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CIVIL BUILDINGS HEATING SYSTEM THERMAL RENEWAL

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An important priority of Ukraine's economic policy is careful use of energy resources. The country has a broad-based energy efficiency policy, and energy efficiency is complex, covering both the legislative framework and technical innovations. One of the effective ways to reduce energy costs for the needs of the national economy is to carry out thermal modernization of the heating system. In this article economic indicators of thermal sanitary measures during reconstruction of the heating system of the object are given. In the reconstruction of the heating system, the following thermal renewal measures were adopted for comparison: the installation of the air solar collectors, the reconstruction of the heating system, and the installation of air solar heating system.

Key words: energy saving; air solar collectors; air solar heating system; thermal renewal measurements; thermo-modernization; energy audit.

Introduction

In our time, the issues of energy saving, energy resources accounting and management are extremely relevant [Baranyai et al., 2014]. In the context of an acute economic crisis, the careful use of energy carriers is an important priority of Ukraine's economic policy. At present, as a priority task, a large-scale energy efficiency policy is being implemented in our country [Law of Ukraine "On Energy Saving"], [Ukraine's energy strategy for the period until 2030]. The tasks of energy saving in Ukraine are comprehensive and cover aspects of both external heat supply and internal engineering systems of buildings (heating, ventilation and air conditioning), as well as the legislative framework and technical innovation. So, a lot of energy is spent on creating a microclimate in industrial and residential premises [Chel et al., 2008]. One of the most energy-efficient ways of heating high premises is the systems with infra-red heaters [Mysak et al., 2014], which allow to purposefully partially heat different zones of the production premises [Kővári et al., 2015]. To reduce heat losses in heat supply systems it is expedient to insulate the fittings and shut-off valves [Zhelykh et al., 2009].

There is no doubt that the energy needs of the heating system need to be reduced as a result of thermo-heating. To achieve maximum effect, it is necessary to determine the economically expedient level of heat protection of heating systems, which should be optimal both in heat engineering and in economic terms. The choice of energy-saving operating conditions for existing heating systems is often carried out using the UNIDO technique.

The purpose of the work is to establish the economic indicators of thermo-renovation measures in the reconstruction of the heating system of a residential building.

The object and methods of research. During the reconstruction of heating systems, such thermo-efficient (energy-saving) measures (TRM) deserves attention: installation of an air solar collector, reconstruction of the heating system, installation of a solar air heating system.

Research results. On the basis of theoretical and experimental researches, an energy-saving design of heating air solar system (HASS) with turbulators of the stream was developed (Fig. 1).

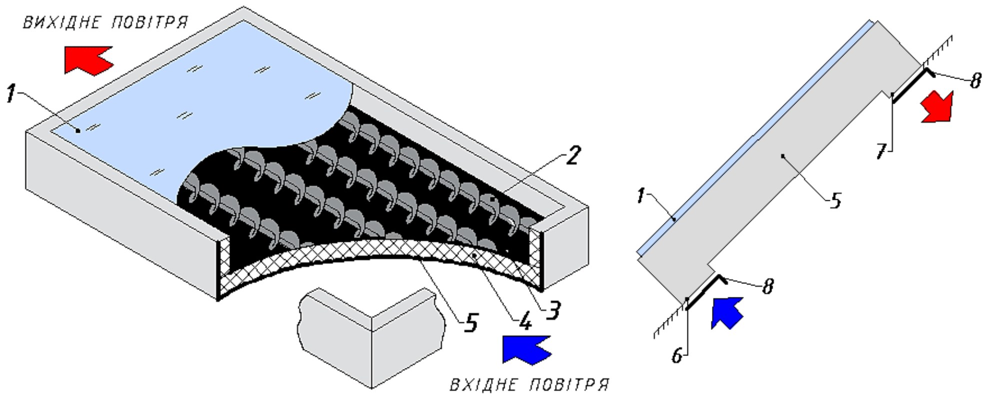

Fig. 1. Structural appearance of proposed HASS:
1 – glass plate; 2 – turbulizer of air flow; 3 – heat-absorbing plate; 4 – thermal insulation;
5 – collector housing; 6 – entrance hole; 7 – outlet; 8 – control valve

The technical solutions for improving the thermal characteristics of the air solar collector are proposed.

