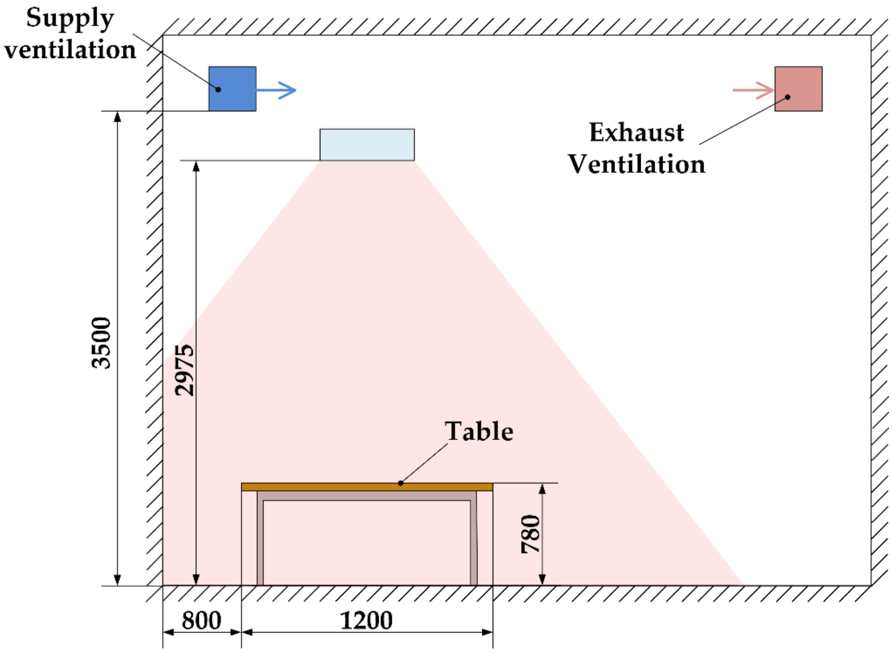

Figure 1. The solution area scheme. Dimensions are in mm.

The main parameters of heating a premise are determined by numerically solving equations, describing heat transfer and taking into account the effect of convection and radiant heat flux similar to [10]. By the initial moment of time, the temperature was assumingly the same throughout the considered area, and the air was motionless. The heating during the supply ventilation operation begins at the working temperature of the GIE radiating surface.

Due to the limited heating time, adiabatic conditions are set on the outer surfaces of the floor, ceiling and walls. The GIE emitting surface is described as a gray one. The adhesion conditions are established for the equations of air motion on solid surfaces. The inflow from the supply ventilation is simulated by setting the flow rate and temperature, and the outflow parameters are determined by setting a constant atmospheric pressure outside the room.

The finite element method was used within the modules "The Heat Transfer in Fluids Interface" and "The Turbulent Flow, k-ε Interface" of the COMSOL Multiphysics software to calculate the heating process in the considered zone. In parallel, the "Surface-to-Surface Radiation" module within the zone model, taking into account the average slope coefficients, determines the parameters of the radiation heat flux.

The physical adequacy of the calculation method was verified during the comparative analysis with the experimental results before carrying out mathematical modeling of heat and mass transfer. A satisfactory agreement between the results of physical and mathematical modeling allowed using the selected mathematical model to assess the supply and exhaust ventilation effect on the main parameters of a premise heating using GIE.

3. The analysis of mathematical modelling results

The calculations use the following basic input data.

Initial room temperature	20°C.
GIE heated surface temperature	800°C.
Air inlet temperature	10°C.
Airflow rate inlet	0.005 (0.01; 0.015; 0.02; 0.03; 0.05) kg/s.

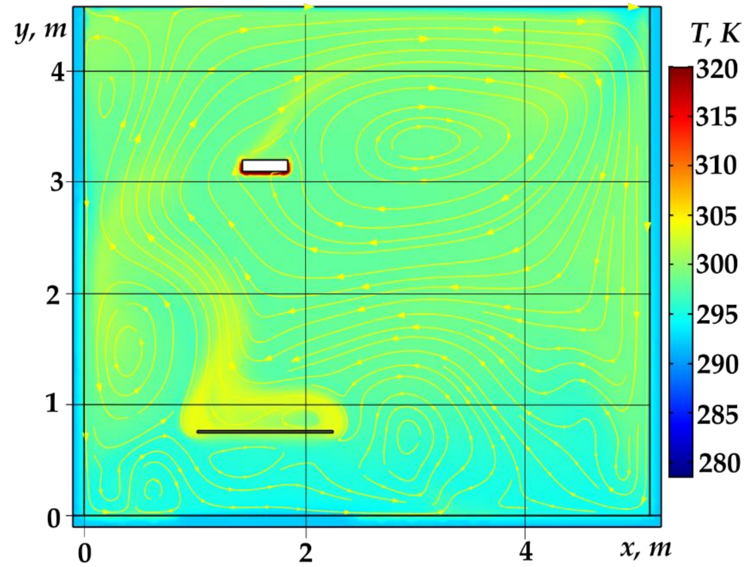

Figure 2. Calculated temperature field and flow lines formed in the premise by the 60th minute of GIE operation under natural convection conditions only.

