Influence of the Laboratory Equipment Mutual Arrangement and an Infrared Emitter on the Heat Transfer Processes in a Heated Room

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Abstract. The temperature and kinematic fields analysis results in a room heated by a gas infrared emitter (GIE) are presented. The analysis has been carried out based on the results of mathematical modeling using the COMSOL Multiphysics environment. The imitators of a laboratory table and a computer system unit located on it hath in modeling area have placed. Based on the calculated analysis of the influence of the laboratory equipment simulators location on heating parameters, it is concluded that this technique should be used at the initial stage of heating systems using GIE.

INTRODUCTION

The effectiveness of a method to heat a room for creating comfortable conditions for human life depends on the choice of heating devices and their placement in a heated room. The heating systems design process includes the preliminary heating characteristics assessment stage for each considered set of heating devices. Increasingly, gas infrared emitters (GIE) are included in the heating system. The latter have an undoubted positive quality, consisting in the possibility of localizing the heating area near the surface on which the radiant heat flux falls. This is the most valuable quality for large-sized industrial premises that do not require maintaining comfortable temperatures throughout the entire volume for human life. GIE are also used for heating laboratory premises with the equipment placed inside. In a number of works [1-5], there is a significant effect on the temperature conditions in the heating zone and throughout the volume of the room of the process of convective heat transfer. Often, the widespread use of GIE in heating systems of various premises is still hampered by insufficient theoretical and experimental support of the methods for a preliminary analysis of the effect of being in the field of radiant heat fluxes from GIE of the objects of furniture, laboratory and industrial equipment.

The purpose of this work is to analyze, based on a mathematical modeling, the influence of the height of the location of laboratory equipment under the GIE on the main parameters of the heating process in the room under consideration.

THEORETICAL METHOD

The mathematical analysis has been carried out on the basis of solving a non-stationary problem in a flat formulation. The solution areas (Fig. 1) have represented a room heated by the GIE. In the room in accordance with the GIE there was a laboratory table in the form of a horizontal panel with a computer system unit located on it. The simulation was carried out in COMSOL Multiphysics. To determine the parameters of heat transfer by radiation heat flux, the “Surface-to-Surface Radiation” tool was used [6]; the calculation of the parameters of convective-conductive heat transfer was carried out using the “Heat Transfer in Fluids” block [6-9], in which the velocity fields were

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determined for the air region in the element “The Turbulent Flow” [8-9]. In the latter, the standard k-ε model was used to take into account the possible turbulent flow [8].

MATHEMATICAL MODEL VERIFICATION

At the verification stage, the adequacy of the mathematical model was assessed in comparison with the balance relations for heat fluxes, and the results of the mathematical and physical experiments [3, 4] were compared. Correlation coefficients were determined based on the results of the comparison. These correlation coefficients took into account the significant (more than 70%) porosity of the radiated surface, which in the “Surface-to-Surface Radiation” element is considered as a solid gray surface, and the actual length of the radiated surface in the direction normal to the XY plane. The need for the latter coefficient is associated with taking into account the real dimensions of a three-dimensional body when using a flat setting.

After obtaining, in the verification process, evidence about the reliability of the results obtained as a mathematical modeling result, this calculation method was used to analyze the results of heating the room in question, taking into account the laboratory equipment located in it.