In particular, in the air channel along the motion of the coolant, turbulators of the flow are installed, which are made of sheet steel in the form of a circular twisted conoid with a selective coating. Flow turbulators provide an additional area of heating and intensification of heat exchange processes in the air channel of the HASS. The bottom and side walls of the collector housing are covered with a layer of thermal insulation to minimize heat loss in the environment.

The developed design can be installed on the outer wall or roof of the building or mounted in an external protection (Fig. 2 (a), (b)).

On this basis, a heating system with developed ASC and a thermal battery (Fig. 3) was proposed.

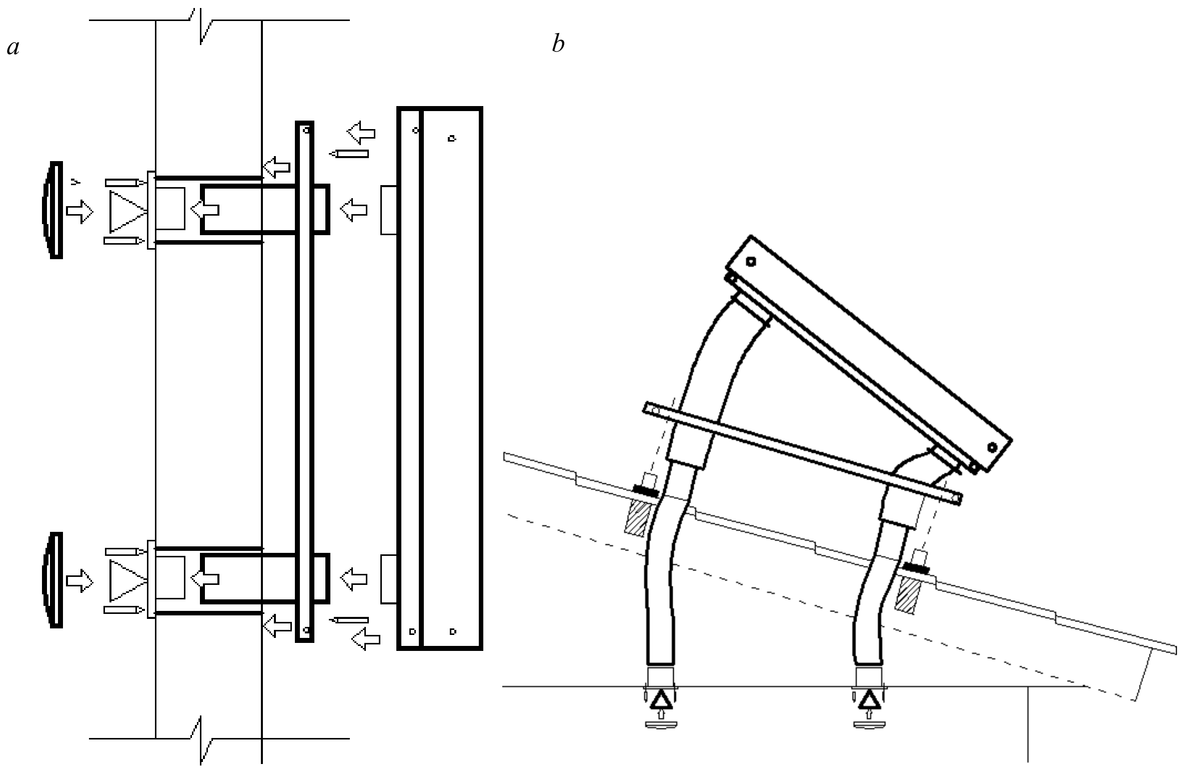

Fig. 2. HASS location options:
a – HASS is located on the wall of the building; b – the HASS is installed on the roof of the building

