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Numerical analysis of the equipment position influence on the premises thermal regime under gas infrared emitter operation and mixed convection conditions

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Abstract. The analysis of mathematical modeling results on premise heating by a gas infrared emitter (GIE) during supply and exhaust ventilation operation is presented in this article. The model is presented in a one-dimensional non-stationary setting for an incompressible medium with allowances for the radiant heat flux transfer between opaque solid surfaces in the air. The air is transparent to thermal radiation. The traditional k-ε model is used for turbulence modeling. The possibility for creating comfortable conditions in the area of a horizontal surface with different heights, imitating laboratory equipment, is analyzed.

1. Introduction

Fresh air, as a rule, is transparent to the radiant heat flux [1]. The possibility of specific surface local heating is an undoubted advantage of GIE [2], especially with local heating of zones in spacious industrial premises [3-6]. The lack of theory about processes arising during these emitters operation, e.g. natural convection and the heating zone temperature field establishment, constrains the widespread use of GIE. The high-intensity GIE type is used more often [7]. The combustion products from high-intensity GIE type enter the atmosphere and must be removed by the ventilation system. As a result, in addition to natural convection, generated by surfaces heated from GIE, the effect of forced convection due to supply ventilation operation arises [8].

The purpose of this article is the analysis of regularities of the temperature field formation in premises with equipment elements as a result of the GIE operation under mixed convection conditions.

2. Mathematical modelling of heat transfer processes

The main parameters of the thermal regime of the premise, schematically shown in Figure 1, were determined by solving a system of differential equations corresponding to the model formulated in [9].

The mathematical model is formulated in a two-dimensional setting in the area under consideration (Fig. 1). To determine the quantities associated with the volume, it is assumed that the region "thickness" in the direction perpendicular to the considered plane is 1 meter. In connection with this assumption, the parameters that determine the mass and energy arrival (the air mass flow from the supply ventilation and the energy flow from GIE) are scaled when moving from the real size of the room of 10 meters to the considered modeling area "thickness" of 1 meter.

It is accepted that the initial temperature is constant for all considered components of the region. The exception is the GIE emitting surface. Air is stationary before calculation. The GIE and ventilation operation with constant parameters begins at the initial moment of time.

The boundary condition of adiabaticity is set at the outer boundaries of the considered area (floor, ceiling, and walls). In a system air-solid surface, heat transfer is modeled in a congregate setting taking into account radiation fluxes passing in the air that is transparent to heat. The convective movement of enthalpy through the ventilation holes is taken into account.

The "No slip" conditions on solid surfaces are applied using the wall functions to determine the velocity field. The airflow from the supply ventilation is set by the mass flow. The outer pressure is set at the hole surface of the exhaust ventilation.

The numerical implementation of this model was carried out by the finite element method using COMSOL Multiphysics software by sequentially applying for the Heat Transfer in Fluids Interface, The Turbulent Flow, k-ε Interface, and Surface-to-Surface Radiation modules at each time step.

A comparative analysis of the numerical results and experimental data of the thermophysical and hydrodynamic processes was conducted in order to verify the methodology of solving the differential equations. Satisfactory agreement between the results of physical and mathematical experiments (the differences between the calculated and experimentally measured temperatures of the floor, table and left wall were less than 3%) has been established. Below there are the results of the analysis of the main heat transfer characteristics in a fairly typical premise with operating GIE and supply and exhaust ventilation.

