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ANALYSIS OF PREMISE INFRARED HEATING AND VENTILATION WITH AN EXHAUST OUTLET AND FLAT DECKING AIR FLOW

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Abstract

The article is devoted to solving of urgent problem to analyse energy saving effect from radiant heating and ventilation of premise with exhaust outlet and flat decking air jet. The aim of the work is analysis of energy efficiency of radiant heating systems using infrared heaters and ventilation of the premise due to the effect of a flat decking air jet on the surface of the heater; determination the amount of heat received both by flat decking air jet from the infrared heater when laying on its flat surface and amount of heat from the exhaust air entering the recuperator. Use of the infrared heaters in combination with an air distribution of the ventilation system with the flat decking air jets is effective, as it allows to achieve savings in heat load of the ventilation system in the range of 11% - 19%. The amount of heat recovery of the exhaust air removed by the exhaust outlet is 30 - 40 W that equals 15% - 20%. Saving the heat load of the ventilation system allows reducing the actual initial temperature of the tidal flat decking air jet and achieving a total saving of thermal energy of 24% - 34%.

Keywords: infrared heater, air distribution, air velocity, flat air jet, flow rate.

Nomenclature
ΔQ – additional amount of heat, W;
α – heat transfer coefficient, W/(m^{2}K);
λ – thermal conductivity coefficient, W/(mK);
ν – viscosity coefficient, m^2/s;
ρ – air density, kg / m^3;
ε – emissivity coefficient of the surface;
ε_r – given emissivity coefficient of the surface;
φ – irradiation view factor;
a – width, m.
b – height of the slit, m;
C_0 – irradiation coefficient of an absolutely black body,
c – specific heat capacity, kJ/(kg K);
F – square, m^2;
H – height of the heater location, m;
k_c – flat jet compression ratio;
L – air volume flow rate, m^3/h;
l – length, m;
m – velocity attenuation coefficient;
n – number of i-th surfaces in the room;
Q – amount of heat, W;
T – absolute temperature, K;
t – temperature, °C;
v – velocity, m/s;
$\overline{v_x}$ – relative current velocity;
x – running coordinate, m

Subscripts
0 – initial; *air* – indoor air; *c* – compressed; *cl* – calculated; *cr* – critical; *e* – exhaust; *fl* – floor; *ih* – infrared heater; *R* – real; *r* – radiant; *rec* – recuperator; *v* – ventilation; *x* – current.

1. INTRODUCTION

Issues of rational use of energy carriers, transition to alternative energy sources and the use of energy-efficient heat generating devices are extremely relevant in the widespread development of the energy crisis. Stable reduction of traditional energy resources makes it important to use energy-efficient heating systems in Europe and Ukraine in particular. A large amount of energy is used to create the necessary microclimate in industrial, agricultural and public premises. Regulatory air parameters such as temperature, mobility and gas content are components of a comfortable microclimate in a closed isolated room. Therefore, an important task in terms of energy saving [17], ecology and human comfort [11] is to ensure these parameters at the required level with a reduction in energy consumption of the building. The main function of heating and ventilation systems of industrial and public buildings is to create comfortable living conditions for people. In particular, the high concentration of CO_2 and other indoor air pollutants [15, 27] in this type of premises results in deterioration of health of people, decrease in their working capacity that influences efficiency of work and quality of the made production.

There is no doubt that energy consumption for heating and ventilation systems of industrial, agricultural and public buildings must be reduced [25]. One of these energy-efficient measures is premises heating with infrared heaters, equipped with exhaust outlets in order to recover [1, 3] the heat of the exhaust air.

At infrared heating of rooms, one of the important tasks is to ensure local heating of the working area [8, 9]. This is the only type of heating device that provides a normalized temperature in the working area, which is important for public and industrial premises. Non-compliance with microclimate norms in the work area can cause both deterioration of human well-being and affect the operation of equipment. The choice of infrared heaters depends on the purpose of the room and the technological processes that take place in it [7, 8].

For the device of ventilation of premise important tasks are creation of the effective organization of air exchange and air distribution [10]. Comfort conditions are primarily determined by the temperature [4] and velocity [12, 13, 16, 23] of indoor air in the working area. These values are maintained by ventilation devices and affect the choice of air distribution scheme. Normalized air parameters must be provided in the working area of the premise, as the maintenance of proper sanitary and hygienic characteristics of the microclimate of the room satisfies the physiological needs of man, which largely depends on health and efficiency. The CO_2 concentration in rooms with long-term and short-term [7] stay of people, noise level, as well as the aspect of energy saving of the building [18, 22, 28], indoor microclimate systems [19, 20], external networks [24] and boiler room [21] as heat sources should also be taken into account. One of the effective measures is to create a dynamic microclimate and utilization of exhaust air by heat recuperators [1, 3].

