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I. M. Cheberiachko,
orcid.org/0000-0002-6193-5729,
O. V. Stolbchenko,
orcid.org/0000-0003-2003-4382,
A. A. Yurchenko,
orcid.org/0000-0002-4998-2047,
I. O. Luts,
orcid.org/0000-0003-0333-5730

Dnipro University of Technology, Dnipro, Ukraine, e-mail: elena_aot@ukr.net

DEFINING THE LEVEL OF HUMAN COMFORT IN THE OFFICE ENVIRONMENT BY THERMAL FACTOR

Purpose. To analyse the process of heat exchange between the man and the environment, including production areas, as well as to develop and study the criterion of workplace comfort by the thermal factor.

To achieve this goal, the following tasks are to be solved:

- to consider the characteristics of the microclimate in the workplace, including that of office space using information technologies;
- to develop a mathematical model of heat exchange between the human body and the environment;
- to develop a criterion for the efficiency of functioning of microclimate normalization systems in the workplace.

Methodology. To perform the tasks in the work, an analysis of the literature and sanitary and hygienic documentation on the specified problem is performed; analytical method is applied for studying the comfort of the sanitary and hygienic condition of the indoor air using a mathematical model of heat exchange between workers and the environment.

Findings. Based on the theoretical analysis, the criterion of microclimate comfort is obtained, which differs from the known ones in that it takes into account all types of heat transfer from the human body to the environment depending on the nature and intensity of human activity, allows estimating the total value of heat flow depending on the environmental condition with fair accuracy for the practical purposes and can be used to substantiate the efficiency of methods and means of normalizing the microclimate when performing work using information technologies.

Originality. A mathematical model of heat transfer in the “man – environment” system is developed and theoretically substantiated. The criterion of microclimate comfort at workplaces is offered and mathematical relation to calculate it is obtained.

Practical value. The results of calculations of the comfort criterion in the workplace can be used when developing tools and methods for normalizing the microclimate in the workplace and assessing the effectiveness of their implementation.

Keywords: *microclimate, heat exchange, mathematical model, comfort criterion*

Introduction. Currently, there is observed a trend of steady growth in demand for clean non-productive premises of high quality, which is caused by an increasing number of companies, small firms as well as by expansion of administrative points. Office space occupies a large share in the field of services and development of intellectual products. Despite the economic crisis, modern office real estate is in great demand.

The environment in which a person works directly affects their health, well-being and, as a consequence, their capacity for work and productivity. Ensuring a high level of comfort and safe working conditions for employees is an important task for the employer.

The main principle in the organization of a standardized microclimate involves performing the tasks of protection, regulation and management.

Comfortable conditions in the workplace of office premises are not only means of office mechanization facilities and other equipment, but, first of all, microclimate parameters at which the worker will feel comfortable. Favourable working conditions for people in the office are created by microclimate normalization systems (ventilation, air conditioning, automated climate control systems). These systems constantly monitor the compliance of the mode of operation of technological equipment to its regular mode. As a rule, they are part of scheduling systems for centralized control and management of technological, information and communication processes. In addition, dispatching systems prevent emergency operation of equipment and protect equipment units from premature wear.

Thus, the assessment of the microclimate in the workplace, its comfort, assessment of the efficiency of the implemented measures and tools for normalization of thermal conditions is an urgent scientific and technical problem.

Literature review. Temperature, humidity, air motion, the temperature of the surrounding surfaces and their thermal emission are the main factors which determine the microclimate of industrial premises. These parameters affect the heat exchange between the human body and the environment and determine the capacity for work, well-being of an employee, and affect their health. Climatic parameters are formed as a result of the impact of the environment, the technological process in the room, and the intensity of ventilation and air conditioning on the space [1]. The human body has the ability to respond to the parameters of the microclimate of the environment, i. e. there is certain dependence of “operating conditions – the body’s response”. For example, increased sweat-

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ing, rapid breathing are a reaction of the human body to high temperatures and high humidity. Adverse parameters of the microclimate result in rapid fatigability, loss of attention, stress, which can result in the worker's getting injured.

It is desirable to assess comfort according to the following criteria: body heat perception (cold, comfortable, hot), the presence of foreign internal and external odours or their absence, the degree of air motion (stuffiness, comfort and draft), and the ability to respond adequately and quickly to dangerous situations (unsatisfactory and good) [2].

