SYNTHESIS OF PHYSICAL AND MATHEMATICAL MODEL OF ENERGY-EFFICIENT MICROCLIMATE MANAGEMENT OF RURAL AREA GYM, TAKING INTO ACCOUNT INDICATORS OF COMFORT AND AIR QUALITY

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Abstract. This article investigates the synthesis and substantiation of a physical and mathematical model of energy-efficient microclimate control of a fitness room in a rural area, which takes into account indicators of comfort and air quality, for further study, improvement and implementation of multi-parameter automatic control systems for the main microclimate indicators (humidity, temperature, air velocity). The main modern requirements for the gas composition of gym air and methods for assessing its safety, which should be performed when designing these premises for their further normal functioning and operation, are considered. An alternative approach to modeling the comfort of a gym with regard to air quality is proposed. The equations, their analytical solutions and numerical calculations are presented, which determine the dynamics of the absolute humidity of the room air, the relationship between absolute humidity and relative humidity, the dependence of the mass balance of the fitness room air, and the dynamics of the room temperature. The equation of the energy balance of the room is established, which is solved analytically, and its solutions optimize energy-efficient performance. A mathematical model of the microclimate of a room for sports activities in rural areas has been developed, which allows the room to be operated in an energy-efficient/energy-saving mode. This mathematical model allows us to consider the microclimate of such premises as a multidimensional chain with five input, five output parameters and five disturbances. The versatility of the proposed model allows for energy-efficient control of the gas composition of the air, its quality, or in accordance with the maximum permissible concentrations established at the industry and state levels. The model uses multiscale cross-correlation of atmospheric pollutants and temperature under various environmental parameters (including the influence of the human body).

Keywords: energy efficient, microclimate, comfort indicators, quality indicators, microclimate systems.

Introduction

The environmental safety of sports facilities has a direct impact on the health and life safety of people who use them. In these facilities, there is an accumulation of harmful substances in the air, particularly in fitness halls. A large number of sports, recreation and training facilities are located in rural areas, far from cities. And a person can stay in these facilities for a long time without breaks under the influence of air pollutants.

Currently, the following problematic tasks require scientific research to address the current problems of social security of people involved in sports (and, in particular, in rural areas): 1) maintaining a safe environment for training or sports activities in indoor sports facilities; 2) implementation of methods for assessing the safety of the environment for physical education and training in various sports; 3) implementation of the latest, innovative technologies for testing the microclimate of indoor sports facilities in terms of environmental parameters, which also allow for energy-efficient operation.

There are two approaches to assessing the air quality of indoor sports facilities: comparing pollutant concentrations with the maximum permissible concentrations; and using air quality indices.

The first approach usually uses maximum permissible concentrations (MPCs) established at the international, national and sectoral levels to assess the degree of pollution in an indoor sports facility (or, more precisely, the air inside the facility). MPCs can be mandatory and recommended, applied exclusively to the outdoor environment (outdoor sports grounds or arenas) or to the air in indoor sports facilities (sports or training halls, etc.). In particular, the microclimate of indoor sports facilities is subject to temperature, humidity and air velocity restrictions. For ventilation systems, there are no air exchange rates or recirculation restrictions to ensure that the concentration of carbon dioxide in the air (CO_2) does not exceed the maximum permissible level. All people engaged in health and medical, training, sports and competitive activities in indoor facilities are exposed to chemical, physical and allergenic factors in one way or another. Chemical factors act both directly through contact with the substance, with sports equipment, simulators, etc., and through inhalation of harmful gases, volatile compounds, and particulate matter.

