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DESIGN, ARRANGEMENT AND OPERATION OF AUTOMATED HEATING AND VENTILATION SYSTEMS IN PREFABRICATED CONCRETE BUILDINGS

ABSTRACT

This article is based on the results of studies carried out by the authors in the area of design, construction and operation of heating and ventilation systems of smart buildings. There was the world and domestic experience studied of automating the functioning of this type of engineering systems. The main components of the automation of heating and ventilation systems in buildings were determined. The classification and analysis of the four most common systems, depending on the methods of monitoring and regulating the air and heat fluxes, as well as the analysis of the applied software packages for their implementation, were carried out. The recommendations were given on the development of a mathematical model for the formation of the thermal mode in buildings. A methodology for designing air conditioning and ventilation systems was developed. There were also the special aspects of automation of heating and ventilation systems during the reconstruction of buildings investigated. The resulting analysis of the engineering practice of the application of automated heating and ventilation systems was carried out.

Keywords: intellectualization of buildings, automated building management system, building engineering systems, heating and ventilation systems, automation equipment, changing environmental parameters, smart building self-regulation, unified information network, building security system, basic functional characteristics.

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ПРОЕКТИРОВАНИЕ, УСТРОЙСТВО И ЭКСПЛУАТАЦИЯ АВТОМАТИЗИРОВАННЫХ СИСТЕМ ОТОПЛЕНИЯ И ВЕНТИЛЯЦИИ В ЗДАНИЯХ ИЗ СБОРНОГО ЖЕЛЕЗОБЕТОНА

АННОТАЦИЯ

Данная статья основана на результатах исследований, выполненных авторами в области проектирования, строительства и эксплуатации систем отопления и вентиляции интеллектуальных зданий. Изучен мировой и отечественный опыт автоматизации функционирования данного вида инженерных систем. Установлены основные компоненты автоматизации систем отопления и вентиляции в зданиях. Проведена классификация и анализ четырех наиболее распространенных систем в зависимости от способов контроля и регулирования воздушных и тепловых потоков, а также анализ применяющихся пакетов программ для их реализации. Приведены рекомендации по разработке математической модели формирования теплового режима в зданиях. Разработана методология проектирования систем кондиционирования и вентиляции воздуха. Исследованы особенности автоматизации систем отопления и вентиляции при реконструкции зданий. Проведен результирующий анализ инженерной практики применения автоматизированных систем отопления и вентиляции.

Ключевые слова: интеллектуализация зданий, автоматизированная система управления зданием, инженерные системы зданий, система отопления и вентиляции, средства автоматики, изменение параметров окружающей среды, саморегуляция интеллектуального здания, единая информационная сеть, система безопасности здания, базовые функциональные характеристики.

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INTRODUCTION

Intellectualization of buildings, or, in other words, the use of automated systems in them that regulate and optimize various parameters of the buildings during their entire life cycle, allows not only to provide comfortable and safe conditions for people in them, but also to reduce operating costs.

Nowadays, the international standards organizations ISO and CEN put into effect the basic regulatory documents [1–4] governing the issues of automation in construction. At the same time, their successful practical application requires the development of recommendations for the design, installation and operation of specific types of buildings and structures, taking into account the economic and technical capabilities of project implementers, as well as the realization by potential investors of the upcoming benefits during operation at some initial costs during the creation of the aforementioned systems. Higher quality of life requires higher costs in the initial stage of creating an object.

In previous publications [5, 6], the authors found that a rationally built structure of a smart building provides for obtaining objective information about the state of engineering systems of a building and their work, optimizing the management of engineering equipment, thus reducing overall costs, ensuring the possibility of making operational decisions and their timely containment in case of emergencies.

The main components of a smart building are installed: elements that react to the presence or absence (action or inaction) of a smart building user and changes in environmental parameters; automation tools that regulate the parameters of a smart building based on an analysis of the state of the environment and changes in its parameters; an algorithm for self-regulation of a smart building aimed at improving the comfort and safety of its user.

