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RESEARCH OF THERMAL PROCESSES IN INDUSTRIAL PREMISES WITH ENERGY-SAVING TECHNOLOGIES OF HEATING

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Abstract

The article presents the results of experimental research of thermal processes in industrial premises with energy-saving technologies of heating and their analysis by geometric modeling tools and graphic computer technologies. The effectiveness of using the method of forced feeding of air heated by infrared emitter involving compromise graphical optimization was analyzed by geometric way.

Key words: energy-saving systems, infrared heating, graphic computer technologies, geometric modeling

BADANIE PROCESÓW CIEPLNYCH W POMIESZCZENIACH PRODUKCYJNYCH Z ENERGOOSZCZĘDNYMI TECHNOLOGIAMI OGRZEWANIA

Streszczenie

W artykule przedstawiono wyniki badań eksperymentalnych procesów termicznych w pomieszczeniach przemysłowych z energooszczędnymi technologiami ogrzewania oraz ich analizę wykonaną z użyciem narzędzi do modelowania geometrycznego oraz graficznych technologii komputerowych. Efektywność stosowania metody wymuszonego podawania powietrza podgrzanego z użyciem promienników podczerwieni z udziałem graficznej optymalizacji została przeanalizowana przy użyciu komputerowych technologii graficznych.

Słowa kluczowe: energooszczędne systemy, ogrzewanie podczerwone, komputerowe technologie graficzne, modelowanie geometryczne

INTRODUCTION

Eurointegrational vector of Ukraine's development covers all the components of its factors of life, and energetics is the basis and the guarantee of these factors. The use of energy requires fundamentally new approaches to their practical application, mainly among which is energy savings. Experience of the global economy confirms the main conclusion that the efficient use of fuel resources is the key to stable economic development and indicates the appropriate level course positive processes in the country.

Saving issues are important for any country with an appropriate level of economic development; taking into account the modern conditions of development of Ukraine. This problem is very important, especially considering incremental resource constraints in all areas of the national economy's development. Because of it problem of economy is extremely important, especially energy carriers. This is one of the practical preconditions for the conservation of European integration course of the state. In conditions of limited resource support of various sectors of the economy to date and practically become important means of preventing the deterioration of economic situation, because the deterioration of resource provision leads to an economic slowdown. First of all, there are issues of resource provision is extremely relevant in the fields of industrial and gricultural production with the use of technological processes in industrial buildings and structures. It is obvious that in matters of price-quality software process flow can be no compromise. The component of quality of such a process requires certain conditions in which there is a need to develop innovative approaches to training and maintenance of production, one of which is to ensure comfortable temperature conditions in production facilities.

The goal of the article is to study regularities of thermal processes in industrial premises using combined energy-saving technologies of heating.

Great scientific contribution to the development of theoretical and practical tools for the use of energy-saving systems for various purposes have a significant number of scientists both in Ukraine and abroad. Particularly noteworthy are those scientific developments relating to the solution of practical problems to ensure a comfortable temperature conditions in industrial premises at low temperatures indoors, sustainable comfort temperature maintenance personnel using the beam component of infrared emitting [1-3]. The results of studies on the use of energy-saving technologies in heating systems of agricultural complexes are shown in scientific exploration [4].

Such studies have shown the advantages of using the beam component of infrared radiation and showed the feasibility of using them as a major element of energy-saving technologies in heating systems [5-7].

Results of research of thermal process in industrial premises by combined use of infrared heaters, with the simultaneous comparison absence and presence of forced air ventilation are described in [1]. In [8] shows the results of temperature investigations in work areas of industrial premises with the use of infrared heaters according to the degree of blackness of heated surface facilities and air velocity in the service area.

The main outcome of research is a thoughtful and careful experimental studies, followed by treatment under study multiparameter systems mathematical and graphical tools [9,10].

Study of the problems of expansion of industries use of energy efficient infrared heating systems is the subject of several scientific publications. For example, in [4,11] is set that the scientific task and practical problem of use of infrared heating in agricultural facilities, especially in the livestock and poultry premises, is solved. At close on the subject of scientific exploration [8] studied the problem of analysis and graphical visualization of heat flows using the specified space heating equipment. The main result of analysis of research is thorough experimental setting and mathematical processing of results involving graphs.

Given the large number of variables studied thermal systems, it is possible to attract the experimental data processing tools multi-dimensional geometry, in particular, [12-16].