Quite often, the production and technological process takes place in small rooms, overloaded with equipment and personnel. This requires the need to supply a large amount of supply air in this type of compressed conditions.

This complicates the task of providing in the working area of air velocity and temperature within the normative limits [12, 13, 16]. They often exceed the normalized values, as proper attenuation of air flow velocity and temperature is not ensured. As a result, the conditions of comfort are not observed and the material and energy consumption of the ventilation system as a whole increases.

A rational solution to this problem is the intensification of the attenuation of the velocity and temperature of the supply air jet using energy-efficient air jets, namely compact, flat and twisted. Existing mathematical models [2, 5, 14] of this type of air flows need to be improved in terms of taking into account the effect of decking.

Today the issue of creating comfortable microclimatic conditions and achieving energy efficiency of air distribution using energy efficient air jets is relevant. This is achieved through proper turbulence of the air flow at its outlet from the supply nozzle.

The study [8] obtained the results of determining air temperature by analytical and experimental methods.

Various designs of infrared heaters are considered, in particular ceramic and tubular gas radiation heaters, as well as the most modern technologies and systems of waste heat recovery [3, 9].

Heat savings in heating and supply and exhaust ventilation systems, in particular exhaust air heat recovery, are important in industrial and public premises. To solve it, it is advisable to use low-temperature heat for further needs of the heat supply system of industrial and office premises [8, 9]. In [9] the use of exhaust heat recuperator is presented as a promising solution that has been developing rapidly in recent years. Possibilities of application of various heat exchangers in the system of gas removal at heating by radiation heaters are also considered.

The choice of both the type of radiation heaters and the heat recovery system requires consideration of many factors.

When choosing the design of the infrared heater, it is advisable to take into account the combined action of the radiant heating system and supply and exhaust ventilation. When choosing the type of infrared heaters must take into account the geometric dimensions of the room, the location of equipment, heat sources, the workplace area [26]. The issue of heat saving in heating and supply and exhaust ventilation systems is relevant and needs a comprehensive solution. Heating devices with a high heat transfer coefficient and a sufficient heat transfer surface are effective for industrial and public premises. They allow maintaining the air temperature in the working area at a stable level.

Due to the use of radiant heating, an increase in the intensity of heat transfer is achieved. The article proposes to use an exhaust outlet for heat utilization and its further use in the recuperator along with the use of infrared heater NL - 12R in the radiant heating system. Additionally, it is proposed to apply the effect of decking of the supply ventilation jet on the surface of the infrared heater [6]. This factor causes an increase in the range of the jet by 1.5 times, and intensifies the process of heat transfer in a public building. The use of swirling or compact supply jets is effective in this aspect, but the contact area in the heat exchange process is insufficient. Given this factor, it is worth proposing flat decking air jets to increase the heat transfer area, as this factor is extremely important. An attractive feature of this type of jets is that they have proper turbulence, providing intensive ejection of indoor air to the supply jet. At the same time, the appropriate damping coefficients of velocity and temperature are obtained. This factor makes it possible to supply a significant amount of supply air in compressed conditions of a small office premises.

In view of the above information, it can be stated that there is a need to increase the energy efficiency of the radiant heating system in conjunction with the supply and exhaust ventilation system. This is achieved through use infrared heaters NL - 12R and the effect of decking of the ventilation supply air jet on the surface of the heater and heat recovery of exhaust air.

At the same time, it is necessary to choose the most expedient type of ventilating air jet, which would provide the maximum efficiency concerning the contact area of a jet with a surface of an infrared heater, coefficients of attenuation of the velocity and temperature of the air flow, the proper range of the ventilation jet. In this aspect, swirling, compact and flat decking jets deserve attention. Ensuring the energy efficiency of the heating and ventilation system of the production premises will be carried out with the use of exhaust heat recuperator.

2. GOAL OF THIS PAPER

The aim of the work is analysis of energy efficiency of radiant heating systems using infrared heaters NL – 12R and ventilation of the premise due to the effect of a flat decking air jet on the surface of the heater; determination the amount of heat received both by flat decking air jet from the infrared heater NL – 12R when laying on its flat surface and amount of heat from the exhaust air entering the recuperator.

