DETERMINING HEAT LOSSES IN UNIVERSITY EDUCATIONAL PREMISES AND DEVELOPING AN ALGORITHM FOR IMPLEMENTING ENERGY-SAVING MEASURES

This paper gives examples of the implementation of energy-saving measures in public premises. The introduction of energy-saving measures at enterprises significantly reduces the fixed component of industrial expenditures.

As a rule, educational institutions, for example, public premises, are financed from the state budget, and saving money on utilities will enable redirecting finances to the development of the university's educational and scientific base.

Thus, the main purpose of implementing such measures is to reduce the cost of maintaining buildings.

The measures are divided into three stages. At the first preparatory stage, the problem elements of a building and communications, which require the introduction of energy-saving measures using a special Fluke Ti25 device, are identified. Problem elements of the building structure were determined by complete scanning of the ceiling, walls, and floor with the help of a thermal imager. A large (more than 10 %) difference between indoor air temperature and the temperature of the building element indicates a problem element. The research method is thermographic.

The study contains an example of scanning the wall of the premises. The temperature difference between the left and the right sides of the wall is 2.6 °C (the difference with the room temperature is 21 %). This indicates significant heat losses through the wall. At the second stage of information processing, measures to reduce energy consumption were determined. At the third stage of the introduction of energy-saving measures, the measures that directly affect the energy consumption of a building and effective functioning of communications were implemented.

The practical relevance of the study is to obtain results and practical recommendations that can be applied in practice to improve the energy efficiency of premises and buildings

Keywords: energy saving in premises, energy audit of buildings, energy sources, energy-saving measures, technological measures, investment measures

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1. Introduction

Unstable pricing policy in the provision of energy resources leads to the actualization of the issue of energy-effective use of thermal energy. The introduction of energy-saving measures is the main direction of reducing the cost of maintaining premises and buildings [1, 2]. In order to enhance the energy efficiency, many enterprises conduct an energy audit, through which the real situation with energy supply and the energy consumption is determined [3, 4]. The use of the method for minimizing the energy consumption process becomes quite relevant [5, 6]. This is done by calculating the justified volumes of energy consumption and approaching them by optimizing heat transfer between processes, methods of energy supply and improving the characteristics of technological processes [7, 8]. This method is called pinch analysis or integration of processes [9]. The issue of the development and improvement of methodological and technical foundations for energy-saving measures is also relevant [1].

Energy efficiency and energy saving are key concepts of ensuring the efficiency of both businesses and the state in general [10]. Energy-saving is a complex of organizational, legal, industrial, scientific, economic, technical, and other

measures aimed at the rational use and economical consumption of fuel and energy resources [11]. Energy intensity of production is the magnitude of energy and fuel consumption for the main and auxiliary technological processes of production in the field of agro-industrial complex [12, 13], the performance of operations, provision of services based on the given technological system [14, 15]. Energy efficiency is one of the main strategic directions of the development of the budget industry [16, 17], a necessary tool for achieving comfortable conditions in the buildings of educational institutions, healthcare, children's, and public institutions [18, 19]. The main purpose of these events is to implement the standards of living of the modern European community [20, 21].

Efficient use of energy is one of the integrated indicators of the development of the economy, science, and socio-cultural development of the nation [22]. According to this indicator, the countries of Eastern Europe are among those countries where the stagnation of the existing provision can provoke a serious economic crisis with subsequent large-scale social shocks. In terms of energy efficiency, the situation in the housing and communal complex remains the most complicated [23, 24]. Worn-out heat and water supply stations operate at low efficiency and supply heat through the same worn-out networks. As a result, energy losses reach 45–50 % [25].

The main task of today when it comes to energy saving is the need to ensure the efficient and rational use of fuel and energy resources (FER) in all industries in Eastern Europe. These countries are energy-deficient states that import 75 % of natural gas and 85 % of oil and petroleum products. This structure of the fuel and energy balance is critical and unacceptable in terms of energy security. Based on this, one of the main tasks of the countries is to significantly reduce the inefficient consumption of energy resources. This task cannot be solved without a targeted energy policy, which would take into consideration the country's capabilities for its hydrocarbon production, development of renewable energy and energy saving, a transition of the economy to the introduction of innovations in production. At the same time, phased and consistent energy-saving measures can save up to 1/3 of energy resources [16]. The issues of energy audit and energy management for the formation of measures to improve the energy efficiency of energy supply systems are relevant.

2. Literature review and problem statement

The authors of [9, 14, 17] considered a significant number of types of energy-saving measures.

Article [9] proposed organizational measures that include internal energy audit, drawing up the energy passport of an enterprise, development of energy-saving measures, and improvement of efficiency of technological processes. These measures also include monitoring of the implementation of the accepted measures to stimulate and motivate energy-saving behavior, the introduction of the right to dispose of funds from energy savings, and the establishment of rules for purchasing the equipment for energy-efficient technologies. However, organizational measures are measures of a quick return and sometimes do not bring the desired result.

The authors of paper [14] explored the technological measures that are more radical and contribute to the rapid implementation of cost-effective and financially attractive investments. They provide for the introduction of energy efficiency standards in the area of using industrial buildings, industrial equipment, the introduction of circulating water supply systems, window cleaning, painting the walls of premises with light paint. These measures also include the application of used-up heat of refrigerators and air conditioners for heating water, introduction of the systems that provide an increase in the efficiency of electric motors in facilities with an alternating load. In addition, financial support from banks and leasing companies may be required to implement energy-efficient projects.

Paper [17] proposed the investment measures that contribute to eliminating the main causes of low energy efficiency and in most cases guarantee more significant energy savings. First of all, it is the transition to alternative sources of energy supply and the use of modern energy-saving production technologies. Although the measures of this group are most effective, they require higher initial costs. In addition, organizational changes at the country and region level are of great importance for the implementation of these measures. These include pricing reform, improvement of electricity and gas markets, transition to integrated planning of various energy sources.

Paper [26] provides the results of research into the analysis of inefficient use of the FER and identifies the ways, means, and methods for their economic use. The reason for this may be objective difficulties associated with the continuous and rapid increase in the cost of the FER, which motivates to find ways to reduce their use.