The engineering systems building a single information network were defined.

Previously, the authors have developed a specific and detailed requirements that allow the most rational and economical way to design automated power supply systems in precast concrete buildings.

This article presents the results of research that formed the basis for the development of similar requirements with regard to the design, installation and operation of automated heating and ventilation systems.

HEATING AND VENTILATION SYSTEMS IN BUILDINGS

The air conditioning and ventilation system is designed to provide optimal climatic conditions in all areas of the building. Flexible control systems are designed for both typical and programmable applications. Using universal controllers, it is necessary to select a control program from existing libraries if there are any specific features of the controlled object.

The analysis of the world and domestic engineering experience shows that currently the most common are the following air conditioning and ventilation systems:

1. Air conditioning and ventilation system with regulation “By return air”.

This system is an example of a simple automation system for an inflow ventilation system, that controls only one parameter – the supply air temperature. The reliability of predicting the air temperature in the room is small, since this system does not take into account the heat generation of people and office equipment, heat gain due to solar radiation. As a rule, the control system “By return air” involves the use of mechanical intake and exhaust ventilation with mechanical induction. It should be noted that the temperature of the exhaust air accurately reflects the actual temperature of the air in the room, due to which a popular solution has been formed – regulation "By return air". The system functions by integrating the supply and exhaust systems via the communication bus (even if the installations are located in different parts of the building) with the controller of the inlet ventilation system operating in accordance with the specified parameters and algorithm. This reduces the cost of heating or cooling the supply air and ensures the required quality of the microclimate.

2. Air conditioning and ventilation with zone control.

This ventilation system is based on a device in the building of general exchange ventilation, which provides most of the premises with fresh air. The use of closers locally ensures the specified air temperature in each separate zone. For example, in an office facility, a manager's office and a large office space divided by open partitions may be located next to each other and the requirements for the microclimate of these two zones may differ. As a rule, ceiling or wall systems based on Fan Coil units are used as fancoils. However, other solutions can be implemented too, for example, cooling ceilings or beams. Fancoils are completed with controllers manufactured by both manufacturers of fancoils and firms specializing in the production of automation systems.

3. Air conditioning and ventilation systems with variable air volume (VAV). This system is very attractive in terms of energy savings. In addition, the system regulates the temperature of the air in the room and provides a predetermined pressure drop, which prevents the flow of polluted air into adjacent rooms. Based on this, rational areas of application of a system with a variable air volume are premises with a complex mode of operation: hazardous industries, chemical laboratories, hospitals, office premises. It should be borne in mind that in the case of using such a scheme, certain restrictions are imposed on the ventilation system – it is necessary to ensure the required static pressure in the duct. Regulation by zones takes place due to the expense of two actuators in each room – installed both on the inflow and on the exhaust. The economic effect is achieved as a result of direct analysis of the functioning mode of the room at the moment: in the absence of people in the room (as determined by the motion sensor, manual setting of the "Not occupied" mode or from the control room, etc.), both dampers are closed, air exchange is equal to zero. In turn, the pressure in the supply duct begins to increase. When the pressure

increases, the system begins to reduce speed due to the use of supply inflow chambers with variable air volume or inverter control. It should be noted that the need to use such devices leads to some complications and higher cost of the ventilation system. However, this increase in price pays off by saving energy by heating or cooling the air.

4. Air conditioning and ventilation with group control.

A typical air conditioning and ventilation system using Fan Coil units with simple thermostatic control (solenoid valve) allows the specified air temperature to be maintained only in one room by using the technology – one control module per one fancoil. This circumstance causes certain problems with the air-conditioning of spacious rooms, where the microclimate is provided by several units. From the point of view of automation, large-volume premises are defined as one climatic zone, in which there should be one temperature mode, and the number of actuators to ensure this mode is large enough. In this case, in the air conditioning and ventilation systems with group control, all actuators are equipped with separate controllers interconnected by a common bus, but one controller operates in the main mode, and the others, respectively, in the slave mode, that is, the so-called "group logic" is implemented. One temperature module (control module) is installed per zone, but it controls the operation of several devices. The limit on the total number of devices is imposed by the protocol used. For example, the LON protocol allows you to control the operation of up to 60 devices in one segment.

