Ensuring Comfort Microclimate for Sportsmen in Sport Halls: Comfort Temperature Case Study

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Abstract. The opinion about the difficulties of maintaining appropriate climatic conditions at sports facilities is quite popular among athletes of various disciplines. This problem can lead to health and economic problems. First of all, users of the facilities are not provided with proper conditions for sports, which can lead to bruises. Secondly, the cost of using the object increases. With the increasing number of sports facilities, maintaining internal thermal comfort in them, while ensuring low operating costs, is becoming increasingly important. The article presents the work on modeling the microclimate in a multifunctional sports hall with the most maximum mode of its use and a detailed analysis of the maintenance of thermal comfort in the hall and cognitive-utilitarian conclusions.

Keywords: Comfort microclimate · Optimization · Sport halls · Comfort temperature

1 Introduction

The air environment in buildings, regulated by many parameters of exposure to exogenous and endogenous factors, determines the working and living conditions, health, and comfort of a person. Providing a "healthy" and comfortable air environment is very expensive, because expensive, technically complex, and multi-functional engineering systems are used [1]. In order to remove only 1 kW of excess heat in buildings or premises (to maintain air temperature), could cost in the region of 300–600 USD [2].

For the above mentioned reasons, today indoor environment quality and comfort have become a topic of relevance, and for this reason heating, ventilation, and air conditioning (HVAC) systems have become popular in many buildings. Reducing the power consumption of these systems, while maintaining a suitable comfort level, is of great interest, and has not yet been completely resolved. Traditionally, HVAC systems have not completely ensured the comfort, as they just attempted to maintain the conditions

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within certain limits. Therefore, comfort optimization depends entirely on the way the system is tailored to the needs of the user.

However, according to some research [3–5], HVAC systems can be regarded as multiple-input multiple-output problems, as they work with interrelated variables to extract sets of output values. Moreover, they are affected by a wide variety of uncertainty parameters as user preferences, occupants' activities, and outdoor environmental parameters that can change their usual operations. Consequently, HVAC control problems can be seen as multi-criteria tasks that are characterized with the help of complex analytical expressions.

Despite conventional PID controllers providing rational solutions, they are not able to completely control the indeterminacy of the dynamics of HVACs that can be readily described by linguistic variables and rules [6]. Fuzzy logic controllers (FLC) act as viable alternatives to traditional controllers, as they do not require mathematical modeling [4], and they are ready to handle different criteria, as they represent the dynamics of the HVAC system in accordance with knowledge. FLCs appear to be a viable solution for conventional controllers, as they are able to handle different criteria that represent the dynamics of the HVAC system. Moreover, they do not require math modeling, and FLC's higher efficiency, and lower power consumption, than PIDs were demonstrated in [7].

Analysis of the structure of energy consumption of residential, public and administrative buildings [8–10] shows that most of the energy consumed by thermal energy is accounted for by thermal energy (Fig. 1). For this reason, and also taking into account the high cost of this resource, energy-saving measures aimed at reducing the consumption of heat energy are most often implemented in buildings.

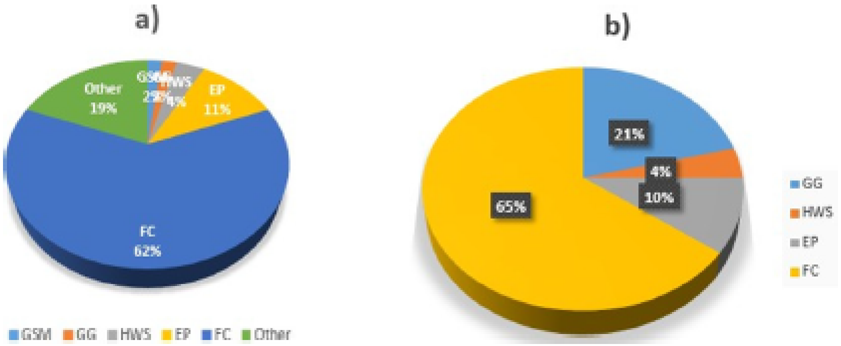


Fig. 1. The distribution of heat energy by types of heat losses through the elements of the building structure is shown in Fig. 1.3 [11].