A quasi-stationary temperature and speed distribution is established by the 60th minute from the start of heating the premise. In the absence of ventilation, the only convection source is the surfaces heated by the radiant flux from the GIE, the main of which is the table due to its location (Figure. 2). The asymmetry of GIE and table position in the premise form a clockwise airflow around the GIE. The premise walls, in accordance with the incidence angles of the radiant flux formed by GIE, heat up less intensely, cool the air flowing nearby, and form downdrafts. Convective air flows relatively uniformly raise the average air temperature above the table level by 5–7°C. Below the table level, the air remains practically unheated.

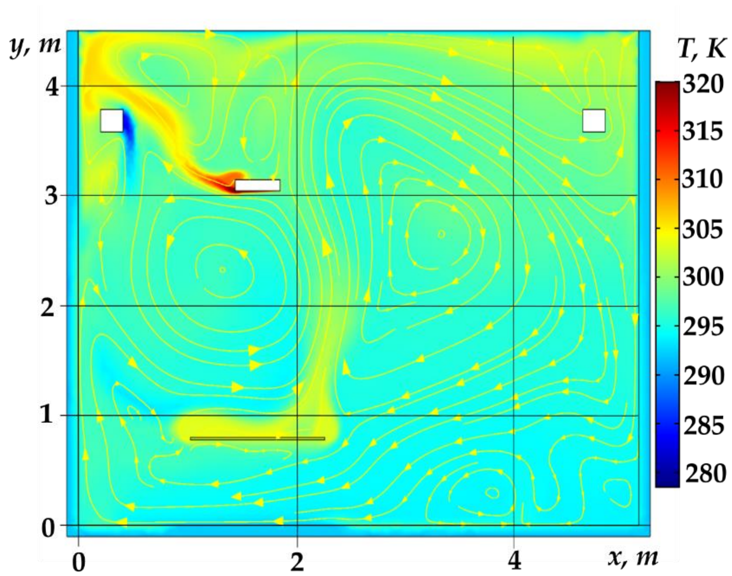

Figure 3. Calculated temperature field and flow lines formed in the premises by the 60th minute of GIE operation in the presence of supply ventilation with 0.005 kg/s air flow rate.

The air inflow with a flow rate of 0.005 kg/s corresponds to the conditions of the physical experiment, which fairly agree with the calculations. A low flow rate from the ventilation only pushes the flow ascending from the table to the right (Figure. 3). At the same time, the cooler air from the ventilation for the first 1.5 m moves almost vertically downward, gradually being warmed up by the ascending flows. In this case, in addition to the table, the premise wall closest to the GIE becomes the heater. Due to the cool airflow from the supply ventilation, the average premise temperature does not rise by more than 3–4°C. The significantly stronger influence of natural convection on the hydrodynamic picture than forced convection due to the airflow from ventilation is confirmed by the estimate of the Richardson number (Ri = 755). The Richardson number is determined by the average flow rate of the inflow, the maximum air superheat in the area of the table, and the width of the premise, which practically coincides with the height. In this convective heat exchange condition, gas heated masses above the GIE are removed through the ventilation system, which significantly lowers the average premise temperature, although the effect of air removal directly on the temperature of the table surface is not so significant.

The Ri≈1 value is reached at an airflow rate of about 0.05 kg/s. In this case, approximately equal impact on the flow of Archimedes and inertial forces forms a clockwise air flow around the GIE (Figure. 4). The table and both walls are heated directly from the GIE by a radiant heat stream and contribute to the formation of an upward heated air motion. A significant air mass inflow with temperature 10˚C lower than the initial temperature, relatively uniformly lowers the average air temperature in the premise by about 2–3°C.

