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IMPROVING THE EFFICIENCY OF THE HEATING SYSTEM FOR PUBLIC BUILDINGS INFRASTRUCTURE IN THE CONTEXT OF DNURT

Purpose. The paper analyses the possibility and terms of increasing the efficiency of heating and ventilation systems of public buildings at the present stage of development and the specific climatic conditions of Ukraine. The main purpose is to develop specific measures for public buildings, which will lead to a significant reduction in energy costs for heating and air conditioning system. The example is similar system of DNURT compact campus, which is heated with its own autonomous boiler that uses natural gas. **Methodology**. The statistical heat loss analysis for the last 5 years allows defining the types and calculating the heat loss values for specific conditions. These losses are compared with those in the world practice and based on the comparison and analysis of the current system there are offered the ways to reduce the heat loss values through the use of various technical and organizational methods. The paper also proposes involvement for this purpose of secondary and alternative energy sources. The secondary energy resources include the heat that is emitted by people and that coming out with the air during ventilation of buildings. The renewable sources include solar and geothermal energy. To enhance the heat transfer medium temperature capacity it is proposed to use the heat pumps. **Findings**. The maximum possible use of the proposed measures and implementation of rational schematic and engineering solutions for heat and hot water supply systems cam reduce the energy loss for heating and hot water by 30-35%. **Originality**. The paper for the first time proposed the use of new integrated approaches to maintain the desired heat balance in the winter period, as well as the new schematic solutions for heating and ventilation systems, both in winter and in summer, based on the use of heat pumps and secondary energy resources. **Practical value**. The introduction of the proposed schematic solutions and approaches demand relatively small capital investments and do not require significant reconstruction of already installed systems.

Keywords: heat and hot water supply system; heat loss; thermal conditions; thermal control; heat exchanger; ventilation; alternative energy sources; secondary energy resources; heat pump

Introduction

At the current period Ukraine is developing in the conditions of growing energy crisis. According to the International Energy Agency (IEA), the today's energy strategies of most consumers of fuel and energy resources (FER) focus on the problem of energy efficiency. The main energy saving potential concentrated in the area of energy use is the district heating systems (DHS). These systems are important settlement infrastructure facilities.

Currently, DHS are widespread and provide a significant share of heat demand in such countries as the Russian Federation (70%), Latvia (70%), Ukraine (66%), Poland (52%), Belarus (50%), Finland (50%), Slovakia (40%), as well as in many other countries. In the European countries (EU27) DHS share in 2010 amounted to 12% [6-9].

Despite the fact that DHS provide a significant proportion of thermal energy consumed in Ukraine, this sector accumulated a number of inter-

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related problems that have the technical, financial, economic, institutional and social aspects [7-8]. This is primarily due to the prices for energy resources and their lack. Therefore, we need a new energy management ideology. All of this is negatively influenced by the energy policy in the modern world. As a result of this, we have insufficient supply of heat and electricity to population and institutions in Ukraine. As a consequence there is a temperature drop in the rooms and classrooms of institutions, cessation of their work in the winter months, and that often has a negative effect on the students' and teachers' health. Therefore the problem of efficient use of primary energy resources in institutions of Ukraine as well as the energy efficiency management is very topical.

Purpose

Ideally, it is desirable to introduce in the University the energy management system (EMS), which is a part of the overall management system and is based on ISO 50001 standard or the Ukrainian standard [1]. EMS consists of organizational structure, planned activities, responsibilities, practices, procedures, processes as well as resources for development, implementation, analysis and revision of energy resource economy policy. The purpose of EMS introduction at the University is a continuous improvement of FER use efficiency. And the main task of EMS at the University is reducing the cost of acquisition of fuel and energy resources. Any EMS is based on the famous management cycle «Plan – Do – Check – Act» («planning – implementation – check – correction») by Edward Deming. From the start of the EMS introduction the University authorities must determine the energy resource economy policy. At the end of each cycle EMS efficiency must be assessed. The most important EMS elements are the following:

− Policy in the field of energy saving;
− FER consumption planning;
− Introduction and functioning of energy management including allocation of duties, personnel training, information exchange, creation of necessary documentation);
− Monitoring and quantitative assessment, identification of non-compliance and introduction of necessary changes;
− Study of EMS efficiency.

