Numerical Modeling of Heat Transfer in a Large Room Heated by a Gas Infrared Emitter and with Equipment Located in it at Different Heights

Vyacheslav I. Maksimov[a)] and Tatiana A. Nagornova

National Research Tomsk Polytechnic University, 634050, Tomsk, Russia.

[a)]Corresponding author: elf@tpu.ru

Abstract. The results of the temperatures and velocities fields calculations in a room heated by a gas infrared emitter are presented taking into account the presence in the field of a radiant flux of a horizontal surface that simulates a laboratory table. The calculations performed in COMSOL Multiphysics provide an estimate of the effect of the presence of the laboratory equipment in the heating field on the characteristics of the heating process.

INTRODUCTION

The choice, according to the preliminary estimates, of an effective method of heating a room to create comfortable conditions for human life is currently an extremely urgent task. Often, the widespread use of gas infrared emitter (GIE) for this, which have undeniable advantages in the possibility of increasing the efficiency of heat use by localizing heating in large rooms, is hampered by the absence or insufficiency of the experimental data on the propagation of a radiant flux from the GIE throughout the room and an accurate theoretical assessment of convective heat transfer from heated surfaces throughout the entire area of the room [1–5].

The purpose of this study is to evaluate, based on the results of the calculations, the effect on the heating characteristics of convective heat transfer from the surfaces heated by means of GIE, which limiting the room and horizontal panel, which simulating a table taking into account its location relative to the GIE.

THEORETICAL METHOD

A room with a GIE and a table in the form of a horizontal panel (Fig. 1) have been chosen as the solution area. For a mathematical modeling, the tools available in the COMSOL Multiphysics environment were used: to estimate the parameters of radiant heat fluxes, the “Surface-to-Surface Radiation” element have been used, the convective heat transfer and thermal conductivity processes have been modeled using “Heat Transfer in Fluids”, and the required velocity fields air have been determined in the “The Turbulent Flow” element, in which the standard k-ε model has been used to take into account possible turbulent flow. A non-stationary problem in a flat formulation has been solved [6-10].

MATHEMATICAL MODEL VERIFICATION

To check the calculation correctness, we have used the experimental data on the assessment of the temperature field and the real values of the incident radiant heat fluxes contained in [3-4]. To reconcile the calculations and experimental data, it has been necessary to correct the emissivity of the GIE hot surface, which is explained by the significant (more than 70%) porosity of the emitted surface, at which the pore surface does not participate in radiation.

Thermophysical Basis of Energy Technologies (TBET 2020)
AIP Conf. Proc. 2337, 020011-1–020011-5; https://doi.org/10.1063/5.0046498
Published by AIP Publishing. 978-0-7354-4081-4/$30.00

The resulting comparison of the emissivity of the ceramic used as a gray body has been $\varepsilon_{GIE} = 0.17$. In addition, the implementation of the flat approach required taking into account the real value of the radiating surface of the GIE, which has been made by introducing a coefficient for the geometry of the radiated surface of equal length of this surface in the direction normal to the XY plane. In the calculations presented, the size of the radiated surface in the direction of the OX axis has been 0.40 m, and in the direction normal to the XY plane — 0.164 m.

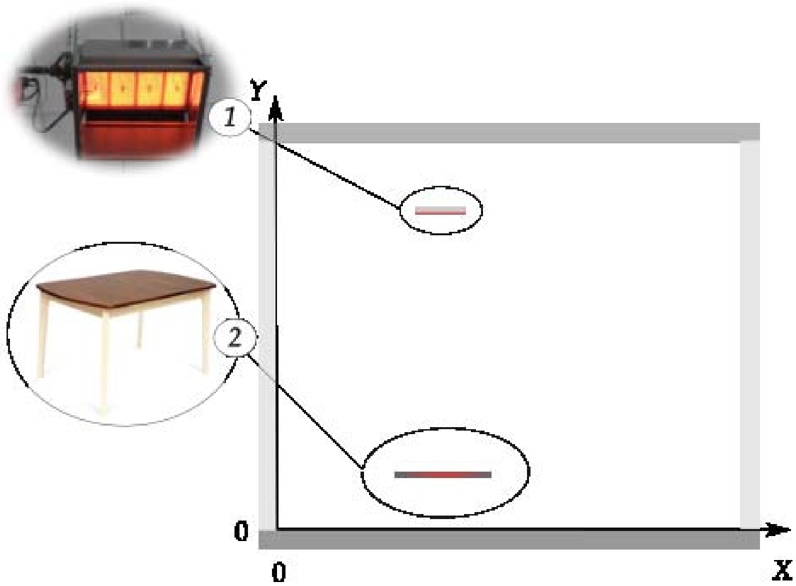


FIGURE 1. Modeling area. 1 — GIE, 2 — a portable horizontal panel (table) for equipment placement