According to research [33], buildings built in Russia before 1990 according to standard projects have significant potential in the field of energy conservation, because in the Soviet period, the policy of "cheap energy carriers" was carried out and scientific and technical documentation on thermal protection of buildings in construction was insufficiently developed (Fig. 2).

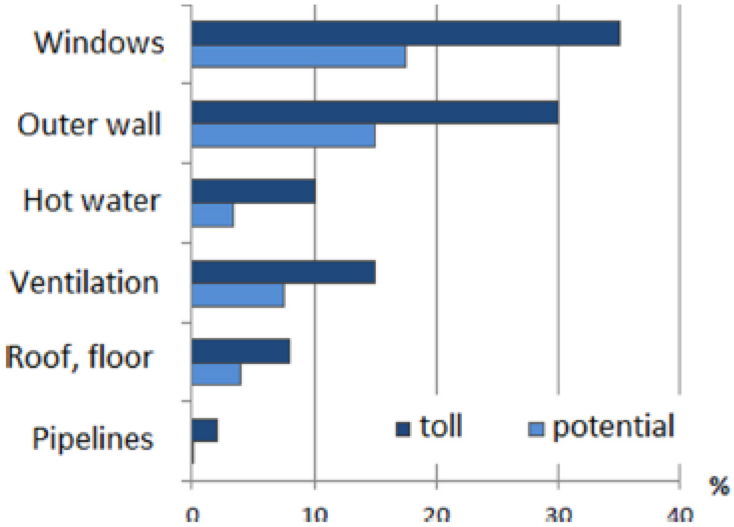


Fig. 2. Heat energy distribution in buildings and energy saving potential.

The potential for improving energy efficiency in systems that form the microclimate of buildings (heating, ventilation and air conditioning), determines the variety of energy-saving measures in this area.

In work [109] three approaches to energy saving in systems of power supply of buildings are allocated:

- increase of accuracy of regulation of the consumed heat energy (units of automatic control of heat load, thermostats, regulation of the flow rate and temperature of the supply air);
- use of heat energy from low-potential sources (heat utilizers, heat pumps);
- improvement of thermal characteristics of enclosing structures and elements of power supply systems (increase of thermal resistance of thermal transfer of enclosing structures, application of heat-reflecting screens, increase of sealing of buildings).

Since a significant potential for energy saving is in the modernization of building envelope structures (Fig. 3), the most appropriate is the introduction of energy-saving measures that increase the heat-protective characteristics of walls, Windows and floors of the building. Insulation and hermetization of buildings due to the imposition of thermal insulation or replacement of individual elements of enclosing structures naturally leads to a reduction in heat losses and, as a result, a decrease in the required amount of heat for heating. However, studies show [11–13], in buildings with natural ventilation worsen hygienic conditions of stay of people due to changes of microclimate and air exchange conditions of: decreasing the flow of fresh air, increased relative humidity, increased the likelihood of mould growth on the inner surface of the enclosing structures, which also adversely affects the quality of indoor air [14]. The problem of air quality deterioration in the use of window units with high tightness in European countries is solved by additional measures that contribute to an increase in air flow (installation of air valves, mechanical ventilation systems) [15].

2 A Case Study of Thermal Comfort in the Indoor Sport Hal

2.1 The Rules Governing the Parameters of the Microclimate in the Premises (the European Union)

EN 13779 standard defines indoor climate quality categories (I – high level; II – normal level; III – satisfactory level; IV-other). When determining the parameters of the microclimate, Stan-dart refers to EN 15251 “Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Air Quality, Thermal Environment, Lighting and Acoustics” (“Initial parameters of the microclimate for the design and evaluation of energy efficiency of buildings in relation to air quality, thermal comfort, lighting and acoustics”) [16].