An extremely important aspect of the energy management system is its continuous improvement.

The University implements the energy saving measures, analyses the effectiveness of organizational and technical measures of energy efficiency. But there are the reserves, not all the energy saving potential is exhausted [2-4]. Let us determine the level of implementation by the University of energy management ideology with the help of the energy matrix (see Table 1). Horizontal rows of the matrix represent the difficulty levels of the six key management aspects specified in the vertical columns. The transition to a higher level indicates the more mature and formal approach to the energy management and means drawing near the «best practices». The University has not adopted an energy saving policy yet, the measures are implemented by pro-rector for administrative matters; there is no organizational structure of energy management at the University, no regular position of energy manager, the energy management functions are partially carried out by the energy department units and the boiler room; there is no bonus motivation to save energy, the FER effectiveness is discussed at the meetings of relevant services and rector's office; DNURT has an automated system of electric energy audit and control (this indicator gets higher mark); investment in energy saving measures is very limited due to lack of funds.

Table 1

EMS matrix implementation

Level	Energy saving policy	Organizational structure	Motivation to save energy	Information systems	Marketing	Investment
4						
3				■		
2	■		■		■	■
1		■				
0						

Analysis of Table 1 shows that there are large reserves in the FER consumption management at the University, which together with appropriate

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technical energy saving measures can lead to significant economic benefits.

Methodology

Let us consider the solving of this problem in the contest of DNURT [5]. Consumption of natural gas by DNURT for the last years is shown in Figure 1.

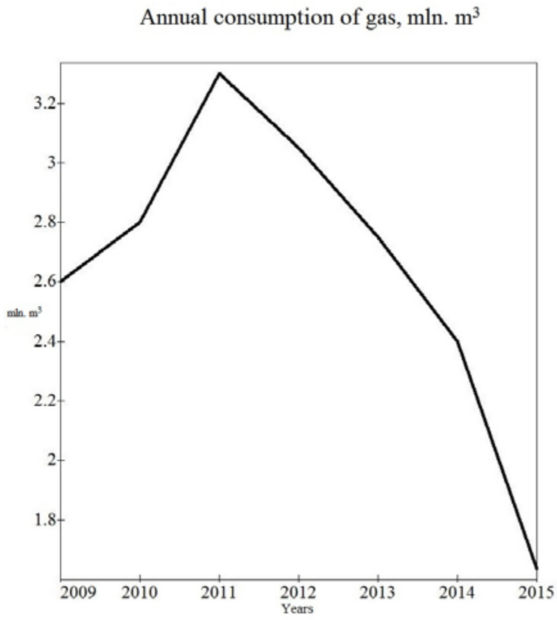

Fig. 1. Annual consumption of natural gas by DNURT

It is seen that in the last four years the natural gas consumption is constantly decreasing. But in order to reach the standards, proposed by DBN (Ukrainian national construction regulation) V 2.6-31-2006 amended as №1 of 2013 it is necessary to reduce these costs further on. Significant natural gas consumption in district heating system by one heating area of the buildings connected to it varies for different cities of Ukraine in a wide range: 130-500 kW·h/ m^{2}year [7-9]. If we take the data of Figure 1 and the total heated area of 131 447.4 m^2, then these figures for DNURT by years are in the range of 127-258 kW·h/m^{2}year. These data are presented in Figure 2.

The main energy loss in heating systems is related to the loss of the heat-generating system, loss in heat networks and loss of energy consumers. Excluding the latter two factors the significant heat energy consumption by buildings for the whole of Ukraine is decreased by 30% and is in the range of 100-350 kW·h/m^{2}year. If this approach is applied to DNURT, its main energy consumption per heating of 1m^2 during the year is in the range of 88-180 kW·h/m^{2}year.