The above analysis of scientific publications on subject under study covers a small fraction of the publications of research results, which have been intensively held in different scientific institutions, but with the sole purpose of saving energy for heating. A review of studies makes it possible to confirm the high level of performances of experimental studies, the accuracy of measurements of many variables and obtained their practical values (temperature, density of the heat flow, thermal power, etc.). The objective lack of any experimental studies is their limitations with respect to the parameters of discrete values, the limited range of parameters, the inability to obtain using existing laboratory equipment or that the required parameters, and so on. These capabilities provide means of applied multi-dimensional geometry. Therefore, not yet occupied by scientific niche is the use of graphic information technologies in multi-dimensional geometry studies of energy-saving infrared heating systems of premises and buildings of industrial and agricultural purposes.

RESEARCH OF THERMAL PROCESSES

One of the many variants of the use of infrared emitting is its attraction as a main element of the internal heating systems of buildings and structures. The beam component, which is constructed on the basis of the use of this type of emitting heater, has the advantage of providing proper conditions of stay in the staff room at lower air temperatures in working areas. Note also its positive effect on equipment located in the room.

The property of warm air is that due to convection it goes up to the upper zone of the room and does not participate in the space heating process. One of the measures to attract it to the heating system is the forced ventilation. The experimental setup contains necessary active elements for research – an infrared heater and a fan, and a control instrument – thermometer with its operational installation anywhere in the turbulent area of industrial premises (Fig. 1). It is possible to carry out research at enabled and disabled modes of fan.

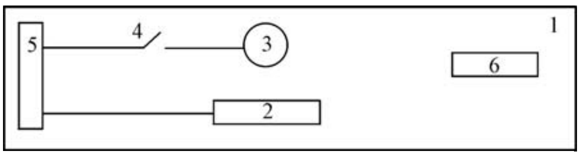

Fig. 1. Block diagram of the experimental system equipment of infrared heating:
1 – room; 2 – infrared heater; 3 – fan; 4 – switch; 5 – block; 6 – thermometer

In the room 1 over infrared heater 2, fan 3 is located, which is powered via a switch 4 from block 5, which is attached to the infrared heater 2. The thermometer 6 can be located at any point of the room 1. However, by given the technical possibilities of experiment, thermal power of infrared heater Q changed between operating range of 500...1500 W in increments ΔQ = 500 W, and height of its installation h was 1.13...1.73 m in increments Δh = 0.3 m [6,7].

Based on the physiological characteristics of growth in staff, conducted an experiment with the measurement of relative air temperature $\bar{t}$ from the density of the heat flow of the emitter q at height of installation 1.73 m (Fig. 2).

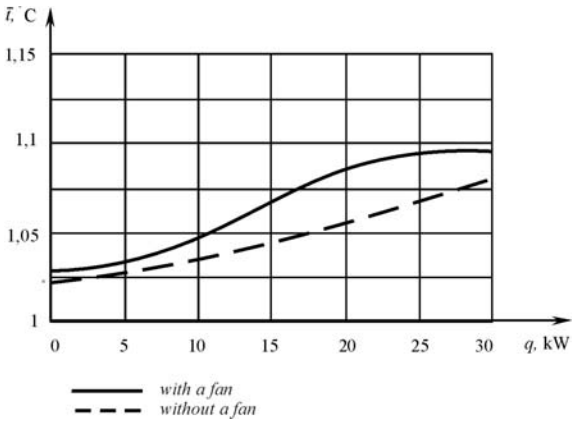

Fig. 2. Effect of the fan to relative air temperature $\bar{t}$ indoors, h = 1.73 m (curves plotted for the five values of density of the heat flow q)

The results of the experiment without and with fan (Fig. 2) show that the intensity of change of relative air temperature $\bar{t} = f(q)$ in working area of change of heat flow density of the emitter q in the range 0...30 kW/m^2 can be divided into a number of ranges (Fig. 3).