In the theory of sports facilities design, there is interest in considering more general problems in which uncertainties would be taken into account. To formulate and solve such problems, a mathematical unit is needed that would be able to take into account a particular uncertainty a priori. In [1; 2] a discrete-time fuzzy model predictive control approach of a greenhouse is investigated. An interval type-2 (IT2) Takagi–Sugeno fuzzy model is employed to represent the nonlinear dynamics of the plant subject to parameter uncertainties, which are effectively captured by interval membership functions. According to [3], prediction and control models guarantee the correct management of environmental variables, for which fuzzy inference systems have been successfully implemented. Papers [3-5] identify the different relationships in fuzzy inference systems currently used for modelling, predicting and controlling humidity in greenhouses and how they have changed over time to be able to develop more reliable and easy to understand models. A wide range of both theoretical and practical applications of fuzzy logic in decision making are outlined in [6-8]. These studies [9-11] present the use of fuzzy logic approach in chemical science, medical science, agriculture, political science, operations research, environmental science and household. There is a problem of research of microclimate control systems based on fuzzy logic for sports facilities, taking into account their peculiarities and providing the required parameters.

Materials and methods

Air safety can be assessed using the Air Quality Index (AQI). Most countries use concentrations of ozone, sulphur dioxide, carbon monoxide, particulate matter of various fractions, and nitrogen dioxide to determine AQI. For each of these pollutants, the corresponding partial index AQI_i is calculated by correlating the short-term average of its concentration, most often eight or twenty hours, with the corresponding MPC. AQI is taken to be equal to the value of the largest of the partial pollutant indices

$$\mathrm{AQI} = \mathrm{MAX}\,(\mathrm{AQI}_i). \tag{1}$$

The US Environmental Protection Agency (US EPA) [12] has established the following AQI scale.

The formula is used to calculate the partial indices for each pollutant:

$$\mathrm{AQI}_i = \frac{I_j - I_{j-1}}{C_{ji} - C_{(j-1)i}} \cdot \left(C_i - C_{(j-1)i}\right) + I_{j-1}, \tag{2}$$

where AQI_i – partial index of the i-th pollutant;
C_i – concentration of the i- th pollutant, mg·m^{-3};
C_{ji} – upper limit of the concentration interval in which C_i falls;
$C_{(j-1)i}$ – lower limit of the concentration interval in which C_i falls;
I_{j-1} – AQI value corresponding to C_{ji};
I_j – AQI value corresponding to $C_{(j-1)i}$.

The dependencies of partial air quality indices [13-14] on pollutant concentrations are essentially continuous piecewise linear functions and can be represented as follows:

$$\mathrm{AQI}_i = a_i \cdot C_i + b_i + \sum_{j=1}^{n} W_{ji}\left[C_i - C_{(j-1)i}\right], \tag{3}$$

where $b_i \equiv I_{j-1}$, i.e.AQI at C_{ji};
$W_{ji} = (k_{ji} - k_{(j-1)i})/2$;
$k_{ji} = (I_j - I_{j-1})/(C_{ji} - C_{(j-1)i})$;
$a_i = (k_{i0} - k_{in})/2$;
k_{ji} – slope angle of segment j of the piecewise linear function of the *i-th* pollutant, m^3·mg^{-1}.

The dynamics of the concentration [15] of pollutants in the air of an indoor sports facility is determined by a dependence:

$$\frac{d_{i_{in}}}{dt} \cdot \mathrm{V} + C_{i_{in}} \cdot q_{in} = C_{i_{ext}} \cdot q_{ext}, \tag{4}$$

where $C_{i_{in}}$ – concentration of the i-th indoor air pollutant, mg·m^{-3};
V – volume of the room, m^3;
q_{in} – volume flow rate of exhaust air, m^3· s^{-1};
q_{ext} – volume flow rate of supply air, m^3· s^{-1};
$C_{i_{ext}}$ – concentration of the i-th pollutant in the supply air, mg·m^{-3};
t – time, s.