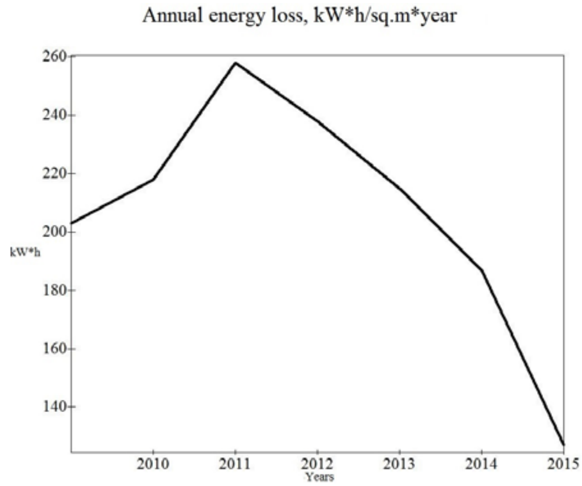

Fig. 2. Annual energy loss for heating of 1m^2 by DNURT

This is a very good indicator. But here we must remember that DNURT in recent years dramatically reduces the area that is heated in January and February.

Analysis of these data shows that the energy consumption for DNURT heating needs is at a fairly good level. But the situation in Ukraine requires further gas consumption reduction.

It should be noted that now there are many approaches when selecting technical solutions regarding energy efficiency of the heating systems. This creates some subjectivity in this field. In our opinion, considering all the features of DNURT, the most effective measures that will have an instant response are as follows: modernization of existing heating and ventilation arrangement of DNURT, the use of more effective insulation of both buildings and heat network, i.e. their thermo-modernization, the use of alternative energy sources.

The peculiarity of the heat supply system during the heating period is the monitoring of boiler performance using the heating system thermal schedules that are common for the whole Dnieper region and are based on annual weather observation of outdoor temperatures in this region [10-11]. This approach allows adjusting the temperature of the heating water exiting the boilers at the boiler

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room depending on the outdoor temperature. Thus, the temperature schedule TS130/70 provides the temperature exiting the boiler equal to 130 °C in case when the outdoor temperature is -23 °C. The heat transfer medium with this temperature reaches the heat distribution stations, which in turn further regulate the temperature of the heat transfer medium for a particular heat energy consumer. Heat distribution station layout is shown in Figure 3.

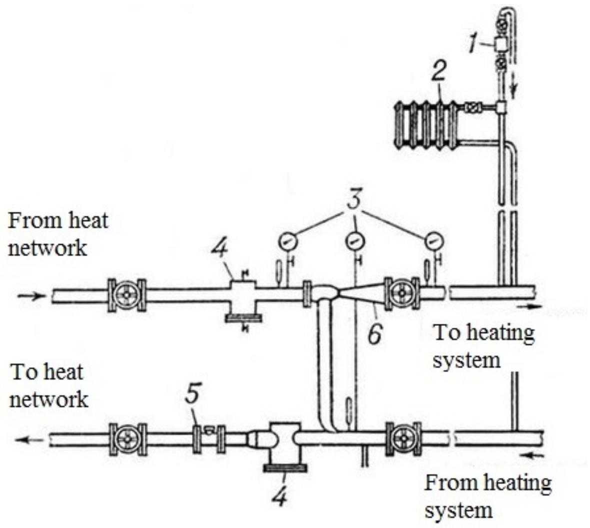

Fig. 3. Heat distribution station layout

Heat distribution stations do not allow automatic weather adjustment and reduction of room temperature in the idle period, as well as responding to the increase in the temperature in the premises with a large number of people. The latter factor is particularly relevant for educational institutions. It is known that a student while listening to lectures emits 150 W of heat energy. Therefore, we can assume that the presence of 30 students in the audience means additional heat capacity of 4 500 W. This means it is possible to reduce the heat in the audience by this value provided the prompt response to changes. In general for the University, if all students and staff are present in the morning hours, this reduction can be up 2500×150 = 375 000 W of heat energy. If we assume that they are at the University for in average 6 hours, the amount of energy to be reduced can equal to combustion heat of 210 m^3 of natural gas per day. If we take the length of the educational process in winter of 110 days, the amount of gas that can be saved by this measure will be approximately 20 000 m^3. Therefore, the existing heat distribution stations of the new and old educational buildings must be changed to more modern systems with automatic temperature control. These buildings consume the most energy. It is shown in Figure 4.

