Experimental study of the temperature distribution over the surface of a heat supply object under heating conditions with a gas infrared emitter

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Abstract. The experimental studies of the heat transfer processes in the system of radiator – air – heat supply object have been carried out to measure the surface temperatures of the fabric covering the model of the worker. The results obtained give grounds to conclude that when developing systems for ensuring the scheduled thermal regime of the local working zones of the large industrial premises under the conditions of radiant heating, it is necessary to take into account the spatial orientation of the surface areas of the clothing of the worker relative to the vector of the radiant energy flux.

1. Introduction

Reducing energy consumption, increasing the energy efficiency of the buildings, and creating thermal comfort in premises is becoming an increasingly urgent task in the contemporary world [1-5]. Increasingly stringent requirements in the field of energy efficiency of the buildings [1, 2] are forcing industrial enterprises to look for ways to increase energy efficiency during their operation. There is a need to use the local heat sources to create the scheduled temperature regimes in the individual working areas of the industrial premises [6-8]. In recent years, the gas infrared emitters (GIE) are increasingly used as one of the effective systems for ensuring thermal conditions in the buildings and structures [9-13].

But their widespread implementation needs objective analysis of the thermal regimes of such objects to predict the main characteristics of thermal comfort in such premises. The purpose of this work is to establish the basic laws of the temperature distribution on the surfaces of a typical heat supply object for the typical operating conditions, time intervals, and heat flows supplied to the working area from a gas infrared emitter.

2. The experimental procedure

The experimental studies were carried out in the operational zone of a single 5 kW gas infrared emitter located in a large room. The initial air temperatures in the experimental box were set from +2 to +15 °C. A schematic diagram of the measurement area is shown in Figure 1. The heating object module was covered with a cloth. The configuration of the cover was generally consistent with that of typical work clothes. The thermocouples were inserted into the interlacing of the fabric threads and fixed in such a way that between the junction and the external environment there was one thread layer no more than 0.2 mm thick. In this case, the thermocouples recorded the actual temperature of the near-surface layer of the fabric at a depth of 200 μm.
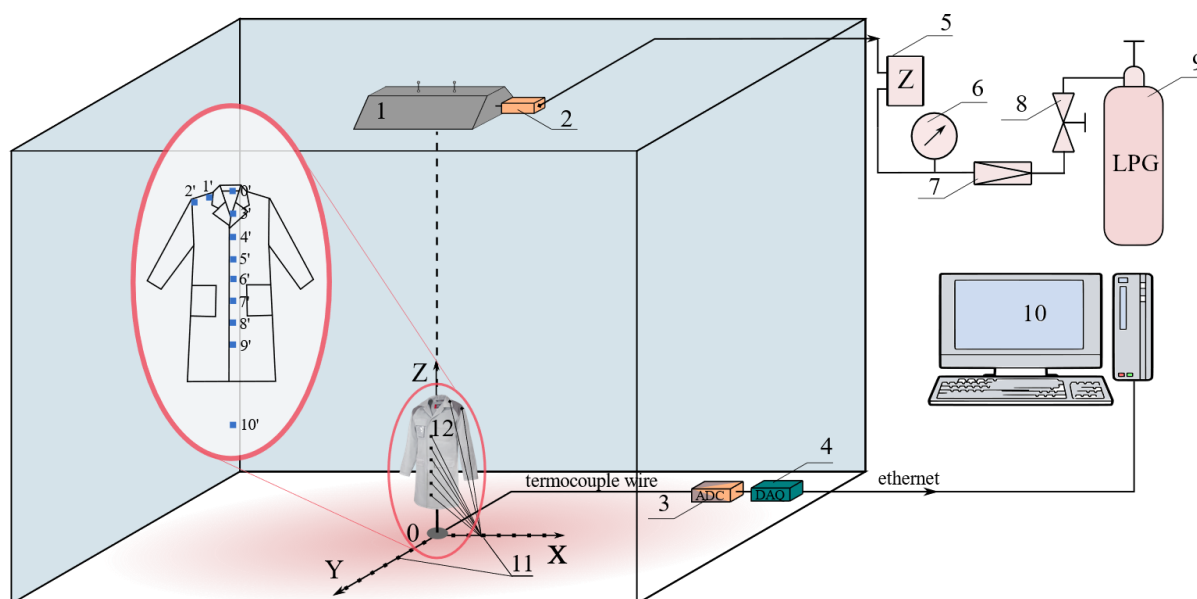
Figure 1. Schematic representation of the experimental area: 1 – GIE, 2 – GIE control unit, 3 – analog-to-digital converter, 4 –data collection system, 5 –gas flow meter, 6 – pressure gauge, 7 – gas pressure regulator, 8 –main disconnecting device, 9 – gas cylinder, 10 – computer, 11 – thermocouples (0 ' – 10' thermocouple numbers), 12 – cloth (work gown).