One of these ways is the reduction of energy consumption by production equipment. One of the most energy-efficient production processes in the processing industry is drying. Article [27] proposes a method for improving the equipment for intensification of the drying process of dispersed food products. It was established that due to the effective use of the volume of a drying chamber and an increase in the surface of the phase contact, the drying process became more intensive, and the cost of the dried product decreased. The authors of paper [28] proposed a combined method for drying fruit and vegetable raw materials using direct electric heating. It was found that the developed method leads to the intensification of the process and a significant decrease in its energy intensity while ensuring the established quality of the finished products. In both cases, a significant reduction in energy consumption was proved, however, very often the improvement of drying technology entails a complication of the production process and a significant increase in the cost of drying equipment.

Another option to reduce FER consumption is to conduct an energy audit on energy efficiency and energy saving.

According to [29, 30], an energy audit is a systematized analysis of use and consumption of energy for determining, quantitative expression, and preparation of the report on the possibility of the improvement of energy efficiency.

The objectives of energy audit of buildings according to [31] are:
– determining the general state of the facility consuming the FER, its main subdivisions, and technological processes as FER consumers;
– analysis of balances of FER consumption separately for each type;
– analysis of balances of FER consumption in energy-intensive technological plants, technological processes, and subdivisions;
– analysis of the FER losses in facilities;
– analysis of the cost of the FER in the cost of production;

– assessment of the potential of energy saving of facilities;

– assessment of the efficiency level of using the FER;

– analysis of specific consumption of the FER and comparison with current norms and standards, preparation of proposals for its reduction;

– assessment of the effectiveness of the ESM functioning;

– development of recommendations for the implementation of energy-saving measures with their technical and economic assessment.

Comprehensive approaches to the examination of structures during energy audit include assessment of [32]:

– the microclimate of premises;

– state of enclosures;

– state of engineering systems of heating, ventilation, and air conditioning;

– fire safety of a building;

– heat-energy state of a building.

The authors of paper [33] provide analytical recommendations that can be used as a template by engineers-practitioners to assess energy use at production facilities and implement certain energy-saving measures. Studies [34, 35] assessed and analyzed energy consumption and implemented a number of energy-saving measures for historic buildings. The proposed measures significantly reduced energy losses, but the options for reducing energy consumption in public premises were studied insufficiently. In addition, their maximum effectiveness was not proved. That is why it is an urgent need to conduct an energy audit on energy efficiency and energy saving in public areas and maximize the reduction of energy and heat losses.

Papers [36, 37] address the issue of the lack of energy resources based on new approaches, using renewable and secondary energy sources. However, the efficiency of using renewable energy sources largely depends on climatic features that make it difficult to use solar and wind energy or other natural phenomena.

The author of research [38] formed approaches to the implementation of energy-saving measures both at enterprises and housing and communal complexes. However, to select a specific group of energy-saving measures, it is necessary to identify and study the sources of energy losses in each case.

The sources analyzed above show that significant changes in the energy development strategy are taking place in the world. The advanced countries of the world identified a set of tasks for building energy strategies in the 21st century. The main direction of development is to adhere to the inseparability and coherence of actions at ensuring three components. The first is energy supply (uninterrupted supply of electricity of appropriate quality), the second – energy availability (energy efficiency and affordable electricity price), the third – energy efficiency (minimal impact on the environment). These components are considered as the basis for achieving the global goal of ensuring sustainable development, which guarantees sustainable economic growth, living standards of the population, environmental protection.

Thus, improvement of energy efficiency of industrial production and reduction of energy consumption in residential areas of Eastern Europe is not a problem of economic feasibility, but rather a problem of survival. If countries have their own sufficient hydrocarbon reserves, energy-consuming production and significant costs in residential buildings can be decreased due to cheaper hydrocarbon prices. However, energy-consuming management methods are unacceptable, as the oil and gas industries do not receive the funds necessary for their sustainable development and begin to decline.

All this suggests that it is advisable to conduct a study on the implementation of energy-saving measures for buildings.

3. The aim and objectives of the study

The aim of the research is to determine the places of significant heat losses in public premises by the thermographic method and to develop an algorithm for the examination of the entire building, which will make it possible to increase the efficiency of implementation of energy-saving measures.

To accomplish the aim, the following tasks have been set:

– to study heat losses through the windows of a building;

– to study heat loss through the walls and the doors of a building;

– to study heat losses through ceilings, floors, and the heating system;

– based on the conducted thermal image scanning of external structures of premises. to develop an algorithm for the implementation of energy-saving measures.

4. Materials and methods of research

Today, the most effective way to find out the causes and sources of heat loss and hidden defects in a building is thermal imaging examination.

Thermal imaging examination is the registration of radiation of an object in the infrared range and conversion of a thermal image into a visible one [39]. This makes it possible to check the quality of joints of panels and seams, window and door openings, and other structures of buildings and facilities. Thermal imaging examination of a building was carried out according to the procedure given in [39, 40].

The research was carried out in the educational premises of the university building as an example of public premises with an area of 5 thousand square meters, where there is a large number of rooms. As a rule, the physical location of educational institutions takes place in buildings that have not been used for 30 years or more and where energy-saving technologies have not been applied.

The research procedure was as follows. Immediately before the test, the temperature of the internal and external air was measured. The enclosures were examined in the absence of direct sunlight. Thermal imaging measurements were carried out at temperature changes between the outside and inner air of at least $10–15\,°C$. Thermal imaging was made sequentially in predetermined areas with a frame-by-frame recording of thermograms and simultaneous photography of these areas.

As a result of fixation, a photo of the room element and a thermal image of the surface temperature and air temperature in the room were obtained. The device fixed the lowest, average, and the highest temperature of the studied surface with the markets and automatically recorded numeric values in $°C$. The results obtained by the device were subjected to expert analysis to determine the places with the largest heat losses. Previously, we set the boundary minimum level of heat losses, above which it is necessary to perform heat-saving measures. In the conducted study, this level was 10 percent or more of the difference between the temperature of the element of the building and the average temperature in the room. The choice of percent depends on the financial capacity of an enterprise. The lower this indicator, the more energy-saving measures will be needed to take, the more money

it will be necessary to spend. Such places were additionally studied by an expert, and recommendations for construction workers were developed to reduce the energy consumption of the building. All procedures for conducting an energy audit of premises were presented in the form of an algorithm that makes it possible to group energy-saving measures for elements of a building (windows, walls, ceiling, floor, doors). The calculation method for determining energy saving in quantitative and cost form was proposed.