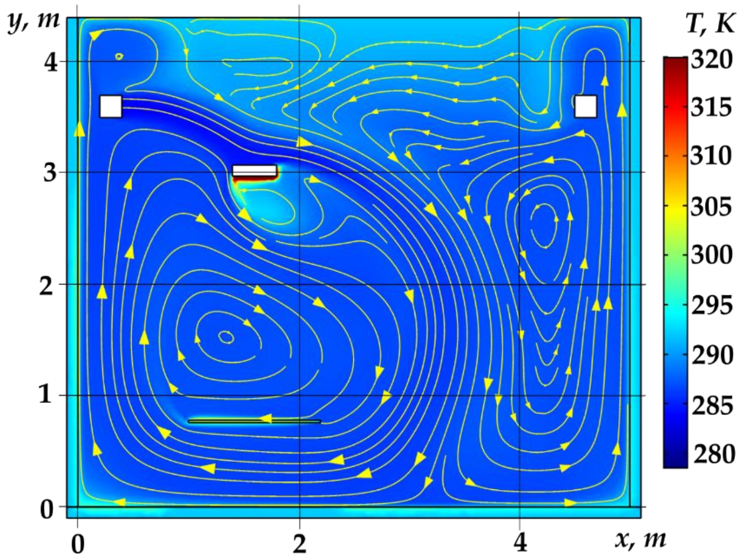

Figure 4. Calculated temperature field and flow lines formed in the premise by the 60th minute of GIE operation in the presence of supply ventilation with 0.05 kg/s air flow rate.

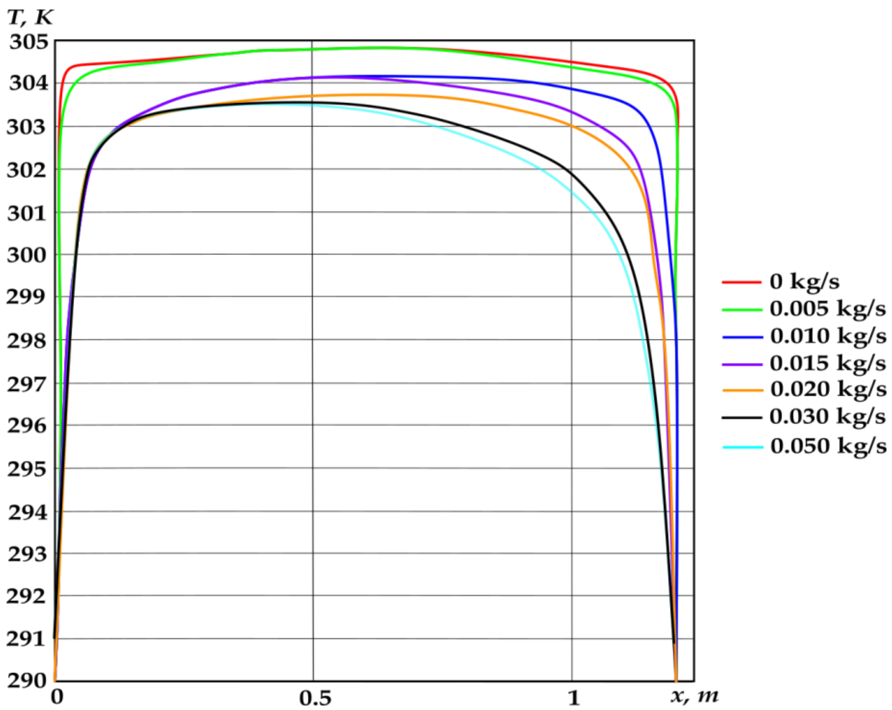

Figure 5. Calculated temperatures of the table surface, formed in the premise by the 60th minute of the GIE operation at various supply ventilation flow rates.

A change in the nature of convection affects heat transfer from the table surface, which forms a corresponding temperature distribution over its surface (Figure. 5). Analysis of the results presented in Figure 5 suggests that up to an airflow rate through the supply ventilation of 0.02 kg/s, the table surface is cooled mainly due to natural convection, which forms the temperature distribution. This is a qualitatively similar temperature field for the case in which ventilation is not taken into account. This distribution is characterized by a conserved axial symmetry with a weakly pronounced maximum in the middle of the table surface. The temperature value of this maximum decreases with an increase in the cool airflow from the supply ventilation. A further airflow rate increase more and more violates the symmetry of the temperature distribution over the table surface in accordance with the case of heat transfer from a plate in a longitudinal flow.

The use of the cool airflow from the supply ventilation in the calculations more clearly characterizes the influence of the Archimedes forces, viscosity and inertia. The airflow formed under their action contributes to the enthalpy transfer, which determines the resulting parameters of heating the premises.

Conclusions

It has been established that the presence and parameters of ventilation system can significantly affect the heating parameters of a premise. It must be taken into account at the initial stage of designing the heating systems in order to achieve the necessary indicators of its efficiency. The obtained temperatures and air velocities distributions serve to assess the mixed convection effect of various intensities on the GIE efficiency in order to ensure the regulatory microclimate conditions of the working zone.

Acknowledgments

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