Analysis of the effectiveness of the systems for providing thermal conditions of the local working areas based on the gas infrared emitters

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Abstract. One of the urgent tasks in recent years is to reduce the cost of thermal energy to ensure the thermal regime of the local working areas in the production facilities. For these purposes, the gas infrared emitters (GIE) are increasingly used, but due to the lack of an informative base that provides the regulated thermal regime of the big-sized workrooms, their implementation is constrained. The article presents the results of the experimental and theoretical studies carried out to assess the efficiency of using such systems. The measurements of the temperatures of the floor surface at the characteristic points were carried out during the operation of the emitter of average power. The article presents the results of mathematical modeling of heat transfer in the surface layer of the floor which receives the heat flux from the GIE.

1. Introduction

The gas infrared emitters (GIE) are increasingly used to heat local working areas [1–4] in recent years. It has been established that when using GIE, the heat transfer mechanism in the zones of heat input differs significantly from the heat transfer mechanism of the convective heating systems [5–10]. In this case, air heating in the local zone occurs due to thermogravitational convection [5–7]. The objects heated by a gas infrared emitter transfer heat to the air, which rises upward and provides a routine thermal regime for a small-sized working area [11]. The implementation of the systems for ensuring the thermal regime of the local working zones based on GIE is hampered by the fact that there are no estimates of their energy efficiency [12]. The work aims to conduct the experimental and theoretical studies of heat transfer processes in areas heated by GIE and analyze the energy efficiency of their use for local heating of the work areas in the large rooms.

2. The experimental procedure

For the research, an experimental box was used (Figure 1), which represented a closed room with a concrete floor covered with white ceramic tiles. Air heating in the local working area was carried out by radiation from a gas infrared emitter. The overall dimensions of the experimental room were 10.2 × 4.9 × 4.4, the height from the floor to the GIE was 2.975 m. The walls of the room were made of bricks 70 cm thick with the plastic window openings. The initial air temperature in the room was varied from 7 to 18°C, while the ambient temperature was varied from -15 to -35°C. The thermocouples were placed on the floor surface and oriented along two directions (Figure 1, Upper View). To improve the thermal contact of the thermocouples with the floor surface and protect them against re-radiation, KPT-8 thermal paste was used. The computer, shut-off and regulating equipment, as well as a gas cylinder, were located outside the study room to exclude their influence on the thermal regime in the study area. The signals from the thermocouples were recorded by a measuring complex (an NI 9214 analog-to-digital converter and an NI cDAQ 9171 National Instruments input/output module) with a time interval of no more than 1 second. The obtained temperature values were transferred to a PC, where they were processed and saved to the file.