The solution to equation (4) is given by (5) and is shown in Fig. 1.

$$C_{i_{in}^{(t)}} = C_{i_{in}}^{(0)} \cdot exp\left\{-\frac{q_{in}}{V} \cdot t\right\} + \frac{C_{i_{ext}} \cdot q_{ext}}{q_{in}}, \tag{5}$$

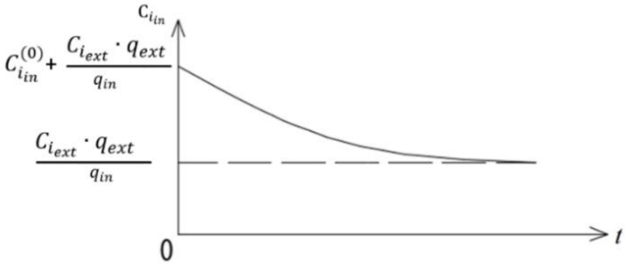

Fig. 1. **Dependency $C_{i_{in}}(t)$**

Results and discussion

In order to ensure proper training and recreation conditions in indoor sports facilities, the air must also meet comfort requirements in addition to safety. The ISO 7730 standard for assessing comfort is based on the analytical dependence of the integrated comfort indicator PMV on air parameters, metabolism and human clothing (sportswear). According to the standard, the algorithm for calculating the PMV indicator at the stage of determining the temperature of the clothing surface requires a numerical solution of the fourth-degree equation (using the Ferrari algorithm). However, another approach is possible - the use of an iterative algorithm. To reduce computational complexity and represent PMV as a differentiated function, various approximation methods can be used. For example, a promising approach to calculating the integral comfort score is to approximate it with a multidimensional polynomial, which can be efficiently calculated using the Horner scheme. To evaluate the accuracy of the approximation, a computational experiment was conducted on a computer using the multivariate polynomial regression method, which was implemented using the Python programming language and the SKIKIT- LEARN software library. The results (Table 1) of the numerical experiment showed a satisfactory accuracy of PMV approximation by multivariate polynomials of the third degree and higher:

$$\mathrm{PMV}\ (T, T_r, v_a, \varphi, \mathrm{MET}, \mathrm{CLO}, W) \approx \mathrm{p}^n\ (T, T_r, v_a, \varphi, \mathrm{MET}, \mathrm{CLO}, W), \tag{6}$$

where T – air temperature, °C;
Tr – average radiation temperature, °C;
va – air velocity, m·s^{-1};
φ – relative humidity;
MET –metabolic rate, met;
CLO – clothing level;
W – effective external work, W·m^{-2};
n – degree of the polynomial ($n > 3$).

The dynamics of the absolute humidity of the air in a sports room can be defined as

$$\frac{d\alpha}{dt} \cdot \mathrm{V} + \propto \cdot\, q_{in} = \propto_{ext} \cdot\, q_{ext} + \dot{m_{in}}, \tag{7}$$

where $\propto$ – absolute humidity of the room air, g·m^{-3};
$\propto_{ext}$ – absolute humidity of the supply air, g·m^{-3};
$\dot{m_{in}}$ – mass flow rate of water vapour from internal sources, g·s^{-1}.

Table 1

Accuracy of PMV approximation with a multivariate polynomial

Degree of the polynomial (*n*)	Standard deviation (σ)	Coefficient of determination (*d*)
2	0.2360	0.9700
3	0.1153	0.9930
4	0.0589	0.9982
5	0.0329	0.9994

The solution to equation (7) is as follows:

$$\propto(t) = \propto_0 \cdot \exp\left\{-\frac{q_{in}}{V} \cdot t\right\} + \frac{\propto_{ext} \cdot q_{ext} + \dot{m_{in}}}{q_{in}}, \tag{8}$$

The dependency $\propto(t)$ is shown in Fig. 2. In relation (8), the notation $\propto(0) = \propto_0$ is introduced.

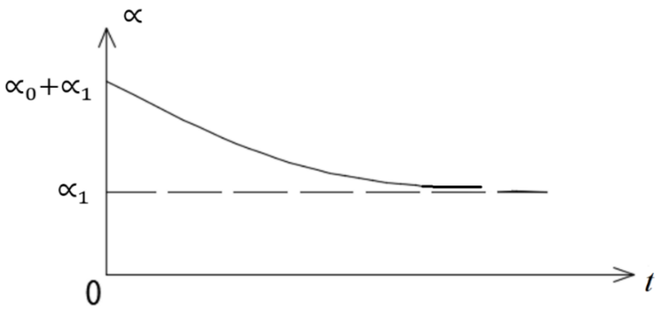

Fig. 2. **Dependence ∝(t):** $\propto_1 = (\propto_{ext} \cdot q_{ext} + \dot{m_{in}})/q_{in}$