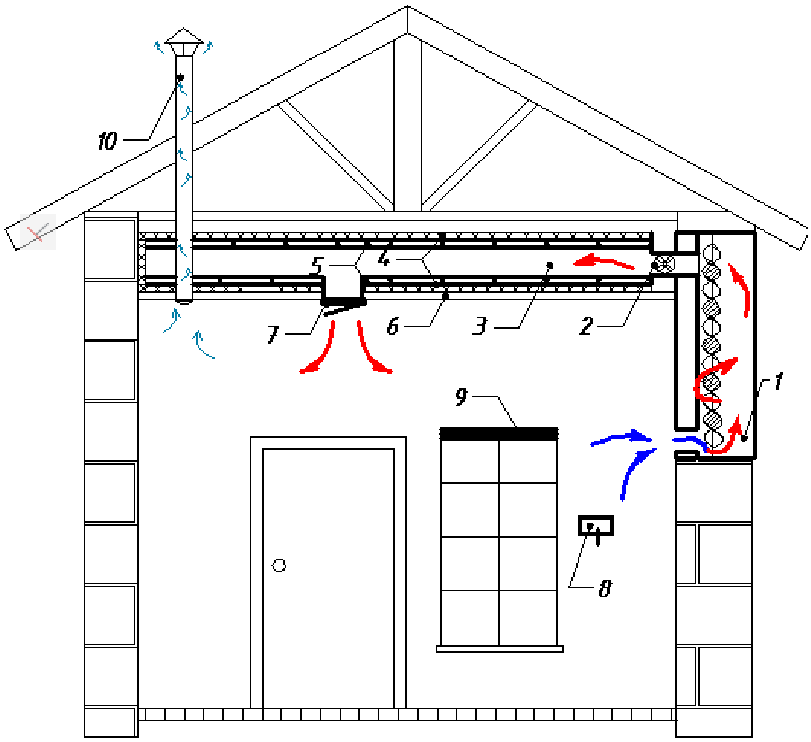

Fig. 3. HASS location options:
heating system with HASS, which is mounted on the exterior wall:
1 – air solar collector; 2 – fan; 3 – air supply; 4 – heat-accumulating coating with saturated solution of Glauber salt; 5 – thermal isolation of the duct; 6 – cushioning ceiling; 7 – air distributor; 8 – temperature sensor; 9 – window ventilation valve; 10 – exhaust ventilation duct

The performed researches made it possible to develop a methodology for engineering calculation of the basic parameters of the heating system operation on the basis of PSK with turbulators of the flow.

According to the concept of UNIDO, by introducing some symbols, for each “simple” TRM, where i = 1÷n, the following basic economic characteristics are defined [Vozniak et al., 2010]:

– I_i – investment funds for the realization of the TRM, UAH;

– K_i – annual funds saved by reducing energy consumption of the system with the possible realization of thermal engineering according to the transit route, UAH/year;

– $SPBT_i$ (Simply Pay Back Time – S_i) – the simple time of returning funds (expenses), which does not take into account the inflation factor, years;

– $NPVR_i$ (Net Present Value Ratio – Y_i) – net worth variable; the profit from the realization of this TRM during the consideration of the investment, UAH;

– IRR_i (Internal Rate of Return) – Internal Rate of Return, %.

There is an objective need to consider additional “cumulative” thermal renewal variants (TRV), with the effect of combining two or more “simple” TRM selected from the “list”. Let us indicate them, according to the selected indexes, in the next way: TRV_{12} (joint activity of fist thermal renewal measure – TRM_1 and 2nd – TRM_2), TRV_{13} (set TRM_1 and TRM_3), TRV_{23} (total effect TRM_2 and TRM_3), TRV_{123} (comprising three thermal renewal measures – TRM_1, TRM_2 and TRM_3) etc. These thermal renewal variations are called ”cumulative” and they should be treated as separate TRV with its indicators: SPBT, NPVR, IRR, etc.

If number of TRM is n, then the total number of TRM is 2^n. The question is which of these 2^n TRV is the most efficient economically? For the answer it is necessary to consider and analyze the method of conducting the energy audit of the system, after some optimization. The number of “aggregate” TRV is determined by the number of combinations C_n^m, where n is the number of possible TRV from the “list”, and m varies from 0 to n. Consequently, the amount of "aggregate" TRV is numerically equal to the sum of the coefficients of the Newton binomial 2^n.