Based on the third main stage of energy audit, the stage of obtaining information as the main stage, which involves in-depth learning of the object of energy audit, documentation on the use of the FER, measurements were carried out at the energy audit object – educational premises. Measurements were performed with the use of the certified thermal imager Fluke Ti25 (serial number Ti 25-09070166) (USA) with a measurement error of 2 % and thermal sensitivity of ≤0.1 °C. During the examination, the air temperature outside was +9 °C. The educational premises have central water heating. According to the examination results, the device captures a light image of a research object and a thermal image, which marks the surface temperature in different colors. The highest temperature and the lowest temperature of the object examined by the device are indicated as a marker with a digital value of absolute temperature. A graph of colors and corresponding temperatures is also added. The examination of a building is presented by groups of research objects: windows, walls, doors, heating system, and other elements.

5. Results of the study of heat losses in premises

5. 1. Studies of heat losses of windows in a building

A building is examined by studying sequentially all premises by their complete scanning. The elements of a building, which have large heat losses, the level of which is indicated in the section of the article about materials and methods, are subject to additional analysis and belong to a certain group (windows, walls, roof, floor, doors, and heating system).

Fig. 1 shows the typical results of the examination of the windows of the premises. The causes of heat energy losses were analyzed and measures to reduce them were proposed. Characteristic places

with a temperature difference of different parts of a window indicate that there are heat losses.

The thermographic image IR004341. IS2 of windows No. 1 in Fig. 1, a, b shows that the maximum wall temperature inside the room is 20.3 °C. Analyzing examination thermogram IR004341.IS2 in Fig. 1, a, we determine that the temperature at the junction of the window to the wall is 16.5 °C, on the glass surface, it is 17.8 °C.

According to [41], the sanitary and hygienic requirements allow the difference between the temperature of the internal air and reduced temperature of the inner surface of the enclosure: for walls – 4 °C, ceiling – 3 °C, floor – 2 °C.

The temperature difference is 12–28 %. Such temperature difference indicates that the compaction between the window and the wall does not retain warmth and neither do double-glazed windows. That is why to reduce the energy losses of heat, it is necessary for builders to replace the compaction and replace the double-glazed windows.
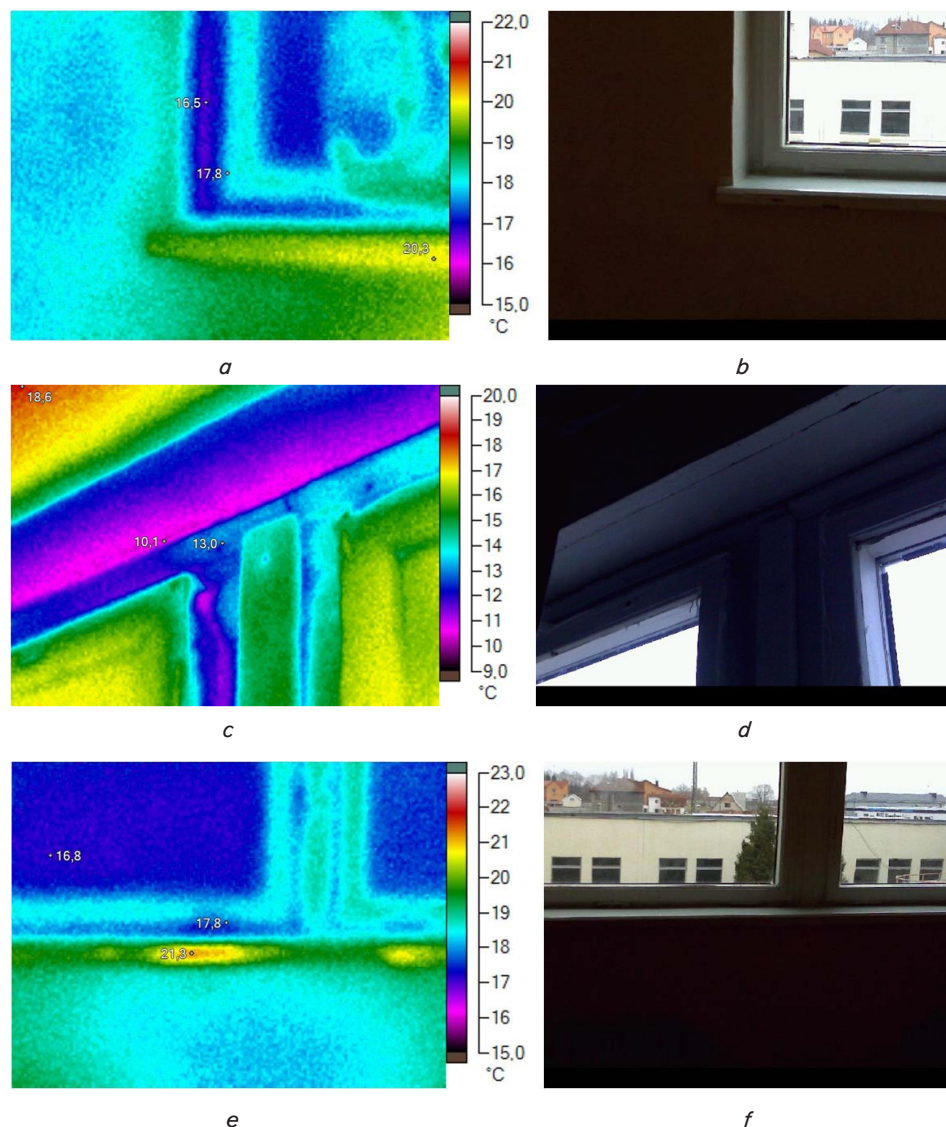

Fig. 1. Results of examination of windows in the premises using the thermal imager:
a — thermogram of window No. 1 IR004341.IS2; b — the visible light image of a window No. 1; c — thermogram of window No. 2 and the ceiling IR004367.IS2; d — visible-light image of window No. 2 and the ceiling; e — thermogram of window No. 3 IR004342.IS2; f — visible-light image of window No. 3

In thermographic image IR004367.IS2 of window number No. 2 in Fig. 1, *c, d* wall temperature is 18.6 °C, the temperature of the ceiling at the junction of the window and wall is 10.1 °C, which is 56 % lower than the air temperature in the premises. Such a large temperature difference indicates window subsidence and the formation of a gap between the top of the window and the wall. That is why to reduce the heat energy losses, it is necessary for construction workers to make compaction of the junction of the window to the wall.