The relationship between absolute humidity and relative humidity is obtained using the equation of state of an ideal gas and a variant of the Magnus-Tetens formula for determining saturated vapour pressure, which was proposed by Bolton [17-18]:

$$\varphi = \frac{\propto \cdot (T + 273{,}15)}{2{,}1674 \cdot 6{,}112 \cdot exp\left\{\frac{17{,}67 \cdot T}{T + 243{,}5}\right\}}. \tag{9}$$

The relationship between the mass balance of the room air and the dynamics of its temperature and pressure is as follows:

$$\left(\frac{1}{p} \cdot \frac{dp}{dt} - \frac{1}{T} \cdot \frac{d\tilde{T}}{dt}\right) \cdot \rho \cdot V + 10^{-3} \cdot \frac{R_{da} - R_{wp}}{R} \cdot (\propto_{ext} \cdot q_{ext} + \dot{m_{in}} - \propto \cdot q_{in}) + \\ + 10^{-3} \cdot \sum_{i=1}^{N} \frac{R_{da} - R_i}{R} \cdot \left(C_{i_{ext}} \cdot q_{ext} - C_i \cdot q_{in}\right) = \rho_{ext} \cdot q_{ext} - \rho \cdot q_{in} + 10^{-3} \cdot \dot{m_{in}}, \tag{10}$$

where p – room air pressure, Pa;
$\tilde{T}$ – room air temperature, K;
ρ – room air density, kg·m^{-3};
R_{da}, R_{wp}, R_i – individual gas constants of dry air, water vapour and the *i*-th pollutant, respectively, J·(kg·K)$^{-1}$;
ρ_{ext} – supply air density, kg·m^{-3}.

The formula for the energy balance of a room is as follows:

$$\rho \cdot c_V \cdot V \cdot \frac{d\tilde{T}}{dt} = u_{ext} \cdot \rho_{ext} \cdot q_{ext} - u \cdot \rho \cdot q_{in} + Q_{in} + Q_0, \tag{11}$$

where c_V – specific heat capacity of the fitness room air, J·(kg·K) $^{-1}$;
u, u_{ext} – specific internal energy of the internal and supply air, J·kg^{-1}, respectively;
Q_0 – heat flux from the envelopes (ceiling, floor, walls), J·s^{-1};
Q_{in} – heat flux from internal sources, J·s^{-1}.

The solution to (11) is as follows:

$$\tilde{T}(t) = \left\{\frac{u_{ext} \cdot \rho_{ext} \cdot q_{ext} - u \cdot \rho \cdot q_{in} + Q_{in} + Q_0}{\rho \cdot C_v \cdot V}\right\} \cdot t_t \cdot \tilde{T}_0. \quad (12)$$

$\tilde{T}$ is a linear function of time (t). In (12), the notation $\tilde{T}_0 = \tilde{T}(0)$ is introduced. The dependence $\tilde{T}(t)$ is shown in Fig. 3.

The above dependencies (1) - (12) constitute a mathematical model of the microclimate of an indoor sports facility, which allows us to consider it as a multidimensional multiconnected chain (Fig. 4) with five input parameters (T_{ext}, φ_{ext}, C_{ext}, q_{ext}, q_{in}), five output parameters (T, φ, C, PMV, AQI) and five disturbances (Q_0, MET, W, m_{in}, CLO).

