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A. L. Voronuk

ABOUT SECONDARY ENERGY RESOURCES, HEAT EXCHANGE VENTILATION

Faculty of Air Navigation, Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine
E-mail: 4103955@stud.nau.edu.ua

Abstract—*The article deals with life support systems, the main purpose of such systems is to make the building suitable for human life, or to create comfortable conditions for work. To create a favorable environment, optimal temperature and humidity in all residential and industrial premises, ventilation and air conditioning systems are used. The main goal of the work was the development of a high-tech energy-saving ventilation and air conditioning system with a modern automated control system. At the same time, the main directions of modernization of energy-saving control systems were developed, the hardware support of the energy-saving ventilation system was developed, the choice of the type of recuperator as an energy conservation subsystem was justified, the main elements of the system were calculated, the components of the ventilation and air conditioning system were modeled, a model of the supply-exhaust ventilation system was developed, and experimental tests were carried out research.*

Index Terms—Ventilation; supply and exhaust system; air environment; heat exchanger; recuperator; secondary energy; a group of tidal chambers.

I. INTRODUCTION

The field of application of ventilation and air conditioning concerns both civil and industrial spheres.

Ventilation is considered an "engineering control" for the removal or control of indoor pollutants. This is one of the best ways to control the effects of air pollution.

The main purpose of mechanical ventilation systems is to clean the air of dust and harmful substances and to warm it up in the cold period of the year, as well as to reduce the potential danger of fire or explosion, to remove or dilute airborne pollutants.

With the increase in energy prices, the problem of providing premises with ventilation in winter conditions became more acute. In modern ventilation systems, the heat of ventilation emissions is used to heat the supply air in special recuperator devices that heat the supply air. Thanks to the heating system, it is possible to use a water heater, thanks to the circulation of water, it heats fresh air thanks to different temperatures.

Ventilation and air conditioning systems are chosen taking into account the purpose of the building; volume of premises; the nature of harmful substances that are released; etc. At the same time, they are guided by state building regulations [7].

II. PROBLEM STATEMENT

Three ways of solving the problem are considered. Engineering energy-saving measures in ventilation and air conditioning systems can be conditionally divided into three groups: firstly, technical energy-saving measures, secondly, the use of secondary energy resources, and thirdly, improvement of the service system (automation).

As shown by the performed studies, up to 40% of energy can be saved.

Due to the use of the intake and exhaust system, the movement of the air flow occurs regardless of weather conditions. Forced systems are able to clean, heat or cool the supplied air, regulate the flow rate. Artificial air exchange systems are quite effective, but more expensive to operate and depend on the supply of electricity. Forced installations are equipped with automatic control.

Fans can be equipped with artificial intelligence (timer, hydrostat, motion sensor), which will also help to avoid excessive consumption of electricity. The operation of the supply and exhaust system should be based on the calculation of the balance of the air exchange.

The set ventilation system has separate elements and devices for ventilation, assembled according to the scheme into one system. The advantage of such a ventilation system is that it can be composed of blocks and devices of individual choice and for different purposes and areas of premises.

A promising direction in the development of ventilation systems is their combination with space heating systems. During the heating period, they work using air recirculation. Depending on the availability of a heat source, air heating installations can be equipped with a water heater.

The presence of automatic control allows you to select the required operating mode and adjust the temperature of the heated room. Air heating systems, combined with ventilation, are quite capable of providing heat to all serviced premises [8].

The control system with automation elements regulates the power of the heater depending on the temperature of the supply air, monitors the cleanliness of the filter, controls the air valve, etc.

Thermostats, hygrostats, pressure sensors, etc. act as sensors for the control system.

In addition to the main mode of control from the control panel, control of the ventilation system by location from push-button control stations (PC) located in the serviced premises should be provided.

The ASK hardware and software platform should provide high flexibility of configuration and programming.

In modern buildings, in winter, 25–50% of the heat is spent on heating the supply air. In the summer period, in buildings equipped with central air conditioning systems, excess heat is removed by cooling the supply air. The increase in energy prices is stimulating the growth of interest in thermal energy recovery in newly designed ventilation and air conditioning systems that are being reconstructed. In this connection, interest in ventilation units, heat exchangers (recuperators) of the "air-to-air" type has increased.

The main goal is the development of a high-tech energy-saving ventilation and air conditioning system with a modern automated control system [9].