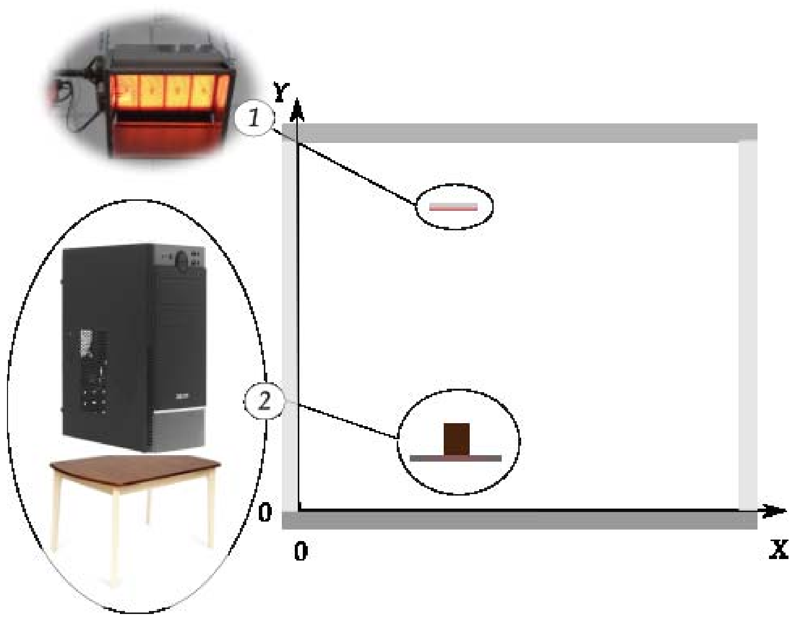
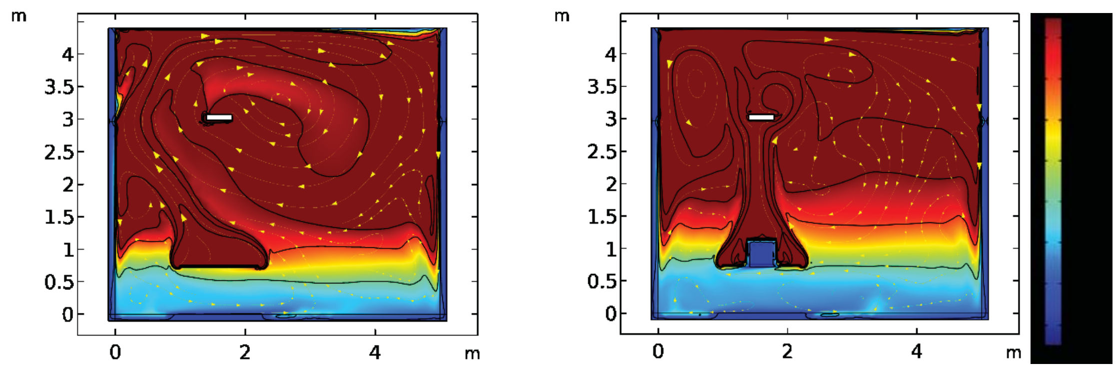


FIGURE 1. The scope of simulation. 1 – GIE, 2 – portable horizontal panel (table) with the placed computer system unit

ANALYSIS OF THE RESULTS

In the calculations, the following main parameters of the solution domain were used as the initial ones. The room had a width of 5 m, a height of 4.4 m and was limited by a concrete floor, walls, and a ceiling of the same thickness of 0.10 m. The GIE radiation surface was located at a distance of 1.40 m from the left wall at a height of 2.975 m. Immediately below the radiation surface, coaxially with GIE housed elements of laboratory equipment in the form of a horizontal wood panel 1.2 m wide and 0.04 m thick, in the center of which was a computer system unit 0.410 m high and 0.455 (or 0.180 m) wide. The height of the panel with the system unit in the calculations varied. The temperature of the heating surface of the GIE was assumed to be 1073 K, and the initial temperature in the room was 280 K. It was assumed that the process of heating the room lasts 1 hour. The final distributions of temperatures and velocities in the solution domain are presented in this work as the calculation results.