ANALYSIS OF THE RESULTS

The calculations used the following basic initial data. A room 5 m wide and 4.4 m high has been considered, fenced off with a concrete floor, walls, and a ceiling of the same thickness of 0.10 m. The GIE radiation surface has been located at a distance of 1.40 m from the left wall at a height of 2.975 m. The wood panel 1.2 m wide and 0.04 m thick had placed in heating area. The temperature of the heating surface of the GIE has been assumed to be 1073 K, and the initial temperature in the room has been 280 K. The process of heating the room for 1 hour has been analyzed. The article presents the temperature and velocity fields as of the end of heating at the end of the sixtieth minute.

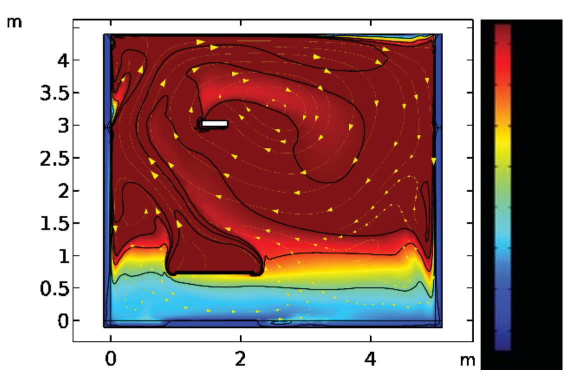
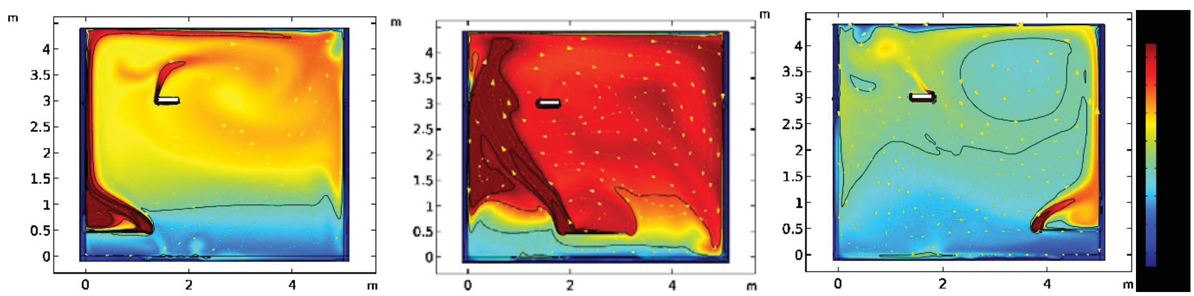


FIGURE 2. Temperatures field and streamlines after 1 hour of GIE operation in a room with the panel at height of 0.755 m

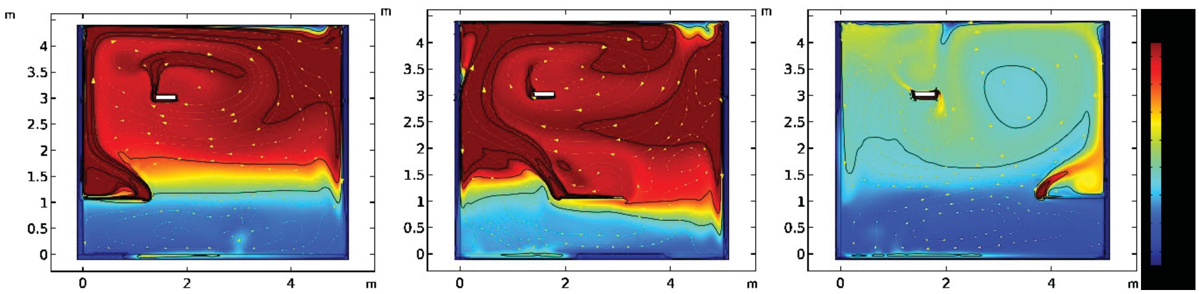
In the course of the calculations, the horizontal panel has been moving from the left wall to the right one and the height of its location has been changed. But first of all, let us analyze the results of the heating process with the main position of the horizontal panel coaxial with the GIE at a height of 0.755 m. In this case (Fig. 2), the panel intercepts the main part of the radiant heat flux, heats up quite seriously and organizes an intense ascending flow of warm air, the maintenance of which is facilitated ascending stream of warm air directly from the heated surface of the GIE. The air velocity module exceeds 0.13 m/s. The concrete thermal conductivity coefficient is more than 5 times higher than the value of the thermal conductivity coefficient of the wood panel; therefore, the removal of heat by the walls, floor and ceiling enclosing the area contributes to a fairly intensive cooling of air near these surfaces and the organization of descending flows along the walls. The asymmetry of the GIE location (closer to the left wall) also has a serious impact on the velocity field. All these aspects contribute to the development of an intense recirculating flow in a clockwise direction around the GIE. On the periphery, this current supports the existence of a smaller to size circulation structures system of lower intensity. Notice that the central circulation flow is rather stable and does not change noticeably over time. The system of peripheral circulation structures is less stable and changes its contours over time. The features of the convective flow in this case determine the establishment of the temperature field throughout the entire area of the room. Involvement in the intensive flow of most part of the air heated from the panel and the GIE around the latter ensures mixing and fairly uniform heating of the area above the horizontal panel. Radiation fluxes of heat reaching the walls and floor to the left and right of the horizontal panel are less intense due to the greater angle of incidence. These streams are more intensively removed by thermal conductivity inside the enclosing structures. The temperature of these surfaces cannot rise significantly and heat up nearby air layers. In this regard, the area below the level of the horizontal panel warms up much less intensively and the speed of movement of air masses does not exceed 0.009 m/s.