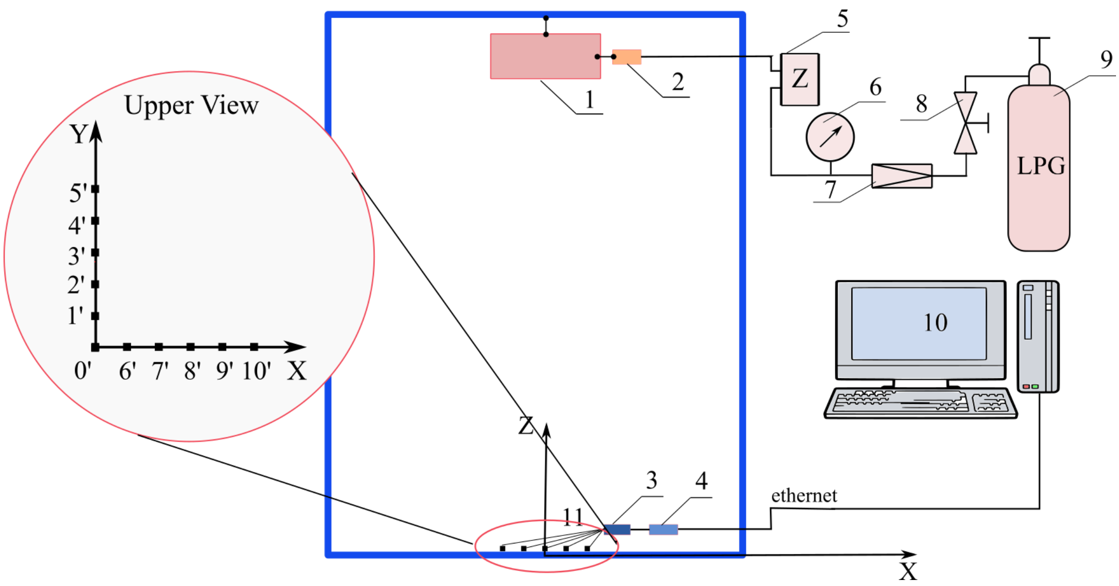

Figure 1. Schematic representation of the experimental area:
1 – GIE, 2 – GIE control unit, 3 – analog-to-digital converter, 4 – data collection system, 5 – gas flow meter, 6 – pressure gauge, 7 – gas pressure regulator, 8 – main disconnecting device, 9 – gas cylinder, 10 – computer, 11 – thermocouples (0 ' – 10' thermocouple numbers).

To ensure the possibility of evaluating random measurement errors, all the experiments under the fixed conditions of their execution were carried out at least three times. After that, the standard deviations and the corresponding coefficients of variation were calculated. The values of the latter in all the experiments did not exceed 1%.

When planning, organizing, and conducting the experiments, the most unfavorable conditions for the formation of the thermal regime of the local working zone were considered – no special enclosing structures were installed along the perimeter of the zone that could reduce heat losses to the area outside the working zone. The experiments reproduced the conditions that were typical enough for the local working zones in the large-sized premises, whose production areas were used to a small extent [9]. The projection of the GIE center was taken as the origin of the coordinates. The distances between two adjacent thermocouples of the same coordinate direction equaled 0.2 m.

3. The results of the experiments

The typical time dependences of the temperatures at the points of the thermocouple junctions on the floor surface obtained from the experiments are shown in Figure 2. It can be noted that all dependencies, shown in Figure 2, $T_f(x, y)$, are somewhat non-monotonic – deviations of a few tenths of a degree at time intervals of several minutes are quite typical for most thermocouple readings. This is most likely due to the thermogravitational air flow near the floor surface. As a result of heat removal from the floor, the air rises and forms the thermal regime of the working area.

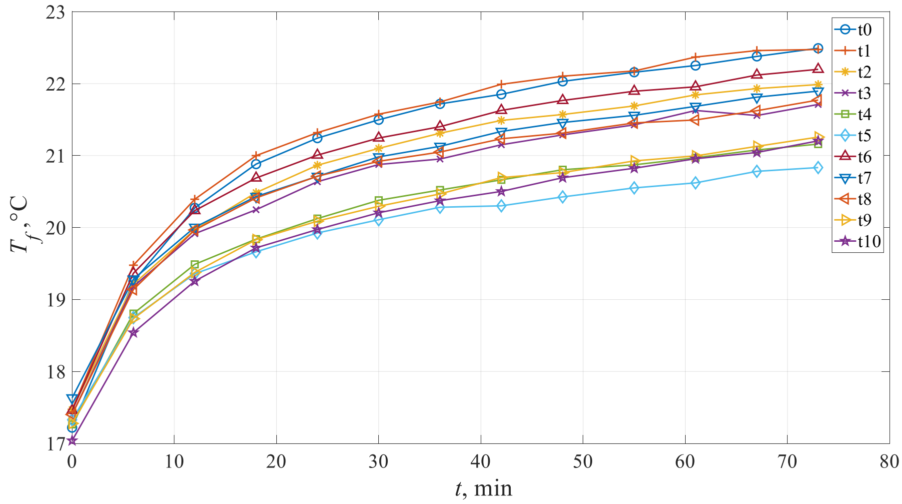

Figure 2. Time behavior of the temperatures at ten points of the floor surface (covered with the ceramic tiles). The numbers correspond to the numbers of thermocouples in Figure 1.