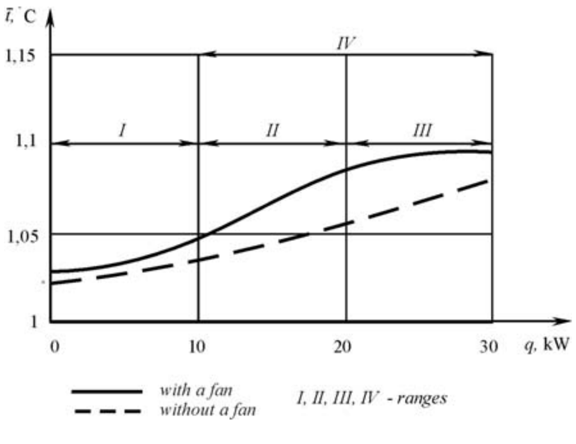

Fig. 3. Ranges of change of relative air temperature $\bar{t}$

In the absence of a fan relative air temperature $\bar{t}$ almost linearly rises in a I range and in a IV range. In the I range when changing the density of the heat flow q between 0...10 kW/m^2, relative air temperature $\bar{t}$ changes by $\Delta\bar{t}$ = 0.01 (Fig. 3), and in the IV range when changing the density of the heat flow q in the range of 10...30 kW/m^2 increase in temperature by $\Delta\bar{t}$ = 0.045 is indicated.

In general, the temperature rise is not uniform in two ranges, and changing the density of the heat flow of emitter q in the range 0...30 kW/m^2 increase in temperature $\Delta\bar{t}$ = 0.055.

When the fan is switched-on relative air temperature $\bar{t}$ varies almost exponentially by the law in three ranges. The intense temperature change takes place in the II range: when you change the density of the heat flow of the emitter q in the range of 10...20 kW/m^2 relative air temperature $\bar{t}$ changes by $\Delta\bar{t}$ = 0.03, and the intensity of relative temperature increase is less in the I and III ranges and, respectively, amounts $\Delta\bar{t}_I$ = 0.02 and $\Delta\bar{t}_{III}$ =0.01.

In the operating range of change of heat flow density in both cases, when using a fan and without it, extrema is absent. The maximum and minimum values of relative temperature are attained at the beginning and the end of range of heat flow density change of emitter q.

The highest amount of power is consumed by the fan use. Exponential dependence $\bar{t} = f(q)$ when the fan is switched on makes it possible to define graphical compromise extreme (Fig. 4).

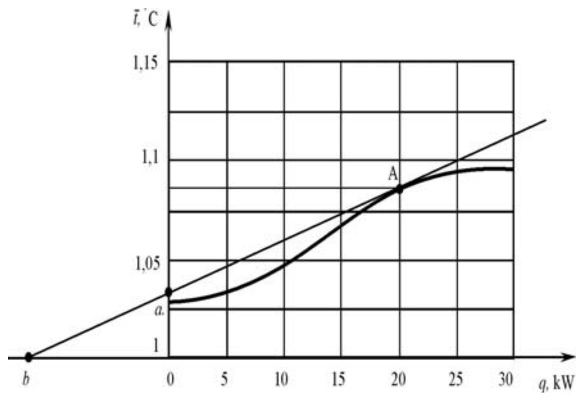

Fig. 4. Determination of compromise extremum

The equation of tangent line to the curve when the fan is powered on has the form:

$$\frac{\bar{t}}{a} + \frac{q}{b} = 1, \qquad (1)$$

where a and b – weights of the optimal relative temperature of the air $\bar{t}$ and densities of the heat flow of emitter q [5].

In accordance with (1) from graphical dependencies $\bar{t} = f(q)$ define compromise meanings of settings for point A: q_0 = 20 kW/m^2, $\bar{t}_0$ = 1,08 (Fig. 4).

Let's define the performance of fan in predetermined range of variation of heat flow density of *q*. Analysis of graphical dependencies (Fig. 3) indicates low fan effect on increasing the relative temperatures in the range of *q* = 0...10 kW/m^2, and its biggest influence is in the range of *q* = 10...20 kW/m^2. Distributing of depending – excess of relative temperature of air $\Delta\bar{t}$ in the range of changes *q* = 0...30 kW/m^2 (Fig. 5) indicates the presence of an absolute extremum, which determines the temperature rise $\Delta\bar{t}$ = 0.03 at the value of heat flow density of emitter *q* = 20 kW/m^2 for height of installation of infrared heater *h* = 1.73 m.

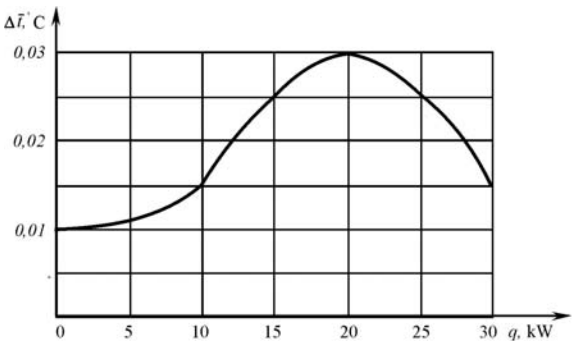

Fig. 5. Excess of relative air temperature on an enabled fan

Studies have shown the undoubted advantages of using fan mounted on the infrared heater. However, the effects of fan are doubly: at minimum and maximum values of heat flow density of emitter *q* have low values of temperature rise $\Delta\bar{t}$, and the largest value $\Delta\bar{t}$ is reached in the range of heat flow density of emitter *q* = 15...25 W/m^2 and height of installation of the infrared heater *h* = 1.73 m.

