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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy
(Doctor of Science)

DEVELOPMENT OF METHODS AND ALGORITHMS FOR THE EFFECTIVE MANAGEMENT AND MEASUREMENT SYSTEMS OF THE MICROCLIMATE IN CLOSED PRODUCTION AREAS

Specialty: **3338.01- System analysis, management and information development (by fields)**

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GENERAL SPECIFICS OF THE WORK

Relevance and development of the topic. At the modern level of the society development, serious attention paid on the organization of adequate working conditions. The increase of the danger in the workplace due to the development of advanced technologies increases the importance of considering the specifics of work in the workplace, which is one of the important conditions for creating an optimal indoor microclimate. A person's working ability widely depends on the level of the microclimate in the workplace. This situation makes it necessary to equip workplaces and living quarters with quality air management systems. According to GOST 12.1005 - "General sanitary and hygienic requirements for ventilation of the working area", the microclimate of indoor areas is determined by the temperature, relative humidity, air velocity, as well as the temperature of the surrounding surfaces. The microclimatic parameters in the workplace determined by the compatibility of temperature, humidity, air and heat rays, as well as some physical factors, that determine a person's mood, ability to work and productivity, and formulated under the influence of heat, humidity and gas mixtures from the environment. Human active work also includes purposeful professional work in specific production conditions. The wrong choice of these conditions can adversely affect the employee's performance and health. Human labour activity and productivity are constantly changing due to the machinery and technology development. All these increases the responsibility of employers to create a favourable microclimate in the workplace. Factors that affect the indoor microclimate have been divided into two groups: unregulated climatic factors and regulated technical and technological factors. The decisive role in creating a microclimate in the workplace belongs to the second group of factors. The design methods for computing and microclimate systems, currently used in the workplace, are based on the usage of computational dimensions that are accurate for the specified operating modes. Thus, microclimate processes, depends on a number of factors and parameters. A significant number of parameters that contribute to the formation of the microclimate determine the complexity and systematization of the issues, addressed in the dissertation. Therefore, the development of new methods for calculating of the optimal parameters in order to improve existing methods and create a comfortable environment for the employees, working indoors have been considered as high importance and urgent.

The purpose of the dissertation. The purpose of the dissertation research is to develop a scientific and methodological basis for the creation of highly effective systems to provide a microclimate in residential and office buildings for civil and industrial needs.

The main issues of the research are:

1. Application of the main provisions of Fanger's theory of thermal comfort to a group of people with different labour performance indicators and study the possibility of developing a single thermal comfort indicator for the whole group;

2. Exploring the possibility of developing an indoor quality index, considering the thermal comfort, air quality, as well as the increased over time tendency of CO_2 concentration in the atmosphere;

3. Development of parametric double-criterion method for the controlling of the indoor temperature and humidity conditions;

4. Development of a new method for three-wave non-dispersive measurement to compensate the effect of formaldehyde concentration on the measurement result of NO_2;

5. To study the possibility of obtaining the high informative results of CO_2 concentration measurements in the different industrial buildings;

6. Investigation of errors in the measurement of CO_2 concentration in the ventilated rooms;

7. Optimization of ventilation regimes in the buildings, considering the minimization of energy consumption and the

reduction of the concentration of CO_2 and *TVOC* (volatile organic compounds);

8. Development of energy-efficient adaptive management of key indicators of the indoor microclimate.

The ways of research. Elements of differential and integral computational theory, multi-criterion optimization methods, variation calculation methods, fuzzy logic methods, and neural network methods, elements of information theory, spectral analysis and thermal engineering methods have been used in the dissertation work.

The main provisions of the defence:

1. A provision on the feasibility and validity of Fanger's theory of thermal comfort for a group of people with different labour activity indicators; average integrated indicator of thermal sensitivity for the specified group, considering the formed and individual *PMV* indicators (expected average value of thermal sensitivity of a particular person); it is possible that the proposed indicator for the assessment of thermal sensitivity has an undesirable and non-valuable extremum (minimum) only if there is a logarithmic relationship between the indicator of metabolic heat generation (M) and the indicator of labour activity (W); however, since such a logarithmic relationship contradicts the well-known fact in Fanger's theory of the linear relationship between the M and W values, it can be concluded that the proposed integral indicator is fully useful for jointly, estimating the thermal sensitivity of a mentioned group of individuals.

2. Proposed multiplicative criterion reflecting the quality of the environment in closed areas - quality index; This index allows to assess the thermal discomfort of people in the long-term dynamics, considering the thermal comfort, air quality, the tendency of the concentration of CO_2 on the atmosphere to be updated over time, the property of zeroing *PMV* on full thermal comfort.

3. Proposed parametric double-criterion method and appropriate operating algorithm for the temperature and humidity regimes control in a protected indoor area.

4. The proposed three-wave length non-dispersive measurement method to compensate the effect of NO_2 on the concentration of formaldehyde (CH_2O) in the indoor area; the proposed formula for calculating the concentration of formaldehyde; functional scheme of the device for measuring the concentration of formaldehyde.