For the most qualified conducting of energy audit it is expedient to consider the maximum possible number of TRM that can be operated by an energy auditor, that is, the so-called "list" should be as complete as possible. In connection with this, there is a need to create such a method of carrying out the energy auditing, which would allow to avoid bulkiness when considering all possible TRV, giving the opportunity to reduce their quantity in a reasonable way, and at the same time, to determine without fail the most optimal final result – the recommendation of the energy auditor to the customer.

Consequently, in order to optimize, it is necessary to compile a square matrix with the number of rows n and columns m, which, in fact, equals the number of all "simple" TRM, namely n. The number of "aggregate" TRV marked with "+" will increase by 1 in each of the following columns until it reaches the last total of "simple" TRM (Table 1). In it Arabic numerals are numbered "simple" TRM, and Roman – "aggregate" TRM. In this regard, we note that the rows need to be filled with the appropriate thermosetting measures as their parameter S_i increases, that is from $SPBT_{min}$ to $SPBT_{max}$.

Output data for conducting energy audit of the heating system are: construction site, construction part (plans, sections, building structures, etc.), annual energy consumption for the needs of the heating system Q_0, GJ/year, cost of energy consumption P_x, UAH/GJ, data for counting estimated cost of thermal modernization works I_i, UAH, the degree of discount r (economic analysis is carried out under conditions of constant prices and timing of investment consideration t = 15 years).

As a result, an optimal thermal design variant and its economic parameters are determined, and the solution is obtained by the following algorithm:

1. Calculation of annual energy consumption for the needs of heating system Q_0, GJ/year and this option is considered "basic" (zero).
2. Choosing a "list" of thermal renewal measures for this system, in particular:
   2.1. Installation of air solar collectors (ASC).
   2.2. Reconstruction of the heating system.
   2.3. Installing of heating air solar system (HASS).
3. Calculating energy efficiency ΔQ_i for each TRM as $\Delta Q_i = Q_o - Q_i$, and hence – annual savings K_i, UAH/year.

$$K_i = \Delta Q_i \cdot P_x. \qquad (1)$$

The results of calculations are listed in Table 1.

Table 1

Characteristics of energy saving measures

No.	Measures	Energy costs for the "basic" option $Q_{o,}$ GJ/year	After the change Q_i, GJ/year	Energy saving ΔQ_i $\Delta Q_i = Q_o - Q_{i,}$ GJ/year	Savings money K_i $K_i = \Delta Q_i \cdot P_{x,}$ UAH/year
1	Installation of only air solar collectors (ASC)	80.5	47.0	33.5	11055
2	Reconstruction of the heating system	80.5	70.5	10.0	3300
3	Installing of heating air solar system (HASS)	80.5	59.2	21.3	7029

4. Capitalization of investment costs I_i and work on each *TRM* (Table 2).
5. Determination of indicators of each TRM: $SPBT_i$, $NPVR_i$ and IRR_i (Table 2).
   5.1. Calculate the value $SPBT_i$ (S_i):

$$S_i = \frac{I_i}{K_i^{'}}. \qquad (2)$$

5.2. Calculation of the indicator $NPVR_i$ (Y_i).

To calculate the $NPVR_i$ for the i-th TRV, the annual profits are pre-determined by the formula:

$$K_i^{'} = K_i - T_i - \Delta T_i , \quad (3)$$

where K_i – annual savings, UAH/year; T_i – taxes, UAH/year; ΔT_i – other expenses, UAH/year (it was adopted T_i = VAT in the amount of 20 %, and the value of ΔT_i neglected).