III. Problem Solution

A large amount of thermal and electrical energy is spent on heating buildings in winter and cooling them in summer.

In the ventilation system, the use of secondary thermal energy resources allows to reduce operating costs. Secondary energy can be obtained: First, by transferring heat or cold from the air removed by the incoming air, Second, by using heat or cold from technological installations.

Preventive inspection and maintenance is mandatory, which is not required at all on a random whim, but for the normal functioning of the equipment, which will contribute, among other things, to energy savings during system operation.

As the studies have shown, up to 40% of energy can be saved if two significant changes are made to a typical supply-exhaust ventilation system:

The first is to supplement the system with a device that will ensure the transfer of part of the heat (energy) carried by the air that is removed from the room to the fresh air flow that is supplied to the room. Let's call such a device a recuperator (Fig. 1).

The second is to apply, as is done in industrial ventilation, a group of supply chambers operating in the mode of maintaining the same supply air temperature.

The functional diagram of the proposed system is shown in Fig. 1.

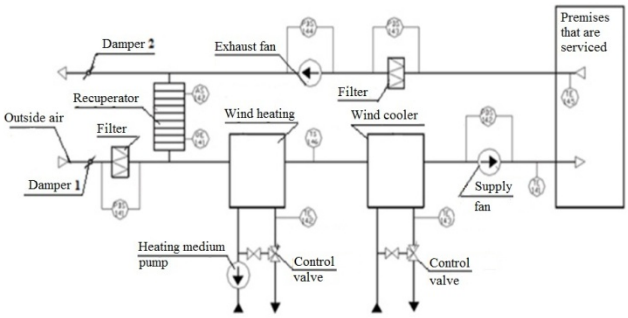


Fig. 1. Functional diagram of the energy-saving system

Recuperators (heat exchangers) that can be used in ventilation systems: plate, rotary and intermediate coolant.

Plate heat exchangers vary in efficiency from 40 to 70%. Plate recuperators have no moving parts, and heat transfer occurs through plates with high thermal conductivity, on both sides of which air flows (inlet and exhaust) pass.

The amount of transferred heat is regulated with the help of a flow valve, which controls the flow of air passing through the heat exchanger.

When using a plate heat exchanger, the possibility of condensation should be taken into account. Therefore, recuperators of this type are equipped with condensate drains and shutters that prevent water from entering the air duct channel, and an ice defrosting system.

Use is possible only if the supply and exhaust ducts cross each other.

Rotary recuperators have a very high efficiency rate – 60–85%. They differ in the presence of a moving part – the rotor, which transfers heat between air flows. It is possible to adjust the intensity of recuperation by changing the speed of rotation of the rotor. The unit as a whole has minimal dimensions

Since in rotary heat exchangers, exhaust and supply air can mix, transmitting odors and pollution, special attention should be paid to the placement of fans. The risk of icing is very low, so a defrost system is not mandatory.

Contaminated air is partially transferred from the exhaust to the inflow.

Use is possible only if the supply and exhaust ducts cross each other.

Recuperators with an intermediate coolant. The ventilation system is equipped with two heat exchangers connected by a hydraulic circuit, in which water or a water-glycol mixture is pumped, placed in the supply-exhaust channel, and the coolant circulates between them, heat is transferred. The efficiency of recuperation from the structure is 45–60%, and the heat transfer can be adjusted by changing the speed of movement of the coolant.

The undoubted advantage of recuperators with an intermediate heat carrier is the complete insulation of the heat carrier, and therefore, the elimination of the possibility of contamination transfer between air streams.

High additional consumption of electricity.

There is no need for adjacent location of supply and exhaust ducts.

Control of a group of tidal chambers is shown in Fig. 2. In this scheme, a group of air heating units of inflow chambers TCII – TCI, connected by the coolant in parallel, is connected to the coolant preparation unit, consisting of pumps P1 and P2 (one reserve), check valve V1, control valve V2 and regulator pressure RP. On the return pipeline in front of the preparation node, a flow relay of the coolant FRC is installed.