5. Results of researching the error of measuring the concentration of CO_2 in ventilated closed rooms:

According to these results: a) the sample selection error of measuring the concentration of CO_2 in ventilated rooms has a certain maximum, which occurs when there is a certain relationship between the maximum time discrete and the rate of air change; b) the dynamic error in controlling the concentration of CO_2 on ventilated rooms has a certain maximum, which occurs when there is a certain relationship between the maximum control time, the volume of the room and the ventilation speed.

6. Formulated and solved model optimization problem to determine the conditions of obtaining high information of CO_2 concentration measurement results in the production areas of different format.

7. Formulated and solved problem on calculation of optimal ventilation modes of indoor areas; In solving this problem, have been taken into account the dependence of the concentrations of the considered types of air pollutants on the electricity consumption for ventilation. The solution of this problem allowed defining two ventilation modes: a) maximum energy consumption mode - in this mode CO_2 and *TVOC* (organic volatile compounds) are fully ventilated; b) minimum energy consumption mode - where (1000-1500 mcg/m^3) the CO_2 is incompletely ventilated.

8. Proposed methods for energy-efficient adaptive management of key microclimate indicators. Operational algorithms developed for the implementation of the proposed methods for microclimate management in summer and winter.

Scientific innovations.

1. For the first time, have been discovered the possibility of applying the Fanger's theory of thermal comfort to a group of workers with different labour performance indicators. Considering the individual indicators of *PMV*, the average heat sensitivity index have been formulated for that group and it was found that the proposed average value received an undesirable extreme (minimum) value only if the heat metabolic generation (M) is logarithmically dependent on the labour activity index (W). This contradicts the fact that M, which have been considered in Fanger's theory, is a linear functional dependence of W. This allowed a group of individuals to conclude that the proposed average integral value for the joint assessment of thermal sensitivity did not have an extremum and was a single value.

2. Multiplicative criterion - air quality index have been proposed, where considered the temperature comfort and the tendency of CO_2 concentration in the atmosphere, changed over time, while the *PMV* indicator is equal to zero at full thermal comfort, allows determining the level of thermal discomfort of the people for a long period of time.

3. A two-criterion method of parameters and an appropriate operating algorithm for controlling indoor temperature and humidity conditions have been proposed.

4. Have been proposed a method of three-wave non-dispersive measurement of the concentration of formaldehyde (CH_2O) with compensation of the effect of NO_2 indoors, a formula for calculating the concentration of formaldehyde was obtained.

5. Model optimization issues have been formed and solved in order to achieve high awareness of the results of CO_2 concentration measurements in the different format industrial buildings. Investigation of errors in the measurement of CO_2 concentration in a ventilated room shows that; a) there is a certain maximum sample selection error in the measurement of CO_2 concentration in ventilated rooms, which occurs when there is a certain dependence between the time selection and the air speed; b) the dynamic error in the control of CO_2 concentration in ventilated rooms reaches a maximum when

there is a certain dependence between the volume of the room and the ventilation speed.

6. An optimization task was formulated to calculate the optimal ventilation regimes in ventilated rooms, which resulted in: a) maximum energy consumption mode when CO_2 and *TVOC* (volatile organic compounds) are fully ventilated, b) minimum energy consumption mode: 1000-1500 μg/m^3 concentration *TVOC* is partially ventilated and CO_2 is fully ventilated at a concentration of 1500-2000 μg/m^3.

7. On the basis of the main provisions of the "ANSI/ASHRAE Standard 55-2010", energy-efficient adaptive control methods of the main indicators of the microclimate of crowded buildings are proposed. Operational algorithms have been developed for the application of the proposed microclimate management methods in summer and winter.

Theoretical and practical significance of the research:

1. The application of Fanger's theory of thermal comfort to a group of workers located in the production area and having different indicators of labour activity was theoretically substantiated and a relevant proposal was made.

2. A new indoor quality index has been proposed, this reflects not only to air temperature and its quality, but also takes into account the trend of CO_2 emissions in the atmosphere over the time. The proposed index allows determining the degree of thermal discomfort of people of the closed area.

3. A two-criterion method for the management of meteorological factors in enclosed areas, as well as a three-wave method for measuring formaldehyde concentrations, has been developed.

4. The extreme properties of the sample selection error, when measuring the concentration of CO_2 in ventilated indoor areas, as well as the dynamic error that occurs during the control of the concentration of this gas were revealed.

5. Energy-efficient adaptive management methods of key microclimate indicators in indoor residential areas have been developed.

6. It appears that when the concentration of CO_2 in the air is measured optically-acoustically by a laser with different wavelengths and different power, if the wavelength decreases in the range of 10,253 μm ÷ 9,569 μm with increasing power, the beam power increases in the range of (3 ÷ 9) *W* The measurement results is maximized when there is an inverse relationship between the value of the measurement signal (*U*) and the number of measurements (*N*). Based on the experimental results, it has been shown that when the concentration of CO_2 in a closed area is high, the value of *N* should increase when the power increases, and decrease at low power.