As Figure 2 shows, the maximum floor surface temperature is reached, expectedly, at the center of the GIE projection. Temperature values similar to it were recorded at a distance of 0.2 m from it along the Y coordinate. This is due to the nonlinear distribution of the heat flux emitted by the GIE (a feature of the ceramic matrix radiation) [5].

Figure 3 shows the typical temperature distributions along the X and Y coordinates for the floor, at characteristic points in time.

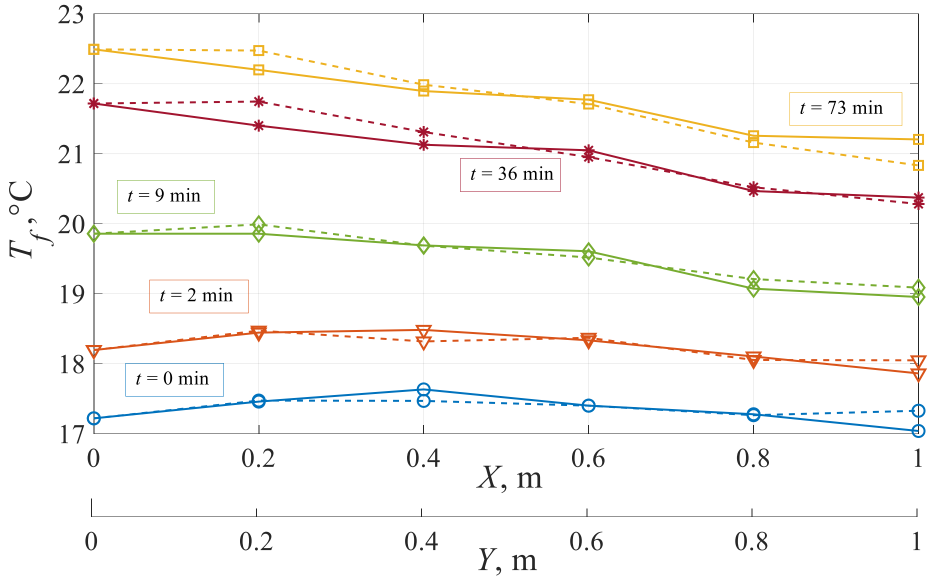

Figure 3. Distribution of the temperature of the floor surface with the ceramic tiles along the coordinates X (solid line) and Y (dashed line) at the characteristic time points.

It should be noted that the methodological error of the thermocouple measurements was about 1%. Therefore, the deviations of ±0.5 ºC, recorded by the thermocouples at the beginning of the experiment (at t = 0), are most likely the result of the methodological errors, as well as random errors caused by uncontrollable insignificant factors (heterogeneity of reinforced concrete, contamination, and unevenness of its surface, etc.). So, for example, the readings of the thermocouples, as shown by the analysis, depend to some extent on the type of the material in the near-surface layer adjacent to the place where the thermocouple was fixed; this could be reinforced concrete steel, stone or sand. Accordingly, the thermophysical properties of steel differ significantly (for example, thermal conductivity) from the similar properties of the stone. Therefore, small (± 0.6 C), but noticeable deviations of $T_f(x)$ are possible.

It was established experimentally that as the thermocouples move away from the center of symmetry of the GIE projection, the temperature values decrease by 0.5÷1.0 ºC (Figure 3). In 50 minutes after switching on the GIE, the temperature in the center of the measurement zone T_f becomes equal to 22.2 ° C. The regularities established in the experiments make it possible to substantiate the hypothesis that the energy transfer in the system of the radiator – air – floor covering takes place, most likely, through all the heat transfer mechanisms [5, 13].