To achieve this goal it is necessary to perform the following research tasks:

- analyze the characteristics of flat air jets, their efficiency and calculated dependences;
- generalize and deepen the theory of aerodynamic processes in the supply of air by flat decking jets;
- perform experimental studies of air distribution by flat decking air jets, determine their characteristics and establish calculated dependences for the theoretical solution of indoor air distribution;
- create a generalized mathematical model of the movement of air flows by flat decking jets;
- compare the theoretically obtained results with experimental data and establish correction factors;
- determine the temperature of the floor surface when irradiated it with an infrared heater;
- determine the amount of heat received by a flat decking air jet from an infrared heater NL - 12R when laying on its flat surface;
- determine energy efficiency indicators of radiant heating system using infrared heater NL - 12R with exhaust outlet.

3. RESEARCH OF ENERGY SAVINGS OF INFRARED HEATERS WITH EXHAUST OUTLET AND FLAT COMPRESSED DECKING JETS

Infrared heaters allow providing local heating of the working area of the room. As a result, the required temperature is maintained in the production premises and a local microclimate is created. In fig. 1 shows the design of an infrared heater with an exhaust outlet.

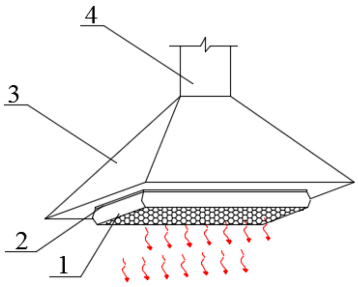

Fig. 1. Infrared heater with an exhaust outlet:
1 – infrared emitter; 2 - reflector;
3 - exhaust outlet; 4 - exhaust pipe

The infrared heater works this way. Infrared emitter 1 carries out local heating of the working area, the reflector 2 directs infrared rays directly into the heating zone, the exhaust outlet 3 removes polluted air from the premises through the exhaust pipe 4, which is used for heat recovery.

To determine the radiation temperature of the surface enclosing structures of the working area when irradiated with an infrared heater, an experimental study was conducted. To ensure the universality of the obtained calculations, the factors influencing this temperature were taken into account, namely: the intensity of irradiation of the infrared heater *q*, W/m^2, thermal power of the infrared heater *Q*, W, the height of its installation *H*, m, and the blackness degree of the surface of the enclosing structures *ε*.

Since the radiant heat is directed to the floor, the influence of other structures can be neglected and limit the study to determine the relative floor surface temperature. It allows taking into account the indoor air temperature, which has a decisive influence on the obtained results. The relative dimensionless temperature is universal, as it is the ratio of experimentally determined surface temperatures of the heated floor t_{fl}, ºC to the air temperature in the production room t_{air}, ºC.

According to the results of the experiment, a nomogram was constructed, shown in fig. 2.

Using the intervals of variation for the input values, an equation was obtained to find the relative temperature of the heated floor surface $\bar{t}_{fl}$ at 400W≤ Q_{ih} ≤1200 W, 1.28 m ≤ H ≤ 1.72 m, 0.3 ≤ ε_{fl} ≤ 0.92.

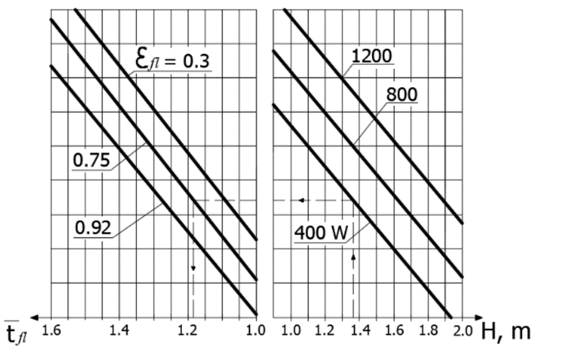

Fig. 2. Dependence of the relative temperature of the irradiation surface on the thermal power of the heater Q_{ih}, W, height of its installation H, m and emissivity coefficient of the surface ε_{fl}

$$\bar{t}_{fl} = 1.255 + 0.1\frac{Q_{ih} - 800}{400} - 0.085\frac{H - 1.5}{0.22} + +0.08\frac{\varepsilon_{fl} - 0.61}{0.31} + 0.03\frac{Q_{ih} - 800}{400}\cdot\frac{\varepsilon_{fl} - 0.61}{0.31} - -0.03\frac{H-1.5}{0.22}\cdot\frac{\varepsilon_{fl}-0.61}{0.31} \quad (1)$$

Since the article proposes to use the effect of decking a flat supply ventilation jet on the surface of the infrared heater NL - 12R, then it is necessary to give theoretical calculations.