7. It appears that when calculating the energy consumption system, that provides a microclimate indoors, it should be taken into account that the neutral value of the amount of *PMV* has the property of adapting to the current temperature in the room, and this effect leads to a reduction in energy consumption. To select the optimal operating mode of the microclimate system based on Pareto, a weight-bearing adaptive-dressing criterion has been proposed, which allows achieving a certain acceptable compromise between the increase in *PMV* and the energy consumption of the microclimate system.

8. Functional schemes of *PID* regulators have been developed to regulate the indoor microclimate using the average integrated indicator of the proposed comfort.

9. Functional schemes of *PID* regulators that can be applied in these sections have been developed using the proposed integrated average of microclimate comfort in an enclosed area with separate sections.

10. The proposed and developed methods and their implementation algorithms allow increase of the efficiency of systems that provide a microclimate in closed areas.

Approbation and implementation of the work. The main provisions of the dissertation and the results of research were presented and discussed at the following international conferences:

- International Scientific-Technical Conference "Current state and development prospects of information and communication technologies" AzTU, October 27-28, 2014;
- International Scientific-Technical Conference "Opportunities and prospects of the application of information technology and systems in construction" 05-06 July, 2018, Baku;
- X International scientific-practical conference "Actual problems of ecology and labour protection". YUZTU. 2019, Russian Federation, Kursk, 2019.

17 articles of the dissertation have been published in foreign and national scientific journals, as well as at international conferences.

The total volume of the work, considering the individual sections. The dissertation work have been carried out at the Azerbaijan Technical University (Department of "Computer Networks and Hyper Security") and partly at the Aerospace Informatics Research Institute of the National Aerospace Agency.

Total volume of the dissertation in characters with an indication of the separate volumes of the structural units. The dissertation consists of the introduction, four chapters, results, the reference list of 138 used literature, and appendices. There are figures, tables and appendices in the dissertation. The introduction consists -10913 characters, the first chapter -52404 characters, the second chapter-22272 characters, the third chapter-28760 characters, the fourth chapter-34739 characters, the results -2647 characters and the reference list of 138 used literature-40339 characters. The dissertation consists of 150 pages of computer typing, the total volume is 203720 characters.

SUMMARY OF THE THESIS PAPER

The first chapter of the dissertation is devoted to the development and improvement of the scientific and methodological basis of microclimate industry and housing systems. At the beginning of the chapter, have been mentioned a brief description of the current state of development and usage of the indoor microclimate systems.

According to the scale of the *ASHRAE* standard, the average value of the temperature sensitivity of a large number of people is defined as the expected temperature comfort level (*PMV*).

O.P. Fanger proposed the following formula for the relationship between *PMV* (predicted average value of thermal comfort) and heat load per person:

$$PMV = 3{,}155 \cdot (0{,}303e^{-o{,}114M} + 0{,}028) \cdot L, \qquad (1)$$

where: M-is the level of metabolic heat generation depending on human activity ($1\ met = 58{,}1W/m^2$).

L-is the difference between the heat, generated inside a person and the loss of that heat in the environment.

A person's metabolic heat loss can be considered as follows:

$$q_{met.heat} = M - w. \qquad (2)$$

Here: $q_{met.heat}$ - an indicator that characterizes metabolic heat losses;

w - is the work, done by man in terms of a single surface area of the human body (Btu/hft^2).

The following issue has been formulated and researched:

Whatever the form of the functional relationship between M and w, the integral value of PMV on W will reach an extreme value.

There are a majority of H people with the following characteristics: Let's suppose that the

$$H = \{h_1, h_2, \dots h_n\} \quad (3)$$

Set is available:

1. All elements of the set H have the same functional dependence: $M = \varphi_1(w)$;

2. The elements of the set H have a value w, the value of which is a regulated set n:

$$W = \{w_1, w_2, \dots w_n\};\ w_i = w_{i-1} + \Delta w;\ i = \overline{1n};\ \Delta w = const. \quad (4)$$

3. The metabolic potential of the elements of the set H is limited as follows:

$$P = \int_{w_{min}}^{w_{max}} \varphi_1(w) dw = c_4 = const. \quad (5)$$

(5) the expression means that the total potential of the elements of the set H in the metabolic generation of heat does not depend on w and is constant.

By performing some intermediate transformations, the integral value is formed on the basis of expression (1):

$$PMV_{or} = \frac{1}{w_{max} - w_{min}} \times$$

$$\times \int_{w_{min}}^{w_{max}} \left(d_1 \cdot e^{-\frac{d_2 \varphi_1}{(w)}} + d_3\right) \cdot [c_3 \cdot \varphi_1(w) + cw - c_1] dw, \quad (6)$$

where: $d_1 = 3{,}155 \cdot 0{,}303;\ d_2 = 0{,}114;\ d_3 = 0{,}028$.

Based on the expressions (5) and (6), the problem of optimization of unconditional variation was developed. Considering the Euler-Lagrange equation, the solution of this problem gave the following function$\varphi_1(w)$, where the function (6) takes an extreme value:

$$M = c_5 \cdot ln(L - c_5) + c_6;\ c_5 = c_6 = const. \quad (7)$$

Thus, when there is a logarithmic dependence between M and L, the minimum of the function (6) is obtained. Since Fanger's theory of temperature comfort assumes that there is a linear relationship between M and L, the suitability of the average integrated indicator applied to a variety of able-bodied persons is confirmed.