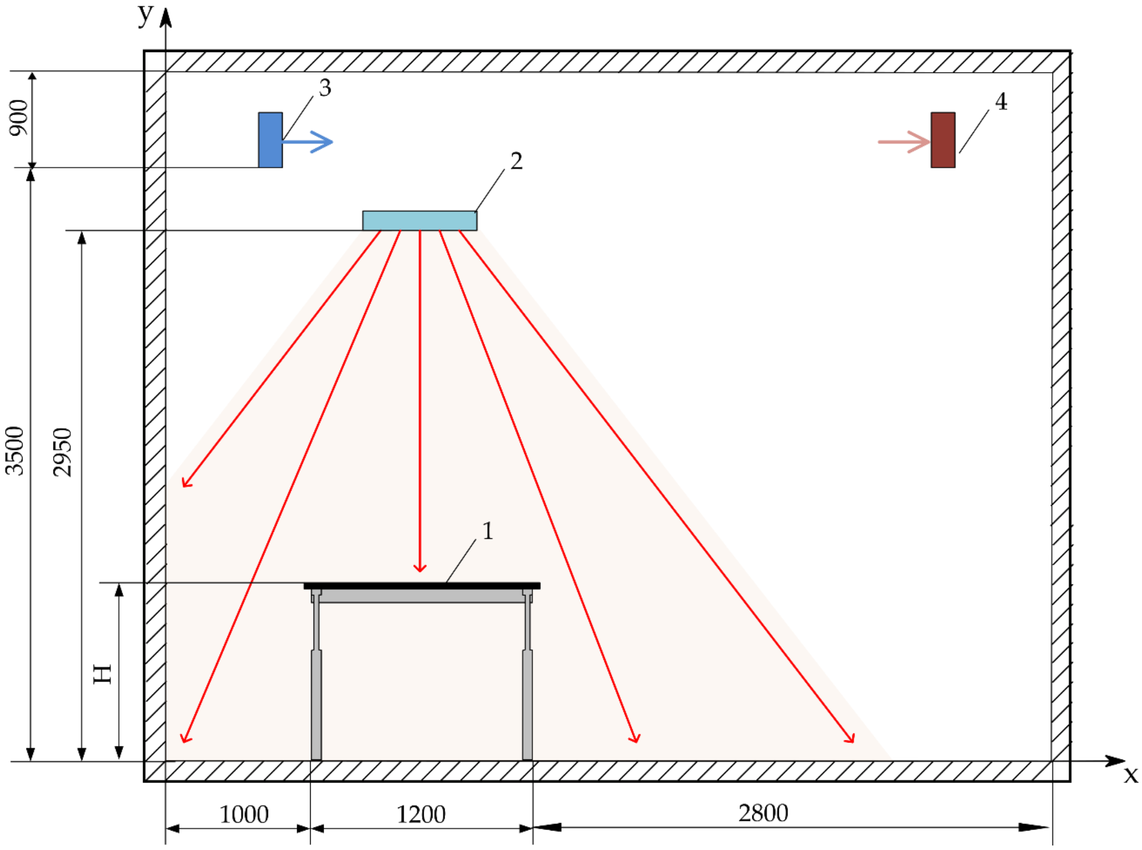

Figure 1. The mathematical model scheme (dimensions in mm): 1 – The study object; 2 – GIE; 3 – The inlet ventilation zone; 4 – The outlet ventilation zone.

3. The analysis of mathematical modelling results

The following initial data were used in calculations:

the initial temperature in the premise	20°C;
the temperature of the GIE heated surface	800°C;
the temperature of the supply air	10°C;
the mass rate of the supply air	0, 0.01 (2.22 10^{-4}) and 0.05 (1.11 10^{-3}), kg/s (kg/s/m^3);
the table surface height	455 mm and 1055 mm.

The enclosing structures and the study object parameters are presented in Table 1.

Table 1. The enclosing structures and the study object parameters

	Thickness (m)	Material	Density (kg·m^{-3})	Heat capacity (J·kg^{-1}·K^{-1})	Thermal conductivity (W·K^{-1}·m^{-1})	Blackness degree
The enclosing structures	0.1	Concrete	2500	2400	1.55	0.95
The study object	0.02	Pine	520	2300	0.2	0.4[a]

[a] The parameter is determined taking into account the coating of the surface with varnish.

Figures 2-5 show the typical characteristics of the heat transfer process in large premise during GIE operation for two options: supply and exhaust ventilation (mixed convection) and under natural convection conditions. The obtained results show that a quasi-stationary condition is established in the premise after the 60th minute of the GIE operation start. This condition is characterized by a slow change in the temperature fields and airflow rates throughout the solution area. The time moment of reaching such a condition is chosen for the illustrations (Fig. 2-5).