It is known [3] that the main factor which creates the climatic conditions of industrial premises is the air temperature in the workplace. It affects thermal comfort, but this effect is still understudied. Thus, the feeling of stuffiness occurs when the air is warm and humid. In winter, warm air is more likely to cause one to feel discomfort than cool air. In the range of air temperature 20–26 °C, the functional relationship between the number of cases of discomfort and the room temperature is close to linear [3].

Air flow rate is one of the main climatic parameters of industrial premises. Considerable air motion results in increased heat exchange due to heat removal from the human body by convection flows, so the minimum allowable value of air motion under comfortable conditions should be taken during cooling period, and the maximum allowable value – during heating period. The average value of air movement increases with increasing need for cooling the room together with the flow of air supplied to the room.

Relative humidity has a significant impact on the feeling of comfort for workers in the production premises [4]. Regulation of the level of humidity in the premises affects not only the general well-being of workers, but also the energy load of air conditioning systems. Increasing the relative humidity, for example, from 40 to 60 % results in a decrease in the required intensity of refrigeration equipment. The required energy consumption of air conditioning systems at a relative humidity of 60 % is only 56 % of the energy consumption at a given relative humidity of 40 % [4–6].

Unsolved aspects of the problem. Methods for assessing the comfort of the working area, proposed in [5, 6], are based on at least three components – the assessment of comfort in the workplace by climatic parameters, the level of dust in the atmosphere and the gas contamination of the working area. The method for assessing comfort in the workplace by climatic parameters is that first, the air temperature is measured with a thermograph or psychrometer, then the humidity is determined with a stationary or aspiration psychrometer and the air motion is measured with a plate or cup anemometer. After that, taking into account certain parameters – air temperature in the workplace, its humidity and motion rate – the degree of comfort is determined according to the following scale: 1 – very hot; 2 – too warm; 3 – warm, but comfortable; 4 – thermally comfortable; 5 – cool, but comfortable; 6 – cold; 7 – very cold. The lack of consideration of all the microclimate parameters when calculating comfort is a drawback of this method. For example, the concentration of ions in production facilities is not taken into account. Moreover, the application of this method in automated control systems for microclimatic parameters is difficult to implement from a technical point of view.

Thus, the results of the studies by domestic and foreign scientists allow us to conclude that the normalization of microclimatic parameters in the workplace as well as the need to develop a criterion of human comfort in the environment, which would take into account all heat exchange factors in the "man – environment" system, is an urgent task.

Theoretical research. Climatic parameters directly affect a person's capacity for work and their well-being. Thus, a high air flow rate and low temperature due to increased convective heat transfer from the human body lead to its hypothermia.

High temperatures in the workplace result in the human body's losing carbohydrates, fats as well as in the destruction of proteins. The heat accumulation in the human body and its overheating above the allowable level is a consequence of high air temperature at high humidity. This leads to hyperthermia, i.e. a condition in which the body temperature can be 38–39 °C [3]. The man's impaired productivity occurs at temperatures of around 30 °C.

The maximum allowable temperature of inhaled air is set depending on the exposure time and the use of protective equipment. The maximum allowable temperature of the inhaled air, at which a person can breathe without special protective equipment for several minutes without any risk of damaging their health, is about 116 °C. An important parameter is the temperature variation with altitude. The vertical temperature gradient should not exceed 5 °C.

Air humidity and air velocity determine the way a person endures the temperature and their thermal sensation. With increasing humidity, the intensity of sweat evaporation decreases, which accelerates the overheating of the human body. High humidity at $t > 30$ °C significantly impairs human well-being, as in this case the sweat does not evaporate and drips off of the surface of the skin. Under these conditions, there is a so-called profuse sweating (excessive perspiration), which exhausts the body, and heat transfer virtually fails to continue.

The thermal effect on a person is caused by infrared radiation. At the same time, certain biochemical changes take place in the body – venous pressure and oxygen saturation of the blood reduce, blood flow slows down, the activity of the cardiovascular and nervous systems is impaired. By the nature of the effect of infrared rays on the man, they are divided into shortwave rays with a wavelength of 0.76–1.5 μm and long-wave ones with a wavelength of over 1.5 μm. Due to the over-penetration into living tissues and their heating, short-wave heat radiation causes impaired concentration, rapid fatigability, excessive sweating, and with prolonged exposure – heat stroke. Long-wave radiation is characterized by low penetration and is delayed by the epidermis.