Then, in the first chapter, has been considered the issue of developing a new dynamic environmental quality index for indoor production facilities. The assessment of the dynamics of the increase in CO_2 concentration in the air, as well as the temperature comfort index, which considers the increase in average temperature on the planet due to the increase in CO_2 concentration in the atmosphere, the possibility of forming a new dynamic index in closed areas with a large number of people has been studied.

Temperature comfort and a very multiplicative indicator of indoor air quality have been proposed.

$$S = \left(PMV^{\lambda_1}\right)\left(\left(C_{out} - C_{st}\right)^2\right)^{\lambda_2}, \quad (8)$$

where: S - is the entered total indicator; *PMV* - is the temperature comfort index proposed by Fanger; $\lambda_1 + \lambda_2 = 1$, λ_1, λ_2 are weight coefficients; C_{out} - is the concentration of CO_2 gas in the environment; C_{st} - is the standard value of CO_2 carbon concentration in the environment;

It is proposed to generalize the *PMV* index in terms of expanding Fanger's theory according to the objectively existing trend of increasing CO_2. Then, in the first chapter, was considered the possibility of developing a two-parametric method for the management of temperature and humidity conditions indoors and outdoors.

One of the main indicators of indoor microclimate is the discomfort index, which has been calculated based on the following weather forecasts of temperature and humidity for the next day:

$$DI = \alpha_1 \cdot T_0 + W_0(\alpha_2 T - \alpha_3) + \alpha_4, \quad (9)$$

where: $\alpha_1 = 0{,}81$; $\alpha_2 = 0{,}99$; $\alpha_3 = 14{,}3$; $\alpha_4 = 46{,}3$; T_0 - indoor temperature; W_0 - indoor humidity; T - temperature in the closed areas.

A special coefficient d - an indicator of the microclimate conversion of air humidity in the environment and considers the conversion of this humidity into indoor humidity. d - defined as follows:

$$d = \frac{RH_k/100}{W_{oc}} \quad (10)$$

where: RH - relative humidity; W_{oc} - is the absolute humidity of the air, coming from the outside.

The following transcendental equation is obtained that

$$\frac{d \cdot b_1 \cdot (DI - \alpha_1 T_0 - \alpha_4)}{P_v(\alpha_2 T - \alpha_3)} = \frac{1}{exp\left[\frac{b_2 \cdot T}{b_3 + T}\right]} \quad (11)$$

This equation allows us to develop a method of determining the safe comfort temperature at given values of the DI and T criteria in protected areas and to develop an appropriate algorithm. A technological scheme for providing indoor microclimate has been developed.

The second chapter of the dissertation is devoted to the methods, developed for small amounts of gas components measuring in closed areas. At the beginning of the chapter, has been introduced a method of non-dispersive measurement of formaldehyde concentration in the ultraviolet range in closed areas.

In the non-dispersive spectroscopy method, the beam passes through a gas tub and the discharge band passes through an optical filter that is aligned with the maximum gas absorption line. A support channel is also used, where the filter discharge band is selected according to the spectral zone, where formaldehyde is not absorbed.

It was noted that using this method, the concentration of formaldehyde molecules in the first approach can be determined by the following formula:

$$N_1 = \frac{c}{l[\alpha_f(340) - \alpha_f(334)]}. \tag{12}$$

Here C- is a constant quantity; l- is the length of the light; α_f- formaldehyde absorption coefficient.

The second chapter describes a method, developed for high-precision measurement of CO_2 concentrations in ventilated rooms.

During the operation of the ventilation system have been investigated the discretization errors of CO_2 measurement in closed areas. We define the sample selection error as the error that occurs due to the

$$\Delta T = \frac{2}{\alpha} \tag{13}$$

change in the measured value of ΔT over time discrete. Error in measuring CO_2 concentration in ventilated rooms reaches a maximum within the condition. This makes it possible to develop recommendations for measuring the sample selection indicators. Has been considered the issue of optimal placement of CO_2 measuring transducers in closed areas with different sizes rooms.

With respect to the continuous model of the indicators under consideration, the conditions for optimal distribution of people in different format rooms were achieved under certain restrictive conditions. In this case, the optimal quantity of CO_2 measuring transducers in the room should correspond to the area of the rooms.

In addition, the second chapter deals with the optimization of the ventilation process and the selection of the accuracy parameters of the relevant CO_2 concentration measurements, considering the dynamic model of carbon dioxide change in a ventilated room. According to this model, at $t = t_0$, the CO_2 concentration in the room is equal to CO_2 (0), and when the number of people in the room begins to increase with the CO_2 concentration Q/v, where Q is the ventilation rate of the building; If V is the volume of the building, the value of Q, which is the extremum of the $C(t)$ concentration, is derived from the following transcendental equation:

$$e^{-Qt/v}\left(\frac{1}{Q}+\frac{t}{v}\right)=\frac{1}{Q}. \quad (14)$$

During the operation of the ventilation system have been investigated the dynamic errors in the monitoring of CO_2 gas in the room. The dynamic error was defined as the error due to the change in concentration during the control period. It is shown that the dynamic error of CO_2 concentration reaches a maximum in ventilated closed areas when the condition $T_{mear.} = 2V/Q$ fulfilled.