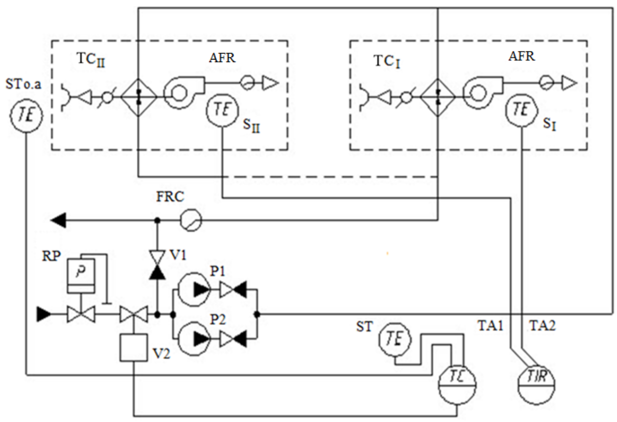


Fig. 2. Scheme of control of a group of inflow cameras

The executive mechanism of the V2 valve is electrically connected to the TA1 regulator, the inputs of which are connected to the ST sensors of the heat carrier temperature in the direct pipeline at the exit from the preparation unit and the STo.a sensor. outside air temperature. The diagram also shows the elements of the signal equipment: the supply air temperature alarm TA2 with sensors SI – SII and the air flow relay AFR, installed in each supply chamber. The TA2 alarm is structurally made in the form of a regulating multi-point RMP bridge, the output contacts of which, as well as the AFR contacts, close the light and sound signaling circuits.

The developed system provides control of a group of inflow cameras in manual and automatic modes [10].

When calculating the ventilation, it is necessary to follow the state standards and rules expressed in SNiP 41-01-2003, as well as in the corresponding sanitary and hygienic requirements.

Air exchange (air productivity) is calculated, which is determined in cubic meters per unit of time (hour).

For the calculation, a diagram of the entire object is drawn up, indicating the dimensions and purpose of each room. Air exchange is calculated according to two indicators: the number of people and multiplicity.

Calculation of air exchange (productivity) by the number of people is carried out according to the algorithm

$$L_1 = L_{\text{norm}} \times N, \tag{1}$$

where L_{norm} are normative costs for 1 person; N is the number of people.

Calculation by multiplicity has the form according to the algorithm

$$L_2 = n \times H \times S, \tag{2}$$

where n is the multiplicity (normative) air exchange; $n = (1-2)$ for residential objects; $n = (2-3)$ – for office. N is the room height, m; S is the area of the premises, m^2.

From the obtained values L_1, L_2 air exchange is taken more for ventilation.

Air ducts are calculated. According to their scheme, the parameters of air ducts and air distributors are calculated.

The formula for calculating the *cross-sectional area* of the (calculated) duct

$$S_p = L\frac{2.778}{V}, \tag{3}$$

where S_p is the area (calculated) cross-section, cm^2; 2.778 is the proportionality factor (h/s, m/cm); L is the flow of air passing through the duct, $\text{m}^{\text{h}}/\text{h}$; V is the air speed, m/s.

Formulas for calculating the *cross-sectional area (actual)*:

- for round cross-section:

$$S_p = \frac{\pi D^2}{400}; \tag{4}$$

- for a rectangular section:

$$S_{\text{c-s a}} = \frac{A+B}{100}, \quad (5)$$

where $S_{\text{c-s a}}$ is the cross-sectional area, cm^2; D is the diameter of circular section, mm; A, B is the height and width of a rectangular section, mm.

The resistance of the air distribution network is calculated.

Each element of the network must be taken into account in the calculation. It is performed by specialists using a specific program or a calculator for ventilation parameters.

The power of the heating element (heater) is calculated.

$$P = \frac{\Delta T \times L \times C_y}{1000}, \quad (6)$$

where ΔT is the temperature difference at the inlet and outlet of the heater, $°C$; C_y is the heat capacity of air (we assume equal to $0.336 \ \text{W} \times \text{h} / \text{m}^3 / °C$); L is the productivity through the air, m^3.

By complying with the requirements of SNiP in calculations, you can minimize costs for all elements of the ventilation installation and its operation [6].

As soon as the installation work is completed, the ventilation systems are tested. The conduct of tests is documented by the Act of completed works.

When developing a dynamic model of a water heater, the following simplifications were adopted: there is no heat exchange with the environment; the model contains three dynamic elements with concentrated parameters (water, heat exchange surface and air); the physical properties of material flows and the heat exchange surface are reduced to the average values of the working range [1].