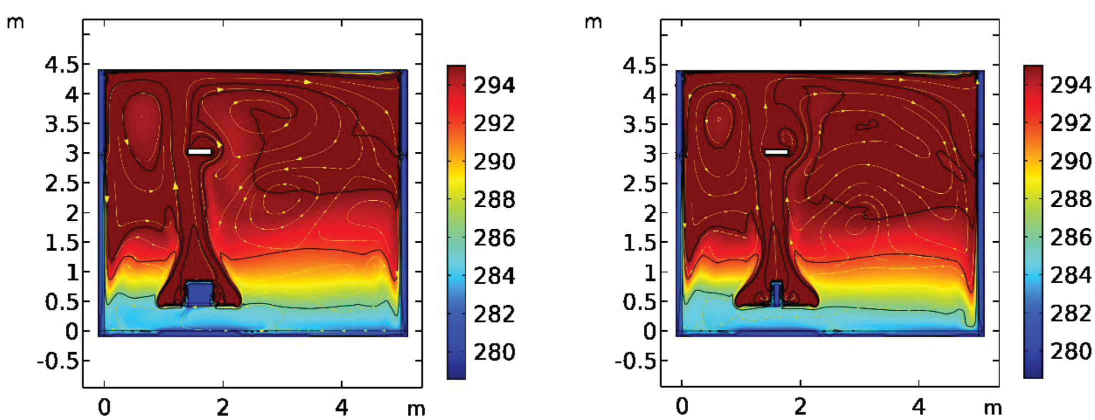
Figure 2 shows the velocity and temperature fields calculations results in the presence of an empty horizontal panel and a panel with a system unit 0.455 m wide in the heating area under the GIE at a height of 0.755 m. Asymmetry of the GIE location in the room and wood panels with low thermal conductivity coefficients location in the zone of exposure to the maximum radiant heat flux generate a transition of the upward flow of heated air from the panel when interacting with the walls and ceiling that remove heat from the air into a recirculating convective movement in a clockwise direction around the GIE. This circulation is enhanced by the updrafts from the heated surface of the GIE and practically does not affect the region of the room below the level of the panel. This kinematic picture of the movement of air masses due to mixing processes clearly separates the heated area in height above the level of the panel from the area below the panel that remains practically at the initial temperature. The serious influence of the remote horizontal panel is explained by the fact that it, like a screen, intercepts the main part of the radiant heat flux in the area of its maximum density and does not allow it to reach the concrete floor, the material of which removes heat by thermal conductivity about 5 times better and does not allow air masses to heat up in this case . Placing a system unit, which has a cramped air space inside, which does not transmit heat well inside on the remote panel, enhances the shielding effect of the floor surface and distributes heat more evenly to the air masses with its side surfaces. An almost vertical flow of heated air arises, which, interacting with the GIE, already forms two zones of the circulation flow. The asymmetry of the flow in this case is not so noticeable, and the air above the level of the remote panel is warmed up more evenly. In this case, the zone of practically cold air increases slightly.



(a) (b)

FIGURE 2. Temperatures field and streamlines after 1 hour of GIE operation in a room with a panel at a height of 0.755 m. a – there is no system unit on the panel, b – in the middle of the panel there is a system unit with a width of 0.455 m

The next series of Figures presents the results of the calculations of the fields and temperatures for various options for placing remote panels in height with the placement of system units of different widths.

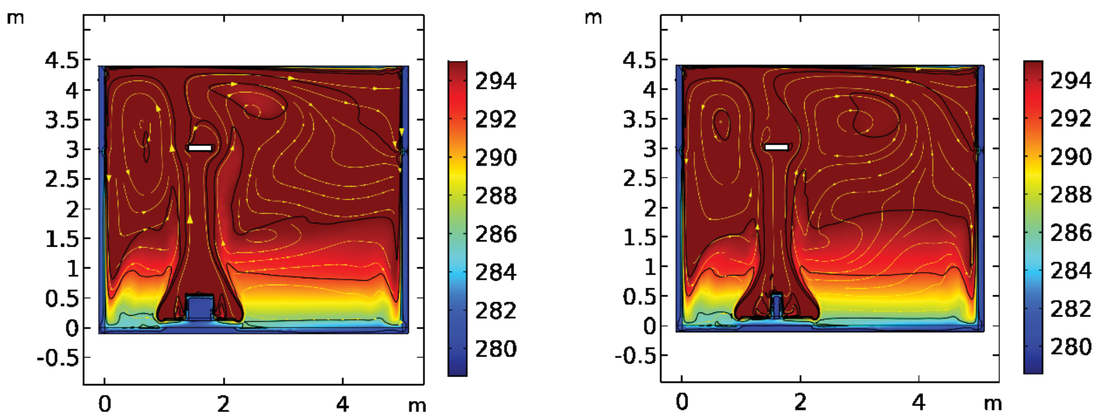


(a) (b)

