Thermal regime of the local working zone in the industrial premises under radiant heating conditions

G V Kuznetsov, V I Maksimov, T A Nagornova and A V Vyatkin
National Research Tomsk Polytechnic University, 634050, Tomsk, Russia

E-mail: elf@tpu.ru

Abstract. The results of experimental studies on recording temperatures and heat fluxes for the local working zone in industrial premises under radiant heating conditions and supply and exhaust ventilation operation are presented. The characteristics are measured on the surface of the horizontal remote panel directly under the radiator and along the wall with the ventilation inlet. Experimental results show that mixed convection caused by the operation of air exchange systems leads to mixing of air masses and more intensive cooling of the horizontal panel surface, as well as air, compared to the natural convection regime.

1. Introduction
The possibility of ensuring the scheduled thermal conditions in the local zone of large-size industrial premises [1, 2] as a result of operation of a radiant heating source, a gas infrared emitter (GIE), is substantiated in the general case experimentally [3] and theoretically [4]. The results [2–4] were obtained for the conditions of premises with no equipment, i.e., with a small area of heated and re-emitting surfaces. In real production processes, equipment occupies a significant part of the local working zone both in terms of surface area and volume. Therefore, the analysis of energy-efficient radiant heating systems [5] of local working zones should be carried out taking into account the equipment located in such zones and the operation of the supply and exhaust air exchange system [6] (mixed convection conditions). The results of analysis of the main characteristics of thermal regime for such conditions (temperatures and heat fluxes) have not been published. The purpose of this work is to experimentally analyze the mixed convection effect on the thermal conditions in a local working zone with equipment under radiant heating conditions.

2. Experimental technique
The closed premise was used as an experimental box for research (Fig. 1). The floor of this premise was covered with white ceramic tiles. A horizontal panel (simulating equipment) with dimensions of 1.2×0.45 m was installed in the room at a height of 0.78 m from the floor surface. Moreover, the room was equipped with supply and exhaust ventilation system located at a distance of 30 cm from the ceiling and generated a mixed convection conditions in the working zone under consideration. The local working zone was heated as a result of a gas infrared emitter operation. The overall experimental premise dimensions were 10.2×4.9×4.4 m, and the height from the floor to the GIE was 2.975 m. The initial air temperature in the premise varied from 18 to 20°C, while the ambient temperature varied from −5 to −20°C. Often, local working areas in large premises are placed in accordance with technological conditions, as a rule, near walls. Therefore, the experiments were carried out in an area that includes a bearing wall as the main element. Thermocouples were placed on floor, panel, wall and in the air.
Figure 1. The scheme of the experimental box: 1 – gas infrared emitter (GIE); 7 – GIE controller; 2, 5 – signal converter; 3, 6 – data collection system; 4 – PC; 8 – gas reducer; 9 – valve; 10 – gas cylinder; 11 – equipment panel; 12 – supply ventilation inlet; 13 – exhaust ventilation outlet; 1q–5q – heat flux sensors; 0a, 2a–9a – thermocouples under GIE; 1t – table thermocouple under GIE; 1w–5w – wall thermocouples.

A computer, regulating equipment, and a gas cylinder were located outside the experimental box to exclude their influence on the thermal conditions in the area of temperature registration. The signals from thermocouple and heat flux sensors were processed by the measuring complex (with a time interval of no more than 1 s) and transmitted to a PC for processing and storage. A supply and exhaust ventilation system was used to create a mixed convection conditions in the experimental box (in the range of Reynolds numbers $10^5 \leq \text{Re} \leq 10^7$). The main characteristics of ventilation system were: airflow rate of 420 m$^3$/h, and air inlet velocity of 2.3 m/s with a temperature of 10°C.

Table 1. Coordinates of heat flux sensors and thermocouples.

| Heat flux sensors | No | x, м | y, м |
|------------------|----|------|------|
| 1q               | 1.6| 0.78 |
| 2q               | 1.6| 1.0  |
| 3q               | 1.6| 1.2  |
| 4q               | 1.6| 1.8  |
| 5q               | 1.6| 2.0  |

| Air and panel thermocouples | No | x, м | y, м |
|-----------------------------|----|------|------|
| 0a                          | 1.6| 0.4  |
| 1t                          | 1.6| 0.78 |
| 2a                          | 1.6| 1.0  |
| 3a                          | 1.6| 1.2  |
| 4a                          | 1.6| 1.4  |
| 5a                          | 1.6| 1.6  |
| 6a                          | 1.6| 1.8  |
| 7a                          | 1.6| 2.0  |
| 8a                          | 1.6| 0.01 |
| 9a                          | 1.6| 0.77 |

| Wall thermocouples | No | x, м | y, м |
|-------------------|----|------|------|
| 1w                | 0  | 0.2  |
| 2w                | 0  | 0.5  |
| 3w                | 0  | 0.8  |
| 4w                | 0  | 1.1  |
| 5w                | 0  | 1.4  |
3. Experimental results

Figure 2 shows the distribution of total heat fluxes along with the height at the GIE projection symmetry center under natural and mixed convection conditions.