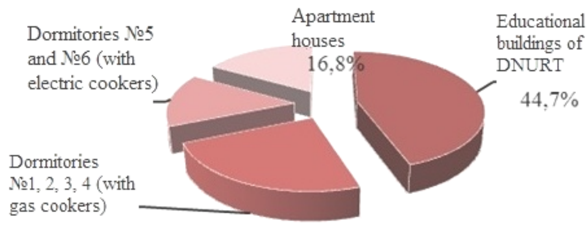

Fig. 4. Consumption of heat energy by DNURT structures.

Thermal energy consumption for heating of educational buildings when using the old and upgraded heating system is shown in Figure 5.

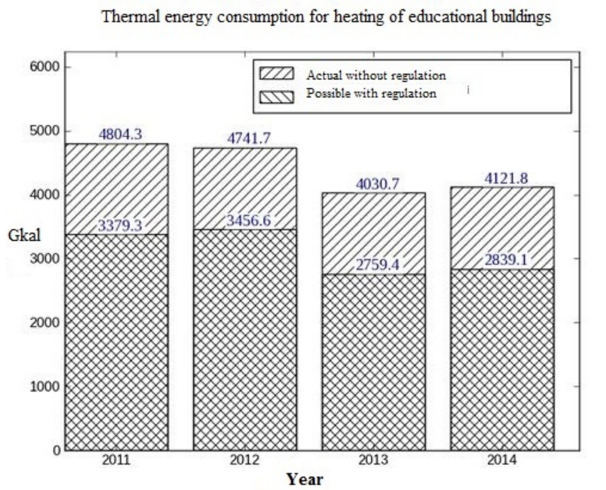

Fig. 5. Thermal energy consumption for heating of educational buildings when using the old and upgraded heating system.

The costs for such project implementation were calculated. Its main components are listed below.

1. Heat supply system renovation project: 160 ths. UAH.
2. Equipment: 600 ths. UAH.
3. Installation: 180 ths. UAH.
4. Administrative costs 60 ths. UAH.

The next step of heat energy saving is associated with ventilation of university premises [11-12]. The matter is that to ensure comfortable conditions by the regulation SNIP 2.04.059*U each person requires 50m^3 of air per hour. For 2,500

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students and employees this value is 2500×50 = = 125 000 m^3 per hour. Under the current system of natural ventilation all this large amount of air at 18 °C temperature is emitted into the environment. If its temperature for emission time is -25 °C, then for an hour we lose the amount of heat energy Q_T, which is:

$$Q_T = C_p \rho W \Delta T \quad (1)$$

C_p heat capacity of air, 1,005 kJ/kg*K, ρ – air density 1,293 kg/m^3, W – air volume emitted during ventilation $W = 50N$, N – amount of persons present in the premises, ΔT − temperature difference between the outdoor and indoor air.

Findings

The amount of energy consumed for heating of ventilation air per hour depends on the number of persons present in DNURT premises and the differential temperature. It is shown in Figure 6, depending on the number of present persons and differential temperature.

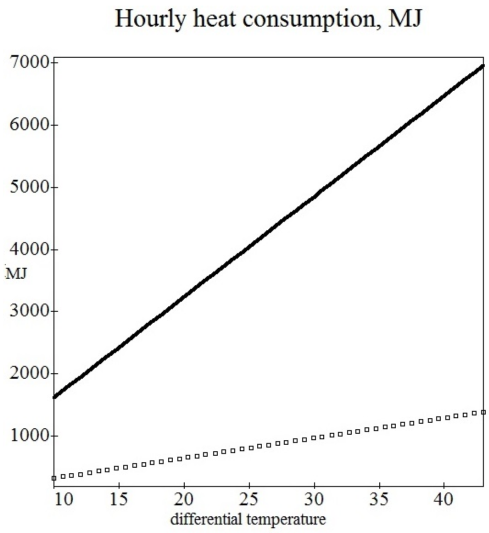

Fig. 6. The amount of energy consumed for ventilation for different quantities of persons present in DNURT premises depending on outdoor temperature (for 2 500 and 500 present persons).