It has been established that most part of the radiation heat flux falls on the horizontal panel under the GIE (Fig. 1). In the heating process, the temperature surface rises by more than 30 K. As a result, a heated horizontal surface generates the movement of ascending airflows (Fig. 2) and, accordingly, descending airflows near the colder walls.

The GIE location asymmetry relative to the enclosing structures is the main reason for circulation flow (Fig. 2). The heated air movement contributes to a significant decrease in the temperature above the horizontal panel level. At the same time, the air heating at a panel higher position (Fig. 2b) is more significant in comparison with a lower position of the panel (Fig. 2a). The radiation heat flux density that reaches the floor is significantly lower than that of the horizontal panel. In this case, the concrete floor thermal conductivity is approximately 20 times greater than the thermal conductivity of the panel material. As a result, the maximum temperature rise of the floor surface does not exceed 5 K, and the air warms up much weaker below the panel level than above it.

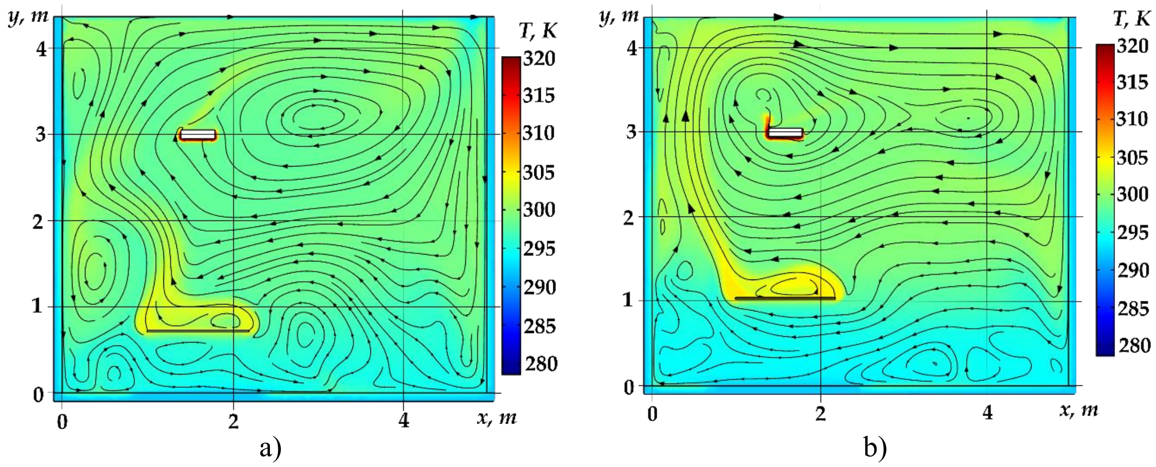

Figure 2. The calculated temperature field and flow lines for H = 455 mm (a) and for H = 1055 mm (b) for natural convection by 60 minutes.

The operation of supply and exhaust ventilation significantly changes the temperature field and the airflows direction (Fig. 3). The relatively cool outside air lowers significantly the air temperature in the premise. The Richardson number $Ri=Gr/Re^2$ is used to assess the influence of natural and forced convection conditions [10]. There is a certain problem to choose the scale values for calculating the Grashof (Gr) and Reynolds (Re) numbers. The analysis of these dimensionless values was carried out when choosing the parameters: the maximum value of the temperature head above the horizontal panel, the premise width, and the average airflow rate in the premise from the ventilation system. Air mass flow of 0.01 kg/s corresponds to single air exchange and Ri≈189. The inflowing jet of cold air contributes to the downward flow formation, which is deflected by the rising heated air from the horizontal panel. In the formation of directions and air masses movement intensity at Ri >> 1, natural airflows have a significant role.