FIGURE 3. The temperatures field and streamlines after 1 hour of GIE operation in a room with a panel at a height of 0.455 m. a – panel with a system unit 0.455 m wide, b – panel with a system unit 0.180 m wide

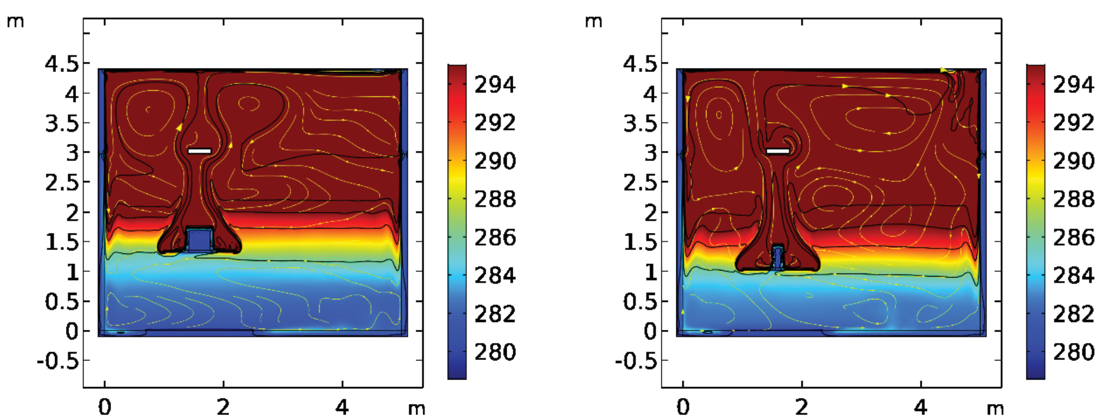
From the analysis of the results presented in (Fig. 3-7) it follows that in the overwhelming majority of the calculations, the width of the system unit insignificantly affected the distribution of speeds and temperatures in the solution area. This is due to the fact that the side surface of the blocks remains the same, and the decrease in the upper surface of the narrower block is partially compensated by the released surface of the remote horizontal panel.

The effect of shielding the radiation flux is noted even in the lowest position of the remote panel with the system unit at a height of the upper surface of the panel of 0.155 m (Fig. 4). In almost all the cases considered, the clearly defined zone of separation of heated and unheated air corresponds to the approximate height of the upper surface of the remote panel. Only in one of the cases considered, this zone has dropped significantly below the level of the panel with a wider system unit (Fig. 6a). Apparently, the influence of the circulation flows generated by the walls of the room affected. At the same time, this effect is not observed in the case of a narrower system unit. This can be explained by a slight difference in the direction of an increase in the velocity of a narrower ascending flow (by about 10%), which makes it possible to organize a more intense circulating flow above the GIE and push the flow under the panel upwards.



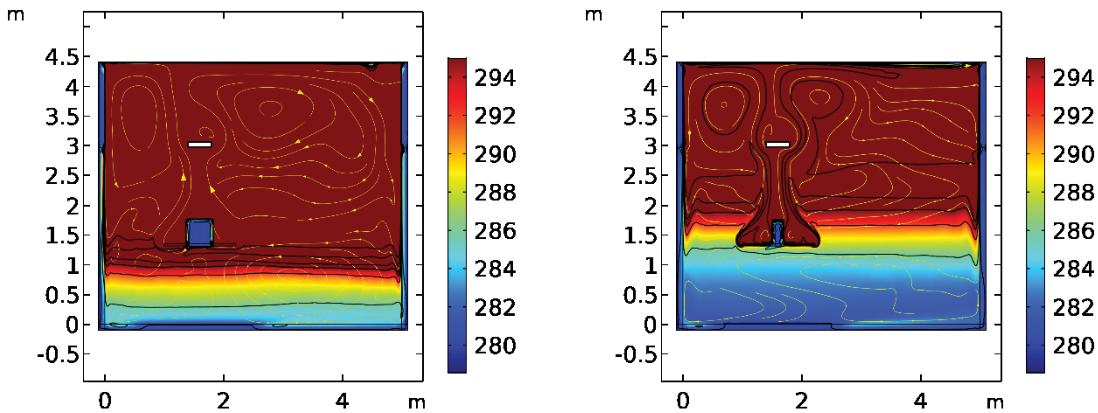
(a) (b)