The amount of energy loss for ventilation is calculated for 500 and 2 500 employees and for various differential temperatures.

Difference is calculated between the indoor temperature of 18 °C and outdoor temperature in the winter period.

The analysis of Figure 6 data shows that with natural air ventilation the University hourly loses a large amount of heat, whose value increases when the number of present persons rises and the outdoor temperature falls. This amount of heat is required to heat the same amount of fresh air that is blown into the room from outdoor temperature lower than 18 °C.

The amount of consumed gas depending on the differential temperature and the number of people for DNURT is shown in Figure 7.

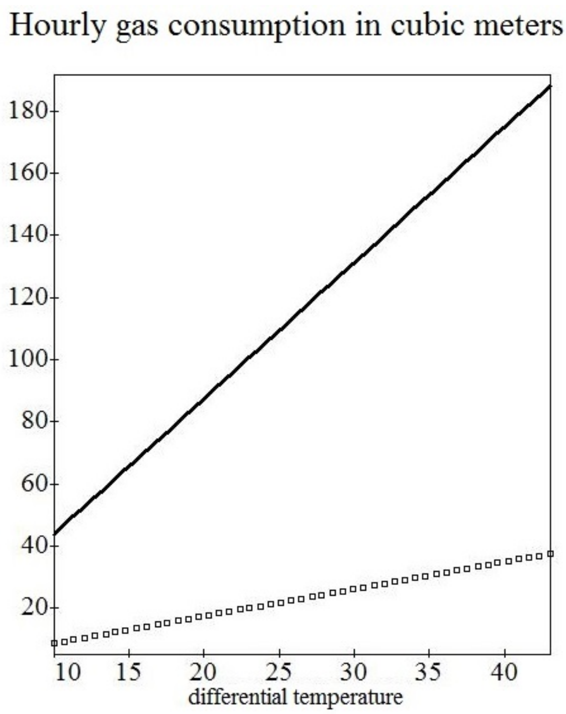

Fig. 7. The amount of natural gas consumed for ventilation air heating per hour at different quantity of persons (2 500 and 500) present in DNURT premises depending on the difference between 18 °C indoor temperature and outdoor temperature in winter.

The calculation is conducted by the ratio:

$$V = \frac{Q_T}{r} \quad (2)$$

r – natural gas combustion heat, 37MJ /m^3.

If this figure is halved due to insufficient ventilation, still the loss will be high.

To close this gap, it is desirable to implement the following measures. To fit the long enough ante-rooms at the front door as shown in Figure 8. This will ensure the heating of the air coming from outside into the large building premises by the

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warm air coming out from the building. With a large window area this ante-room will also take the energy of sunlight.

The better measure is to install rotary doors at the entrance to this ante-room. The configuration of these doors always inhibits the direct access of outdoor air into the building.

The most desirable and the most effective measure is to create a forced ventilation system.

This system can actively use recuperative heat exchangers HE, which will return to 70% of the heat energy coming out with the air emitted to the environment.

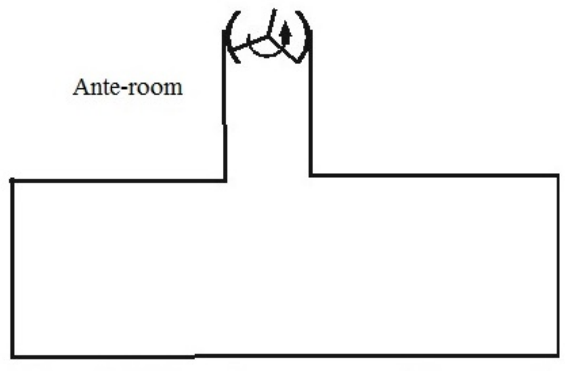

Fig. 8. Fitting of ante-room with rotary doors to reduce heating loss during students' entrance to the University