When developing a mathematical model to build a thermal regime, one should, as a rule, choose a system approach that allows considering the system "heating unit – object" as an interconnected non-linear system with a variable structure. A mathematical model is a system of heat balance equations describing air exchange, operational and technological heat gains, outdoor climatic influences, heat losses through external fences due to heat conduction and by filtering outside air, heat content of process equipment, products and internal structures, heat exchange processes in calorifiers.

The package of specialized programs is divided into three groups: optimizing, main operation and auxiliary servicing systems.

The heat consumption optimization program for heating performs two main functions: it calculates the heat consumption from time to time which is necessary to maintain a given microclimate in certain parts of the building during working hours and determines the mode for reducing the temperature during non-working hours and increasing it to a specified value during working hours.

The observer program allows you to monitor the development of the process for a long time, it gives messages about deviations for the upper or lower limits of the specified parameters. The information obtained is necessary for monitoring and evaluating the operation of the system.

The alarm program responds to various emergencies (failure of heating and ventilation equipment and automation, broken glass, etc.) and diagnoses them. The program for starting and turning on control heating devices works in conjunction with the optimization program and uses information about specific control actuators.

The operation program communicates with the operator system in the form of a dialogue. With the help of this program you can change the mode of system operation, as well as obtain various information about its work.

Accounting programs controlling the operation of actuators accumulate information on the hours of their work and report on malfunctions, as well as on the timing of preventive work.

Programs for calculating the total energy consumption and the accumulation of this consumption in time receive and accumulate information for the day, week, month, etc.

Reporting programs maintain statistics on measurement and calculation data, as well as on the status of heating and ventilation equipment, print reports daily, weekly, monthly on average, minimum and maximum values, alarms, costs, energy savings, etc.

METHODOLOGY FOR DESIGNING AIR CONDITIONING AND VENTILATION SYSTEMS

As a result of the research, the authors developed a methodology for the design of air conditioning and ventilation systems:

1. The basis for the development of an intelligent element for air conditioning and ventilation of buildings is a structural information scheme that defines a set of control objects, sensors, control devices, including computing and others, a control computer, executive and control devices that establish the necessary information links between them.

2. When designing an intellectual element, the general requirements of automated process control systems should be considered regarding the following aspects:
   - accuracy and speed of input operations from the object of measurement information control;
   - structure of communication devices of a control computer with a control object;
   - parameters of the equipment for normalization, switching, transmission and conversion of signals;
   - methods of dealing with interferences;
   - algorithms and programs of information transfer and conversion procedures.
3. To control the thermal regime of a building, it is reasonable to have a control structure in which individual parameters of the thermal regime are regulated by appropriate automatic devices, and the control module which processes the measurement information, calculates and optimizes the settings. Due to such a management structure, sufficient reliability of the system as a whole is ensured, since the system's performance remains unchanged even if the control computer fails. In addition, with such a structure, a simpler controlling computing machine can be used, the requirements for its speed and other characteristics are reduced, it becomes possible to practically implement more efficient process optimization algorithms that require more computation.
4. The measured unregulated environmental parameters are the temperature and humidity of the outside air, wind speed and direction, atmospheric pressure, solar radiation, water temperature and pressure in the flow pipe of the heating network, temperature and vapor pressure in the heating network.
5. Measured output parameters characterizing the thermal regime are air temperature, relative air humidity, air velocity in operation areas, carbon dioxide concentration, etc.
6. Measured output parameters, which can be used to determine the control efficiency directly or by calculation are the following: the temperature and pressure of water in the return pipelines, the consumption of heating water, cold water and steam and the power consumption.