FIGURE 4. Temperatures field and streamlines after 1 hour of GIE operation in a room with a panel at a height of 0.155 m. a – panel with a system unit 0.455 m wide, b – panel with a system unit 0.180 m wide



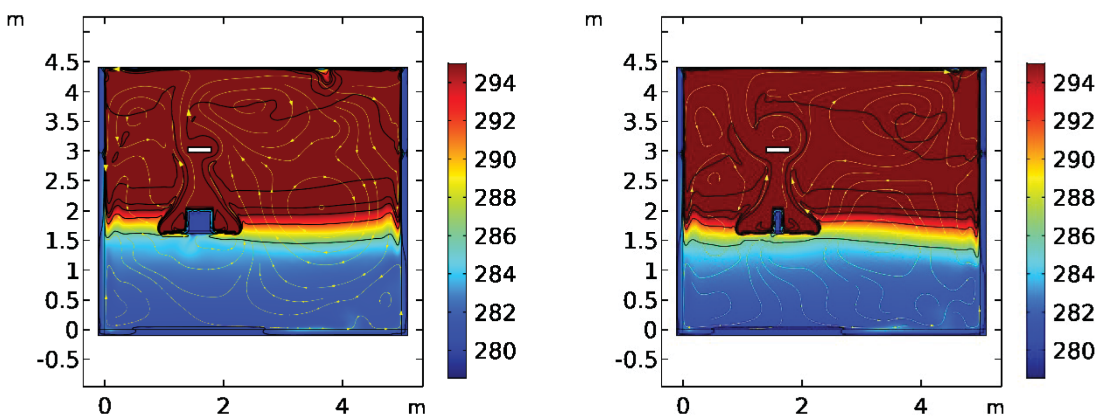
(a) (b)

FIGURE 5. Temperatures field and streamlines after 1 hour of GIE operation in a room with a panel at a height of 1.055 m. a – panel with a system unit 0.455 m wide, b – panel with a system unit 0.180 m wide



(a) (b)

FIGURE 6. Temperatures field and streamlines after 1 hour of GIS operation in a room with a panel at a height of 1.355 m. a – panel with a system unit 0.455 m wide, b – panel with a system unit 0.180 m wide



(a) (b)

FIGURE 7. Temperatures field and streamlines after 1 hour of GIS operation in a room with a panel at a height of 1.655 m. a – panel with a system unit 0.455 m wide, b – panel with a system unit 0.180 m wide

CONCLUSIONS

A series of the calculations of the main parameters of region heating using the GIE was carried out. A mathematical modeling was carried out taking into account a laboratory equipment simulator in the form of a remote horizontal panel with a computer system unit located in its middle. The described laboratory equipment was located coaxially with the GIE at various heights from the floor. The simulation was carried out in a nonstationary planar setting using the COMSOL Multiphysics environment.

As the analysis of the calculation results showed, the presence of laboratory equipment in the region of maximum radiant heat flux density has a shielding effect preventing the radiant heat flux from reaching the floor and dissipating through it by thermal conductivity. This effect was present in all the calculations.

The preliminary verification of the method has proved the sufficient physical adequacy of the results of a mathematical modeling and their required reliability, which gives the right to recommend this method for practical application at the preliminary stage of designing a heating system with the involvement of GIE.

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