This standard considers the perception of human microclimate parameters in terms of the thermal balance of his body. This approach is used to calculate the Predicted Mean Vote (PMV) - the predicted average estimate of the level of thermal comfort [17]:

$$\begin{aligned}\mathrm{PMV} = &\left(0.303\mathrm{e}^{-0.036}\mathrm{q}_{\mathrm{MT}}+0.028\right)\left(\left(\mathrm{q}_{\mathrm{MT}} = \mathrm{q}_{\mathrm{p}}\right) - 3.05 * 10^{-3}(5733 - 6.99) - \mathrm{p}_{\mathrm{B}}\right)\\ &- 0.42\left(\left(\mathrm{q}_{\mathrm{MT}} - \mathrm{q}_{\mathrm{p}}\right) - 58.15\right) - 1.7 * 10^{-5}\mathrm{q}_{\mathrm{MT}}\left(5867 - \mathrm{p}_{\mathrm{B}}\right) - 0.0014\mathrm{q}_{\mathrm{MT}}(34 - \mathrm{T}_{\mathrm{B}})\\ &- 3.96 * 10^{-8}\mathit{fo}\left((T_0 + 273)^4 - (Tw, p + 273)^4 - \mathit{fo}\alpha(\mathrm{T}_0 - \mathrm{T}_{\mathrm{B}})\right)\end{aligned} \tag{1}$$

$$\begin{aligned}&\mathrm{T}_0 = 35.7\ -\ 0.028\left(\mathrm{q}_{\mathrm{MT}} - \mathrm{q}_{\mathrm{p}}\right)\ -\ 0.155\mathrm{R}_0\\ &\left(3.96 * 10^{-8}\mathit{fo}\left((T_0 + 273)^4 - (Tw, p + 273)4 - \mathit{fo}\alpha(\mathrm{T}_0 - \mathrm{T}_{\mathrm{B}})\right)\right);\end{aligned} \tag{2}$$

$$\begin{aligned}\alpha &= 2.38(\mathrm{T}_0 - \mathrm{T}_{\mathrm{B}})^{0.25}\mathrm{by}\ 2.38(\mathrm{T}_0 - \mathrm{T}_{\mathrm{B}})^{0.25} > 12.1\mathrm{w}_{\mathrm{e}}^{0.5.\,\mathit{and}}\\ \alpha &= 2.1\mathrm{w}_{\mathrm{e}}^{0.5}\mathrm{by}\ 2.38(\mathrm{T0} - \mathrm{T}_{\mathrm{B}})^{0.25} < 12.1\mathrm{w}_{\mathrm{e}}^{0.5}\end{aligned}$$

$$\begin{aligned}&\mathit{fo} = 1 + 0.29\mathrm{R}_0\mathrm{by}\mathrm{R}_0 \leq \left(0.078\mathrm{m}^2 * {}^\circ\mathrm{C}/\mathrm{W}\right)\ \text{and}\\ &\mathit{fo} = 1.05 + 0.1\mathrm{R}_0\mathrm{by}\mathrm{R}_0 > \left(0.078\mathrm{m}^2 * {}^\circ\mathrm{C}/\mathrm{W}\right);\end{aligned} \tag{3}$$

Where *qMT* – human metabolism, W/m2;

qp – energy costs for performing work to employees, W/m2;
pв – partial pressure of water vapor, Pa;
Tв – air temperature, °C;
fo – coefficient of covering a part of the body with clothes in relation to naked skin;
Tw,p – the average radiation temperature, °C;
α – convective heat transfer coefficient, W/(m2$\cdot^{0}$C); *Ro* – thermal insulation coefficient of clothing; *wo,*в – relative air mobility in the room, m/s:

$$W_{O,\mathrm{B}} = W_{\mathrm{B}} + 0.005(q_{MT} - 58) \tag{4}$$

here wв – the average mobility of the air in the room, m/s.

On the basis of PV, the Predicted Percentage of Dissatisfied (PPD) is calculated – the predicted percentage of people dissatisfied with the quality of the microclimate:

$$\mathrm{PPD} = 100 - 95\mathrm{e}^{-(0.03353\mathrm{PMV}^4 + 0.2179\mathrm{PMV}^2)} \tag{5}$$

Since the feeling of heat in people comes with a different combination of parameters of the microclimate, the value of this indicator will always be different from zero.

