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Analysis of modern approaches for maintaining a comfortable microclimate in the buildings

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Abstract. This paper identifies the technical and economic aspects of application of intelligent technologies to maintain a comfortable indoor microclimate on the basis of statistical data. In the process of studying works of foreign authors, examples of the climate control systems are considered, which are developed based on the use of various intelligent technologies (fuzzy systems, neural networks, neuro-fuzzy modeling). The results of analysis have revealed the advantages and disadvantages of the given control systems and has defined promising further directions.

1. Introduction

Maintaining a favorable microclimate in residential and industrial premises is known as a multidimensional problem, which has no single solution.

Heating, ventilation and air conditioning (HVAC) systems are considered as engineering systems that provide favorable microclimate in a premise.

Existing HVAC systems are characterized by the rigid logic. Each system with its specific functional purpose is used in the standalone mode. Control of engineering equipment for each of the systems is implemented by the application of classical control theory (using conventional P, PI, PID tuners).

The application of classical control theory is feasible in case of present of the formalized control object. This is caused due to the fact that the construction of a traditional control system requires preliminarily formally described object of control [1] and generation of the control criteria, based on the mathematical apparatus, which operates quantitative categories.

Whereas, the microclimate maintenance system is a nonlinear system with dynamically changing parameters that are difficult to describe using traditional differential equations.

Therefore, the effectiveness of control systems for microclimate maintenance, related to complex objects, refers to the creation of intelligent control systems that can more or less replicate certain intellectual action of human, connected to the acquisition, analysis, classification of knowledge in the subject area of technological process control, as well as operating expertise accumulated by a human operator or by the system during the practice of object control activities [2-5].

The accelerated development of computer technology now facilitates the development, deployment and use of new intelligent control methods in many areas. Meanwhile, intelligent control system enables reducing the resource use and energy costs and provides a higher resistance to perturbing factors, compared with the conventional one.

The purpose of this research is a comparative analysis of modern approaches based on the use of intelligent technologies (fuzzy logic, neural networks, neuro-fuzzy modeling) to maintain a comfortable indoor microclimate.

2. Technical and economic aspects of application of intelligent technologies to maintain a comfortable indoor microclimate

Maintaining favorable microclimate initially corresponds to a twofold problem: the maintenance of climate control settings to a comfortable level in accordance with the preferences of users residing in the premises (when it comes to a residential area) and the activities they perform (when it comes to office and production facilities), meanwhile ensuring the energy efficiency of the building [6].

It has been discovered that the speed of thinking processes are less by 10% and the number of errors is more by 30% during the work in uncomfortable conditions inside the building.

Regarding indicators of energy consumption, more than 40% of primary energy consumption of the European Union is related to buildings. About two-thirds of the energy consumed correspond to the residential buildings and one-third to the non-residential buildings. Whereas two-thirds of the energy consumption in buildings are associated with the work of the heating, ventilation and air conditioning systems [7].

There are various energy efficiency improvements of buildings such as architectural construction measures, modernization of engineering equipment and automation of engineering equipment (use of modern intelligent technologies) (Figure 1).

The size of investment and payback period are considered as primary factors when deciding on their implementation.

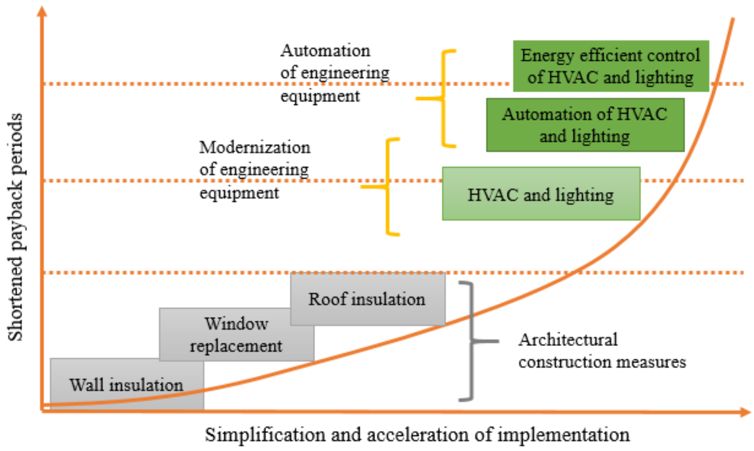

Figure 1. Improvements in energy efficiency of buildings.