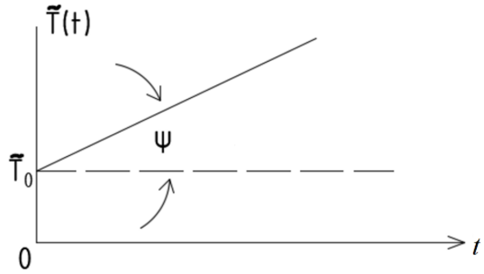

Fig. 3. **Dependency $\tilde{T}(t)$: $\tilde{T}(t) = \tilde{k} \cdot t + \tilde{T}_0$,**
$\boldsymbol{\tilde{k} = tg\Psi = (u_{ext} \cdot \rho_{ext} \cdot q_{ext} - u \cdot \rho \cdot q_{in} + Q_{in} + Q_0)/\rho \cdot C_v \cdot V}$

In operator form, a multidimensional multicoupled circuit of this type can be represented as a matrix product

$$Y(p) = \overline{W}(p) \cdot X(p), \quad (13)$$

$$\overline{W}(p) = \begin{bmatrix} \overline{W}_{11}(p) & \overline{W}_{12}(p) \cdots & \overline{W}_{1n}(p) \\ \overline{W}_{21}(p) & \overline{W}_{22}(p) \cdots & \overline{W}_{2n}(p) \\ \overline{W}_{m1}(p) & \overline{W}_{m2}(p) \ldots & \overline{W}_{mn}(p) \end{bmatrix}, \quad (14)$$

where $Y(p)$ – vector of output parameters;
$X(p)$ – vector of input parameters;
$\overline{W}(p)$ – matrix of transfer functions.

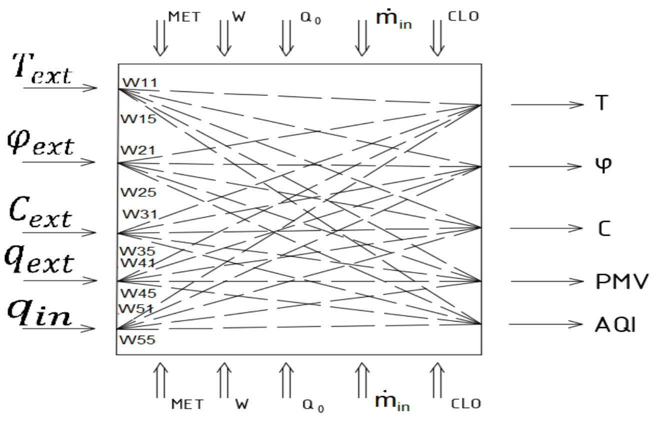

Fig. 4. **Block diagram of a room (fitness room) as a multidimensional interconnected chain:**
T_{ext}, φ_{ext}, – respectively, temperature, relative humidity

It should be noted that for an efficient and energy-saving mode of operation of the premises, it is necessary to use an extensive system of sensors (humidity, pressure, temperature, CO_2 and air velocity) in an indoor sports facility, which provide monitoring and regulation of parameters that determine the optimal values of the latter and maintain comfortable conditions for training sessions, air quality and the necessary microclimate in the fitness room.

In the mathematical model of the geometric control theory, the equation for the total pressure takes into account the presence of a gas-air mixture (mainly N_2 and O_2) and water vapour in the air:

$$P_{gen} = \left\{\frac{m_{air}}{\mu_{air}} + \frac{m_{H2O}}{\mu_{H2O}}\right\} \cdot \frac{RT}{V} + \frac{v^2}{2} \cdot \{\rho_{air} + \rho_{H2O}\}, \tag{15}$$

where R – universal gaseous constant, 8.314 J·(mol·K)$^{-1}$;
V – volume of the room, m^3;
ρ_{air}, φ_{H2O} – densities of air and water vapour, respectively, kg·m^{-3};
m_{air}, m_{H2O} – masses of air and water vapour, respectively, kg;
P_{gen} – total pressure of air masses in the room, Pa;
μ_{air}, μ_{H2O} – masses of 1 kg-mole of air and water vapour, respectively, kg·mol^{-1}.