Radiant heat not only affects a person, but also heats the surrounding constructional equipment. Through radiation and convection, the heated surfaces of these structures give off the heat to the environment, which results in an increase in the indoor air temperature. The amount of heat absorbed by the human body is affected by the area of the irradiated surface, as well as the temperature of the radiation source and the distance to it. Thermal radiation is characterized by the power of the radiant flux per unit of irradiated surface, i.e. the intensity of thermal radiation. With low doses of radiant heat, radiation of the human body is useful; however, with increasing radiation intensity and air temperature, there is a negative effect on humans.

The heat released by the human body as a result of physiological processes is to be generally discharged into the environment for their normal conduct, i.e. the thermal balance of the human body must be maintained. Disturbance can result in overheating or hypothermia, which leads to rapid fatigability, reduced efficiency and even loss of consciousness or death [3].

The process of the man's adaptation to changes in the physical state of the environment is due to thermoregulation, i.e. a set of physiological and chemical processes aimed at maintaining constant body temperature (≈ 36–37 °C), which is the main integral indicator of the thermal state of the human body.

The process of thermoregulation depends on the level of heat imbalance and activity-related energy expenditure. If the work is of moderate and high intensity at high air temperature, the body temperature rises to 1–2 °C [3]. The boundary temperatures of the internal organs, at which there occur irreversible processes in the human body, are: maximum +43 °C, and minimum +25 °C.

Skin temperature is the main factor in the process of heat dissipation from the human body, which varies within a wide range and under normal conditions, is 30–34 °C on average under clothing. Under adverse climatic conditions, it decreases to 20 °C or, sometimes, less in some skin areas.

A person feels comfortable when the heat released by their body (heat production Q_{HP}) is completely discharged into the environment and the full heat transfer Q_{HT} occurs. In this case, there is a thermal balance $Q_{HP} = Q_{TB}$, i. e. the human body temperature remains constant.

According to the method by P. Fanger, the body's heat production is determined by the ratio, W/m^2,

$$Q_{HP} = \frac{M}{F_B}(1-\eta), \tag{1}$$

where M is metabolic heat of the person, whose size depends on the nature of the works performed, W; F_B is the estimated surface area of the adult body, which is assumed to be equal 1.75 m^2; η is the thermal coefficient of metabolic heat loss.

The thermal coefficient of metabolic heat loss depends on the intensity of the work performed, which can be expressed through the amount of energy expenditure by the employee (Table 1).

In the case when the heat production from the human body is not completely released into the environment ($Q_{HP} > Q_{TB}$), there is an increase in human body temperature, and thermal sensation is characterized by the concept of hot.

When a motionless person is thermally isolated from the environment, the increase in body temperature after one hour makes 1.2 °C [7]. If the work of moderate intensity is performed under the same conditions, the increase in body temperature will make 5 °C approaching the maximum allowable temperature. If the environment perceives more heat than the human body produces ($Q_{HP} < Q_{HT}$), then the body cools down. At the same time the general condition by the thermal factor is characterized as being cold.

Heat transfer Q_{HT} between the human body and the environment is due to: infrared radiation of the body Q_R; diffusion of moisture through the skin Q_{dms}; evaporation of moisture from the surface of the body and mucous membranes Q_{evap}; the hidden heat Q_{he} and the sensible heat Q_{sh} given off with the exhaled air; air movement (convection) Q_c

$$Q_{HT} = Q_R + Q_{dms} + Q_{evap} + Q_{he} + Q_{sh} + Q_c. \tag{2}$$

With changes in the ambient temperature and its various combinations with other factors (humidity, air velocity, radiant heat), the ratio of heat transfer ways can vary widely. For example, at elevated temperatures of the air, the leading and often the only way of heat transfer is sweat evaporation.

The body gives off the heat through emission when the temperature of the surfaces around the person in the room is below the temperature of the outer layers of clothing (on average 27–28 °C) or the exposed surface of the skin. Heat transfer through emission is physiologically the easiest way for the body. During heat exchange through emission, the lower the temperature of the surrounding surfaces is, the greater the radiant flux gets. It can be calculated using the Stefan-Boltzmann law, W/m^2

$$Q_R = \varepsilon\sigma\varphi_{a-r}\left[\left(T_0+273\right)^4-\left(T_{t,r}+273\right)^4\right], \tag{3}$$

where ε is emitting capacity of a clothed man, which equals 0.8; σ is the Stefan Boltzmann constant, whose value is equal to 5.67 W/(m$^2 \cdot$ K^4); φ_{a-r} is the angular coefficient of radiation from the surface of the human body into the environment; T_c is the temperature of human clothing surface, °C; $T_{t,r}$ is the average radiation temperature of the room, which is taken to be 2 °C lower than the temperature of the air in the room.