Architectural measures are more labor-intensive and costly, as well as with a long payback period - more than 10 years. Modernization of engineering equipment is a less time-consuming and costly measure with a payback period of less than 10 years. Experience of the "Siemens" company in the implementation of energy-saving technologies in the European Union has demonstrated that the least time-consuming and costly measure with a payback period of 5 years is automation of engineering equipment (use of energy efficient automation systems and control methods).

In accordance with European Norm EN 15232 and Russian standard - GOST P 54862-2011, building automation systems and control methods of engineering systems are divided into four classes of energy efficiency: A, B, C and D (Figure 2).

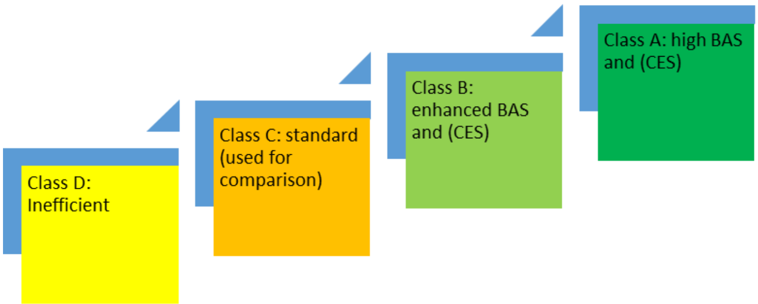

Figure 2. Classes of energy characteristics of automation systems
(BAS - building automation systems; CES - control of engineering systems).

Class D includes energy inefficient building automation systems and control methods of engineering systems, which should not be applied in the design decisions. The class C is called the standard or comparative. Power consumption in engineering systems, automated and controlled by the class C, is conventionally taken as a unit for comparison. Class B includes systems with enhanced energy efficiency and Class A is the highest energy efficiency. The method of determining the savings potential is based on the coefficients. Since 2003 this method has justified itself for many years of operation of building engineering systems. Coefficients of energy efficiency for thermal and electric energy in different types of buildings are presented in Table 1.

Table 1. Coefficients of energy efficiency.

	Thermal power				Electric power			
Building type:	D	C	B	A	D	C	B	A
Office building	1.51	1	0.8	0.7	1.1	1	0.93	0.87
Concert hall or conference hall	1.24	1	0.75	0.5	1.06	1	0.94	0.89
Institution	1.2	1	0.88	0.8	1.07	1	0.93	0.86
Hospital	1.31	1	0.91	0.86	1.05	1	0.98	0.96
Hotel	1.31	1	0.85	0.68	1.07	1	0.95	0.9
Restaurant	1.23	1	0.77	0.68	1.04	1	0.96	0.92
Shopping center	1.56	1	0.73	0.6	1.08	1	0.95	0.91
House	1.1	1	0.88	0.81	1.08	1	0.93	0.92

As it can be seen from Table 1, for example, if the automation system in office corresponds to inefficient the class D, then the power consumption of engineering systems is approximately 1.5 times higher compared to the class C systems. If they correspond to the class B, then the power consumption is by 20% lower than the class C systems. While if they correspond to the class A, the power consumption is 30% lower compared to the class C systems. Therefore, at the stage of design or selection of the equipment, it is possible to pre-evaluate the cost savings potential.

Based on an example of automation of building heating system, the differences of various classes of automation systems are shown (Table 2).

As it can be seen from Table 2, if automatic adjustment of the heating temperature is limited to central heating unit, then the system corresponds to the inefficient Class D, since heat transfer agent of one temperature is supplied to different buildings with different thermal characteristics and different heating requirements. If automatic temperature regulation of heating is limited to individual heating units (IHU), the system also corresponds to the Class D, since the heat transfer agent delivers the same temperature to different rooms of a building with different heating requirements. In order to meet at least Class C

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standard, it is necessary to provide individual room temperature regulation at least with one of the following methods: radiator valves, thermostats, room controllers. For meeting the Class B standards, it is required to organize individual room temperature regulation with communication between the controllers and the central station. Communication in the form of a feedback loop allows introducing an additional potential of saving in the heating system. Finally, to comply with the Class A standards, it is necessary to provide individual room temperature regulation with communication between controllers and central control station in addition to human presence control in the room. Thus, the higher the level of automation, the more possibilities to find the potential of savings in engineering systems.