4. The physical and mathematical formulation of the problem

To establish the proportion of heat generated by GIE that is directly spent on heating the air in the working area, the heat accumulated by the floor of the room was determined. For this purpose, the energy equation for a two-layer (Figure 4) floor was solved, corresponding to the experiment, with the experimentally established heat fluxes (q_t) to the floor surface (Table 1).

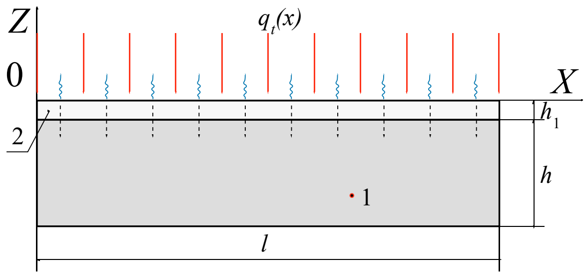

Figure 4. Scheme for solving the problem for a two-layer floor: 1 – concrete, 2 – ceramic tiles.

To calculate the heat transfer process in such a two-layer plate (Figure 4), two-dimensional non-stationary heat conduction equations with the corresponding boundary conditions were used: on the right-side boundary, the condition of thermal insulation was taken, on the lower boundary, convective heat exchange with the air (basement) was taken into account, while the left-side – the condition of symmetry was considered. On the top – the heat flow from the GIE (Table 1) and convective heat exchange with the air was set, while at the interface between the concrete floor and ceramic tiles, the condition of equality of the heat flows was taken.

Table 1. Distribution of the specific heat flux over the surface of the concrete floor in the section $Y = 0$ at $0 < X < 2.3$ m (Figure 1).

Coordinate X, m	0	0.5	0.8	1.3	1.7	2.1	2.3
q_t, W / m^2	135	125	102	68	40	20	0.1

The system of the heat conduction equations with the corresponding initial and boundary conditions was solved by the finite difference method using an implicit difference scheme on a uniform grid. To solve the system of the algebraic equations, the run method has been used [5, 6]. Figure 5 shows the typical results of the numerical solution to the problem.

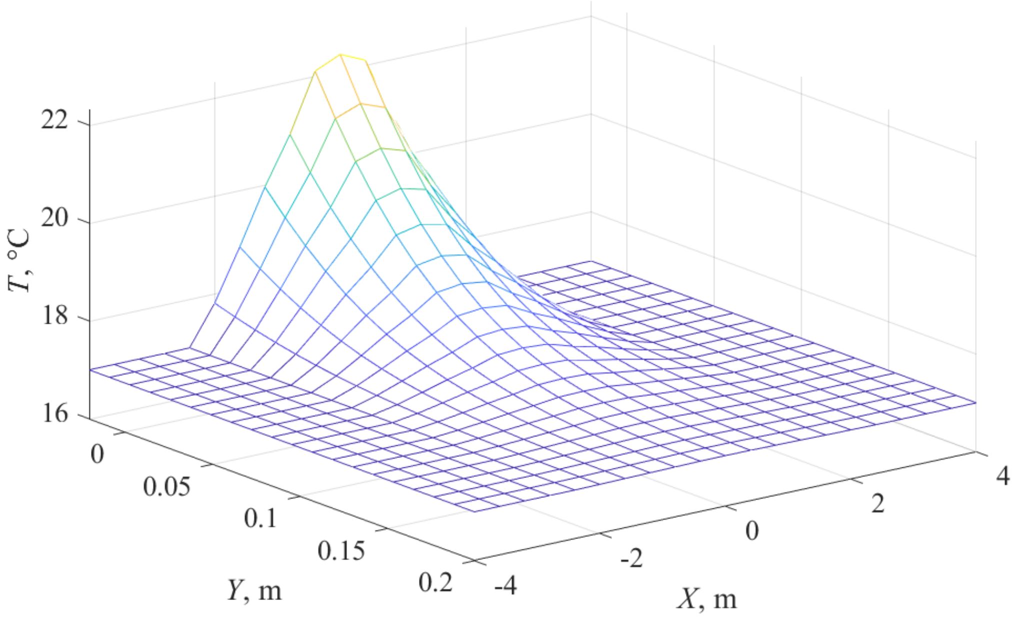

Figure 5. Temperature distribution in the analysis area at the heat flow, Table 1 over 73 minutes.