The heating medium is water with consumption $G_W(t)$, the temperature of the heat carrier at the entrance to the heater $\theta_{W0}(t)$, at the exit – $\theta_W(t)$. The radiator contains *n* tubes of length *H*. The heat carrier heats the heat exchange tubes, whose temperature is averaged $\theta_M(t)$. Transversely to the movement of the heat carrier, air flows into the heater with flow rate $G_A(t)$. Inlet air temperature – $\theta_{A0}(t)$, of exit – $\theta_A(t)$. Geometric dimensions of the heat exchanger: L, C, H – depth, width and height of the heater [2].

So, the mathematical model of the heater:

$$\begin{cases} T_W \dfrac{d\Delta\theta_W}{dt} + \Delta\theta_W = k_0\Delta\theta_{W0} + k_1\Delta\theta_M + k_2\Delta G_W, \\ T_M \dfrac{d\Delta\theta_M}{dt} + \Delta\theta_M = k_3\Delta\theta_W + k_4\Delta\theta_A, \\ T_A \dfrac{d\Delta\theta_A}{dt} + \Delta\theta_A = k_5\Delta\theta_A + k_6\Delta\theta_M + k_7\Delta G_A. \end{cases} \quad (7)$$

We will use the numerical version using Matlab.

In the Matlab environment, a program was created for this, the elements of which are listed below:

```
pw=986;            pm=3334.8;     Gw=2.44;
cw=4185;           cm=866.5;
Mw=18.54;  Mm=21;
F0=6.54;           F1=274;
a1=80;             a0=800.
```

According to the result of the calculation, the values of the coefficients of the equation were obtained. [11]

The heater model in the Matlab Simulink environment is shown in Fig. 3. [12]

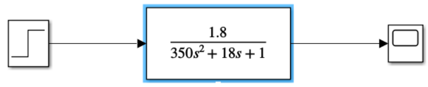


Fig. 3. Model of the heater

Transient processes of the heater are shown in Fig. 4.

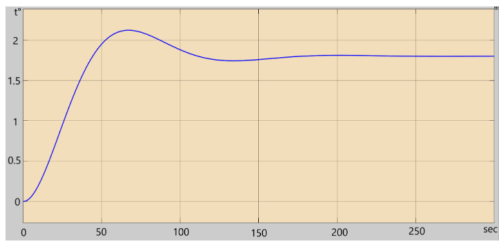


Fig. 4. Transient characteristics of the heater

So, we see the inertia of the process, since the transmission is through the walls and first you need to heat the metal, and then the metal heats the air.

Let's consider the calculation diagram of the room, which is shown in Fig. 5.

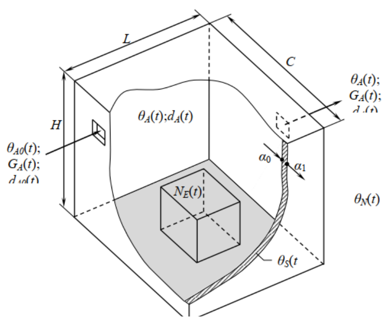


Fig. 5. Calculation diagram of the room

In the air space of the room in volume $VA = H\times L\times C$ prepared air, the temperature of which comes from the supply ventilation system $\theta_{A0}(t)$, moisture content $dA_0(t)$, cost $G_A(t)$. In the process of heat exchange between technological equipment (power of the equipment N_E) and walls (temperature of the wall θ_s) the air temperature in the room is set $\theta_A(t)$ with moisture content $d_A(t)$. The exhaust ventilation system provides air removal. Ambient air temperature – $\theta_N(t)$ [3].

The room model is based on the flow capacity. The following simplifications were adopted in the modeling: there are no moisture sources in the room, since their presence is determined by a specific technological process, which is not considered; the reduced heat capacity of the technological and heat engineering equipment takes into account the heat release of the service personnel; the model contains two dynamic elements with concentrated parameters (air space and walls of the room); the physical properties of material flows and the heat exchange surface are reduced to the average values of the working range:

$$\begin{cases} T_A \dfrac{d\Delta\theta_A}{dt} + \Delta\theta_A = k_0\Delta\theta_{A0} + k_1\Delta G_A + k_2\Delta\theta_S + k_3\Delta N_E, \\ T_S \dfrac{d\Delta\theta_A}{dt} + \Delta\theta_A = k_0\Delta\theta_{A0} + k_1\Delta G_A + k_2\Delta\theta_S + k_3\Delta N_E. \end{cases} \quad (8)$$

Based on the dynamic model, simulation of transient processes was carried out according to the main channels of influence for a room with a volume of 3.3m×30m×30m = 2970 m^3 [4].