Table 2. Automation systems of heating for different classes.

	Automation of heating systems	D	C	B	A
0	Automatic temperature regulation in the central heating unit.				
1	Automatic temperature regulation in the individual heating units.				
2	Individual room temperature control (radiator valves, thermostats, etc.).				
3	Individual room control with communication between the controllers and the central station.				
4	Individual room control with communication and consideration of human presence conditions.				

Based on the data provided in the report of Vice-President of ABOK Naumov A.L., a comparative analysis of energy intensity of traditional and energy efficient buildings is presented (figure 3).

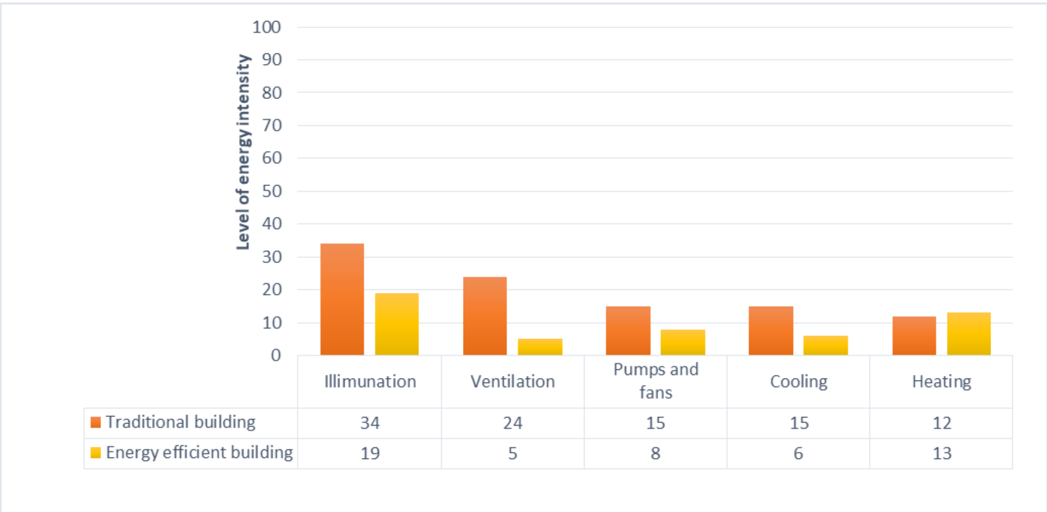

Figure 3. Comparative level of energy intensity of the building engineering systems.

The diagram in figure 3 shows that the energy intensity of energy efficient buildings decreases for illumination systems and pumps and fan drives almost by two times, for the cooling system almost by 3 times, for the ventilation system almost by 5 times.

3. Analysis of modern approaches to maintain a comfortable microclimate in buildings

Systems based on neural networks, fuzzy logic, neuro-fuzzy modeling are widespread among intelligent technology to ensure a comfortable microclimate.

Neural network is a powerful tool for searching patterns, forecasting, qualitative analysis. Nowadays, there are many different neural network configurations with different principles of operation, which aim solving a variety of problems. Neural networks can change their behavior depending on the state of their environment. After analyzing the input signals, they are trained and they adjust themselves to ensure proper reaction.

Examples of the application of neural networks to maintain the indoor climate are presented in papers of following authors: Huang [8], Argiriou [9], Ferreira [10], Jaeseok Yun [11].

In [11], they develop an intelligent system based on the use of ubiquitous sensing and machine learning technologies.

In the first stage of this, training of the neural network is performed. For training the network, data on temperature and humidity, collected by use of wireless sensors, is used. Based on a set of collected data about the temperature and humidity, using algorithms of SOM and k-Mean, clustering of the building environment is done. In total, 10 clusters of the building environment are identified.

In the next phase called "Feedback", the level of comfort of the tenants is estimated in accordance with the cluster of building environment by the message received directly from the tenant (by e-mail, Facebook, Twitter). At the same time, the HVAC system receives a set of temperature and humidity data for the last hour, classifies the data set in the respective clusters formed during the training phase, and finally decides to which cluster the building environment belongs to. Each cluster has a counter that increases when the cluster receives a notification message about human discomfort. Each cluster whose count exceeds a predetermined threshold is marked as an inconvenient cluster and the remaining clusters are marked as convenient.