For comfortable conditions in which people should be in a given room, the notation (c) is introduced above the specific variable in equation (15), in addition to the universal constants. It follows from formula (15):

$$P_{gen}{}^{(c)} = \left\{\frac{m_{air}{}^{(c)}}{\mu_{air}} + \frac{m_{H2O}{}^{(c)}}{\mu_{H2O}}\right\} \cdot \frac{RT^{(c)}}{V} + \frac{\left[v^{(c)}\right]^2}{2} \cdot \{\rho_{air} + \rho_{H2O}\}. \tag{16}$$

Since P_{gen} should always correspond to comfortable conditions of staying in the room, then for changes in the physical parameters of the microclimate (m_{H2O}, T, v), which we will conventionally denote as:

$$\Delta m_{H2O} = m_{H2O} - m_{H2O}{}^{(c)};\ \Delta T = T - T^{(c)};\ \Delta v = v - v^{(c)}. \tag{17}$$

From (17) we have:

$$\left\{\frac{m_{air}{}^{(c)}}{\mu_{air}} + \frac{m_{H2O}{}^{(c)}}{\mu_{H2O}}\right\} \cdot \frac{R}{V} \cdot \Delta T + \frac{RT^{(c)}}{\mu_{H2O} \cdot V} \cdot \Delta m_{H2O} + (\rho_{air} + \rho_{H2O}) \cdot v^{(c)} \cdot \Delta v = 0. \tag{18}$$

Let us introduce the notation:

$$a_1 = \left\{\frac{m_{air}{}^{(c)}}{\mu_{air}} + \frac{m_{H2O}{}^{(c)}}{\mu_{H2O}}\right\} \cdot \frac{R}{V};\ a_2 = \frac{RT^{(c)}}{\mu_{H2O} \cdot V};\ a_3 = (\rho_{air} + \rho_{H2O}) \cdot v^{(c)}. \tag{19}$$

Then (19) can be written as:

$$a_1 \cdot \Delta T + a_2 \cdot \Delta m_{H2O} + a_3 \cdot \Delta v = 0 \tag{20}$$

Let us consider three possible situations of regulation (correlation) of deviations of two variables out of three, if one physical parameter remains unchanged. This creates the possibility of regulating the quantities themselves according to the laws of linear control.

$$\Delta T = 0: \Delta m_{H2O} = -\frac{a_3 \cdot \Delta v}{a_2} \tag{21}$$

$$\Delta m_{H2O} = 0: \cdot \Delta T = -\frac{a_3 \cdot \Delta v}{a_1} \tag{22}$$

$$\Delta v = 0: \cdot \Delta T = -\frac{a_2 \cdot \Delta m_{H2O}}{a_1} \tag{23}$$

At the same time, fuzzy logic controllers are not necessarily involved, because the control takes place according to the laws of linear control theory. Conventional controllers operating according to the laws of clear or defined logic are sufficient.

In the case when all three changes in the physical parameters of the room microclimate are varied simultaneously, it is necessary to use fuzzy modelling at all three stages: 1) phasing stage; 2) analysis or optimisation stage; 3) defuzzification stage. We consider the system of controlling deviations of physical parameters of the microclimate as a system described by the following state equation:

$$(x,\nu): f(x, \nu) \rightarrow y, \tag{24}$$

where x, ν – vectors formed, respectively, from unchanged and changed initial parameters;
y – vector of results;
f – real-valued function determined by elements x, ν on the sets X, $\tilde{V}$, taking the values of elements on the set Y. In this case $x \in X \subseteq F^n$; $\nu \in \tilde{V} \subseteq F^m$.

The vector ν contains the elements: $\nu_i = \xi_i$; $I = \overline{(1, \overline{t})}$, which are of uncertain nature, in particular fuzzy, i.e.:

$$\nu = (\nu 1, \nu 2, \ldots \nu r, \xi 1, \xi 2, \ldots \xi \overline{t}); \; r + \overline{t} = m. \tag{25}$$

The function of belonging of the element ξ_i to the fuzzy set Ω, which is defined on the universal set U, that is, $\nu \in \Omega \subseteq U \subseteq F$.