Heat loss through the human skin due to the diffusion of Q_{dms} vapours makes [8], W/m^2

$$Q_{dms} = 0.41(1.92T_s - 25.3 - p_w), \tag{4}$$

where T_s is the human skin temperature, °C; p_w is partial water vapour pressure in the air, kPa. Within the temperature range from 10 to 30 ° C, the dependence of the partial water vapour pressure on temperature is described by the expression [8]

$$p_w = 0.01\varphi\left(0.305T_a^2 - 0.1027T_a + 7.3596\right), \tag{5}$$

where φ is relative humidity, %; T_a is the ambient temperature, °C.

Moisture-yielding ability, i. e. hidden heat transfer from the human body, depends on air temperature and velocity (Fig. 1). At a temperature of 28–29 °C sweating begins, and at a temperature over 34 °C heat transfer by evaporation remains the only method of heat transfer [9].

The data on sweating depending on the air temperature and the characteristics of the work performed by the man are given in Table 2.

From the data in the table, it is seen that sweating varies widely. At the air temperature of 28 °C the motionless person's sweating is 1.69 g/min, and when they are performing heavy work, it reaches 8.9 g/min.

It is known that the amount of heat transferred to the environment from the surface of the human body by evaporation of

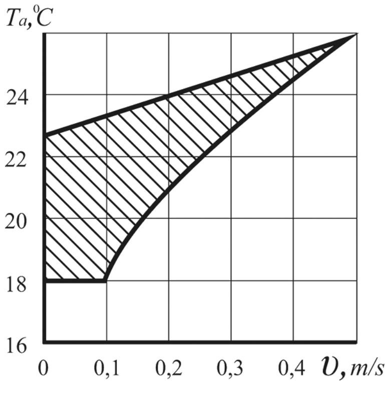

Fig. 1. Zone of comfortable combination of air velocity and its temperature

Table 1

Thermal coefficient of metabolic heat loss

Intensity of the work performed	Categories of work intensity according to the State sanitary norms (ДСН 3.3.6.042-99)	Energy expenditure, W	η
Sedentary			0
Light work	I-a	105–140	0
	I-b	141–175	0
Medium work	II-a	176–232	0–0.05
	II-b	233–290	0–0.1
Heavy work	III	291–349	0.1–0.2

Table 2

Moisture from the surface of the skin and lungs of a person depending on the air temperature and the characteristics of the work performed, g/min

Characteristics of the work performed (by N. K. Vitte)	Air temperature, °C				
	16	18	28	35	45
Sedentary, $J = 100$ W	0.6	0.74	1.69	3.25	6.2
Light, $J = 200$ W	1.8	2.4	3.0	5.2	8.8
Medium, $J = 350$ W	2.6	3.0	5.0	7.0	11.3
Heavy, $J = 490$ W	4.9	6.7	8.9	11.4	18.6
Very heavy, $J = 695$ W	6.4	10.4	11.0	16.0	21.0

sweat depends not only on the air temperature and performance characteristics, but also on the velocity of the ambient air and its relative humidity, i.e. $Q_s = f(t_{oc}; B; \upsilon; \varphi; J)$, where J is the intensity of work produced by man, W.

To determine the heat given off from the surface formula is used [8], W/m^2,

$$Q_{evap} = 0.49\left[\frac{M}{F_B}(1-\eta)-50\right]. \tag{6}$$

The hidden heat given off by the exhaled air is determined from the expression [8], W/m^2,

$$Q_{he} = 0.0196\frac{M}{F_B}(5.9-p_w). \tag{7}$$

The sensible heat given off by the exhaled air is determined from the expression [8], W/m^2,

$$Q_{sh} = 0.0014\frac{M}{F_B}(34-T_a), \tag{8}$$

where T_a is the air temperature, °C.

Convection heat transfer depends on: microclimate parameters, human body surface temperature (about 31.5 °C in summer, about 27.7 °C in winter); ambient air temperature; the magnitude of the effective surface area of the human body, which depends on the orientation of the body in space and is approximately 50–80 % of its outer geometric surface.