7. The intake air temperature, the temperature of the hot water after the mixing pumps and the amount of intake air are considered as adjustable parameters that are measured by the appropriate actuators.
8. For rooms in which emergency quantities of explosive gases and vapors forming explosive mixtures can be released, gas analyzers blocked with light-signaling devices should be installed, indicating that there is a concentration of a substance reaching 20 % of the lower explosive limit in the room air, or automatic gas analyzers interlocked with a device for starting systems used for emergency ventilation in the presence of such a concentration.
9. The software of the system should consist of the operating system of the control computer providing the possibility of working in real time, in the dialogue mode, and the software package of the system. The programs of the system should also ensure the possibility of their broadcasting, editing, linking and debugging. The operating system should include tools associated with the time service, that is, waiting for a given moment in time to start the process and control the operation of communication devices with the object, as well as tools for working with files stored in the external memory of the computer.
10. The software package should be presented in the form of separate interrelated subprograms. Large subprograms should be segmented based on the specified amount of RAM in the computer.
11. The software package is designed to control the operation of the entire system. It is divided into optimizing programs, main operation programs and auxiliary system maintenance programs.

AUTOMATION OF HEATING AND VENTILATION SYSTEMS DURING THE RECONSTRUCTION OF BUILDINGS

It is worth noting that the intellectualization of air conditioning and ventilation systems is possible not only at the stage of new construction, but also at the stage of reconstruction and modernization of existing buildings. In this case, the main tasks for the reconstruction are the following:

– saving energy spent on heating and ventilation;
– improving the quality of thermal comfort;
– improving the quality control of the technical condition of the air conditioning and ventilation equipment;
– creating a database of possible emergencies, their diagnostics and recommendations for the conduct of the technological process – heating of buildings and the work of the staff in these conditions, that is, the development of an intelligent element of the HVC system of the building in operation.

The reconstruction of the air-conditioning and ventilation system involves the following works:

– further equipping of heating and ventilation units with devices for controlling the amount of fresh air;
– mixing unit device providing regulation of the water temperature supplied to the heaters of the heating and ventilation units with devices for controlling the amount of fresh air;
– mixing unit device providing regulation of the water temperature supplied to the heaters of the heating and ventilation units by mixing the cooled water from the return heat pipe;
– creating of an automated control system for the thermal conditions of production premises.

Heating and ventilation units, equipped with devices for regulating the amount of fresh air, provide energy saving by reducing the rate of ventilation air exchange in rooms on holidays, Sundays and non-working night hours, reducing the amount of heated air supplied to the rooms as a result of taking into account the air in the air balance ensuring regulatory air exchange.

PRACTICAL RESULTS OF AUTOMATION OF HEATING AND VENTILATION SYSTEMS

The analysis of the engineering practice of the application of automated heating and ventilation systems has shown the following.

The Building AdVent project of the European Union was carried out with the aim of instrumental measurement of the microclimate parameters in the building after its commissioning, as well as on the subjective assessment of the microclimate quality obtained by interviewing employees. The main microclimate parameters were measured:

- air temperature;
- air flow rate;
- air exchange during the summer and winter periods.

In addition, the Building AdVent project was not limited to the inspection of ventilation systems, since the quality of the internal microclimate and the energy efficiency of a building depend on many different factors, including architectural and engineering solutions of the building. To assess the energy efficiency of buildings, data on heating, ventilation and air conditioning systems was summarized, as well as on other systems consuming thermal energy and electricity. Below are the results of the assessment of the three buildings.