In thermographic image IR004342.IS2 of windows No. 3, Fig. 1, *e, f,* the maximum wall temperature in the room is 21.3 °C. The temperature of the double-glazed window is 16.8 °C, the temperature at the junction of the double-glazed window to the frame is 17.8 °C. The temperature difference is 7–27 %. Such temperature difference indicates that the double-glazed window is not compacted and does not keep warmth, the compaction between the double-glazed window and the frame does not fit completely. That is why to reduce heat energy losses, it is necessary to replace the double-glazed windows and replace the compaction.

5. 2. The studies of heat losses of walls and doors of a building

Fig. 2 shows the results of the examination of the walls of the premises of a building. The air temperature in rooms 1 and 2 is 22.5 °C. Thermogram IR004358.IS2 of the walls of premises 1 in Fig. 2, *a, b* shows that the maximum wall temperature of room 1 is 20.5 °C.

Analyzing thermographic image IR004358.IS2 made by device Fluke Ti25 (Fig. 2, *a*), it possible to determine two zones with much lower temperatures. The first zone has a temperature of 17.8 °C, where the temperature difference is 21 %, the second zone has a temperature of 15.2 °C, where the temperature difference is 32 % relative to the air temperature in the room.

A similar zone of sharp separation of temperature difference can be determined by thermal image IR004361.IS2 of wall 2 in the room in Fig. 2, *c, d*. The temperature difference can be determined from 19.3 °C to 17.3 °C, the difference is 10 %. Additional analysis of the structure of the building in places of temperature drop made it possible to determine the causes of heat losses. Thus, the element of the building, which is shown in Fig. 2, *a, b* has a temperature of 15.2 °C, has a leakage of moisture from the roof of the room, and, accordingly, this element has a tendency to freezing and excessive cooling. That is why to reduce heat energy losses, it is necessary to eliminate the causes of the leakage of external moisture from the roof of the room. Analysis of the structure of the building in areas of temperature difference up to 17.3 °C and up to 15.2 °C according to Fig. 2, *a, b* during additional examinations indicated that part of the wall of room 2 is shared with other premises outside. That is, this part of the wall is not an external element of the building, and the second part of the wall is an external element of the building. The part that is the external element of the building has losses of thermal energy, according to Fig. 2, *a, b* – 13 %, according to Fig. 2, *c, d* – 10 %. That is why to reduce heat energy losses, it is necessary to perform external wall insulation.
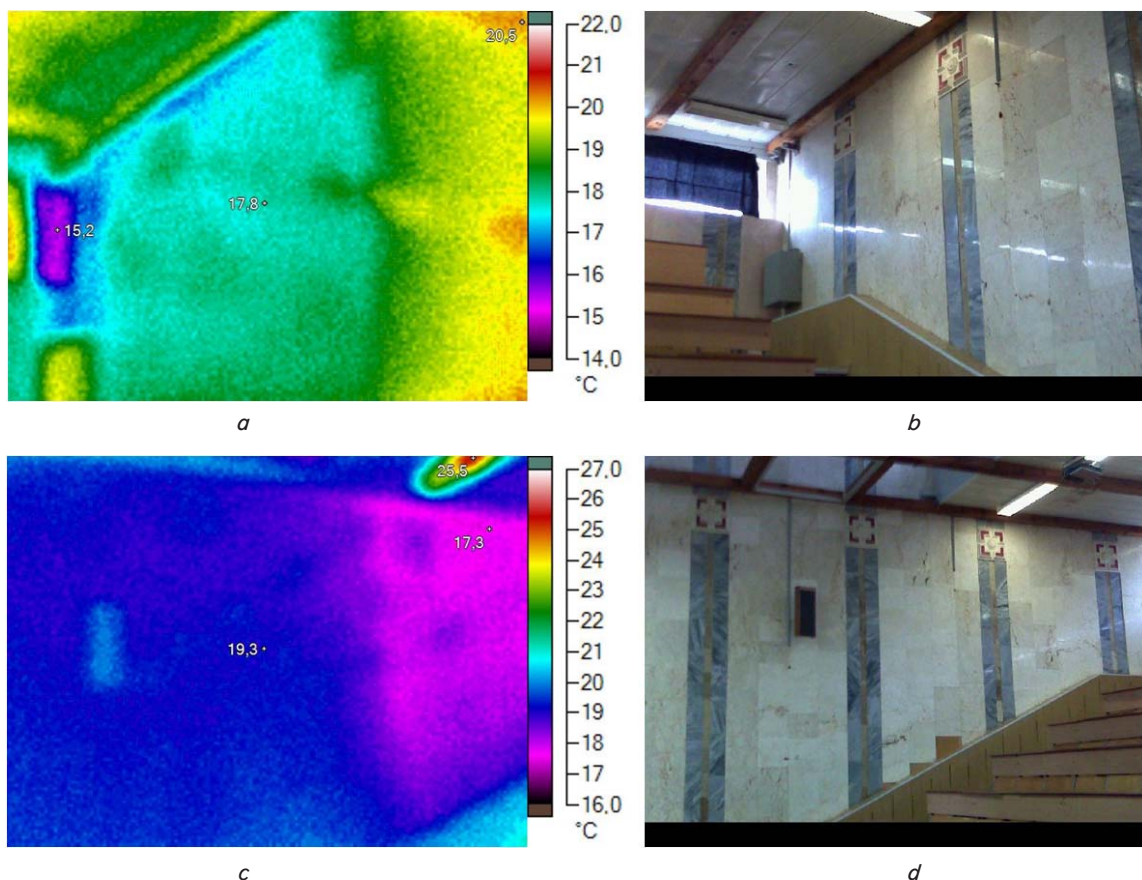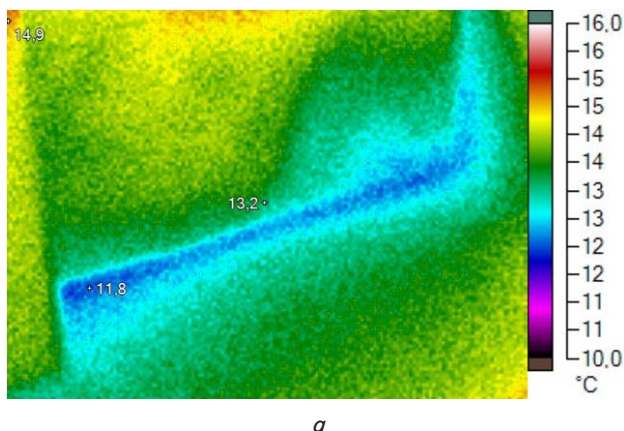