The measurements were carried out using the chromel-alumel thermocouples with a junction diameter of 80 μm (the measurement error according to the description was not more than 0.4 °C). The thermocouples were introduced into the fabric of the object model coating from the inside at different heights from the floor (Table 1). The thermocouple welds were placed in such a way as to avoid direct radiation heating.

Table 1. Thermocouples location coordinates on the model of the heat supply object and the angles between the direction of the radiant heat flux and the normal to the surface (α_f).

Thermocouple numbers	0'	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'
Distance to floor, m	1.55	1.55	1.5	1.5	1.4	1.3	1.2	1.1	0.9	0.7	0
α_f, hail	90	20	20	90	90	90	90	90	90	90	0

The signals from the thermocouples were recorded by a measuring complex (NI 9214 analog-to-digital converter, and NI cDAQ 9171 National Instruments input/output module) with a time interval of no more than 2 seconds. The measurement results were processed using a personal computer. To ensure the possibility of evaluating random measurement errors, all the experiments were carried out at least three times under the same conditions. After that, the standard deviations and the corresponding variation coefficients were calculated. The values of the latter in all the experiments did not exceed 4%. Statistical processing of the measurement results was necessary due to possible influence of the factors of the second and third levels of significance (air humidity, pressure, changes in the ambient temperature during the long-term experiments) on the readings of the measuring instruments.

3. The results of the experiments

The experiments were carried out employing the models covered with the fabrics of different colors (100% cotton, gray; 100% cotton, blue). The temperature measurement results are shown in Fig. 2-3.
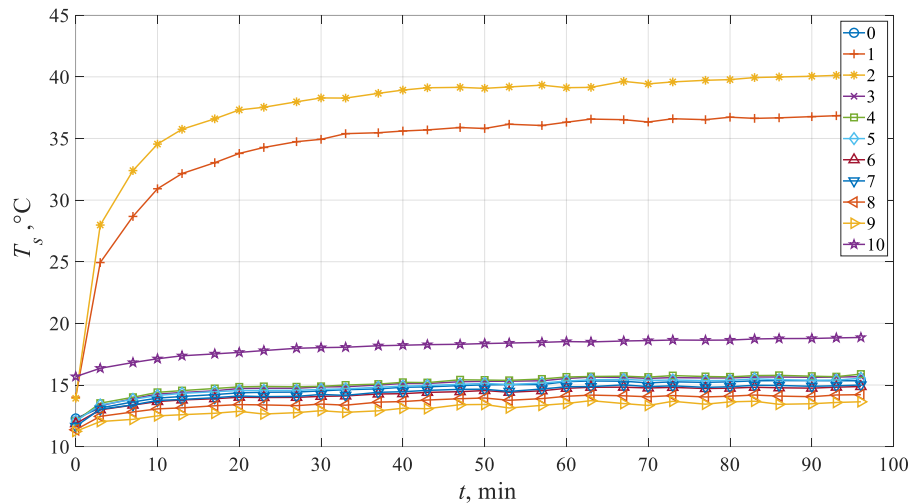

Figure 2. Variations in the temperature of the test object and the floor surface over time (fabric – 100% cotton, grey color, thermocouple numbers according to Table 1).
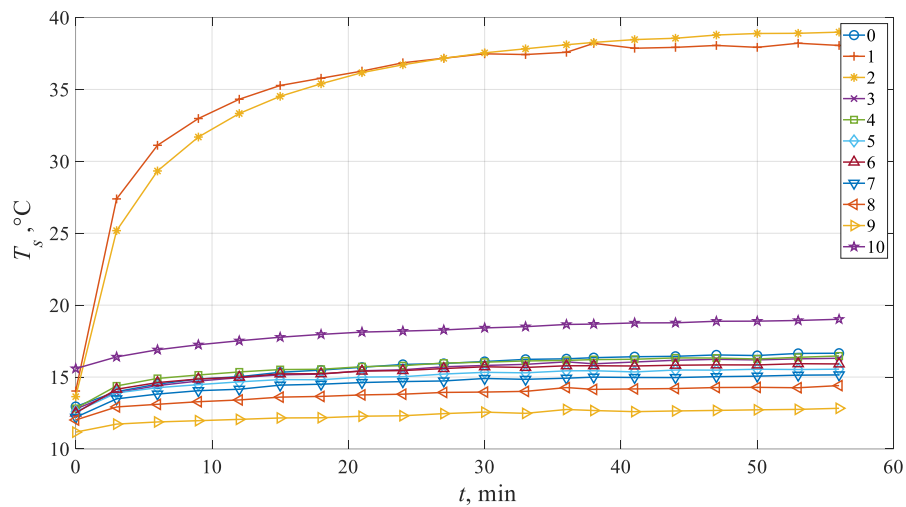

Figure 3. Variations in the temperature of the test object and the floor surface over time (fabric – 100% cotton, blue color, thermocouple numbers according to Table 1).