Representative buildings were located in three different regions with different climatic conditions determining the composition of engineering equipment. The climatic conditions of Greece in the general case caused a high load on the cooling system, the UK – moderate loads on the heating and cooling systems, Finland - high load on the heating system. Representative buildings in Greece and Finland were equipped with air conditioning systems and central mechanical ventilation systems. In a building located in the UK, natural ventilation was used and the rooms were cooled using night ventilation. In all three representative buildings, the possibility of natural ventilation of the premises by opening windows was allowed.

Parameters of energy efficiency of representative buildings are given in table 1.

Table 1

Annual energy consumption of buildings

Energy consumption[1)], kW • h/m2	Finland	Greece	Great Britain
Heating (heat energy)	54	34	66
Cold supply (electrical energy)	11	47	0

Table 1 (ending)

Energy consumption[1), kW • h/m2	**Finland**	**Greece**	**Great Britain**
Other power consumption	95	65	127
Total power consumption	160	146	193
[1)] Energy costs for heating and cooling are not adjusted for the climatic characteristics of the construction area			

The quality of the microclimate in the representative buildings:

1. Building located in Finland. During the study of the microclimate quality, there were measurements of the temperature and air flow rates made. The flow of ventilation air was adopted according to the protocols of the building commissioning. The local criterion of thermal comfort (draft level), the predicted mean vote (PMV) and the predicted percent dissatisfied (PPD) were determined from short-term observations of air velocity and temperature. The results showed good overall and local thermal comfort (table 2).
2. The building located in the UK. Air temperature measurements have been carried out in the building for six months. Additional observations in cold, warm and transitional periods, including measurements of air temperature, relative humidity and carbon dioxide concentration, showed that temperatures are significantly lower than initial measurements.
3. The building located in Greece. Typical values of air temperature in the summer period in office premises were from +27.5 to +28.5 °C. The number of hours with temperatures above +30 °C was minimal. Even with extreme outdoor temperatures (above +41 °C), the internal air temperature was constant and remained at least 10 °C below the outdoor temperature. Among all office premises, the highest concentration of carbon dioxide was noted in offices with the maximum density of users. However, even in these zones, the average concentration was in the range from 600 to 800 ppm and complied with the ASHRAE standards (maximum 1,000 ppm for 8 continuous hours).

Table 2

Air velocity, drafts and overall thermal comfort in a building located in Finland

Measuring points[1)]	Microclimate parameters	The premises in which measurements were made											
		1	2	3	4	5	6	7	8	9	10	11	12
0.1	Air velocity, m/s	0,27	0,11	0,12	0,05	0,08	0,06	0,07	0,06	0,08	0,07	0,06	0,05
	Air temperature, °C	24,4	22,6	22,5	24,5	24,7	24,0	23,5	23,8	24,4	23,9	24,1	24,1
	Turbulence intensity, %	14	4	9	8	6	9	11	11	12	14	21	11
	Draft level, %	17	7	7	1	3	2	3	1	4	3	4	2
0.6	Operating temperature, °C	24,5	23,2	22,3	24,2	24,7	24,1	23,4	23,6	24,3	23,6	24,3	24,1
	PMV	0,18	-0,22	-0,40	0,02	0,18	-0,01	-0,15	-0,10	0,09	-0,16	0,08	0,05
	PPD, %	6	6	8	5	6	5	6	5	5	6	5	5
1.1	Air velocity, m/s	0,01	0,09	0,05	0,12	0,10	0,10	0,07	0,09	0,07	0,12	0,06	0,07
	Air temperature, °C	24,8	22,8	22,6	24,5	24,6	23,9	23,2	23,9	24,5	23,5	24,1	24,4
	Turbulence intensity, %	17	12	15	6	8	9	14	9	15	16	11	8
	Draft level, %	0	5	2	6	4	5	4	4	3	7	4	3
1.7	Air velocity, m/s	0,01	0,12	0,05	0,04	0,03	0,07	0,08	0,06	0,08	0,24	0,09	
	Air temperature, °C	24,7	22,8	22,5	24,6	24,9	24,1	23,3	24,0	24,5	23,5	24,2	
	Turbulence intensity, %	17	13	13	10	12	13	10	12	15	12	10	
	Draft level, %	0	8	2	1	1	3	4	2	4	16	4	