It is clearly seen that after 80 minutes of GIE operation, the floor is warmed up by 0.16 m (from the initial temperature of 17.5 °C), and the maximum surface temperature reaches 22.3 ° C. While comparing calculated temperatures of the floor surface with those obtained experimentally up to 40 minutes, the differences between the experimental and calculated values of T_f are about 1 °C (Figure 6). Then, with increasing time, this difference decreases (becomes less than 0.2 °C).

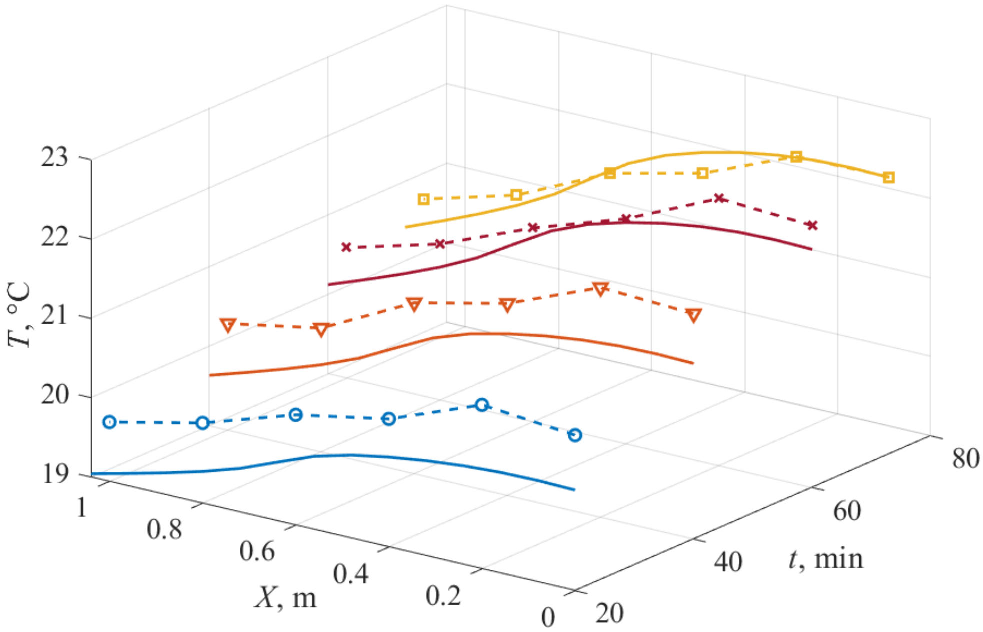

Figure 6. Distributions of the floor surface temperature in the X direction obtained experimentally (a dashed line) and resulted from a numerical simulation (a solid line) at different times.

Analyzing the change in the surface temperature averaged over the *X* coordinate in time (Figure 6), one can notice a good agreement between the numerical and experimental results. An intensive increase in temperature continues up to 40 min, after which the rate of this increase decreases.

It was established that out of all the heat coming from the GIE to the floor covering, about 70% is spent on heating the floor and accumulating in it, while 30% is spent on heating the air in the working area. It can be concluded that the use of heat supply systems based on GIE for local heating of the working area in closed rooms is quite an energy-efficient.

Conclusions

As a result of experimental and theoretical studies of the main regularities of heat transfer processes in the heating systems of local working zones using gas infrared emitters, the high efficiency of radiant heating systems has been established in the formation of thermal regimes of local workplaces located in large-sized industrial premises.

Acknowledgments

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