Influence of the height of installation of infrared heater *h* to relative air temperature in service area $\bar{t}$ can be examined by analyzing the plots with different values of thermal power of the infrared heater *Q*. Note that the experiment was carried out taking into account technical possibilities for discrete values of the variables *h* and *Q*. As a result of the data analysis three experimental graphical dependences obtained by experiment (Fig. 6).

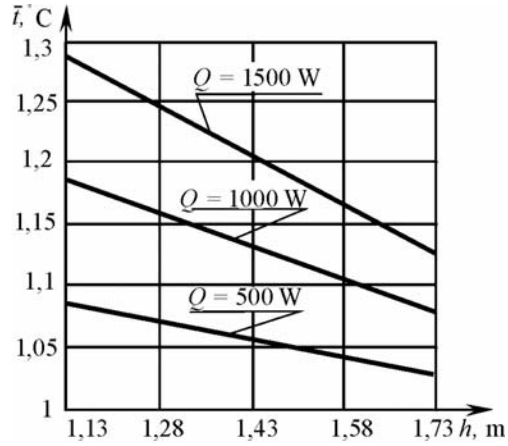

Fig. 6. Influence of height of installation *h* and thermal power of infrared heater *Q* to relative air temperature $\bar{t}$ in the service area

Analysis of plots shows the positive impact of thermal power of infrared heater *Q* to increase relative air temperature $\bar{t}$ within the range of variation of height of installation of the infrared heater *h*. By increasing the thermal power of the infrared heater *Q* by the same amount ΔQ = 500 W have the same change $\Delta\bar{t}$: when *h* = 1.13 m temperature rises $\Delta\bar{t}$ = 0.1, when *h* = 1.43 m temperature rises $\Delta\bar{t}$ = 0.08, and when *h* = 1.73 m excess temperature delta = 0.05, that is by increasing height of installation of infrared heater *h* on Δh = 0.6 m have a decrease in the relative temperature $\Delta\bar{t}$ twice.

However, established values of thermal power of the infrared heater *Q* we have a smooth decrease in the relative air temperature $\bar{t}$ almost linearly.

This fact can be explained by an increase of the absolute temperature with increasing height. Typically, cold air sinks to the floor and the warm air on the contrary goes up to the upper zone of the room.

The obtained graphical dependences (Fig. 6) show a simultaneous impact on the relative temperature of the air $\bar{t}$ at once two parameters – thermal power of the infrared heater *Q* and height of its installation *h* – and connect in one functional expression these three parameters.

In three-dimensional space $O\bar{t}hQ$ parameters associated with simple analytical expression $\bar{t} = f(Q,h)$ are visualized by the surface, and graphic dependences shown in Figure 6 are projections of this surface obtained at constant thermal power of the infrared heater *Q* (Fig. 7).

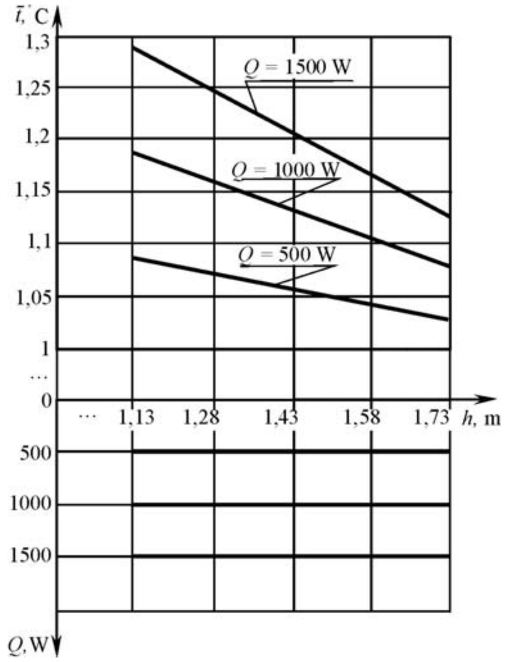

Fig. 7. Surface projections $\bar{t} = f(Q,h)$

Constant values of thermal power of the infrared heater Q determine position in the space of intersecting front level planes whose intersections with the surface $\bar{t} = f(Q,h)$ produce a set of curves $\bar{t} = f(h)$ in the frontal plane of projections $O\bar{t}h$ (Fig. 8).