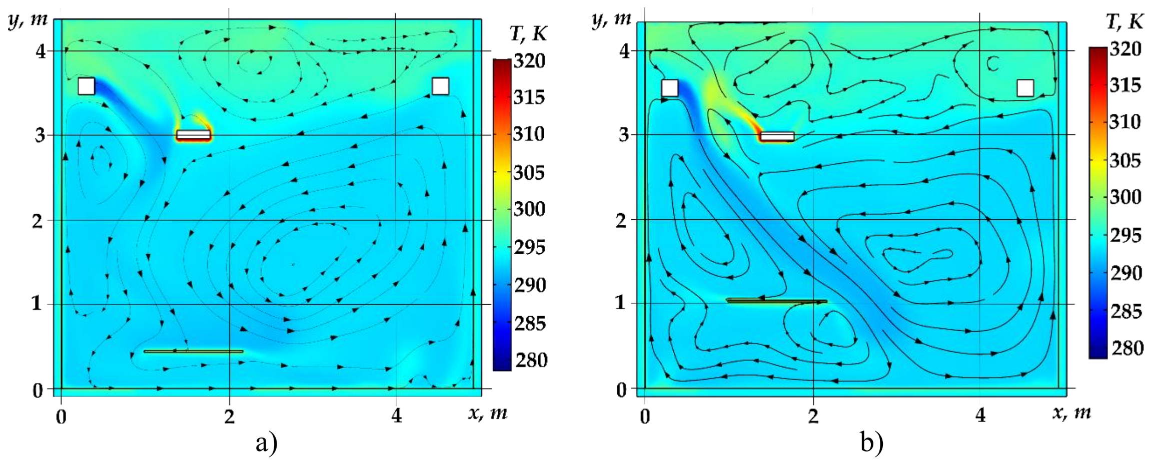

Figure 3. The calculated temperature field and flow lines for H = 455 mm (a) and for H = 1055 mm (b) for mix convection with inlet ventilation flow rate of 0.01 kg/s by 60 minutes.

The effect of forced convection becomes dominant (Fig. 4) at an airflow rate of 0.05 kg/s, which corresponds to Ri≈7.5. The relatively cool ambient airflows lower the overall air temperature and form a developed circulation flow, largely suppressing natural convection from weakly heated walls and floors, and limiting the area of its influence above the horizontal panel.

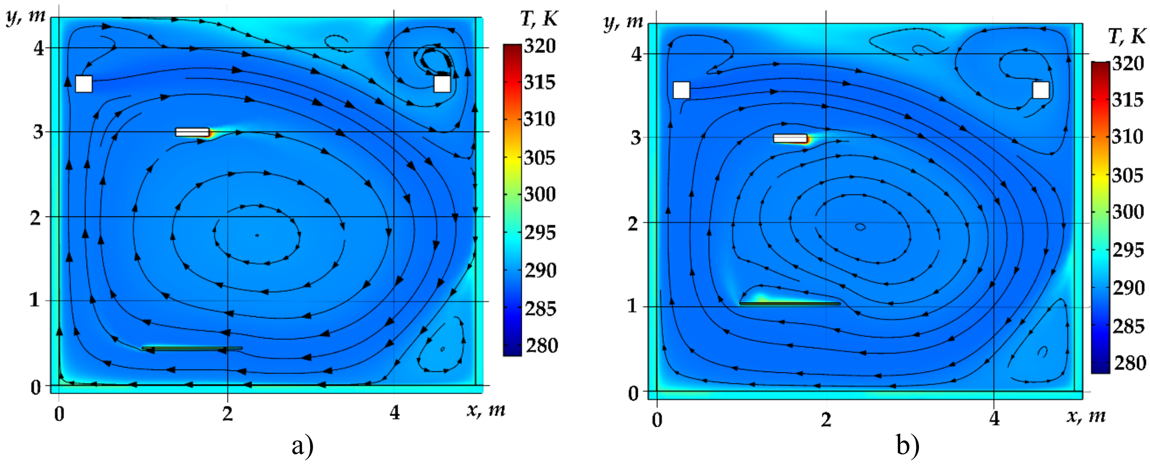

Figure 4. The calculated temperature field and flow lines for H = 455 mm (a) and for H = 1055 mm (b) for mix convection with inlet ventilation flow rate 0,05 kg/s by 60 minutes.

The influence of the air inflow intensity on the horizontal panel surface temperature distribution is illustrated in Fig. 5.