Consider the output of a flat compressed air jet from the supply slit (fig. 3). The air distributor in the form of a flat slit with the ratio of its length to the height l/b = 10 (30x3 cm) forms a flat air jet. It is characterized by sufficient uniformity of the initial velocity field over the area of the air outlet. This is in favor of the use of flat air distributors along with panel air distributions, in particular PWM (panel wall-mounted) and other panel air distributions. An important advantage of air distributors in the form of a flat slit (fig. 3) is a high turbulence of the flow at its outlet of the nozzle. This is confirmed by the corresponding numerical values of the damping coefficients of velocity m and temperature n, which is an advantage over compact and swirling air jets.

In addition, the use of flat air jets allows to get small values of air velocity in the working area of small premises while ensuring a high air exchange rate. In small rooms, there are compressed conditions of leakage of supply ventilation jets. As a result, the velocity decreases more intensely, and long-range decreases.

Fig. 3. Experimental installation and nozzle with the aspect ratio l/b = 10 (30x3 cm), which forms a flat compressed air jet

To enhance the effect of providing large air exchange rate in small premises, it is advisable to use the effect of decking of air jet on a flat surface. This increases the range of the jet and reduces the performance of the ventilation system. In the process of laying, the crucial is the area of contact of the air flow with the heated surface. In this aspect, the most effective of these are flat jets.

In addition, the effect of laying a flat air jet on the surface of the infrared heater NL - 12R intensifies the heat transfer process from the heater to the ambient air. As a result, the air flat deck jet receives an additional amount of heat ΔQ, which depends on the air velocity. The result is an increase in the uniformity of the temperature field of indoor air in the production room, which improves the comfort conditions of the premise. However, the more important advantage is to achieve savings of this value ΔQ for the heat load of the ventilation system Q_v, as in general the thermal balance of the premise takes into account the heat load of both the heating system and the ventilation system.

To confirm or refute the hypothesis, it is advisable to conduct experimental studies. Figure 3 shows the experimental setup.

Experimental studies were conducted under the following conditions and simplifications:
- area of the flat tidal slit was F_0 = 0.009 m^2;
- air consumption was within L = 100 – 500 m^3/h;
- initial velocity of the flat compressed air jet was within v_0 = 3 – 14 m/s;
- ratio of the sides of the inflow flat slit l/b = 10;
- floor and wall surfaces receive heat due to radiant heat transfer;
- heated floor and wall surfaces give off heat to the air by convection;
- one-time radiant heat transfer from the surface of the infrared heater to the surfaces in the room is accepted;
- temperature distribution on each characteristic element is uniform.

The absolute velocity of the compressed air flow was measured with a thermoelectro-anemometer Testo-405 at the specified numerical values. However, it is advisable to operate with dimensionless values of relative velocities as the ratio of the absolute current velocity v_x, m/s, to the absolute initial v_0, m/s. This allows obtaining universal results for different initial, boundary and design conditions. The obtained results of relative axial velocities of a flat compressed air jet are presented in fig. 4. According to these data, taking into account the variety of initial, boundary and design conditions, it is possible to estimate the velocity of a flat compressed decking jet. At a distance from the supply nozzle to the device NL - 12R within 1 - 5 m, the relative velocity is in the range of 0.2 - 0.45 according to fig. 4.

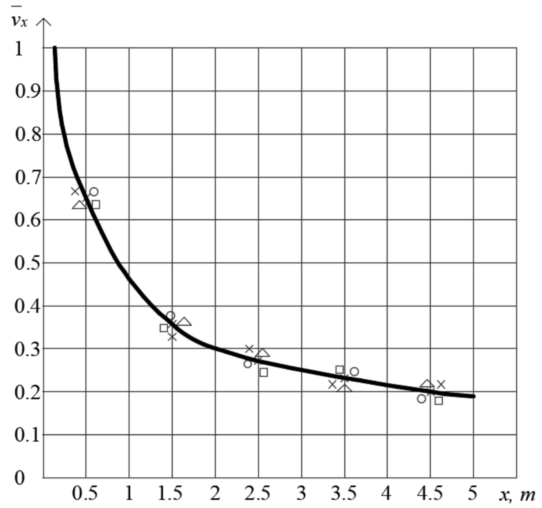

Fig. 4. Graph of the dependence of the relative axial velocity of a plane jet on the current coordinate

In particular, this corresponds to the absolute velocity of the compressed flat decking air jet when flowing around the surface of the infrared heater v_x=2.0 – 4.5 m/s under the condition of initial velocity v_0 = 10 m/s.

Along with the graphical (fig. 4) dependence of the relative axial velocity of the flat compressed jet on the current coordinate, there is also an analytical (2):

$$\overline{v_x} = m \cdot k_c \sqrt{\frac{b}{x}} \qquad (2),$$

where x – current coordinate, m;

b – height of the inflow flat slit, m;

m – air flow rate damping coefficient;

k_c – flat jet compression ratio;

$\overline{v_x}$ – relative current velocity of a flat air jet.