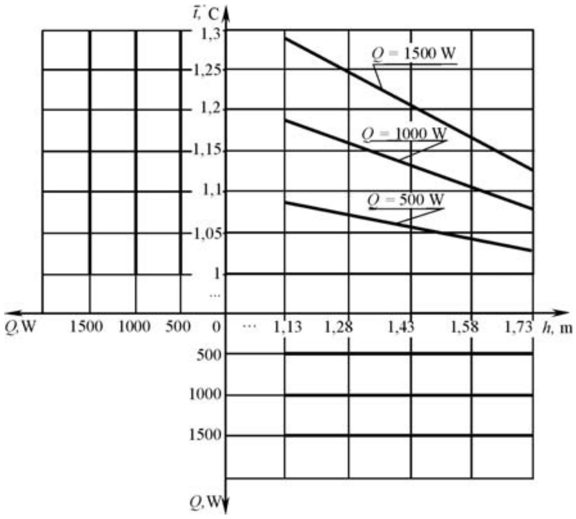

Fig. 8. Setting the surface $\bar{t} = f(Q,h)$ by line frame

Each of obtained curves $\bar{t} = f(h)$ project on the horizontal plane of projections OhQ in the corresponding following projection intersecting the front level plane. It is evident that such projections placed in the profile plane of projections $O\bar{t}Q$ and collectively form a discrete frame of surface $\bar{t} = f(Q,h)$.

This frame makes it possible to receive the projections, and consequently, the coordinates, the numerical values of parameters of point B, belonging to the surface $\bar{t} = f(Q,h)$.

Complete the following projection of arbitrary frontal project plane φ in the frontal plane of projections (Fig. 9) which point B belongs to. After the corresponding constructions, we obtain the projection of point B in the horizontal plane of projections OhQ (B_1) and profile plane of projections $O\bar{t}Q$ (B_3). According to the projections we determine the numerical values of parameters $\bar{t}_B$, Q_B, h_B.

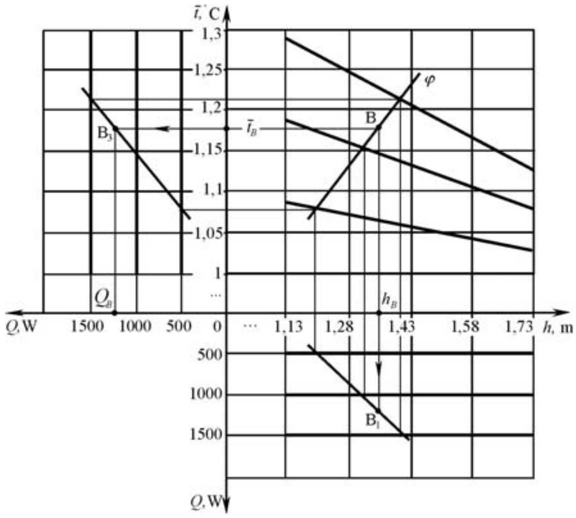

Fig. 9. Definition of the numerical values of parameters h, Q, $\bar{t}$ at any point in the space of premises

According to position of the section plane φ, such diagrams give the opportunity to build dependences of parameters that in the experimental conditions are often difficult to obtain, if not impossible. In addition to specific coordinates of point B, plane φ made it possible to build dependences $Q = f(h)$ and $\bar{t} = f(Q)$.

Using the proposed method, we construct the frame of the surface $\bar{t} = f(Q,h)$ based on values Q = 500 W, Q = 625 W, Q = 750 W, Q = 875 W, Q = 1000 W, Q = 1125 W, Q = 1250 W, Q = 1375 W and Q = 1500 W (Fig. 10).

Built surface of the frame makes it possible to both determine the numerical values of parameters h, Q, $\bar{t}$ at an arbitrary point in space in working area of parameters changes, and build relationships which are impossible to obtain due to the technical conditions of the experiment. Figure 10 shows the dependence at constant h = 1.2 m section of the surface of the profile plane with trace levels of δ-projection of h = 1.2 in the Oh axis.