The second chapter deals with the optimization of two limits of CO_2 concentration in the air in residential and industrial facilities using optical-acoustic spectrometers.

The block diagram of the optical-acoustic measuring device is shown in Figure 1.

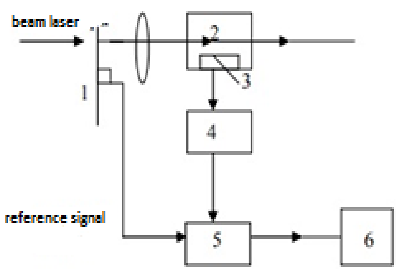


Figure 1. Block diagram of optical-acoustic measuring device: 1 - mechanical cutter; 2 - Sample tub; 3 - microphones; 4 - primary amplifier; 5 - synchronous amplifier; 6 - registration device.

The measuring device uses an adjustable laser whose wavelength coincides with the absorption wavelength of the gas being studied. The laser beam is quickly modulated to provide the optimal value of the signal/noise ratio.

When performing optical-acoustic measurements of CO_2 in the air using different laser sources of different wavelengths and different strengths, as the wavelength of radiation in the (3 ÷ 9) Wt power range decreases with increasing power in the 10,253 mkm ÷ 9,569 mkm range, the measurement results will reach a maximum by observing the inverse of the change in the size of the U signal and the number of N measurements.

The third chapter of the dissertation has been devoted to the issues of increasing the efficiency of indoor microclimate systems. At the beginning of the chapter, has been considered the issue of optimizing the ventilation of office buildings. Let's calculate the electric equivalent of the cost function:

$$\zeta = \gamma \cdot (max(C_{mtr}, C_{thr}) - C_{thr})^{1,3}, \quad (15)$$

where: ζ -is the electrical equivalent of the contaminant; γ - scaling factor; C_{mtr} - transformed value of the considered type of pollutant; C_{thr} - is the background value of the contaminant that does not lead to the imposition of any penalty.

It is stipulated that the electricity equivalent of the types of air pollution considered in terms of electricity costs for closed areas ventilation has reached an extreme level.

In third chapter, the issue of optimizing the operation of microclimate systems, considering the energy efficiency and comfortable temperature in the room. The basis of the adaptive model of the comfortable temperature is an experimentally determined fact that confirms the strong correlation between comfortable temperature and average room temperature.

There are the following dependencies:

$$T_n = 11{,}9 + 0{,}534\, T_0, \quad (16)$$

Here: T_n - neutral temperature; T_0 - is the indoor temperature.

The inverse relationship between the variable (adaptive) value of *PMV* (PMV_n) and the energy consumption of air conditioning systems raises the problem of optimal selection of a compromise-based operating point of these interrelated indicators.

Numerous experimental studies show that a linear increase in $PMV_{\max}$ as well as T_n leads to an exponential decrease in required energy. Therefore, the parameters PMV_n and *E* can be described in the form of M_1 and M_2 Pareto-dependence criteria, where;

$$M_1 = PMV_n(PMV_{max}); \quad (17)$$

$$M_2 = E(PMV_{max}); \quad (18)$$

where: E - is an indicator of energy consumption.

Considering (17) and (18), the purpose of the optimization has been designed functionally:

$$M_0 = \alpha_1 \cdot PMV_n(PMV_{max}) + \alpha_2 \cdot E(PMV_{max}); \; \alpha_1 + \alpha_2 = 1. \quad (19)$$

In the linear interpolation of function (17) and in the exponential approximation of function (18), has been obtained the condition of M_0 - minimized, depending on PMV_{max}.

$$PMV_{max} = \frac{1}{k_2} \ln\left(\frac{\alpha_2 A_2 k_2}{\alpha_1 k_1}\right). \quad (20)$$

The feature of the above-mentioned function M_0 allows presenting it as a criterion for optimization of the microclimate system based on Fanger's theory.

Then, in the third chapter, has been considered the issue of optimizing of indoor microclimate systems according to the criteria of energy efficiency based on the multiplicative criteria.

Let's describe the proposed multiplicative criterion Π as (21):

$$\Pi = M_1^{\beta_1} \cdot M_2^{\beta_2}, \quad \beta_1 + \beta_2. \tag{21}$$

Taking into account the above approximations, we obtain the following:

$$\Pi = (k_1 \cdot PMV_{max} + A_1)^{\beta_1} \cdot (A_2 e^{-k_2 PMV_{max}} + A_3)^{\beta_2}. \tag{22}$$

To facilitate the analysis, let's accept that

$$\beta_1 = \beta_2; \;\; A_1 = A_3 = 0.$$

It is shown that

$$PMV_{max} = \frac{1}{k_2}$$

when the condition is fulfilled, Π will reach the extreme. It has been determined that when it is

$$PMV_{max} > \frac{2}{k_2}$$

reaches the minimum, otherwise it reaches the maximum.