Fig. 2. Results of the examination of the walls of premises with the help of a thermal imager:
a — thermogram of the wall of premises 1 IR004358.IS2; *b* — visible-light image of the wall of premises 1;
c — thermogram of the wall of premises 2 IR004361.IS2; *d* — visible-light image of the wall of premises 2

Fig. 3 shows the result of the examination of the external doors of premises No. 1, which are used for the passage of people.
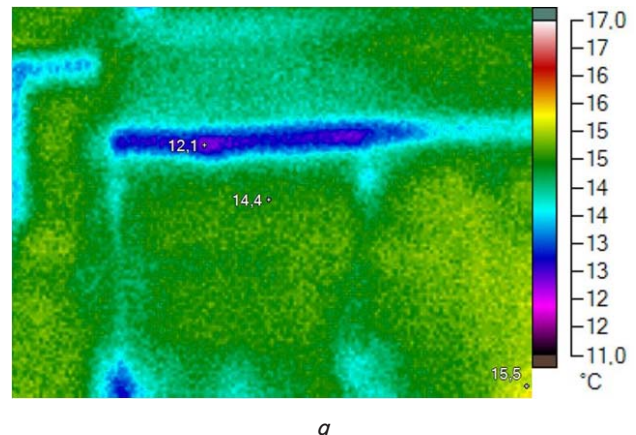

a

b

Fig. 3. Results of the examination of the external doors of premises No. 1 with the help of a thermal imager:
a — thermogram of doors IR004500.IS2;
b — the visible image of the door

Analyzing thermographic image IR004500.IS2 of device Fluke Ti25 (Fig. 3), one can determine the area at the lower part of the door, which has a temperature of 11.8 °C, which is 31 % lower than the temperature in the premises, which is 16 °C. Analysis of the structure of the door and the door frame in the temperature difference zone indicated that the compaction was not in order. That is why to reduce heat energy losses, it is necessary to replace the compaction at the bottom of the door.

Fig. 4 shows the results of the examination of external doors No. 2 of the premises used for the passage of automobiles.

Analyzing thermographic image IR004491.IS2, it is possible to determine the zone with a temperature of 12.1 °C, which is 21 % lower than the room temperature, which is 15.5 °C. Analysis of the door structure indicated that the upper compaction between the door and the door frame had failed. That is why to reduce heat energy losses, it is necessary to replace the upper door compaction.

a

b

Fig. 4. The results of an examination of external door No. 2 of the premises by a thermal imager: *a* — thermogram of doors IR004491.IS2; *b* — the visible image of the door

5. 3. Studies of heat thermal losses of the ceiling, floor, and heating systems

Fig. 5, 6 show the results of the examination of the ceiling of the premises.

Characteristic places of a decrease in the temperature of the ceiling surface, according to thermogram IR004487.IS2 are shown in Fig. 5, with a temperature of 12.1 °C, which is 23 % lower than the temperature in premises 1, which is equal to 15.7 °C. The problem zones of the ceiling, according to thermogram IR004498.IS2, shown in Fig. 6, have a temperature of 14.0 °C, which is 22.6 % lower than the temperature in the premises that is equal to 18.1 °C.

Additional analysis of the structure of the roof above these problem places of the ceiling of the premises indicated moisture leakage through the roof covering. That is why to reduce heat energy losses, it is necessary to repair the roof covering over the premises.

Fig. 7 shows the results of the examination of the floor of the premises of the building.

Analysis of thermography image IR004422.IS2 of the device Fluke Ti25 indicates a decrease in temperature on the floor stairs to 16.3 °C, which is 18.5 % lower than the temperature in the premises, which is equal to 20 °C.

Such a sharp temperature difference indicates heat energy losses from the premises to the non-heated basement. That is why to reduce heat losses, it is necessary to insulate the floor outside in the basement.
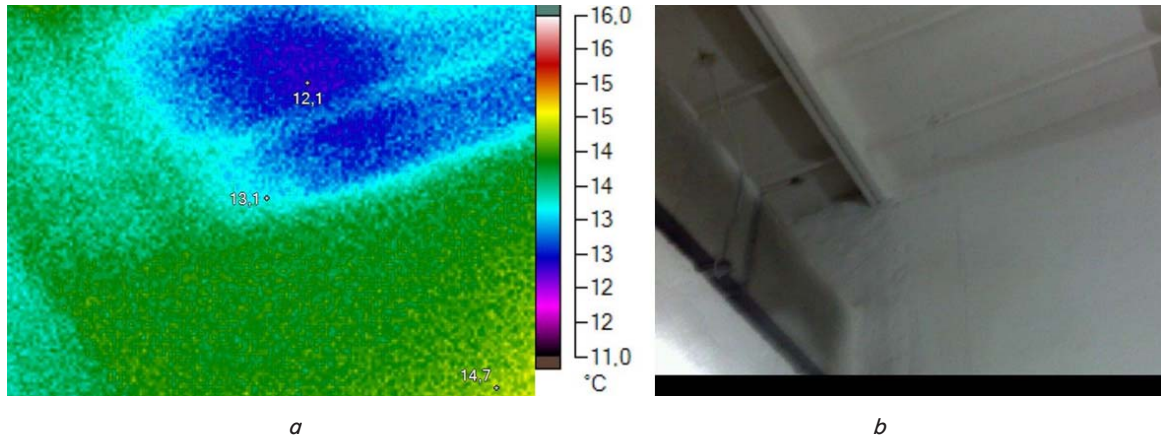
a   b