1) height from the floor level, m

Subjective assessment of the quality of the microclimate by employees (table 3):

1. In a building located in Finland, most of the premises are not equipped with individual temperature control. The level of satisfaction with air temperature was practically expected for offices without individual controls. The level of satisfaction with the general microclimate, internal air quality and lighting was high.
2. In a building located in Greece, most of the employees were not satisfied with the temperature and ventilation level at workplaces, but were more satisfied with the lighting (natural and artificial) and the noise level. Despite the identified problems with temperature and air quality (ventilation), most people positively assessed the quality of the internal microclimate.
3. The building in the UK is characterized by a high level of satisfaction with the quality of the internal microclimate in the summer. Thermal comfort in winter was assessed as low, which may indicate problems with drafts in a building with natural ventilation. As in Finland, the level of satisfaction with acoustic comfort was low.

Table 3

Subjective assessment of the quality of indoor climate according to the results of employee surveys

Indicator name	Finland		Greece	Great Britain	
	Summer	Winter		Summer	Winter
Percentage of employees satisfied with the general quality of the indoor microclimate, %	86	91	73	82	69
Percentage of employees satisfied with the general quality of thermal comfort, %	73	76	43	77	61
Percentage of employees satisfied with the quality of indoor air, %	82	90	42	93	90
Percentage of employees satisfied with the quality of acoustic comfort, %	59	57	68	51	65
Percentage of employees satisfied with the quality of lighting, %	95	95	82	97	90

1. The results of studies of three buildings showed that employees are more satisfied with the quality of the microclimate in the summer period in a building with natural ventilation without

cooling (UK) than the quality of the microclimate in an office equipped with central air conditioning with high values of ventilation air exchange (10.8 m^3/m^2) and low density of employees (Finland). At the same time, the building in Finland, according to measurements, had an excellent quality of the internal microclimate.

2. Airflow rates and draft levels were low and the internal climate was rated as appropriate for the highest category. Given this measurement data, it is surprising that user satisfaction was lower than 80 %. In part, these results can be explained by the very low level of satisfaction with acoustic comfort. It is likely that some users do not feel comfortable in large office spaces, and the lack of individual temperature control can increase dissatisfaction with thermal comfort.
3. The results of the research showed that in the representative buildings the increased ventilation air exchange does not have a significant impact on the energy efficiency: heat consumption in a building located in Finland was lower than in a building in the UK. This observation demonstrates the efficiency of recovery (regeneration) of the heat of the ventilation air. On the other hand, research results show that a significant proportion of energy consumption is not the cost of thermal energy for heating and cold supply, but of electrical energy for cold supply, lighting and other needs. The best accounting and optimization of energy consumption are implemented in a building located in Greece, which indicates the need for more thorough development of projects in terms of electricity supply. As a priority, it is advisable to improve the quality of energy consumption metering.

CONCLUSION

Intellectualization of buildings, or, in other words, the use of automated systems in them that regulate and optimize various parameters of the buildings during their entire life cycle, allows not only to provide comfortable and safe conditions for people in them, but also to reduce operating costs.

The studies carried out have allowed us to do the following:

– build the well-minded structure of a smart building which provides for obtaining objective information about the state of engineering systems of a building and their work, optimizing the management of engineering equipment, thus reducing overall costs, ensuring the possibility of making operational decisions in case of emergencies and their timely localization.
– determine the sustainable types of heating and ventilation systems included in a single information network of engineering systems in the building.
– develop a methodology for the design of air conditioning and ventilation systems.
– identify the features of automation of air conditioning systems and air ventilation during the reconstruction of buildings.
– review and analyze the practical results of the automation of air conditioning and ventilation systems.

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