Phasing stage. Without violating the generality of the approach, consider the case when $\overline{t} = 1$, and the membership function is triangular (Fig. 5) for the fuzzy set $A(\nu_i) \subseteq U$:

$$\mu_A(\nu) = \begin{cases} \dfrac{\nu - a}{m - a}, a \le \nu < m; \\ 1, \nu = m; \\ \dfrac{b - \nu}{b - m}, m < \nu \le b; \\ 0, \nu \notin [a; b]. \end{cases} \tag{26}$$

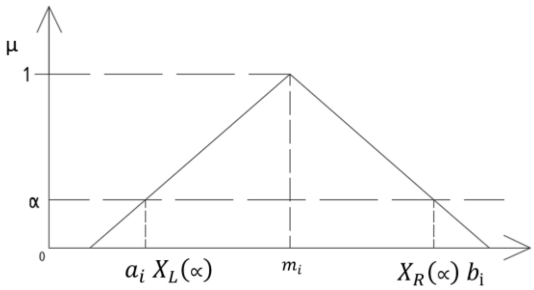

Fig. 5. **Graphical interpretation of the ∝ - level cross section for a triangular membership function**

In this case, the carrier of the set A is written as A (a, m, b)$_\Delta$, i.e., the function μ in the interval [a, b] has a positive value. Using the ∝ - level cross section of the function $\mu_A(\nu)$, we can obtain the bounds $X_L(\propto)$ and $X_R(\propto)$ of the fuzzy set A by solving the equation $\mu(\nu) = \propto$, namely:

$$X_L(\propto) = m \cdot \propto + (1-\propto) \cdot a; \; X_R(\propto) = m \cdot \propto + (1-\propto) \cdot b; \; \propto \in [0;1]. \tag{27}$$

Given that $X_L(\propto)$ is the lower bound of A for each ∝-level, and $X_R(\propto)$ is the upper bound, we have the following fuzzy set operation:

$$A = \sum_{i=0}^{N-1} \left(\frac{\mu_i}{\nu_{1i}}\right) + \frac{1}{\nu_{1N}} + \sum_{i=N+1}^{2N} \left(\frac{\mu_i}{\nu_{1i}}\right), \tag{28}$$

where N – number of ∝ levels and $\Delta\propto = 1/N$;
$\mu_i = i \cdot \Delta\propto$, $\nu_{1i} = X_L(\propto_i)$ for $i = \overline{(1, N-1)}$;
$\nu_{1i} = X_R(\propto_i)$ for $i = \overline{(N+1, 2N)}$.

The points of level ∝ = 0 for the Gaussian membership function (Fig. 6) are not considered:

$$\mu_A(\mathrm{x}) = \begin{cases} +\infty, \mathrm{x} \to \infty; \\ \exp\left\{-\dfrac{(x-m)^2}{2\sigma^2}\right\}, a \le x \le b; \\ -\infty, \mathrm{x} \to -\infty. \end{cases} \quad (29)$$

In this case, the solution should start from the level $\propto = \Delta\propto = 1/N$, for which we have:

$$X_L(\propto) = m - \Delta;\ X_R(\propto) = m + \Delta, \quad (30)$$

where $\Delta = \sigma \cdot \sqrt{-2 \cdot ln \propto}$; $0 < \propto \le 1$.

It is the Gaussian membership functions (Fig. 6) that are used in the mathematical support of intelligent microclimate control systems programs.

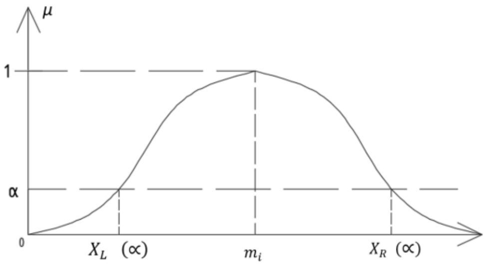

Fig. 6. **Graphical interpretation of the ∝ - level cross-section for the Gaussian membership function**