Depending on the values of PMV and PPD, rooms are divided into 4 categories according to the quality of the microclimate (Table 1).

Table 1. Categories of premises depending on the quality of the microclimate

Category	PPD, %	PMV, %	Climate comfort level
I	< 6	$-0.2 < \mathrm{PMV} < 0.2$	High: recommended for areas where there are very sensitive people with special requirements: the elderly, the disabled, sick people, small children
II	< 10	$-0.5 < \mathrm{PMV} < 0.5$	Normal: should be used fornewly constructed and reconstructed buildings
III	< 15	$-0.7 < \mathrm{PMV} < 0.7$	Satisfactory: can be used for existing buildings
IV	> 15	$\mathrm{PMV} < -0.7$ or $0.7 < \mathrm{PMV}$	Other: the category can only be used for a limited time of year

In addition to recommendations for PMV and PPD values, EN 15251 contains recommended values for temperature, humidity, energy consumption, thermal insulation of clothing, fresh air intake, which consists of the consumption of air per person (depending on the quality category of the microclimate and PPD) and the consumption per 1 m2 of floor (depending on the allocation of hazards in the environment), etc.

To avoid air quality reduction during the implementation of energy-saving measures, it is necessary to determine the actual air exchange of the premises of the object and to forecast changes in air exchange after the implementation of energy-saving measures. Air quality is an important indicator when analyzing the level of comfort of the environment in the room.

2.2 The Principle of Air-Tightness

Leaking air leads to heat leakage, which in turn leads to excessive energy consumption. [18] Uncontrolled movement of air and its loss through the enclosing structures (walls) of buildings and structures can not be called ventilation.

To provide buildings and structures with low energy consumption, such walls and enclosing elements are necessary that would have an airtight property, so that the ventilation of the building and structure was controlled [19].

Only with the provision of all the above mentioned thermal insulation of buildings and structures can be effective. The Congress on environmental protection has developed requirements for air tightness of buildings and structures. These recommendations are an indication only for new construction [20].

Energy consumption of new buildings and structures that meet these guidelines should be reduced by 2/3, which corresponds to the following indicators: 50 kWh/m2/year (this value may vary depending on the area and the size of the living area) [21].

According to these requirements, it is necessary to conduct a mandatory test to ensure the airtightness of the premises before putting objects into operation [22].

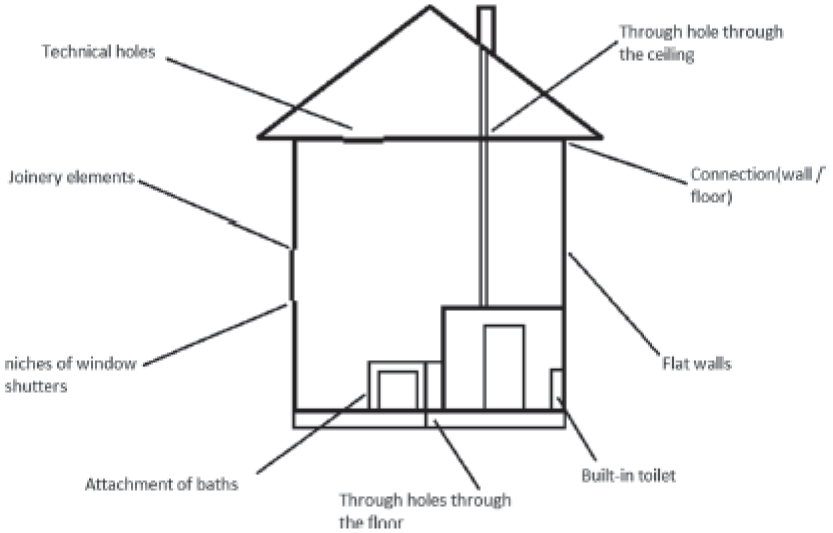


Fig. 3. Sources of the leaks.