Fig. 5. Results of examination of the ceiling of premises 1 with thermal imager:
a — thermogram of the ceiling of premises 1 IR004487.IS2; *b* — visible-light image of premises 1
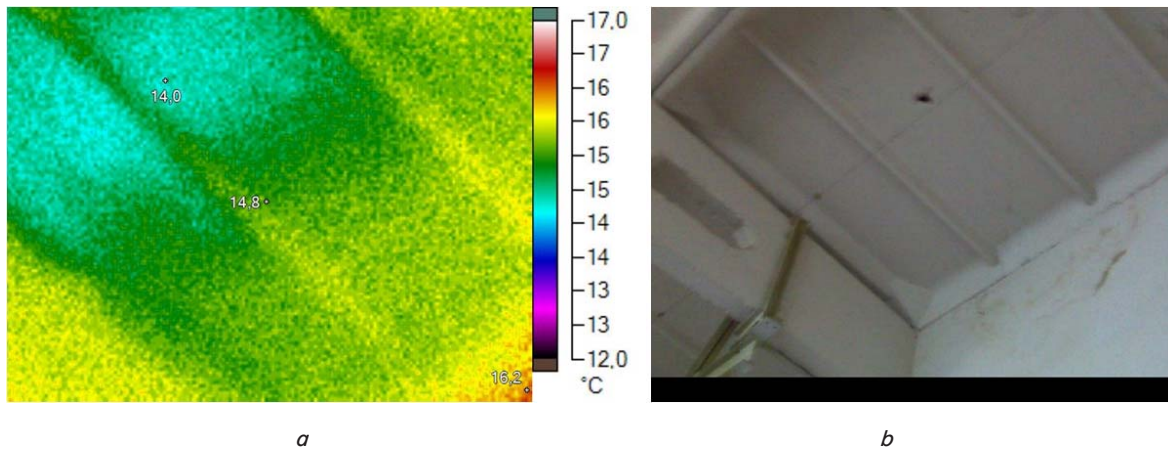

a   b

Fig. 6. Results of examination of the ceiling of premises 2 by the thermal imager:
a — thermogram of the ceiling of premises 2 IR004498.IS2; *b* — visible-light image of the ceiling of premises 2
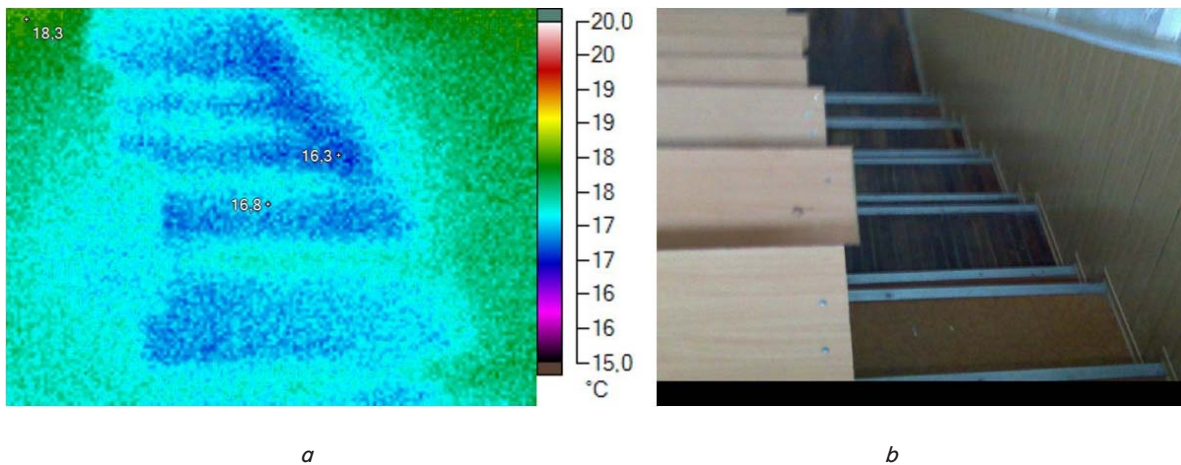

a   b

Fig. 7. Results of the examination of the floor of the premises with a thermal imager:
a — a thermogram of the floor of the premises IR004422.IS2; *b* — the visible light image of the floor of the premises

Fig. 8 shows an example of the result of the examination of the elements of the heating system, namely, the radiator. Analysis of thermographic image IR004443.IS2 of device Fluke Ti25 indicates that the coolant distribution occurs from the bottom right side in two sections, and then from the top of the radiator.
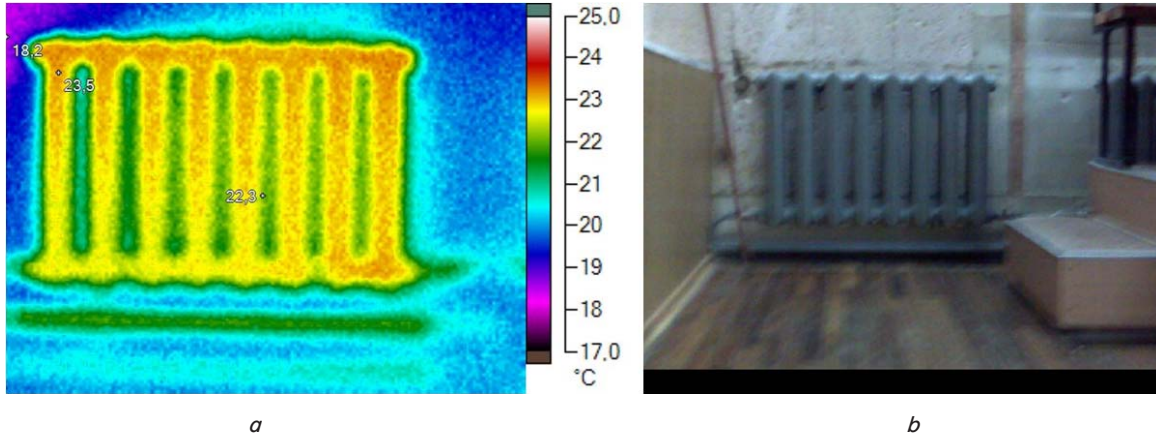
Fig. 8. Results of the examination of the heating system of the premises by a thermal imager:
a — thermogram of the examination of the heating radiator IR004443.IS2; *b* — visible-light image of the heating radiator

According to the radiator connection circuit, which is shown in Fig. 8, the heat carrier is supplied from the bottom right and comes out from the bottom left. Thus, the lower radiator line should have the lowest hydraulic resistance and the heat carrier should be of the same temperature at this place. Given that the radiator design makes it possible to give off heat in a convective way, that is, when heated, the outer air moves from the bottom of the radiator to the top, the upper part of the radiator should have the highest overall temperature. This is seen in the thermographic image. Thus, it was established that the radiator between the second and third sections at the bottom is clogged, which prevents the heat carrier from being distributed from the bottom up. Thus, in order to increase the uniformity of heating of the radiator surface, and thereby increase its efficiency, it is necessary to wash it with a special solution that washes the litter from its section.