In the Matlab environment, we will create an m-file that contains all the parameters of the room for determining transient processes. m-file code:

```
pa=1.2;          ps=1750;
Va=2970;         Ga=16.67;
ca=1010;         cs=920;
Ma=3564;         Ms=544320;
F0=1296;         F1=1342.6;
al0=8.7;         al1=23.
```

The room model in the Matlab Simulink environment is shown in Fig. 6 [13].

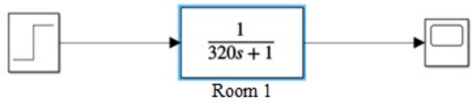


Fig. 6. Room model

The transitional process for the room is shown in Fig. 7 [14].

So, we see the inertia of the process of heating the room, which can be explained based on its dimensions and heat exchange properties.

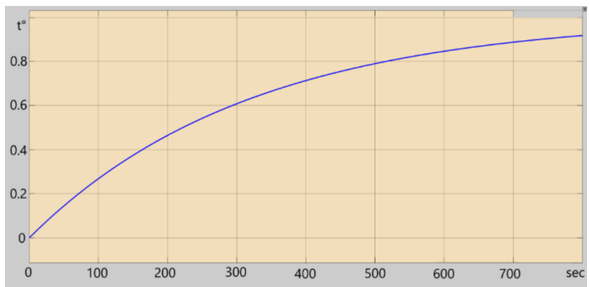


Fig. 7. Transitional characteristics of the premises

We will model the system taking into account disturbances. The temperature of the outside air is a concern. Let's set an input signal equal to 25 °C, and as a disturbance – a temperature jump of 10 °C. From the TAU theory and to simplify the graph analysis, we will take the input signal equal to 1, and the disturbance equal to 0.3. Accordingly, 1 is equal to 25 °C, and 0.3 is equal to 30% of 25 °C, which is ≈ 10 °C. When modeling, we are based on the fact that if the system can handle a sharp and large jump in temperature, it can also cope with other disturbing influences [5].

We will build simulation schemes in the Simulink package based on the functional scheme of the control system. The model is shown in Fig. 8.

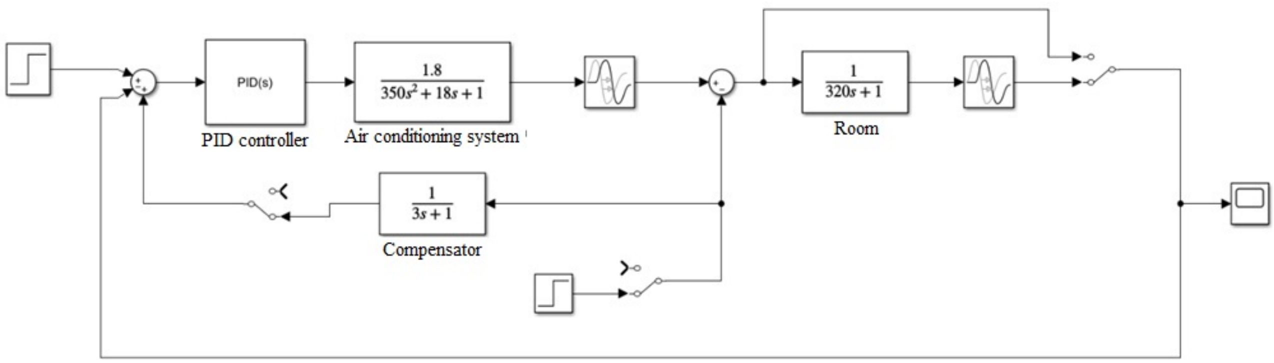


Fig. 8. Model of the ventilation and air conditioning system

We have an automatic deviation control system with a PID controller.