The coefficient of compression of a flat jet k_c depends on several factors: velocity damping coefficient m, the height of the inflow slit b and current coordinates x. These factors form the determining simplex (fig. 5), and the compression ratio k_c determined graphically from Fig. 5 or analytically from formula (3).

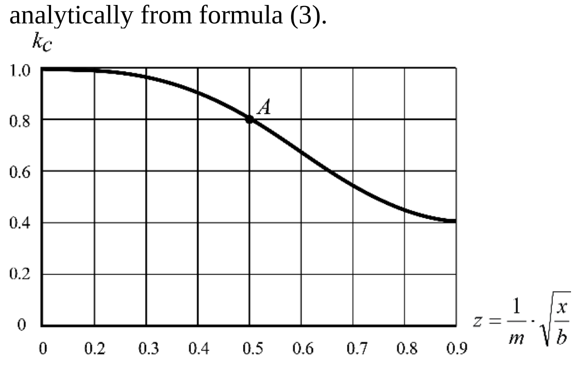

Fig. 5. Graph of the dependence of the compression ratio k_c flat jet from the defining simplex

In this formula, it is advisable to denote the simplex by z:

$$k_c = 1 + 1.56 \cdot z - 5.74 \cdot z^2 + 3.65 \cdot z^3 \quad (3),$$

where $z = \frac{1}{m} \cdot \sqrt{\frac{x}{b}}$ – defining simplex.

On the graph (fig. 5) in the environment of point A, the abscissa of which Z_A = 0.5, the inflection of the concavity-convexity of the curve is viewed. This means that point A is a critical point of the second order, ie the second derivative of the function k_c (2) is equal to zero. The analytical verification of this fact deserves attention. To do this, determine the first derivative of expression (3) and obtain (4):

$$k_c' = 1.56 - 11.48 \cdot z + 10.95 \cdot z^2 \qquad (4).$$

When determining the second derivative can be obtained equation (5):

$$k_c'' = -11.48 + 21.9 \cdot z \qquad (5).$$

Equating expression (5) to zero, the result z_A = 0.524 can be obtained. As can be seen, there is a satisfactory convergence of graphics (z_A = 0.5) and analytical (z_A = 0.524) results.

When using the decking effect, a convective component additionally appears next to the radiation component of the heat flux of the radiant heating system, namely heat transfer from the surface of the infrared heater NL - 12R to the flat decking air jet of the ventilation system, which wraps around the surface of the infrared heater.

Consider the process of heat transfer by convection with forced longitudinal flow around the flat surface of the infrared heater NL - 12R (fig. 6). Let a longitudinal air flow be laid on the flat surface of the infrared heater of length l and width a. Let us denote the current velocity and temperature of this air jet, respectively v_x, m/s and t_x, °C, and the surface temperature of the infrared heater – t_{ih}, °C. Since the surface temperature of the infrared heater NL - 12R significantly exceeds the current air flow temperature $t_{ih} >> t_x$, which differs from the indoor air temperature t_{air} slightly ($t_x \approx t_{air}$), it is more convenient to operate with quantity t_{air} instead t_x.

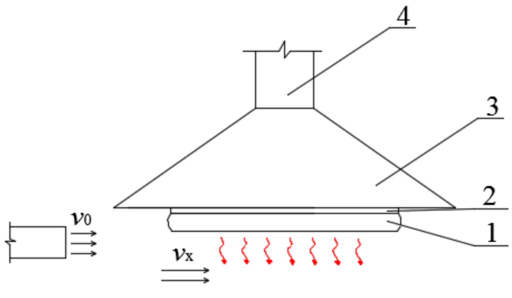

Fig. 6. Scheme of decking of a ventilating air jet on a flat surface at the forced longitudinal flow around an infrared heater of NL - 12R: 1 – infrared emitter; 2 - reflector; 3 - exhaust outlet; 4 - exhaust pipe

According to the Stefan-Boltzmann law of radiant heat transfer, it is possible to determine the radiation power of an infrared heater Q_{ih} taking into account all surfaces of a protection of the premise:

$$Q_{\mathrm{ih}} = C_0 \cdot \varepsilon_{\mathrm{ih-i}} \cdot F_{\mathrm{ih}} \cdot \phi_{\mathrm{ih-i}} \left[\left(\frac{T_{\mathrm{ih}}}{100}\right)^4 - \sum_{i=1}^{n} \left(\frac{T_i}{100}\right)^4 \right] \quad (6),$$

where $\phi_{\mathrm{ih-i}}$ – view factor between the surface of the heater and the *i*-th surface of fencing of the premise; F_{ih}, – surface area of the infrared heater, m^2; $\varepsilon_{\mathrm{ih-i}}$ – relative emissivity coefficient of the heater surface and the *i*-th surface in the premise; C_0 – the coefficient of radiation of an absolutely black body, C_0=5.67W/(m$^2\cdot$°K^4); T_{ih}, T_i – absolute temperatures, respectively, the surface of the infrared heater and the *i*-th surface in the premise, K; n – the number of *i*-th surfaces in the premise.