The fourth chapter of the dissertation has been devoted to the construction of a microclimate supply system, based on the modified Fanger thermal comfort indicator.

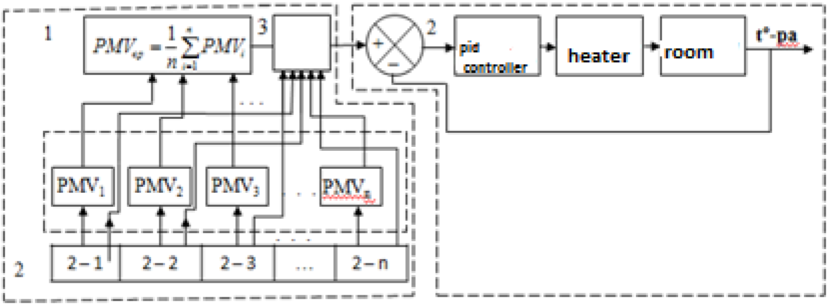
Using the *PID* regulation method has been considered the establishment of an indoor microclimate regulation system.

In the proposed variant, the *PID* regulator provides high accuracy of temperature maintenance.

The N power dissipated by the heater as a percentage of the maximum power has been defined as follows:

$$N = \frac{100}{k_p}\left(\Delta T + \frac{1}{k_i}\int_0^1 \Delta T dt - k_d \frac{dT}{dt}\right). \tag{23}$$

Here: k_p, k_i, k_d – are the *PID* coefficients.



Fiqure 2. Functional scheme of regulator of the temperature on the base of *PID* regulator using suggested averaged integral PMV **parameter:**
1 - the junction of the formation of the average integral indicator of comfort temperature; 2 - *PID* temperature regulator junction.

Figure 2 shows a functional diagram of a *PID* controller-based temperature controller using the proposed average integral index for the calculation of the comfortable temperature.

As can be seen from the functional diagram of the device, at junction 1, PMV_i individual indicators has been formulated for each person remaining in the room, and then the average value of these indicators has been calculated. Based on the calculated PMV_{val} value, has been determined the final temperature for the indoor area.

In the second option, the *PMV* junction has been included to the circuit of the control node. The functional diagram of the device has been indicated in Figure 3:

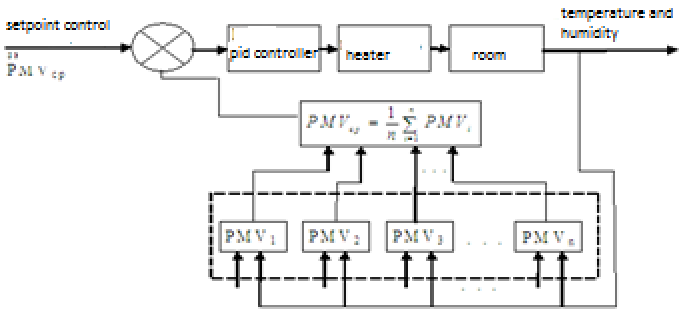


Figure 3. Functional scheme of microclimate control device based on *PID* regulator using *PMV* average integrated value indicator.

As can be seen from the functional diagram of the device, in this case the control circuit has been closed by $PMV_1 \div PMV_n$ nodes, which form the individual values of the *PMV* indicator per each person in the room. In the device, the difference between the current and ideal value of *PMV* has been calculated, the current value in the form of PMV_{med} has been formed considering the characteristics of all people in the room.

The fourth chapter discusses the possibility of using a medium-integrated Fanger model to control the comfortable temperature, considering the adaptive effect of the people in the room.

This section then discusses the establishment of an indoor microclimate control system using separate *PID* controllers. The desired room temperature has been intalled and the *PID* regulator has been used to maintain this temperature in the room. The *PID* regulator provides high accuracy for maintaining the temperature.

Figure 4 shows a functional diagram of a *PID* based temperature controller to calculate a comfortable temperature using a medium-integrated indicator, considering the adaptation effect.

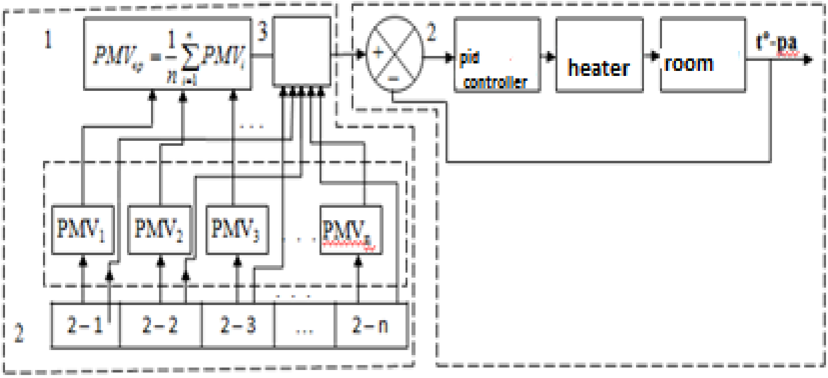


Figure 4. Functional diagram of a PID regulator-based temperature controller to calculate a comfortable temperature using an average integrated indicator, considering the adaptation effect. Marked with numbers:
1 - *PMV* average integration indicator formation node; 2 - departments of the environment (2-1, 2-2, 2-3, …, 2-n); 3 - reporting node of a given temperature.