Research was conducted for the following cases:

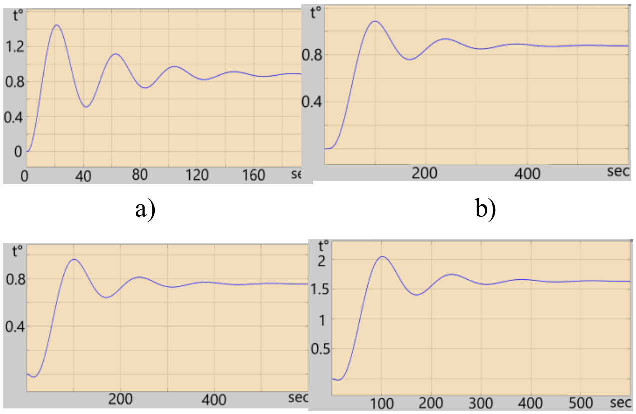
a) the system works autonomously without load at the ambient temperature $+25\,°\mathrm{C}$;

b) the system works on the load (room) providing the air temperature in it $+25\,°\mathrm{C}$;

c) the system works on the load (room) with the supply of cooled air from the outside with a temperature of $+10\,°\mathrm{C}$, ensuring the air temperature in the room up to $+25\,°\mathrm{C}$;

d) the system works on the load (room) when supplying cooled air with a temperature of $+10\,°\mathrm{C}$ providing the air temperature in the room up to $+25\,°\mathrm{C}$ in the presence of a compensator of cold influence.

Transitional characteristics of each stage of the experiment are shown in Fig. 9.



c) d)

Fig. 9. Transition characteristics: (a) is the autonomously; (b) is the for load (room); (c) is the when supplying air from the outside; (d) in the presence of a compensator

Let's analyze the above graphs. From the dependence of temperature on time, we can observe the operation of the system both autonomously and on load with the absence or presence of external disturbance. It can be seen that the deviation is a little more than 10%, which fully satisfies the requirements of the system. On the graphs, we can observe that at a certain point in time an external disturbance was applied, namely a drop in the temperature of the environment. The room heating time naturally increased. The best mode is the mode of operation with a compensator. After analyzing it, we observe that the overregulation is also no more than 10% and the system copes with the disturbance properly.

Analyzing the graphs presented above, we can come to the comforting conclusion that the system fully meets the quality requirements.

IV. Conclusions

Ventilation systems and air conditioning should be classified as the most important subsystems of life support, without which the existence of a person in the room will be complicated or become impossible at all.

Ventilation and air conditioning are widely used to maintain sanitary and production conditions in industrial (residential) premises.

The first step of energy saving when using a water heater that interacts with room heating will save electricity, which will heat air flows.

In the course of the work, an analysis of the types of recuperators was carried out, which will help save heat, the most economical, which does not use electricity, is plate, if more efficient energy storage is required, a rotary recuperator is needed, which is much smaller but consumes a small amount of energy, and the installation of these two recuperators is possible only if the air ducts placed parallel to each other, if this is not possible, a recuperator with an intermediate heat carrier will help, but it has large dimensions and higher installation costs and consumes the largest amount of electricity compared to others.

Calculations of the room were carried out, according to the heat and physical parameters, a listing was made in the Matlab environment, according to which models of the main elements of the heater were obtained, and their transient characteristics were measured in the room. The ventilation model was built, the analysis showed that in the presence of a compensator, which provided faster correction of external disturbances.

Correct and timely operation of ventilation units and maintenance of their components will lead to longer operation of the equipment.

References

[1] O. K. Ablesimov, *A course in the theory of automatic control*, Kyiv: Education of Ukraine, 2015, 270 p.

[2] O. K. Ablesimov, E. E. Aleksandrov, I. E. Aleksandrova, *Automatic control of moving objects and technological processes*, Kharkiv: NTU "KhPI", 2008, 443 p.

[3] G. F. Zaitsev, V. K. Steklov, and O. I. Britskyi, *Theory of automatic control*, Kyiv: Technika, 2002, 688 p.

[4] O. K. Ablesimov, *Theory of automatic control. Laboratory practice*, Kyiv: Print Center, 2013, 120 p.

[5] Ch. Phillips, R. Harbor, *Feedback control systems*, Moscow: LBZ, 2001, 615 p.

[6] DBN V.2.5-28-2006. *Engineering equipment of buildings and structures. Natural and artificial lighting* [Text]. View. officer - with the cancellation of SNiP II-4-79; enter 2006.10.01. Kyiv: Min. building of Ukraine, 2006.