![Figure 2: Total heat fluxes change with increasing time in natural (solid line) and mixed (dashed line) convection conditions (1–5 numbers of heat flux sensors corresponding to Table 1).](image)

It can be seen that as the sensors approach the emitter, the value of the heat flux \( q \) increases significantly. For example, if at a height of 1.2 m from the floor, the heat flux is about 100 W/m\(^2\), then at 1.8 m (60 cm higher) it is already 270 W/m\(^2\) (2.7 times). The effect of mixed convection on the heat flux intensity also increases. At a distance from the floor of up to 1.2 m, mixed convection practically does not affect the heat flux, but with an increase in height, the influence becomes significant, the heat flux, in this case, decreases (at a height of 1.8 m in the mixed convection condition, \( q \) is less by 25 W/m\(^2\) compared to natural one). This is due to the air masses movement intensification and, accordingly, convective heat transfer in this area because of the supply and exhaust air exchange system operation (Fig. 3).

Figure 3 shows the established changes of the air velocity over time in the characteristic zones.

![Figure 3: Changes in the air velocity values over time along with the height at the center of symmetry of the GIE projection (a) and at a distance of 20 mm from the wall (b) in natural (solid line) and mixed (dashed line) convection conditions.](image)

The air velocity during the air exchange system operation doubles (from 0.06 m/s to 0.12 m/s) near the floor, and at a height of 2 m it increases 2.7 times. Supply and exhaust ventilation intensifies.
movement in the upper area of the box, creating a large-scale circulating vortex along its periphery (Fig. 3b) and entraining air masses, increasing their speed in the lower part of the room. In the center of the area (above the panel), a stagnant zone forms and the air velocity decreases to 0.003 m/s (curve 0.78 m, Fig. 3a).

Figure 4 shows temperature changes of the panel surface and air at different heights in the GIE influence zone for cases of natural and mixed convection. The experimental results show that mixed convection caused by the air exchange systems operation leads to air masses mixing and more intensive cooling of the horizontal panel surface (by 4°C, Fig. 4, Fig. 5a), as well as air, in comparison with the natural convection conditions. In this case, the difference in the air temperature values for different conditions of its movement decreases with distance from the GIE and at a height of 0.4 m from the floor is already 2°C (Fig. 5a).

![Figure 4](image)

**Figure 4.** Changes of air and panel temperatures (0.78 m) over time in the GIE influence zone under the natural (a) and mixed (b) convection conditions at different heights from the floor surface.

![Figure 5](image)

**Figure 5.** Distribution of the air (a) and wall (b) temperatures along the y coordinate in the GIE influence zone under natural (solid line) and mixed (dashed line) convection conditions (0–9 thermocouple numbers corresponding to Table 1).

Similar differences in the temperatures of the wall surface were recorded in experiments with different convection conditions in the premises (Fig. 5b). The values of the wall surface temperature also increase (from 0.2 to 1.4 m, the difference is 3°C) with y coordinate increase. This heating is due to the influence of the direct impact of GIE radiation and the upward heated air movement. The increase of the wall air velocities (mixed convection conditions) also leads to a decrease in the wall surface temperature (by 2.5–3°C) and temperature difference equalization over the height (2.3°C).
The part of relatively cool air coming from the air supply system, is mixed with warm air and goes into the outflow zone from the room. A significant part goes down, cooling the air of the lower layers and at the same time heating up itself. The air masses movement occurs in the supply and exhaust ventilation operation area (the upper area of the room) and with distance from it the air velocity decreases, the intensity of convective heat exchange, respectively, slightly differs from the natural convection conditions.

**Conclusions**
The obtained experimental results allow establishing the effect of supply and exhaust ventilation system on the temperature conditions in a room heated by gas infrared emitter. The supply and exhaust ventilation system operation leads to less heating of the remote horizontal panel and the wall surface on which the air exchange system is located. The influence of the air exchange system significantly changes the parameters near the wall, but at a large distance, it becomes less noticeable. The obtained characteristics and their analysis in the future will serve to give more specific recommendations for predicting the operating schedule of gas infrared emitters in large rooms with equipment.

**Acknowledgments**
This work is supported by the Russian Science Foundation (grant No. 20-19-00226).

**References**
[1] Lee E-H 2021 *Innovative Food Processing Technologies* **2.30** 431–55
[2] Dudkiewicz E, Jeżowiecki J 2009 *Energ. and Buildings* **41** 27–35
[3] Kuznetsov G V, Maksimov V I, Nagornova T A, Voloshko I V, Gutareva N Y and Kurilenko N I 2021 *Thermal Science and Engineering Progress* **22** 100851
[4] Kuznetsov G V, Kurilenko N I, Maksimov V I and Nagornova T A 2020 *Int. J. Therm. Sci.* **154** 106396
[5] Brown K J, Farrelly R, O’Shaughnessy S M and Robinson A J 2016 *Appl. Energ.* **162** 581–88
[6] Chen C, Lai D, Chen Q 2020 *Energ. and Buildings* **224** 110272