Sources of air leaks:

1. Flat walls. Facing facades provides air tightness of vertical walls, but non-plastered areas (garage walls, roof, joints, etc.) allow air to pass through.
2. Connection (wall/floor). When installing floor slabs, voids may form along its perimeter. It is necessary to seal this circuit to prevent the movement of air flow through the joints.
3. Niches of window shutters. Leaks may form in the places where mobile shutters are installed.
4. Joinery elements. Joiner's elements should be sealed in places of fastenings from outside and from inside by means of mastic.

5. Through holes through the floor/ceiling. These holes must be carefully treated.
6. Electricity. Air leaks in places of laying of electric wires and switches are insignificant, but places of laying of electric networks through walls and protecting designs can serve as a source of air filtration.
7. Fixing baths. Failure to isolate the mounting holes may result in significant air loss.
8. Built-in toilets.
9. Technical holes.

3 Math Model

To obtain information about the state parameters of the HVAC system, a variety of sensors are used, including temperature sensors, humidity sensors, air flow pressure sensors, subject occupancy sensors, air quality sensors humidity, air quality sensors. All received data will be saved in the database (DB). This database will allow you to create specific solutions for climate management. In addition, each solution is unique in the data warehouse and has a unique set of identifiers.

The temperature at any time is determined by the formula

$$T = T_0 + \frac{Q}{c \cdot m} dt, \tag{6}$$

Where T 0 – temperature at the previous time, (°C);

Q – thermal balance of the object, W;
c – the heat capacity of the object, W/(kg*°C);
m – the mass of an object, kg;
dt – the account interval, c.

4 Experiment Results

In this study, the mixing ventilation system was modeled. It is organized with the help of air distributors that supply air to the room with air jets that have high speed and turbulence, causing intense air circulation. As a result, the fresh air of the supply jet is mixed with the air of the room. If complete mixing occurs, the air parameters (temperature, relative humidity, speed of movement), as well as the content of pollutants will be the same at any point of the serviced room at a certain distance from the inflow site.

The initial data and theoretical calculations of the expected parameters of the microclimate adopted during the study are shown in Table 1.

In the present article, the study simulated the following situation: airflow is determined by the rate of supply of sanitary standards (80 m^3/h per person), the supply air is supplied with ambient air temperature at parameter A.

Ideally, the results of the theoretical calculations given in the table above and the results of the numerical simulation should converge, i.e. the moisture content of the air, the air temperature and the carbon dioxide content in the exhaust should be equal.

Table 2. The source data and the theoretical calculations of the expected parameters

Source data	
Hall type	Universal (Group strength training)
Type of load	Moderate severity (II a)
Number of persons	25
Air consumption, m3/h	2000
Air temperature at the tributary, 0 C	22
Moisture content of the air at the inflow g/kg	10
CO$_2$ content at the inflow kg/kg	0.00061
Room temperature, 0 C	25
Air density, kg/m3	1.19
Heat gain	
From 1 person explicit/full, W	73/194
From the people in the room a clear/complete, W	1825/4850
From equipment, W	0
From lighting, W	1680
From solar radiation, W	2210
Total explicit/full, W	5788/8934
Moisture access	
From 1 person, kg/h	0.185
From people, kg/h	4.625
From other sources, kg/h	0
Moisture loss, kg/h	0
Total, kg/h	4.625
CO2 gain	
From 1 person, kg/h	0.07
From people, kg/h	1.75
From other sources, kg/h	0
Total, kg/h	1.75
Calculation of the expected parameters	
Temperature, 0 C	30.7
CO2 on the hood, kg/kg; ppm	0.0013/876.41
Moisture content on the hood, g/kg	11.88
Process beam, kJ/kg	6954

a) Plan of the testing sport hall b) Sport hall

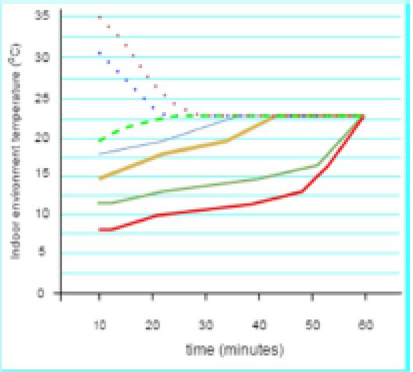
Fig. 4. Testing facility

Description of the Facility. We provided experiments in the Sport Hall of A. Yasawi International Kazakh-Turkish University during the sportsmen did different type of sport games. The experiments were carried out on the previously described test facility (Fig. 4).