5. 4. Development of an algorithm for the implementation of energy-saving measures in general-purpose premises

Our research makes it possible to devise energy-saving measures. The third stage of the energy audit can be presented in the form of the algorithm, which is shown in Fig. 9.

Each enterprise can set the ΔT indicator to determine the list of energy-saving measures depending on financial capacity. The lower this indicator, the more money will be needed to spend on energy-saving measures.
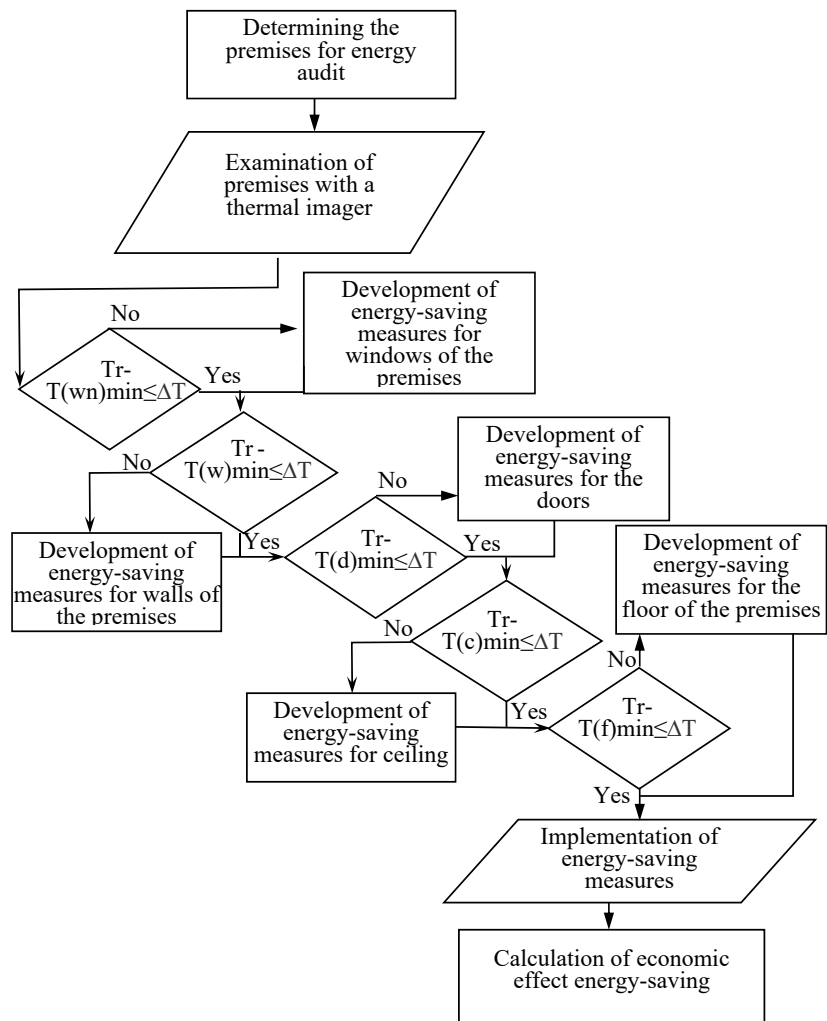

Fig. 9. Algorithm for the third stage of energy audit of the premises for general purposes: Tr — air temperature in the examined premises; T(wn)min — minimum temperature on the window surface in the premises; T(w)min — minimum temperature on the wall surface of the premises; T(d)min — minimum temperature on the door surface in premises; T(c)min — minimum temperature on the ceiling surface of the premises; T(f)min — minimum temperature on the floor surface in the premises; ΔT — permissible deviation of the surface temperature from the indoor air temperature in the premises

It is possible to state that a positive effect from the use of energy-saving measures is achieved based on the assessment of energy saving in quantitative and cost form. Comparison of current economic indicators of the activities of an educational institution before and after the implementation of energy-saving measures is determined from formula [26]:

$$\Delta P_t = Cf_t \cdot \Delta Qf_t + Ch_t \cdot \Delta Qh_t + \\ + Ce_t \cdot \Delta Qe_t + \Delta E_t - (C_t + n \cdot I_t) + \Delta Z_t, \tag{1}$$

where Cf_t is the price of saved conditional fuel at current tariffs within year t, c. u./t. c. f.;

ΔQf_t is the decrease in the supply of conditional fuel to an enterprise within year t, t. c. f./year;

Ch_t is the tariff for purchasing heat energy within a year t, c. u./GJ;

ΔQh_t is the decrease in heat consumption from outside within year t due to implementation of measures on energy saving, GJ/year;

Ce_t is the tariff for electric energy obtained from the energy system within year t, c.u./kW-h;

ΔQe_t is the decrease in consumption of electric energy from the energy system within year t due to implementation of energy-saving measures, kW-h/year;

ΔE_t is the decrease of payment of an enterprise for the environmental pollution within year t, which was due to the implementation of energy-effectiveness measures, c. u./year;

C_t, I_t are the current costs and capital investment within year t, related to purchasing, installation, and operation of energy-saving equipment, c. u.;

n is the internal norm of profitability;

ΔZ_t is the decrease of operating costs at an enterprise within year t, caused by the implementation of energy-saving measures, except for the costs of maintenance of energy-saving equipment, c.u./year.

Thus, the energy efficiency of the implementation of energy-saving measures E_j can be calculated from the following formula:

$$E_j = E \left(\frac{1}{1 - \frac{\Delta P}{P}} \right), \tag{2}$$

where E is the original energy effectiveness.