Heat transfer under forced convection is determined from the expression [8], W/m^2

$$Q_c = 12.1(T_a - T_s)\sqrt{\upsilon + \upsilon_0}, \tag{9}$$

where υ is estimated air motion in the workplace, m/s; υ_0 is the relative speed of a person in still air, m/s.

Simultaneous action of the microclimatic factor and other adverse factors is of a cumulative nature:

- adverse microclimatic conditions, loop of thermal control enhance the effect of other harmful factors on the body – a synergistic effect. It is established that the toxicity of poisons increases both with increasing and decreasing air temperature. Unfavourable microclimate (elevated temperature, humidity) increases the risk of electric shock;
- low air temperatures reduce the level of influence of a number of biological factors on the body, having an antagonistic effect.

After analysing the equations above, we can conclude that the thermal balance in the "man – life environment" system and hence the human's feeling comfortable by the thermal factor, depends on the ambient temperature, air motion and relative humidity, barometric pressure, the temperature of the ambient objects and characteristics of the work performed

$$Q_{TB} = f(T_a; \upsilon; \varphi; B; T_s; J).$$

Substituting expressions (3, 4, 6, 7–9) in (2) taking into account (5), we obtain

$$\begin{aligned} Q_{HT} &= 0.41(1.92T_s - 25.3 - p_w) + 0.49\left[\frac{M}{F_B}(1-\eta)-50\right] + \\ &+ 0.0196\frac{M}{F_B}(5.9-p_w) + 0.0014\frac{M}{F_B}(34-T_a) + \\ &+ \varepsilon\sigma\varphi_{ar}[(T_0+273)^4 - (T_{t,r}+273)^4] + 12.1(T_a - T_s)\sqrt{\upsilon+\upsilon_0}. \end{aligned} \tag{10}$$

Comfortable conditions for the man are determined by the optimal parameters of the microclimate, which are regulated by normative documents [2, 10].

The criterion of comfort can be expressed through the ratio of heat generated by a person when doing a particular type of work (heat production Q_{HP}) and the actual heat loss from the surface of the human body at a given microclimate parameters (heat transfer Q_{HT})

$$R_{com} = \frac{Q_{HP}}{Q_{HT}}. \tag{11}$$

According to (11), the highest level of comfort occurs at $R_{com} = 1$, when $Q_{HP} = Q_{HT}$, i.e. the human thermoregulatory system does not feel the load and the person feels comfortable. If $R_{com} < 1$, there is discomfort which is associated with a rise in the body temperature and "hot" sensation, and if $R_{com} > 1$, the discomfort is associated with a decrease in the body temperature and a "cold" sensation.

The body's heat production Q_{HP} is determined by the ratio (1).

The heat transfer Q_{HT} by different ways is determined by the right-hand side of the heat balance equation (10). Therefore, the heat transfer from the entire surface area of an adult for the category of work difficulty (light work) according to Table 1 and State sanitary norms (ДСН 3.3.6.042-99) is determined from the equation

$$\begin{aligned} Q_{H\grave{O}} &= 0.41(1.92T_s - 25.3 - p_w) + 0.49(M-50) + \\ &+ 0.0196M[5.9 - 0.01\varphi(0.305T_a^2 - 0.1027T_a + 7.3596)] + \\ &+ 0.0017M(34-T_a) + \varepsilon\sigma\varphi_{ar}[(T_0+273)^4 - (T_{t,r}+273)^4] + \\ &+ 12.1(T_a - T_s)\sqrt{\upsilon+\upsilon_0}. \end{aligned} \tag{12}$$

Substituting (1 and 12) into expression (11), we obtain the expression for determining the criterion of comfort

$$\begin{aligned} R_{com} &= M \big/ \{(68.54 - 0.061M) - 25.3 - \\ &- 0.01\varphi(0.305T_a^2 - 0.1027T_a + 7.3596) + 0.49(M-50) + \\ &+ 0.0196M[5.9 - 0.01\varphi(0.305T_a^2 - 0.1027T_a + 7.3596)] + \\ &+ 0.0017M(34-T_a) + \varepsilon\sigma\varphi_{ar}[(T_0+273)^4 - (T_{t,r}+273)^4] + \\ &+ 12.1(T_a - T_s)\sqrt{\upsilon+\upsilon_0}\}. \end{aligned} \tag{13}$$

Metabolic processes occurring in the human body (the process of storage, excretion and absorption, products of life) determine the cycle of energy expenditure for oxidation of nutrients, metabolism of heat products and mechanical work of muscles. At the same time the energy balance does not change if the amount of energy produced by the body, which is estimated by the amount of oxygen consumed, is equal to the amount of energy dissipated. At rest, an adult consumes 15 l/h of oxygen (with a heat output of 88 W), when performing physical work, their consumption increases to almost 180 l/h (with the amount of heat reaching 1,060 W) [11].