Schematic diagram of such a ventilation system is shown in Figure 9. The system contains two air ducts: outlet and inlet. From each duct one channel will come to each room R of educational building EB. Air will move through these channels with the help of fans F1 and F2. The output of the outlet duct and the input of the inlet duct must be equipped with a heat exchanger HE. In this heat exchanger the outlet air heated to 18…22 ^{o}C temperature will give the heat to the inlet air temperature of -1…-25 ^{o}C. Since the ratio of water equivalent of inlet and outlet air W_1/W_2 is equal to 1, it can be assumed that the heat transfer coefficients on hot and cold air will be equal to each other and make approximately 100W/m^{2}K. Under these parameters the heat exchanger depending on the design will take up to 80% of the outlet air heat.

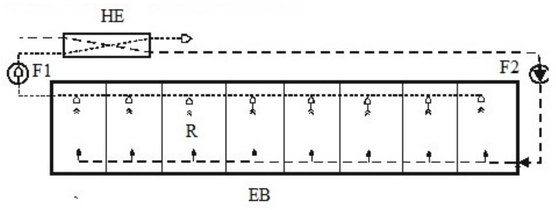

Fig. 9. Forced ventilation diagram of educational building premises with heat exchanger:
HE – recuperative heat exchanger, *F1* and *F2* – fans on the outlet and inlet ventilation ducts, *EB* – educational building, *R* – room of educational building

Heat consumption for ventilation will be reduced by the same percentage. This will save fuel which is consumed for heating the air supplied to the premises.

The advantages of such a system may also include an accurate following to the sanitary and hygienic ventilation norms. Such a system, when developed, will quite easily integrate a heat pump, which can greatly reduce the premises climatisation costs.

Another approach with a great potential is increase in the premises heat-saving properties due to improvement of insulating properties of walls and windows of the buildings. If the old building walls are thick enough (0.65 M) and have good insulating properties, the wall thickness of the new building is smaller (0.5 m), which leads to greater heat loss through the wall of about 25%. Large losses occur because of outdated window design in old and new buildings. The gap between the two glass surfaces is too large, leading to the development of free convection in this gap. This, in its turn, results in increased intensity of heat transfer through a large window surfaces. Therefore, replacement of old windows with the new insulating glass units will allow reducing the heat loss by about 30% in the heating period.

The next area of the energy efficiency of heat supply is the use of renewable energy sources. We believe that the effective real measure is the use of pellets to heat the transfer medium in the heating and hot water supply system. Pellets are the fuel pellet made of sunflower husk, straw, sawdust, waste paper, peat and peat dust, crushed chips, dry ground plant residues (leaves, twigs, hay, straw, etc.) and other solid fuel of fraction ≤ 50mm. Their application requires installation of new boilers of Grandpal Mega, Kriger GP, Bioplex type. These boilers can use the most common for Dnipropet-

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rovsk region biological resources in the form of straw and corn stems. If DNURT uses thermal capacity of 3 MW of biomass, the daily straw need will make 20000 kg.

The daily demand of DNURT boiler, if the fuel is straw, depending on thermal capacity engaged, is shown in Figure 10. The calculations included three fuel combustion heat values: lower than 13.5 MJ/kg, higher than 15.01 MJ/kg and the combustion heat of dry fuel of 16.77 MJ/kg.

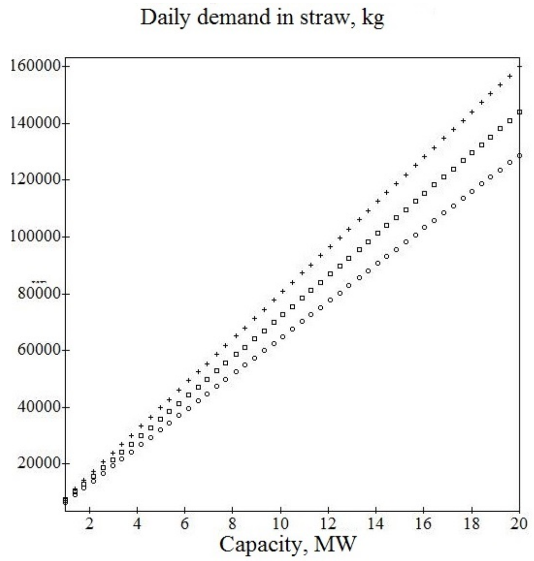

Fig. 10. Daily demand in straw by DNURT boiler depending on thermal capacity engaged

Figure 10 shows, that if the capacity is more than 3MW, the need in straw makes more than 20 tons per day. This requires substantial costs for straw delivery. That is why it is not rational to transfer the heating facilities to biofuel of more than 3MW capacity.