(a) (b) (c)

FIGURE 3. Temperatures field and streamlines after 1 hour of GIE operation in the room with the panel at height of 0.455 m: next to the left wall (a), in the middle of the room (b), near the right wall (c)

Figure 3 shows the mathematical modeling results of heat and mass transfer processes under conditions of moving the heated surface of the horizontal panel from the left wall of the room to the right at a height of 0.455 m. The analysis of the presented results suggests that the regularity of the formation of a zone of cold air at the floor below the panel level remains. This is due to the fact that the maximum intensity of the falling radiation heat flux only partially falls on the horizontal panel, contributes to the heating of its surface and the formation of ascending flows of heated air (Fig. 3a, Fig. 3b). When the panel is positioned against the right wall (Fig. 3c), the radiation flux falls on it at a large angle and significantly heats only a small part of its surface. In all three cases, a significant part of the radiant heat flux hits the floor surface and is intensively removed by thermal conductivity. The analysis of the calculation results shows a decrease in the average air temperature in the room as a result of the above reasons. And the decrease value by the more of the radiation heat flux falls on the floor bypassing the horizontal panel. Additionally, we note that a change in the position of the heated surfaces also affects the velocity field of the transported air up to the change in the direction of the main recirculation movement to the opposite (Fig. 3c).



(a) (b) (c)

FIGURE 4. Temperatures field and streamlines after 1 hour of GIE operation in the room with the panel at height of 1.055 m: next to the left wall (a), in the middle of the room (b), near the right wall (c)

Changing the height of the horizontal panel surface heated by radiant heat flux from the GIE from 0.455 m (Fig. 3.) to 1.055 m (Fig. 4) does not significantly change the direction of movement of the heated air masses. But the panel surface located above is more intensely heated by the thermal radiation flux from the GIE if it is located near the left wall (Fig. 4a) and in the middle of the room (Fig. 4b). When the panel is near the right wall (Fig. 4c), an increase in the height of its position leads to an increase in the angle of incidence of the radiant heat flux and, as a consequence, a decrease in the radiation flux intensity and the degree of heating of the horizontal panel in this case. As it is shown by a comparative analysis of the results presented in (Fig. 3) and (Fig. 4), the movement of the surface heated from the GIE upward due to the above reasons led to an increase in the zone of cold air under the panel. At the same time, a higher location of the horizontal panel near the left wall and in the middle of the room (Fig. 4a, Fig. 4b) has led to an increase in the average temperature of the heated air above the level of the panel, and in the case of a heated surface near the right wall (Fig. 3c) to a decrease in the average air temperature above the panel level.

CONCLUSIONS

Based on the results of a mathematical modeling, the analysis of heat and mass transfer processes in a room heated by the GIE has been carried out. The simulation has been carried out in a non-stationary planar setting using the COMSOL Multiphysics environment. When evaluating temperature fields, a horizontal panel has been placed in the solution area simulating an element of the laboratory equipment. The analysis of the calculation results has shown a serious effect of the location of the laboratory equipment simulator relative to the radiating surface of the GIE and the floor on the occurrence, intensity and direction of air flows caused by thermogravitational convection. In turn, convective heat transfer in the process of a mathematical modeling has determined the finite temperature fields in the room under study.

The process of a mathematical modeling has included a preliminary verification results stage in comparison with the physical experiments results. The physical adequacy of the results of a mathematical modeling, the results of a comparative analysis of the numerical and physical experiments give the right to recommend the obligatory preliminary estimates of the temperature fields according to the proposed method in the process of designing a heating system for the large-sized premises with the involvement of GIE.

ACKNOWLEDGMENTS

This work is supported by the Russian Science Foundation (number grant 20-19-00226).

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