Metabolic heat energy M by the amount of oxygen consumed, W/m^2, is calculated by the formula [8]

$$M = 5.8\overline{V}\frac{V_{O_2}}{F_B},$$

where 5.8 is energy equivalent of 1 litre of oxygen at zero air temperature and normal atmospheric pressure; $\overline{V}$ is the ratio of the amount of carbon dioxide exhaled and oxygen inhaled, changes from 0.83 (off-work time) to 1 (very heavy work); V_{O_2} is oxygen consumption in normal climatic conditions, l/h; F_B is the human body surface area, m^2, which is found by the Mosteller formula [8]

$$F_B = 0.203 \cdot G^{0.425}L^{0.725},$$

where G is human weight, kg; L is human height, m.

As an example, we performed calculations of the criterion of comfort of the premises of NTU "Dnipro Polytechnic" using information technologies.

When performing calculations on the obtained expression (13), we considered the following:

- metabolic heat which is characteristic of a certain type of work along with taking into account the body surface area of an adult of 1.75 m^2 is equal to M = 162.75 W;

- the efficiency factor of mechanical work performed by employees, $\eta = 0$;
- the relative speed of workers' movement in the stationary air $\upsilon_0 = 0$ m/s;
- microclimate parameters (experimental values): T_s = 23 °C; $\varphi = 45$ %; $T_a = 29$ °C; $\upsilon = 0.05$ m/s; $T_{t,r.} = 21$ °C; $\varepsilon = 0.8$; $\sigma = 5.67 \cdot 10^{-8}$; $\varphi_{ar} = 0.136$.

The study on comfort will be conducted according to the 3D model in Figs.2 and 3, which show an office worker in the office building. Modelling of comfort will be performed by changing its heating element from 30 to 60 °C, the velocity of the air in the room being 0.1–3 m/s, humidity – 55–80 %.

The studies conducted using the mathematical model (13) and measurements performed at NTU "Dnipro Polytechnic" show that when the ambient air temperature changes being in various combinations with other factors (humidity, air velocity, and others), heat transfer from humans in different ways can vary considerably, and this can result in significant deviation from the level of comfort (Fig. 4).

The calculations conducted for working conditions using IT technologies allowed obtaining and comparing comfort levels depending on the air temperature (Fig. 5).

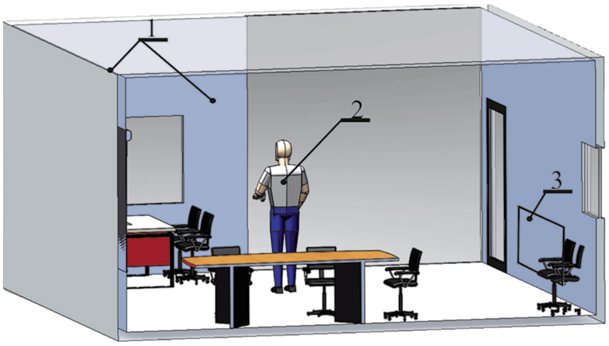

Fig. 2. Research model of influence of microclimate parameters on the person:

1 – office building; 2 – office worker; 3 – heating element

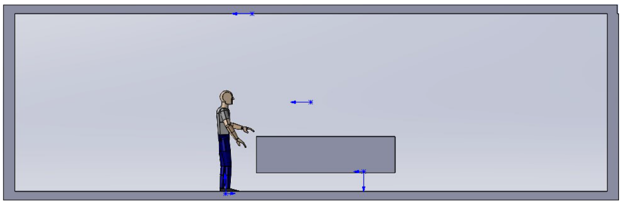

Fig. 3. Simplified calculation model

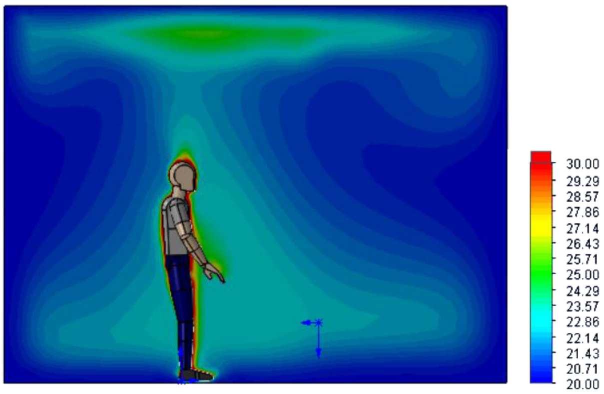

Fig. 4. The results of calculating the temperature parameters in an office in degrees Celsius

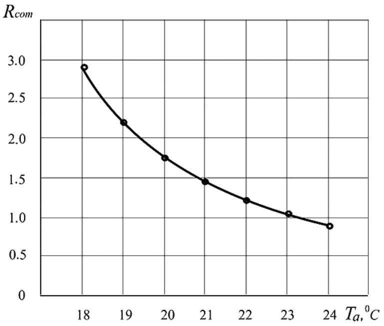

Fig. 5. Dependence of the comfort level R_{com} on the air temperature T_a

The dependence is described by a polynomial of the third degree

$$R_{com} = -0.083 \cdot T_a^3 + 0.5781 \cdot T_a^2 + 13.513 \cdot T_a + 107.42.$$

The results of the calculations prove that the minimum deviation from comfort is at the air temperature of 23.2 °C (Fig. 6).

Subsequent calculations related to the effect of humidity on the comfort level allowed obtaining the dependence of the comfort level on the air humidity (Fig. 7).

The dependence of comfort on the air humidity is described by the equation

$$R_{com} = 818.12\varphi^{-1.74}.$$

Minimum deviation from comfort is observed at the air humidity of 45 % (Fig. 8).

One of the main components of the microclimate of industrial premises is the air flow velocity. Increasing air flow velocity causes intensification of the heat exchange process due to convection, therefore, the maximum allowable value (in terms of comfort) of air velocity is perceived during cooling, and the minimum allowable value – during warming. The average value of air motion will increase with an increasing need to cool the room along with the volume of the air supplied.

The dependence of the comfort level on the air velocity is shown in Fig. 9.

The graph shows that the air velocity in the room affects the comfort level.

The velocity has a significant effect at values higher than 0.05 m/s, as indicated by the graph shown in Fig. 10.

Since the amount of heat received or given by the body varies widely depending on energy consumption and the thermal state of the environment, the thermoregulatory system of the body must be quite flexible and efficient. The body responds to extreme thermal or cold influences by the strain of thermoregulatory mechanisms, and in the case of further growth of thermal or cold stress – by pathological reactions and lesions. To eliminate these phenomena, it is necessary to design microclimate control systems which maintain the climatic parameters in the room at a level that ensures the man's comfort.

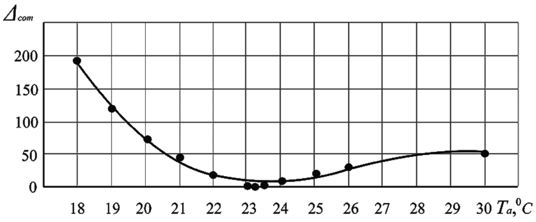

Fig. 6. Deviation Δ from the comfort index R_{com} depending on the room temperature

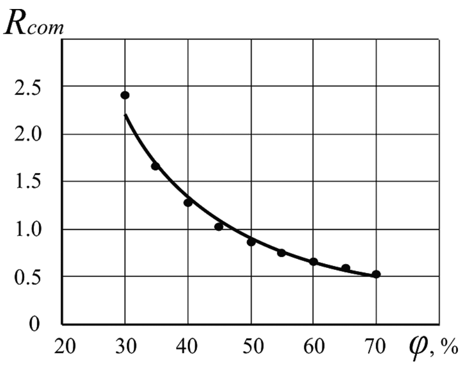

Fig. 7. Dependence of the comfort level R_{com} on the air humidity φ

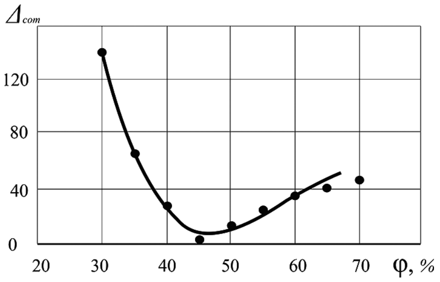

Fig. 8. Deviation Δ from the comfort index R_{com} depending on the air humidity indoors