Energy effectiveness after the implementation of an energy-saving measure is the summand of original energy efficiency by the coefficient depending on relative energy saving. This coefficient indicates by how many times the energy efficiency of the considered efficiency increases at relative energy saving equal to $\Delta P/P$.

6. Discussion of the results of studying thermal losses in general-purpose premises and the proposed algorithm for their elimination

The studies performed in the research prove the expediency of using the thermographic analysis of sources of thermal losses in premises.

Examination of the elements of the premises – windows, walls, ceilings, floors, doors, heating systems – with a special device Fluke Ti25 thermal imager makes it possible to identify the places that have increased heat losses. Additional analysis of such places allows determining the causes of energy losses and proposes the measures to reduce them.

The data on thermographic examination of the surfaces of the elements of buildings (Fig. 1–7) indicate significant heat losses. Temperature difference at the junctions of building structures relative to the temperature in the room varies in a significant range.

Thermographic scanning of the junctions of window blocks to the walls (Fig. 1) shows the temperature difference relative to the air temperature in the room equal to 6.5–13 °C. This temperature difference is explained by poor-quality installation work, window frames subsidence and the formation of gaps between the window and the wall, the failure of compactions between the elements of building structures, and the non-hermeticity of double-glazed windows.

Scanning the walls of the premises (Fig. 2) shows a difference in the temperature of the surface of the walls and air in the room of 2–7.3 °C. First of all, this is due to the unsatisfactory heat transfer resistance of wall enclosures. In addition, some elements of the wall allow a leak of external moisture through the cracks, which leads to freezing and excessive cooling of the walls.

The resulting thermograms of the examination of the doors of the premises (Fig. 3, 4) show that the temperature of the surfaces of enclosures is by 3–4 °C less than that of the air in the room. This is due to the absence or failure of compactions between the doors and their frame. In addition, the studied windows and doors have been in operation for more than 30 years and do not meet the requirements of the current standards [42].

The obtained values of the temperature of the walls and junctions of building elements exceed the permissible value of the temperature difference by 1.6–3.3 times, which according to [41] for walls should not be more than 4 °C.

Analysis of the thermograms of examination of the roof of the premises (Fig. 5, 6) shows the difference of temperatures of the surfaces and that of internal air by 3.6–4.1 °C. This is explained by a low value of heat transfer resistance of the ceiling. Additional analysis of the roof structure over the problem areas of the ceiling of the room indicated moisture leaking through the roof covering, which leads to its freezing.

The difference in temperature for the floor according to the thermogram (Fig. 7) is 3.7 °C. Such a sharp temperature difference indicates an unsatisfactory value of the heat transfer resistance of the floor and the loss of heat energy from the room to the basement, which is not heated.

Permissible values of temperature difference according to sanitary and hygienic requirements of regulatory documents are 3 °C for the ceiling and 2 °C for the floor, respectively [41]. The obtained results of the studies show an excess of normative values by 1.2–1.4 times for the ceiling and almost by 2 times for the floor.

Most premises of public institutions were built in the 70–80s of the last century. As practice shows, the heating systems of these premises are obsolete and need modernization. The conducted analysis of the heating system examination (Fig. 8) indicates a strong clogging of heat exchangers, which is explained by improper preparation of the heat carrier and obsolete equipment. In order to ensure uniform heating of radiator surfaces, and thereby increase their ef-

ficiency, it is necessary to regularly wash radiator sections with special solutions.

For thermographic analysis of the premises of the building, an algorithm for conducting the third stage of energy audit was proposed. The developed algorithm (Fig. 9) makes it possible to systematize the process of energy audit of premises, break it into components, and, as a result, group energy-saving measures by elements of the building (windows, walls, roof, floor, doors).

The specific feature of this algorithm is that permissible deviation of surface temperature from the air temperature in room ΔT is used as the main audit parameter. Each enterprise can set the level of ΔT deviation to determine the list of energy-saving measures depending on its financial capacity.

The places with increased heat loss have a surface temperature much lower than the air temperature in the room. This research considered the places of heat losses, which have more than 10 % of the temperature difference ΔT of the surface and air temperature in the room. This difference is used to obtain a significant economic effect.

The proposed algorithm can be used during the third stage of an energy audit for any premises of sizeable buildings, that is, a large number of premises. The algorithm makes it possible to group problem elements of premises (windows, walls, roof, floor, doors, heating systems) throughout the building. At the stage of removal of identified shortcomings, it is possible to use specialized teams of builders, which will affect the improvement of quality, reducing the costs and terms of these works.

The implementation of any energy-saving measures should be justified by the relevant economic calculations that make it possible to compare the activities of an enterprise before and after the implementation of energy-saving measures.

Internal defects of enclosing structures of premises during scanning by a thermal imager can be detected only in cases where they make changes in the temperature field on the surface of an object. This is the limitation of this study and there is a need for preliminary calculations and experiments. Thermal imaging examination can reveal a defect, the size, depth of location, and thermal characteristics of which create a change in the temperature field on the surface of an object, which is equal to the temperature sensitivity of the device.

A further direction of work is to determine thermal losses of premises through ventilation emissions and study the options for their disposal through the use of recuperative systems.

7. Conclusions

1. The conducted examination of the windows of the premises revealed the causes and places of heat energy losses. It was established that the temperature difference between the surface of the elements in the junction of windows with the walls and the ceiling is 17–45 %.

2. The places and causes of heat energy losses through the walls and doors of the premises were determined. It was established that the temperature of the surface of problem areas is 10–21 % lower than the air temperature in the rooms.

3. The places and causes of heat energy losses through the ceiling and the floor of the premises were determined. The results of the examination show that in characteristic places of heat losses, the surface temperature of the elements is 10–18 % lower than the air temperature in the room. Thermographic analysis of the heating system was performed and the measures to increase its efficiency were proposed.

4. We proposed the algorithm for conducting the third stage of energy audit of premises, which makes it possible to systematize this process, break it down into components, and, as a result, group energy-saving measures into elements of the building, which will affect the improvement of the quality of work, reducing the cost and timing of their implementation. The algorithm can be used during the third stage of an energy audit for any buildings where the normative sanitary and hygienic requirements were not met. Such buildings are rather sizeable, in other words, they have a large number of rooms.

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