The fourth chapter then discusses the creation of adaptive efficient energy systems in the microclimate in the environment.

“ASHRAE Standard 55 – 2004” defines a comfortable area where a person has different levels of activity, with a possible change in metabolic rate from 1,0 to 1,3 meters, as well as the thermal insulation of clothing reflects the change in the range 0,5 Clo ÷ 1,0Clo. The comfort zone has been determined by the *PMV* criterion, which value is in the range of ± 0,5.

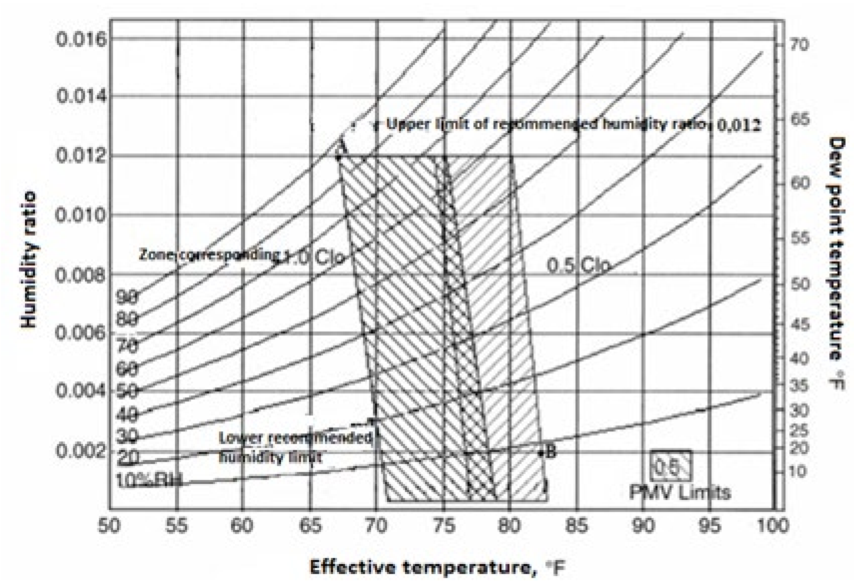


Figure 5. Psychometric diagram according to the "ASHRAE standard 55 – 2004".

The purpose of the study is the adaptive management of the microclimate based on the psychometric diagram given in the standards. Based on the psychometric diagram, the essence of the general principle of adaptive control in a microclimate system in a crowded environment is to implement technical measures for adaptive management of key microclimate indicators according to the criteria of complete implementation of microclimate regimes corresponding to the comfort area shown in this diagram.

We can mention the following adaptive methods of adaptive indoor microclimate:

1. Some operating temperature range of ambient temperature has been provided by heating or cooling. Then, adaptive control of humidity has been carried out in such a way that the (T_g; RH) point to be located within the specified hatched comfort area shown in image 5.

2. A certain relative humidity has been provided by changing the ventilation mode in a closed area full of people. Effective temperature adaptive control should be applied so that the (T_g; RH) point to be located within the specified hatched comfort area.

We can show the following possibilities for saving electricity consumption in terms of minimizing the energy consumption for seasonal regulation of air temperature (heating in winter and cooling in summer). For example, in winter, in terms of electricity consumption in cold weather, it is necessary to choose point A in order to create a comfortable environment with minimal heating of the workplace. In spring, B should choose a workplace that requires zero cooling.

Has been developed a block diagram of the algorithm of the proposed adaptive methods of saving electricity, used to manage the microclimate during the winter months.

MAIN RESULTS

1. The proposed theoretical substantiation of the application of Fanger's theory of thermal comfort to a group of workers with different labour activity and the formed average integral of the thermal sensitivity for such a group, considering the individual indicators of the expected average value of thermal sensitivity of different workers creates great opportunities for the proper organization of working conditions of teams.

2. The dynamic criterion reflecting the quality of the environment in closed areas allows to determine the degree of thermal discomfort more accurately, considering the long-term trend of increasing the concentration of CO_2 on the atmosphere and compare the values of similar indicators, calculated over several years or decades.

3. The parametric double-criterion method developed for providing indoor microclimate, allows high-efficiency control of temperature and humidity regimes.

4. The developed non-dispersive three-wave measurement method of formaldehyde concentration in indoor areas allows to improve the quality of the microclimate in civil and industrial areas by compensating the effects of NO_2 and protects the staff from the harmful effects of formaldehyde.

5. The results of solution of the optimization problem for the implementation of highly informative measurements of CO_2 concentrations in closed production areas, as well as the results of searching the measurement errors in ventilated areas allows to manage the microclimate more efficiently in those areas, and the ventilation regime of the area should be determined correctly.