With the help of transformations of equation (6) it is possible to obtain the dependence (7), which determines the absolute surface temperature of the infrared heater:

$$\frac{T_{\mathrm{ih}}}{100} = \sqrt[4]{\frac{Q_{ih}}{C_0 \cdot \varepsilon_{\mathrm{ih-i}} \cdot F_{\mathrm{ih}} \cdot \phi_{\mathrm{ih-i}}} + \sum_{i=1}^{n} \left(\frac{T_i}{100}\right)^4} \quad (7).$$

It is advisable to accept the simplification and take into account only the determining factor of the floor, and the slight influence of other structures to neglect. As a result, the dependence (7) takes the form (8):

$$\frac{T_{\mathrm{ih}}}{100} = \sqrt[4]{\frac{Q_{ih}}{C_0 \cdot \varepsilon_{\mathrm{ih-i}} \cdot F_{\mathrm{ih}} \cdot \phi_{\mathrm{ih-i}}} + \left(\frac{T}{100}\right)^4} \quad (8).$$

where T – the absolute temperature of the floor surface as having a dominant area of all *i*-th surfaces in the premise, K.

Therefore, the surface temperature of the infrared heater in degrees Celsius is: $t_{\mathrm{ih}} = T_{\mathrm{ih}} - 273$.

The next step is to determine the average on the surface of the infrared heater NL - 12R heat transfer coefficient α, W/(m$^2\cdot$K) and the amount of heat ΔQ, W, which is perceived by the ambient air from the surface of the device NL - 12R. At the standard air temperature t_{air} when ventilating the premise it is necessary to use the following indicators of its thermophysical properties: kinematic viscosity coefficient – ν, m^2/s, thermal conductivity coefficient – λ, W/(m·K), Prandtl's criterion – *Pr* . In particular at air temperature t_{air}=20°C these parameters are respectively: ν=15.06 10^{-6} m^2/s, λ = 2.59 10^{-2} W/(m·K), *Pr*=0.703.

The hydraulic flow regime is determined by the criterion *Re* by the formula (9):

$$Re = \frac{v_x l_o}{\nu} \quad (9),$$

where v_x – current air flow velocity, m/s;

ν – kinematic viscosity coefficient, m^2/s;

l_0 – determining size, m.

It is advisable to accept the simplification of the current estimated velocity v_x. Since the width of the infrared heater is a = 0.1 m, which is much less than the width of the flat air jet, the change in flow rate in its profile can be neglected. The determining size l_0 is the length l of the infrared heater NL – 12R. As its length is l = 0.54 m, ie is insignificant to change the flow rate, it is correct to assume a constant velocity at the calculation point in the center of the infrared heater.

Often for practical calculations of heat transfer at the forced longitudinal air flow of a flat surface (in our case the surface of the infrared heater NL – 12R) take the critical value of the Reynolds criterion Re_{cr} = 5·10^5. If Re < 5·10^5, then the flow regime in the boundary layer is laminar. Nusselt's criterion *Nu* in this case is determined by the formula (10):

$$Nu = 0.67\, Re^{1/2}\, Pr^{1/3} \quad (10),$$

where *Re* and *Pr* - Reynolds and Prandtl criteria, respectively.

If Re > 5·10^5, then the flow regime in the boundary layer is highly turbulent. In this case, the Nusselt *Nu* criterion is determined by the formula (11):

$$Nu = 0.032\, Re^{0,8} \quad (11),$$

where *Nu* – this is Nusselt's criterion, which by definition is expressed by an equation (12):

$$Nu = \frac{\alpha l_o}{\lambda} \quad (12),$$

where

α – heat transfer coefficient from the surface of the infrared heater NL - 12R to a flat air jet, W/(m^{2}K);

λ – thermal conductivity coefficient of air, W/(m K).