Fig. 11. Solar collector on the building roof

Another area for use of alternative energy sources is the use of solar collectors for hot water supply. The appearance of a solar collector is shown in Figure 11. Monthly supply of dormitory needs by solar heat system is shown in Figure 12.

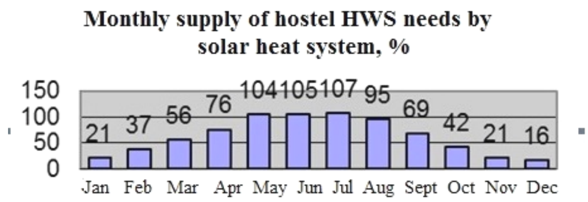

Fig. 12. Monthly supply of dormitory needs by solar heat system

Summing up the results shown in Figure 12, it can be claimed that solar collectors in general can supply more than 60% of the dormitory needs in hot water. The project provisional budget will be the following:

1. Equipment costs 520 ths. UAH;
2. Design work costs 31.2 ths. UAH;
3. Construction and erection work 312 ths. UAH;
4. Commissioning costs 52 ths. UAH;
5. Administrative costs 50 ths. UAH.

Originality and practical value

The paper for the first time proposed the use of new integrated approaches to maintain the desired heat balance in the winter period. This involves the use of such energy sources as the heat emitted by people, the heat coming out with the ventilation air and the heat of renewable energy sources. It also proposes the new schematic solutions for heating and ventilation systems that shall be integrated in one system. This system combined with a heat pump shall work efficiently both in winter and in summer.

Conclusion

Thus, this work presents only several of possible energy saving measures. There are approaches left out of consideration: use of heat pumps, geothermal heat, energy-active protection. Preliminary calculations of possible savings due to the proposed measures for various buildings of DNURT are shown in Table 2.

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Table 2

Possible saving from the proposed measures for different buildings of DNURT

Heating season	Building	Heat loss, Гкал	Possible saving			Reduction of greenhouse gases, t
			Heat, Gcal (%)	Gas, ths. m^3	In money terms, ths.UAH	
2012-2013	New educa-tional building	945.72	298.28 (31.54)	46.3	289.72	87.07
	Old educa-tional building	2716.75	856.85 (31.54)	133.05	832.29	250.14
	Assembly hall extension	368.19	116.13 (31.54)	18.03	112.8	33.9

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ РОБОТИ СИСТЕМИ ТЕПЛОПОСТАЧАННЯ ІНФРАСТРУКТУРИ ГРОМАДСЬКИХ БУДІВЕЛЬ НА ПРИКЛАДІ ДНУЗТ