It can be seen that in 30-40 minutes after the start of heating, the process of forming the temperature field of the object completes. The results of the experiments show that under the conditions of radiant heating of the worker's clothes, various surface sections undergo different thermal regimes. In the upper part of clothing with a surface of $\alpha=0\div20°$, the thermal regime is similar to working in a room with a temperature of $33\div35$ °C, which differs from comfortable conditions. In the middle and lower parts of the clothing ($\alpha=90°$), the surface temperatures differ insignificantly and fall within the range from 13 to 16°C. In this regard, it is advisable to use the fabrics with the highest thermal conductivity and minimum absorbency when manufacturing the overalls for work under radiant heating conditions.

The analysis of the dependences T_s (t) gives the grounds to conclude about the monotonic nature of the increase in the temperature of the surface of the clothing fabric during a long (about 1.5 hours) heating process.

The comparison of the temperature values on the surface ($\alpha=90°$) of the heat supply object model along the height Z (Figure 4) was also carried out. It is clearly seen that the difference in T_s values is up to 3 °C.

The latter illustrates the significance of the orientation of the surface of the heat supply object with respect to the radiation flux, on the one hand, and the scale of the influence of thermogravitational air convection on the thermal regime of the object.
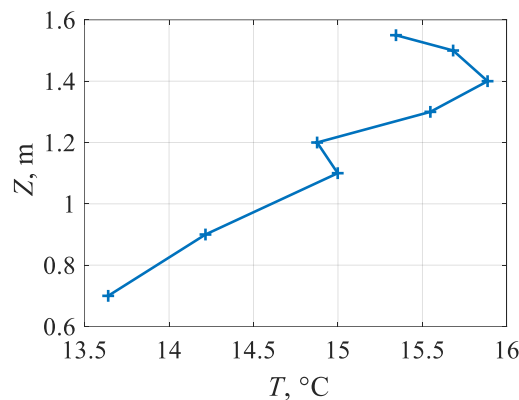

Figure 4. Distribution of the temperatures on the surface of the fabric along the
Z coordinate at t=90 min (thermocouple numbers according to Table 1).

The temperature distributions of air and fabric surface along the Z coordinate differ insignificantly. It can be concluded that if the radiant flux from the GIE does not fall on the fabric, then its temperature depends only on the temperature of the surrounding air. In the same areas that are heated directly by radiation (Figures 2, 3 Thermocouples No. 1, 2), the surface of the fabric is heated to 40 °C. In this case, the temperature of the surface of the fabric depends both on the temperature of the surrounding air, and also, to a greater extent, on the intensity of the radiant flux directed to its surface.

The experiments have shown that the temperature of many vertical areas of the model's fabric surface depends only on the temperature of the surrounding air. The air temperature depends on the intensity of convection. But if the surface of the fabric is oriented at a certain angle to the direction of the thermal radiation flux, then the fabric is heated up much more intensively than air and the surface temperature of the heat supply object, in this case, will strongly depend on its orientation relative to the GIE.

It was revealed that the degree of emissivity (in the infrared range) of the surface of an object under consideration has a moderate effect on the accumulation of heat in the surface layer of the material heated during the operation of the infrared emitter [14]. The efficiency of such systems on the horizontal surfaces (or with small angles of inclination) is close to the maximum – almost all the energy supplied from the emitter is spent on increasing the temperature of a section of the object's surface to a certain level corresponding to the stationary conditions of heat transfer in this section.

It was also established that when using the gas infrared emitters, in addition to convection, an important role in the formation of the temperature field of the surface of the worker's clothing is played by direct radiation entering the areas of the fabric surface of the worker's work clothes.

Conclusions
Based on the analysis of the experimental results obtained when studying the heating process of the fabric of the heat supply object's model under the operating conditions of the radiant heating system, it is shown that the surface temperature of the fabric depends on the orientation of the surface of the latter relative to the direction of the radiant heat flux generated by the gas infrared radiation. It was

established that the temperature of the individual sections of the worker's clothing fabric can differ significantly (up to 15°C) from the air temperature. Accordingly, when predicting the main characteristics of the microclimate of the local working zones, in particular, temperature, it is impossible to use the models and calculation methods developed for the traditional convective heating systems.

The regularities and characteristics of the investigated heat transfer processes in the local working zones of the large-sized industrial premises heated by the radiant heating systems established in the experiments can be used to construct the models of such processes and significantly develop the theory of the microclimate formation processes in the industrial premises.

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