Taking into account fig. 4 (according to the values of the current velocity) and the dimensions of the design of the infrared heater NL – 12R Reynolds' criterion is within Re = 0.72·10^5 – 1.61·10^5. This means that in this mode of movement of the air jet when it flows around the surface of the infrared heater NL – 12R formula (10) should be used, and taking into account (11) the heat transfer coefficient α, W/(m$^2\cdot$K), is determined from the formula (13):

$$\alpha = Nu \frac{\lambda}{l_o} \quad (13)$$

Based on certain intervals of criteria Re=0.72·10^5 – 1.61·10^5 Nusselt's criterion by formula (10) is within Nu = 160.0 – 239.3. Accordingly, the heat transfer coefficient according to formula (12) is within α = 7.67–11.48W/(m$^2\cdot$K).

The amount of heat ΔQ, W, which is perceived by the air flow from the surface of the infrared heater NL - 12R by convection:

$$\Delta Q = \alpha (t_{ih} - t_{air}) la \quad (14),$$

where α – heat transfer coefficient from the surface of the device NL - 12R to the air flow, W/(m$^2\cdot$K);

t_{ih} and t_{air} – temperature, respectively, the surface of the infrared heater and indoor air, °C.

l and a – respectively length and width of infrared heater NL - 12R, m.

Given the numerical range of α, the amount of saved heat ΔQ is in the range of 20 - 30 W.

Analysis of formula (12) shows that the amount of saved heat ΔQ is greater than the greater the heat transfer coefficient α. Formula (13) shows that this requires achieving a greater value of the Nusselt criterion *Nu*, which depends on the Reynolds criterion *Re* (10). In turn, the Reynolds criterion Re depends on the current velocity v_x flow around of the air flat decking jet of the infrared heater surface NL – 12R. To achieve the maximum effect, the current velocity v_x should be as large as possible. Fig. 4 indicates that the infrared heater NL - 12R should be installed as close as possible to the air distribution device.

It is expedient to establish the dependence of the amount of saved heat ΔQ on the velocity of flat decking air flow v_x. In a convenient tabular form (Table 1), these data are displayed by temperature t_{air} = 20 °C.

Since in formula (10) the number *Re* is under the sign of the root, in table 1 it is presented in even degree.

Table 1. Dependence of the amount of saved heat ΔQ on the velocity of the flat decking air flow v_x

No	v_x, m/s	*Re*	*Nu*	α, W/(m²K)	ΔQ, W
1	2.0	7.2 10^4	160.0	7.67	20.7
2	2.5	9.0 10^4	178.9	8.58	23.2
3	3.0	10.8 10^4	196.0	9.40	25.4
4	3.5	12.6 10^4	211.7	10.15	27.4
5	4.0	14.3 10^4	225.6	10.82	29.2
6	4.5	16.1 10^4	239.3	11.48	30.1

For the convenience of further approximation, it is necessary to present this dependence in the form of a graph (fig. 7). The graph is approximated by the empirical formula (15), which is valid in the interval v_x = 2.0 – 4.5 m/s:

$$\Delta Q = 7.541 + 7.833v_x - 0.627v_x^2 \quad (15).$$

Formula (15) allows operating with arbitrary data of the current velocity v_x on a continuous interval of 2.0 - 4.5 m /s and obtaining satisfactory results for ΔQ.

Based on this, can be summarized that due to the saved heat ΔQ the actual initial temperature of the air jet t_{0R} can be achieved slightly below the design temperature t_{0cl}, namely the quantity $\Delta t = t_{ocl} - t_{0R}$. Thus, it is possible to achieve savings ΔQ of heat load on the ventilation system Q_v. Estimated heat performance of the ventilation system Q_v, kW is determined by the formula (16):

$$Q_v = \rho_a Lc(t_{air} - t_{0cl}) \quad (16),$$

where ρ_{air} – air density at the temperature t_{air}, kg/m³;

L – productivity of ventilation system, m³/h;

c – specific isobaric heat capacity of air, kJ/(kg·K);

t_{air} and t_{0cl} – air temperature, respectively, in the premise and at the outlet of the nozzle (initial calculated), °C.

The actual heat productivity of the ventilation system is obtained lower by the value ΔQ due to the decking of a flat air jet on the surface of the infrared heater NL – 12R and obtaining an additional convective component in the heat transfer process.