Мета. У дослідженні необхідно проаналізувати можливість і умови підвищення ефективності роботи систем теплопостачання та вентиляції громадських будівель на сучасному етапі розвитку країни й характерних кліматичних особливостей України. Головною метою роботи є розробка конкретних заходів для громадських будівель, які призведуть до значного скорочення витрат енергетичних ресурсів на опалення та систему кондиціювання повітря. В якості приклада беруться аналогічні системи компактного містечка Дніпропетровського національного університету залізничного транспорту імені академіка В. Лазаряна (ДНУЗТ), який опалюється за допомогою власної автономної котельні, що споживає природний газ. **Методика**. На основі аналізу статистичних витрат теплової енергії за останні 5 років визначаються види та розраховуються величини теплових втрат для конкретних умов використання. Ці втрати порівнюються з аналогічними у світовій практиці, й на основі порівняння та аналізу діючої системи пропонуються шляхи зниження величини теплових втрат за рахунок застосування різних технічних та організаційних методів. В роботі пропонується також залучення для цієї мети вторинних та альтернативних джерел енергії. В якості вторинних енергоресурсів розглядаються теплота, яка виділяється людиною, та теплота, яка виходить із повітрям, що вилучається при вентиляції будівель. А в якості поновлювальних джерел – сонячна та геотермальна енергії. Для підвищення температурного потенціалу теплоносіїв пропонується застосовувати теплові насоси. **Результати**. При максимально можливому використанні всіх запропонованих заходів і впровадженні раціональних схемних та технічних рішень, які пропонуються для систем тепло- та гарячого водопостачання, витрати енергії на тепло та гаряче водопостачання можуть бути знижені на 30–35 %. **Наукова новизна**. Вперше запропоновано використовувати нові комплексні підходи для підтримки необхідного теплового балансу в зимовий період. Авторами також запропоновані нові схемні рішення для системи теплопостачання та вентиляції (як в зимовий, так і в літній періоди), що базуються на використанні теплового насосу та вторинних енергоресурсів. **Практична значимість**. Введення запропонованих схемних рішень і підходів до забезпечення теплом та повітрям можуть бути реалізовані при відносно невеликих капіталовкладеннях та не вимагають істотного переобладнання вже встановлених систем.

Ключові слова: система тепло- та гарячого водопостачання; теплові втрати; тепловий режим; регулювання теплового режиму; теплообмінник; вентиляція; альтернативні джерела енергії; вторинні енергоресурси; тепловий насос

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ РАБОТЫ СИСТЕМЫ ТЕПЛОСНАБЖЕНИЯ ИНФРАСТРУКТУРЫ ОБЩЕСТВЕННЫХ ЗДАНИЙ НА ПРИМЕРЕ ДНУЖТ

Цель. В исследовании необходимо проанализировать возможность и условия повышения эффективности работы систем теплоснабжения и вентиляции общественных зданий на современном этапе развития страны и характерных климатических особенностей Украины. Главной целью работы является разработка конкретных мероприятий для общественных зданий, которые приведут к значительному сокращению затрат энергетических ресурсов на отопление и систему кондиционирования воздуха. В качестве примера берутся аналогичные системы компактного городка Днепропетровского национального университета железнодорожного транспорта имени академика В. Лазаряна (ДНУЖТ), который отапливается с помощью собственной автономной котельной, потребляющей природный газ. **Методика.** На основе анализа статистических расходов тепловой энергии за последние 5 лет определяются виды и рассчитываются величины тепловых потерь для конкретных условий использования. Эти потери сравниваются с аналогичными в мировой практике, и на основе сравнения и анализа действующей системы предлагаются пути снижения величины тепловых потерь за счет применения различных технических и организационных методов. В работе предлагается также привлечение для этой цели вторичных и альтернативных источников энергии. В качестве вторичных энергоресурсов рассматриваются теплота, выделяемая человеком, и теплота, которая выходит с воздухом, изымается при вентиляции зданий. А в качестве возобновляемых источников – солнечная и геотермальная энергии. Для повышения температурного потенциала теплоносителей предлагается применять тепловые насосы. **Результаты.** При максимально возможном использовании всех предложенных мероприятий и внедрении рациональных схемных и технических решений, которые предлагаются для систем тепло- и горячего водоснабжения, затраты энергии на тепло и горячее водоснабжение могут быть снижены на 30–35 %. **Научная новизна**. Впервые предложено использовать новые комплексные подходы для поддержания необходимого теплового баланса в зимний период. Авторами также предложены новые схемные решения для системы теплоснабжения и вентиляции (как в зимний, так и в летний периоды), основанные на использовании теплового насоса и вторичных энергоресурсов. **Практическая значимость**. Введение предложенных схемных решений и подходов к обеспечению теплом и воздухом могут быть реализованы при относительно небольших капиталовложениях и не требуют существенного переоборудования уже установленных систем.

Ключевые слова: система тепло- и горячего водоснабжения; тепловые потери; тепловой режим; регулирование теплового режима; теплообменник; вентиляция; альтернативные источники энергии; вторичные энергоресурсы; тепловой насос

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