6. The formula for determining the optimal ventilation modes and the results of the solved problem allow to choose the ventilation modes in an alternative way, where in the first case the area is fully ventilated due to the maximum energy consumption; in the second case, it is partially ventilated in the given concentration ranges of CO_2 and TVOC (organic volatiles) due to minimal energy consumption.

7. Have been indicated the possibilities of developing energy-efficient adaptive control systems based on the main provisions of ANSI / ASHRAE Standard 55-2010 of the microclimate.

The main results of the dissertation were published in the following scientific articles:

1. Алиев С.Г., Гусейнова, М.В. Нечеткий ситуационный логический вывод в сложных технических объектах // Beynəlxalq Elmi - Texniki konfrans. "İnformasiya və kommunikasiya texnologiyalarının müasir vəziyyəti və inkişaf perspektivləri", AzTU, 27-28 oktyabr. Bakı. -2014, - s.433-439.

2. Гусейнова М.В. Вопросы разработки системы обеспечения микроклимата в помещении по средне интегрированной модификации показателя теплового комфорта Фангера // Климат и природа, Москва. -2018. №3 (28). - с.51-58.

3. Гусейнова М.В. Вопросы обеспечения безопасного температурного и влажностного режима в замкнутых и защищенных помещениях // Проблемы безопасности и чрезвычайных ситуаций, Москва. - 2018. №4. - с.102-107.

4. Гусейнова М.В. Двухкритериальный параметрический метод определения оптимальной температуры в замкнутых помещениях // "İnşaat İnformasiya texnologiyaları və Sistemlərin Tətbiqi İmkanları və Perspektivləri" mövzusunda Beynəlxalq Elmi-Praktiki konfransın materialları, Bakı. - 05-06 iyul, 2018. - s.116-119.

5. Гусейнова М.В., Джавадов, Н.Г., Исмаилов, К.Х. Двухкритериальный параметрический метод контроля оптимальной температуры в производственных помещениях // Нефтегазовое дело, Сетевое издание, Москва. - 2018. №5. - с.214-228.

6. Гусейнова М.В. Вопросы разработки измерительной системы для определения концентрации CO_2 в вентилируемых помещениях // Измерение. Мониторинг. Управление. Контроль (ИМУК), Москва. - 2019. №1 (27). - с.12-18.

7. Гусейнова М.В. Вопросы разработки нового динамического индекса качества окружающей среды для жилых

и производственных помещений // Безопасность труда в промышленности. Москва. - 2019. №1. - с.37-41.

8. Гусейнова М.В. Построение подсистемы измерителей концентрации CO_2 в вентилируемых помещениях // Датчики и системы, Москва. - 2019. №1 (232). - с.46-49.

9. Гусейнова М.В. Разработка метода недисперсивного измерения концентрации формальдегида в ультра фиолетовом диапазоне в замкнутых помещениях // Мир Измерений, Москва. - 2019. №1. - с.34-37.

10. Гусейнова М.В. Исследование возможности использования групповой оценки теплового комфорта по теории Фангера применительно ко множеству лиц с разными трудовыми показателями // Экология человека, г. Арханьгелск. - 2019. №4. - с.60-64.

11. Гусейнова М.В. Асадов Х.Г., Ибрагимова А.Э. Вопросы оптимизации функционирования систем микроклимата с учетом их энергоэффективности и комфортной температуры в помещениях // Промышленная Энергетика, Москва. - 2019. №4. - с.49-53.

12. Гусейнова М.В. Асадов, Х.Г., Махмудова, В.Х., Шамохина, С.А. Вопросы создания адаптивных энергоэффективных систем управления микроклиматом в людских помещениях // Сборник статей 11-й Международной научно-практической конференции «Актуальные проблемы экологии и охраны труда». Курск. - 2019. - с.290-297.

13. Гусейнова М.В., Махмудова В.Х., Шамохина, С.А. О возможности использования среднеинтегрированной модели Фангера для контроля температурного комфорта в помещениях // Сборник статей 11-й Международной научно-практической конференции «Актуальные проблемы экологии и охраны труда». Курск. - 2019. - с.317-325.

14. Гусейнова М.В., Гостев, А.А Оптимизация измерения концентрации CO_2 в воздухе жилых и производственных помещений методом оптико-акустической спектрометрии // Сборник статей 11-й Международной научно-практической

конференции «Актуальные проблемы экологии и охраны труда». Курск. - 2019. - с.312-316.

15. Гусейнова М.В., Гостев, А.А Вопросы оптимизации вентилирования производственных помещений // Автоматизация. Современные технологии, Москва. - 2019. .№9, том 73, - с.411-413.

16. Гусейнова М.В. Оптимизация измерения концентрации CO_2 в воздухе жилых и производственных помещений методом оптико-акустической спектрометрии // Автоматизация. Современные технологии, Москва. - 2019. .№10, - с.435-437.

17. Гусейнова М.В., Юсубова А.Х., Ларина Е.А., Барков А.Н. Вопросы оптимизации вентилирования офисных помещений // Сборник статей 13-й Международной научно-практической конференции «Актуальные проблемы экологии и охраны труда». Курск. - 2021. - с.331-336.

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