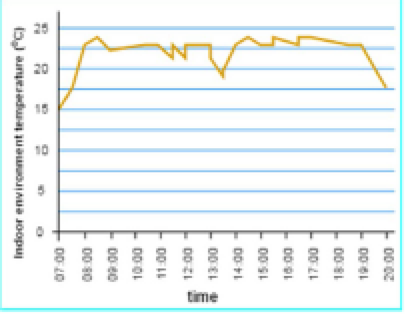
Figure 5a shows the result of the experiment with the proposed fuzzy-PID controller. To bring the monitored zone to a given point from different values of the initial temperature, it takes between 30–60 min. It becomes shorter if the initial temperature is higher, close to target temperature, and the air conditioning zone is well sealed (windows are not open). If the initial temperature is lower and the door and windows are often opened, the controller takes longer to reach the set temperature. Eventually, the controller did not take more than sixty minutes to achieve a room temperature of up to 21°C, which corresponds to 80% bandwidth satisfaction in accordance with ASHRAE 55-2010 [8] under all conditions. Everywhere the statement that the PID controller is fuzzy starts to working and operate the heater at 8:00, in our experiments it is one hour before the starting working time.

Figure 5b shows the results of temperature changes for a single day on the premises, January 17, 2017. The initial room temperature is about 15 °C, and rises rapidly to the set value when heated. During working hours from 9:00 to 18:00, the room temperature is usually maintained between 20 °C and 21 °C. From this it follows that the temperature curve inside the room is relatively stable and there are no abrupt changes during working hours. This means that the controller with a fuzzy-PID controller controls the room temperature well.

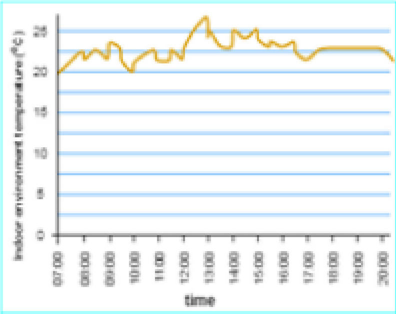
Figure 5c demonstrates the indoor air temperature that observed in May 2017, when average outdoor temperature was 25 °C in daytime, and 11.5 °C at night. The day when the experiment conducted is May 18, 2017, that time the highest outdoor temperature was 29 °C. In this temperature the controller keeps the desired temperature due to working power of conditioning system. When the working day starts initial temperature was about 20 °C, from 8.00 the PID controller starts to regulating. There is the highest temperature can be observed between 12.00 and 14.00 because of opening the window that time. Despite, does not exceed 26 °C, although it needs more working power of conditioner and requires more power consumption (Table 2).



a) Indoor temperature measurement



b) Indoor temperature monitored in Dec- 2016



c) Indoor temperature monitored in May- 2017

Fig. 5. PID parameters regulating process

5 Conclusion

Ensure a comfortable climate in a building, considering energy-efficient operation, attracts a great deal of attention worldwide. In this paper, we proposed a model to ensure a comfortable indoor environment for sportsmen. To obtain high accuracy in controlling the comfort parameters, mathematical models of the parameters are investigated, after which decoupling strategies for comfort parameters are considered. By applying the developed mathematical model, the proposed fuzzy based self-adjusted PID controller was designed.

Experimental results demonstrated the effectiveness of the proposed controller. Comfort values of the indoor environment parameters were according to international standards for indoor environment comfort as specified by ASHRAE and ISO. In future, in order to get higher accuracy, we will improve the system by using a presence detector, and training the system in GPU.

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