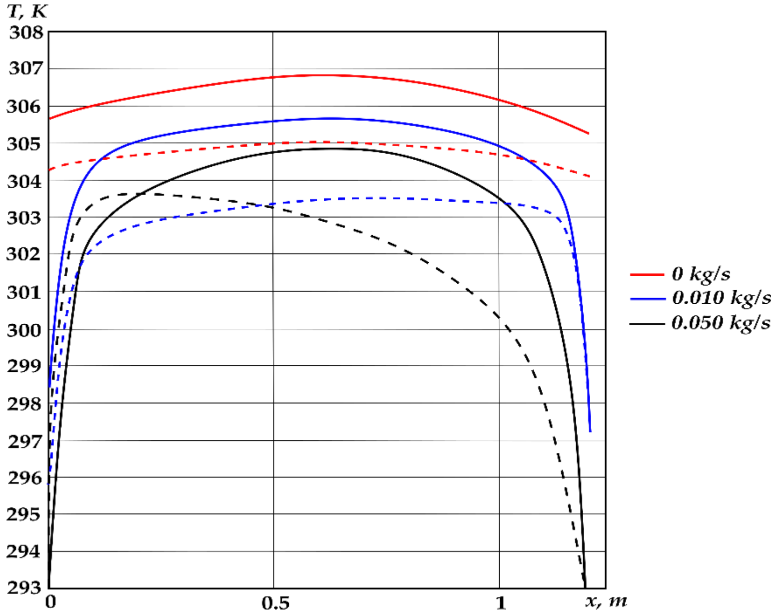

Figure 5. Temperature distribution for surfaces with a height of 455 mm (dashed line) and 1055 mm (solid line) under natural and mixed convection conditions by 60 minutes of research.

The temperature distribution is characterized by a pronounced temperature maximum in the natural convection conditions, the maximum value of which increases with the displacement of the panel surface towards the GIE. The temperature distribution pattern over the horizontal panel surface does not change at Ri≈189, and the overall premise temperature decrease reduces the heating degree of the panel surface. The temperature distribution resembles the heat transfer graphs when a longitudinal flow around a plane is made at Ri≈7.5 for a horizontal panel with H = 455 mm. The panel location at a height of H = 1055 mm leads to its flow around it to a greater extent from below and it contributes to the formation of a temperature distribution close to symmetric.

Conclusion

The mathematical modeling of the premises thermal regime characteristics during the GIE operation under supply and exhaust ventilation conditions has been carried out. A more significant influence of natural forces is manifested due to the inlet air with a temperature significantly lower than the initial air temperature in the premises.

It was found that the equipment temperature condition located in the GIE radiation zone is significantly influenced not only by its location but also by the convective heat transfer (natural, mixed, or forced) conditions that occur in the premises.

It is advisable to take into account operation of the air exchange system and the laboratory equipment location to predict the main characteristics of the process forming the premise thermal regime during the GIE operation.

Acknowledgments

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References

[1] Brown K J, Farrelly R, O'Shaughnessy S M, Robinson A J 2016 *Applied Energy* **162** 581–8
[2] Wang H, Kaur S, Elzouka M, Prasher R 2019 *Applied Thermal Engineering* **153** 221–4
[3] Dudkiewicz E, Jeżowiecki J 2009 *Energy and Buildings* 2009 **41** (1) 27–35
[4] Chinese D, Nardin G, Saro O 2011 *Energy* **36** 556–65
[5] Kuznetsov G, Maksimov V, Nagornova T A, Voloshko I V, Gutareva N Y, Kurilenko N I 2021 *Thermal Science and Engineering Progress* **22** 100851
[6] Kavga A, Karanastasi E, Konstas I, Panidis Th 2013 *IFAC Proceedings Volumes* **46** (18) 235–40.
[7] Luminous Heaters | Schwank [Internet]. Schwank GmbH. [cited 2021 Jul 10]. Available from: https://schwank.co.uk/products/heating-solutions/luminous-heaters/
[8] Chen C, Lai D, Chen 2020 *Q Energy and Buildings* **224** 110272
[9] Borisov B V, Kuznetsov G V, Maksimov V I, Nagornova T A, Gutareva N Y 2020 *J Phys: Conf Ser.* **1675** 012074
[10] Pop I, Ingham D B 2001 Convective heat transfer: mathematical and computational modelling of viscous fluids and porous media. 1st ed. Amsterdam *New York: Pergamon* p. 652