[7] SNiP 2.04.05-91 U. *Heating, ventilation and conditioning* [Text]. Ed. non-official – instead of SNiP 2.04.05-86; entered 1996.06.27, Order No. 117, Kyiv: Kyiv ZNIIEP, 1996, 89 p.

[8] Profiling / Wikipedia [Electronic resource]. Access mode: http://ru.wikipedia.org/wiki/ 13.06.2013.

[9] S. S. Zhukovsky, O. M. Dovbush, O. T. Wozniak, Z. S. Lyulchak, and others, *Ventilation of premises*, Education. Manual, Lviv: Publishing House of NU "LP", 2007, 476 p.

[10] Catalogs of the main manufacturers of ventilation equipment and other component elements of ventilation systems.

[11] V. Dyakonov, *Simulink 4. Special reference*. Peter, 2002, 528 p.

[12] Yu. A. Kryzhanivska, *MatLAB for discrete control systems*. VDU, 2005, 27 p.

[13] Yu. M. Sokolov, *Computer analysis and design of control systems*. Kharkiv: KHAI, 2010, 343 p.

[14] Y. M. Chaban, *Some issues of ship automation: lecture notes*, Study guide, 2001, 20 p.

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Voronuk Andrey. Student.
Faculty of Air Navigation, Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2022).
Research area: energy-saving ventilation and air conditioning systems in industrial and residential rooms.
Publications: 1.
E-mail: 4103955@stud.nau.edu.ua

А. Л. Воронюк. Про вторинні енергоресурси, теплообмін вентиляції
У статті розглянуто систему життєзабезпечення, основне призначення такої системи полягає в тому, щоб зробити споруду придатною для життєдіяльності людини, або створити комфортні умови для роботи. Для створення сприятливого середовища, оптимальної температури і вологості у всіх житлових і виробничих приміщеннях використовують системи вентиляції та кондиціювання. Розроблено високотехнологічну енергозберігаючу систему вентиляції і кондиціювання з сучасною автоматизованою системою керування. При цьому було розглянуто основні напрямки модернізації енергозберігаючих систем керування, розроблено апаратне забезпечення системи енергозберігаючої вентиляції, обґрунтовано вибір типу рекуператора, як підсистеми збереження енергії, розраховані основні елементи системи, змодельовані компоненти системи вентиляції і кондиціювання, розроблено модель припливно-витяжної системи вентиляції та проведено експериментальні дослідження.
Ключові слова: вентиляція; припливно-витяжна система; повітряне середовище; теплообмінник; рекуператор; вторинна енергія; група припливних камер.

Воронюк Андрій Леонідович. Студент.
Факультет аеронавігації, електроніки та телекомунікацій, Національний авіаційний університет, Київ, Україна.
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Напрям наукової діяльності: енергозберігаючі системи вентиляції та кондиціювання в промислових та житлових кімнатах.
Кількість публікацій: 1.
E-mail: 4103955@stud.nau.edu.ua

А. Л. Воронюк. О вторичных энергоресурсах, теплообмене вентиляции
В статье рассмотрена система жизнеобеспечения, основное предназначение такой системы состоит в том, чтобы сделать сооружение пригодным для жизнедеятельности человека, или создать комфортные условия для работы. Для создания благоприятной среды, оптимальной температуры и влажности во всех жилых и производственных помещениях используются системы вентиляции и кондиционирования. Разработана высокотехнологичная энергосберегающая система вентиляции и кондиционирования с современной автоматизированной системой управления. При этом были рассмотрены основные направления модернизации энергосберегающих систем управления, разработано аппаратное обеспечение системы энергосберегающей вентиляции, обоснован выбор типа рекуператора, как подсистемы сохранения энергии, рассчитаны основные элементы системы, смоделированы компоненты системы вентиляции и кондиционирования, разработана модель приточно-вытяжной системы вентиляции исследование.
Ключевые слова: вентиляция; приточно-вытяжная система; воздушная среда; теплообменник; рекуператор; вторичная энергия; группа приточных камер.

Воронюк Андрей Леонидович. Студент.
Факультет аэронавигации, электроники и телекоммуникаций, Национальный авиационный университет, Киев, Украина.
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E-mail: 4103955@stud.nau.edu.ua