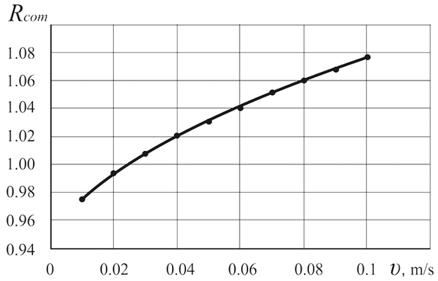

Fig. 9. Dependence of the comfort level R_{com} on the air velocity, υ

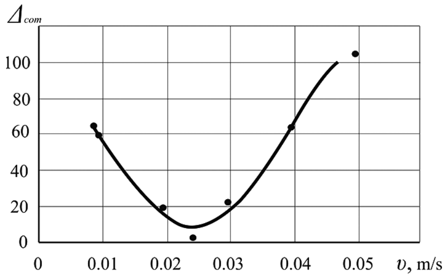

Fig. 10. Deviation Δ from the comfort index R_{com} depending on the air velocity υ indoors

Conclusions.

1. The analysis of influence of external environment and technological processes on microclimate formation processes indoors is conducted.

2. The mathematical model of heat exchange in the "man-environment" system is substantiated.

3. On the basis of the theoretical analysis, the microclimate comfort criterion is obtained. Compared to the known ones, the criterion considers all types of human body heat transfer to the environment depending on the nature and intensity of people's activity; with fair accuracy for practical purposes, it allows estimating the total value of thermal fluxes depending on the environment and can be used to ground the efficiency of methods and means to normalize the microclimate when performing work using information technologies.

4. As a result of the performed experimental measurements of the microclimate parameters, the influence of the factors of the indoor environment on the level of microclimate comfort was determined.

The results of the calculations prove that the minimum deviation from comfort occurs at the air temperature of 23.2 °C, relative humidity of 45 % and air velocity of 0.025 m/s.

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Визначення рівня комфортності людини в навколишньому середовищі за тепловим фактором

І. М. Чеберячко, О. В. Столбченко, А. А. Юрченко, І. О. Лутс

Національний технічний університет «Дніпровська політехніка», м. Дніпро, Україна, e-mail: elena_aot@ukr.net

Мета. Аналіз процесу теплообміну між людиною й навколишнім середовищем, у тому числі виробничих приміщень, та розробка й дослідження критерія комфортності робочих місць за тепловим фактором.

Для досягнення поставленої мети потрібно вирішити наступні задачі:

- розглянути характеристики мікроклімату на робочих місцях, у тому числі в офісних приміщеннях, із використанням засобів інформаційних технологій;

- розробити математичну модель теплообміну між людиною й навколишнім середовищем;

- розробити критерій ефективності функціонування систем нормалізації мікроклімату на робочих місцях.

Методика. Для виконання поставлених завдань у роботі проведено аналіз літератури та санітарно-гігієнічної документації зі згаданої проблеми; використано аналітичний метод дослідження комфортності санітарно-гігієнічного стану повітряного середовища приміщень на математичній моделі теплообміну між працюючими та навколишнім середовищем.

Результати. На підставі теоретичного аналізу отримано критерій комфортності мікроклімату, який відрізняється від відомих тим, що враховує всі види передачі тепла в навколишнє середовище організмом людини залежно від характеру та інтенсивності його діяльності, дозволяє з достатньою для практичних цілей точністю оцінити сумарну величину теплових потоків у залежності від стану навколишнього середовища та може бути використаний для обґрунтування ефективності способів і засобів нормалізації мікроклімату при виконанні робіт з використанням засобів інформаційних технологій.

Наукова новизна. Розроблена й теоретично обґрунтована математична модель теплообміну в системі «людина – навколишнє середовище». Запропоновано критерій комфортності мікроклімату на робочих місцях та одержано математичну залежність для його розрахунків.

Практична значимість. Результати розрахунків критерію комфортності на робочих місцях можуть бути використані при розробці засобів і способів нормалізації мікроклімату на робочих місцях, оцінки ефективності їх упровадження.

Ключові слова: *мікроклімат, теплообмін, математична модель, критерій комфортності*

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