The last stage is named "Control". At this stage, the control of HVAC system is done to provide a constant level of comfort for tenants. With regular intervals (e.g., one hour) HVAC control system classifies the current status of comfort in certain room to clusters of building environment, constructed during the training phase. If the classified cluster has been marked as one of the inconvenient clusters in the feedback phase, direct HVAC control of system is activated by shifting the current state of the comfort in building environment to the nearest convenient cluster.

During the study, the limitation is identified. Certain marked data sets are required, so any automatic recognition system shows good performance. However, unfortunately, to get such marked data sets is difficult in practice, because the user feedback indicating their level of comfort is not evenly distributed between "hot" and "cold", also there is different frequency of feedback among residents. Therefore, in the course of research, instead of building a classifier of comfort level from sparse and inadequately marked datasets, the scheduled data sets are selected on the basis of which the clustering is performed.

Also this study proposes the idea of using smartphones as a data acquisition device of the user that is suitable for further analysis during the control of microclimate parameters. A modern smartphone is equipped with a wide variety of sensors (gyroscope, accelerometer, microphone, temperature and humidity sensor, illumination sensor, etc.) and it is capable of collecting data and generating important information about the user (e.g., user location), or even finding the high-level context (e.g., everyday user actions). Accordingly, smartphones may become a multimodal human comfort sensor that can evaluate the thermal comfort, visual comfort, air comfort in the room and acoustic comfort.

Designs of fuzzy control systems for microclimate parameters are given in works of Calvino [12], Dounis [13], Berk [14], Tarun [15], Al-Gunaid [16].

The advantages of fuzzy control systems compared to classical models are smooth change in temperature and relative humidity; maintenance of carbon dioxide concentration at the maximum acceptable level; selection of the optimum operation mode for engineering equipment; energy savings up to 20%; less number of sensors being used; quick system output to set parameters.

The disadvantage of fuzzy systems is a significant increase in the rule base during increasing the number of input variables, which leads to a complication of system understanding. To overcome this problem and to develop the base of optimal rules, neuro-fuzzy models are used, that combine both fuzzy logic (fuzzy rules) and artificial neural networks (neural mechanism for the implementation of these rules).

Shared use of artificial neural networks (ANN) and fuzzy logic controller (FLC) allows the identification of complex nonlinear dynamic objects and synthesis of nonlinear control rules, which makes it possible to solve the studied synthesis problem of control system in fuzzy conditions on the basis of the available experimental data obtained on facility. A model of neuro-fuzzy controller is shown in the work Karpenko [17]. The aim of this study is to develop a model of neuro-fuzzy regulation for the microclimate in the room. The proposed model consists of an artificial neural network which serves to form a comfort index Predicted Mean Vote (PMV), a fuzzy logic controller for controlling the temperature and humidity in the room.

PMV (Predicted Mean Vote) – an indicator with the help of which it is possible to predict the value of the average sensitivity to temperature of a big group of people based on the balance of human body temperature according to 7-point scale.

The approach presented in Karpenko, makes it easy to control these parameters by evaluating PMV index that indicates a level of thermal comfort in the room. But there are limitations in this model:

Firstly, it does not take into account all the factors which characterize the level of comfort in the room (for example, variables related to the calculation of PMV). In addition, during the simulation it is assumed that the temperature is the same for the entire room. Hence, this approach does not consider local discomfort due to the uneven temperature in the room and the temperature difference between floor and ceiling.

Secondly, the current ANN structure does not allow to predict the temperature with respect to time change. Currently, ANN can provide the PMV value only for the specific input parameters. The model also ignores the number of sensors and their arrangement in the room.

4. Conclusion

Based on the conducted analysis it has been identified that there are various control technologies of microclimate parameters in the room. In order to maintain the parameters of nonlinear systems with dynamically changing parameters, as well as when there is no a priori information about the control object or it is incomplete, the use of intelligent technologies such as neural networks, fuzzy logic controller, neuro-fuzzy systems is effective.

Systems based on intelligent technology enable achieving the desired balance between maintaining the parameter at the required level and reducing resource and power consumption. Although these methods have a number of disadvantages, the advantages such as high precision, performance speed, resistance to the dynamically changing external environment, reliable prediction and control flexibility demonstrate a promising direction.

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