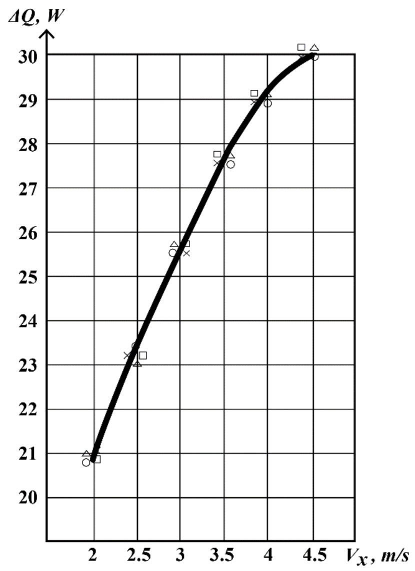

Fig. 7. Graph of the dependence of the amount of saved heat ΔQ on the velocity of the flat decking air flow v_x

Taking into account the energy savings ΔQ, the actual heat productivity of the ventilation system Q_{vR}, W is obtained:

$$Q_{vR} = Q_{vcl} - \Delta Q = \rho Lc(t_{air} - t_{0R}) \quad (17)$$

The heat balance equation (20) is valid if the heat flux q_r (18), W/m², given by radiation of infrared heater NL – 12R is taken into account and obtained the specific heat Δq (19), W/m² by flat compressed air jet due to convection in the process of decking it on the surface of the device NL – 12R:

$$q_r = C_0 \cdot \varepsilon_r \cdot \left[\left(\frac{T_{ih}}{100}\right)^4 - \left(\frac{T_{air}}{100}\right)^4\right] \quad (18),$$

$$\Delta q = \alpha(t_{ih} - t_{air}) \quad (19),$$

$$C_0 \cdot \varepsilon_r \cdot \left[\left(\frac{T_{ih}}{100}\right)^4 - \left(\frac{T_{air}}{100}\right)^4\right] = \alpha(t_{ih} - t_{air}) \quad (20).$$

Solving the transcendental equation (20) with respect to the surface temperature t_{ih} of infrared heater NL - 12R and considering $t_{ih} = T_{ih} - 273$, the result t_{ih} = °70 C is obtained. This temperature satisfactorily coincides with the passport data of the infrared heater NL - 12R and the results of experimental studies.

If the share of energy savings take $\beta = \Delta Q/Q_{vcl}$, it is possible to obtain the actual heat output of the ventilation system from (21):

$$Q_{vR} = (1 - \beta)Q_{vcl} \quad (21).$$

Taking into account formulas (16), (17) and (21) it is possible to obtain (22):

$$t_{air} - t_{0cl} = (1 - \beta)(t_a - t_{0R}) \quad (22).$$

Therefore, the dependence (23) was obtained to determine the actual initial temperature of the flat air jet:

$$t_{0R} = (1 - \beta)t_{0cl} + \beta t_{air} \quad (23)$$

The research results showed that taking into account formula (14) the value of the share of energy savings β is within 9% – 14% from the heat output of the ventilation system.

Energy efficiency should be assessed by recovering the heat of the exhaust air. If the productivity of the exhaust outlet is L_e, then the heat output of the recuperator Q_{rec}, kW is determined by the formula (16):

$$Q_{rec} = \rho_e L_e c(t_e - t_{air}) \tag{24}$$

where ρ_e – air density at temperature t_e, kg/m^3;

L_e – productivity of an exhaust outlet, m^3/h;

c – specific isobaric heat capacity of air, kJ/(kg·K);

t_e and t_{air} – air temperature in the exhaust outlet and indoors, respectively, °C.

The amount of heat recovery of the exhaust air removed by the exhaust outlet is 30 - 40 W, ie 15% – 20%. The total energy savings is 24% - 34%.

Therefore, the expediency of using radiant heating with the use of infrared heaters NL – 12R and use in the system of ventilation of flat decking jets and heat recovery of exhaust air is obvious.

Together, these measures will provide comfortable conditions in industrial and public premises and get savings in thermal energy in the amount 24% – 34%.

The research results can be used in the design of energy-saving microclimate systems, namely, a radiant heating system using infrared heaters for industrial and public buildings and ventilation systems using flat decking jets and heat recovery of exhaust air.

CONCLUSIONS

1. Use of NL - 12R infrared heaters allows to design energy-saving radiant heating systems for industrial and public buildings, as it provides the regulatory temperature of indoor air.
2. Use of NL - 12R infrared heaters in combination with air distribution of the ventilation system with flat decking jets is effective, as it allows to achieve savings in heat load of the ventilation system in the range of 11% - 19%.
3. The amount of heat recovery of the exhaust air removed by the exhaust outlet is 30 - 40 W, ie 15% - 20%.
4. Saving the heat load of the ventilation system allows to reduce the actual initial temperature of the tidal flat decking air jet to the value $t_{0R} = (1 - \beta)\, t_{0cl} + \beta\, t_{air}$ and achieve a total saving of thermal energy of 24% - 34%.

DISCUSSION

The research results of experimental and analytical determination of energy saving of heating and ventilation systems due to infrared heater with exhaust outlet and flat laying air jet application are presented. Since the experimental studies were conducted in stationary mode, the results for compressed flat laying air jets at alternating mode would be interesting.

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