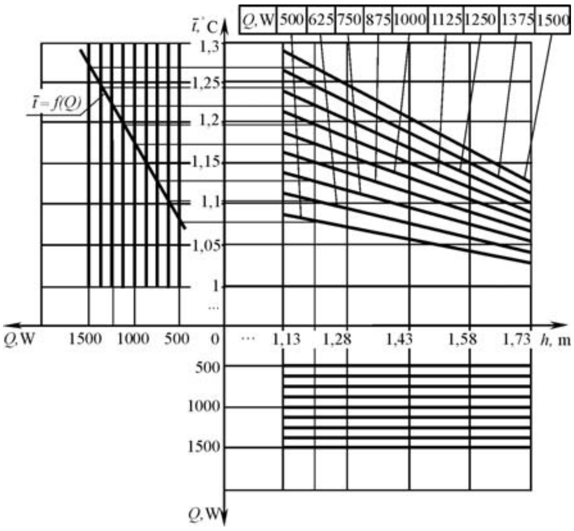

Fig. 10. Construction of the surface frame for nine thermal power values of infrared heater Q

Built surface of the frame can also be used to find equation of the surface. Let us assume that $Q = y$, we have there $z = f(x, y)$.

By analyzing each of the curves at a constant value, we take a lot of curves as algebraic curves of the second order. They are forming an algebraic surface lines of the second order:

$$Ax^2 + By^2 + Cz^2 + 2Dxy + 2Exz + \\ + 2Fyz + 2Gx + 2Hy + 2Kz + L = 0. \tag{2}$$

Cutting this surface with a cross-section plane of the level, for example, $y_1 = 500$, we obtain a surface line, which in the Figure 10 is supplied with graphical dependence at $y_1 = 500$. Substituting the value y_1 in (2), we obtain the equation of the line:

$$Ax^2 + By_1^2 + Cz^2 + 2Dxy_1 + 2Exz + \\ + 2Fy_1z + 2Gx + 2Hy_1 + 2Kz + L = 0. \tag{3}$$

To determine constant values of coefficients of algebraic equation of the second order we set some constant values y_i (3). Solving the system of nine equations, we obtain the numerical values of the coefficients (2), which uniquely identify the equation of the surface:

$$\bar{t} = 1.14 + 1.54e^{-4}(Q - 1000) - 0.2(h - \\ - 1.43) - 1.53e^{-4}(Q - 1000)(h - 1.43). \tag{4}$$

It is obvious that such an equation approximately describes the surface and corresponds to a received working range of the variation of the parameters Q and h.

Computer visualization of equation (4) gives the opportunity to present a surface shape of temperature in the room (Fig. 11).

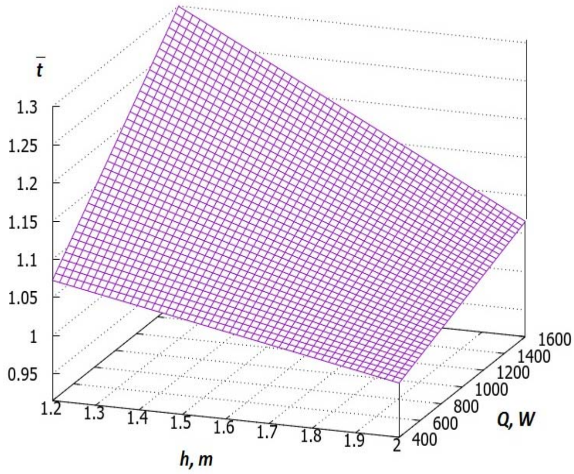

Fig. 11. The surface of temperature in service area

The limits of variation of the input factors have changed as follows. For thermal capacity of infrared heater: 500W $\le Q \le$ 1500W; for height of installing the heater: $1.13 \le h \le$ 1.73.

SUMMARY

The results of experimental studies as well as their geometric interpretation lead to the following conclusions:

1. As a result of research of thermal processes in industrial premises the problem of establishing a comfortable way of heating of the working zone combining the use of infrared heaters with forced ventilation was formulated and solved.
2. On the basis of use dependences obtained experimentally of three parameters of thermal process – air temperature, heat flow power and height of installation of infrared heater – graphical tools were proposed and approved in processing experimental data. This made it possible to apply the dependence of these parameters by second order surface of three-dimensional parameter space of the thermal process.
3. Using all suggested geometric tools can significantly reduce the costs for carrying out the experiment and get the results, the accuracy of which is determined by the accuracy and correctness of the experiment.

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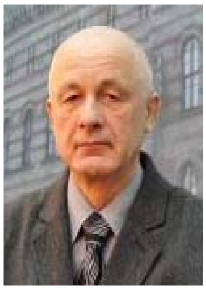

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