Analysis or optimisation stage. In this case, the triangular and Gaussian types of membership functions are used to model verbal definitions of quantifiers such as 'approximately' and others for physical parameters of the indoor climate and deviations of these parameters, respectively. From the obtained convex set A (28), for each value of ν_{1i}, i = $(\overline{1, 2N})$, the value $y_i = f(x, \nu, \nu_{1i})$ is calculated, from which the fuzzy set Y of results $\{y_1\}$, i = $(\overline{1, 2N})$, with the membership function $\mu_A(\nu)$ formed.

$$Y = \sum_{i=0}^{N-1}\left(\frac{\mu_{Yi}}{y_i}\right) + \frac{1}{y(x = m)} + \sum_{i=N+1}^{2N}\left(\frac{\mu_{Yi}}{y_i}\right). \quad (31)$$

The stage of defuzzification. The essence of the defuzzification stage is to transform the fuzzy value Y into a clear number Ydef using, for example, the rule of the mean centre:

$$Y^{\mathrm{def}} = \frac{\sum_{i=0}^{2N} \mu_i \cdot y_i}{\sum_{i=0}^{2N}}, \quad (32)$$

or by B. Liu's rule in the practice of uncertain programming, which is as follows:

$$Y^{\mathrm{def}} = \sum_{i=0}^{2N} w_i, \quad (33)$$

Where the weighting coefficients are defined as:

$$\begin{gathered} w_i = w_i\,(\mu_1, \mu_2, \ldots \mu_m);\ m = 2N - 1;\ \mu_0 = \mu_{2N} = 0; \\ w_1 = \frac{1}{2}(\mu_1 + A_0 - B_0), \\ w_i = \frac{1}{2}(C_0 - D_0 + Q_0 - S_0), \text{для } 2 \le i \le m - 1; \\ w_m = \frac{1}{2}(A_0 - P_0 + \mu_m). \end{gathered} \quad (34)$$

In this case A_0 = max $\{\mu_j\}$, $1 \le j \le m$; B_0 = max $\{\mu_j\}$, $1 \le j \le m$; C_0 = max $\{\mu_j\}$, $1 \le j \le i$; D_0 = max $\{\mu_j\}$, $1 \le j \le i$; S_0 = max $\{\mu_j\}$, $1 \le j \le m$; Q_0 = max $\{\mu_j\}$, $1 \le j \le m$; P_0 = max $\{\mu_j\}$, $1 \le j \le m$.

It follows that the implementation of intelligent microclimate control systems for control and regulation makes it possible to reduce the frequency of changes in the number of switching on and off of air conditioners, which leads to significant energy savings (about 12.5%) and increases the reliability and durability of their operation.

Conclusions

The article substantiates a mathematical model of the indoor microclimate (fitness room) of an indoor sports facility as a multi-connected system that allows synthesising multi-parameter automatic control systems for comfort and air quality and studying their effectiveness. The versatility of the model makes it possible to control the gas composition of the air in terms of its quality or in accordance with MPC established by sanitary standards for indoor sports facilities at the sectoral and state levels, using mechatronic systems for monitoring, controlling and regulating the relevant key parameters of the microclimate of such premises, as well as to ensure comfortable conditions for people engaged in sports, training and health improving physical culture. An example of varying simultaneously three changes in the physical parameters of the room microclimate is presented, in which it is necessary to use fuzzy modelling at all three stages: 1) the stage of phasing; 2) the stage of analysis or optimisation; 3) the stage of defuzzification. A mathematical model of the geometric control theory for a gymnasium has been developed. The implementation of intelligent microclimate control systems for control and adjustment gives the possibility of reduction in the frequency of changes the quantity of air conditioners on and off, which leads to significant electricity saving (about 12.5%) and increases the reliability and durability of their operation.

Author contributions

Conceptualization, Y.C.; methodology, A.M. and O.K.; software, Y.C.; validation, O.K. and O.S.; formal analysis, Y.C., A.M. and O.K..; investigation, Y.C., A.M., O.S. and O.K.; data curation, O.S., and O.K.; writing – original draft preparation, Y.C.; writing – review and editing, A.M. and O.K.; visualization, O.S. and O.K.; project administration, A.M.; funding acquisition, O.K. All authors have read and agreed to the published version of the manuscript.

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