During t years cash flow CF_i:

$$CF_i = K_i^{'} \cdot t . \quad (4)$$

The inflation rate A for t years has been determined with a certain degree of discount r, which is taken according to the data of banking institutions:

$$A = \frac{1}{(1+r)^t} . \quad (5)$$

Total revenue B during time t:

$$B_i = CF_i \cdot A . \quad (6)$$

Net price variable $NPVR_i$ (Y_i):

$$Y_i = B_i - I_i . \quad (7)$$

Table 2

Economic indicators of the thermal renewal measures

№	Measures	I_i	$K_i^{'}$	$SPBT_i$ (S_i)	$NPVR_i$ (Y_i)	IRR_i
		UAH	UAH/year	year	UAH	%
1	Installation of only air solar collectors (ASC)	78000	11055	7.1	+33224	+4.77
2	Reconstruction of the heating system	34000	3300	10.3	+12543	+7.89
3	Installing of heating air solar system (HASS)	104000	7029	14.8	+17963	+5.14

5.3. IRR_i – is numerically equal to the discount rate ri under the condition $NPVR_i$ = 0 (Y_i= 0), that is, the maximum inflation (r_i), in which the funds invested will pay off inflation, but without profit.

$$Y_i = \frac{K_i^{'} \cdot t}{(1+r_i)^t} - I_i \quad (8)$$

Since the condition Y_i = 0, then:

$$\frac{K_i^{'} \cdot t}{(1+IRR_i)^t} = I_i \quad (9)$$

Since, by the definition t = 15 years, then $15K_i^{'} = I_i(1+IRR_i)^{15}$, from where:

$$IRR_i = \left(\frac{15K_i}{I_i}\right)^{\frac{1}{15}} - 1 . \quad (10)$$

1. Conducting optimization for getting of maximal economic effect (Table 3).

Since the consideration of TRM in the amount of 2^n is an extremely cumbersome process, it is advisable to simplify it, using a scientifically based methodology aimed at reducing the required amount of TRM, that is, to carry out appropriate optimization (Table 3).

Table 3

Optimization of options for getting of maximal economic effect according to paragraph 6

№	Measures	Variants		
		I	II	III
1	Installation of only air solar collectors (ASC)	+	+	+
2	Reconstruction of the heating system		+	+
3	Installing of heating air solar system (HASS)			+
	Indexes			
1	Investment expenses *I,* UAH	78000	112000	216000
2	Annual savings *K,* UAH	11055	*14355*	*21384*
3	Simple time of returning expenses– *SPBT* (year)	7.1	7.8	10.1
4	Net Present Value Ratio – *NPVR,* UAH	+33224	+56132	+61423
5	Internal Rate of Return – *IRR,* %	*+4.77*	*+6.55*	*+7.93*

To carry out such optimization, a square matrix (Table 3) with a number of rows n and columns n was constructed, which, in fact, equals the number of all "simple" TRM, namely n.

The number of "aggregate" TPM marked with "+" marks will increase by 1 in each subsequent column until it reaches the last total of "simple" TRM (Table 3). In it Arabic numerals are numbered "simple" TRM, and Roman – "aggregate" TRM. The rows in Table 3 are filled with the appropriate thermosetting measures as their S_i parameter rises, that is from $SPBT_{\min}$ to $SPBT_{\max}$. After determining the economic indicators of all "aggregate" TRM from the composite matrix, the variant with an $NPVR_{\max}(Y_j = \max)$ is considered optimal.

Thus, in the general case, the TRM are located in Table 3 in the order of increasing value of $SPBT_i$, and the required TRM_j are considered as aggregate TRM, and the optimal one is considered the TRM, in which the $NPVR_j$ (Y_j) is the largest.

It should be noted that the TRM with the $NPVR_i > 0$ and $IRR_i > r$ will be profitable, and $NPVR_j < 0$ and $IRR_j < r$, will be unprofitable. At the same time, it is important to note that a unprofitable TRM in combination with profitable TRM sometimes generates a profitable TRM. But this TRM somewhat worsens the situation and can not have an $NPVR_{\max}$, that is, it will not be optimal.

We will optimize the SRT taking into account the data of p. 6 and compile Table 3 ordered from the first TRM_1 " Installation of only air solar collectors (ASC)", in which the parameter $SPBT_1$ is minimal, until the last (third) "Installing of heating air solar system (HASS)" with a maximum $SPBT_5$.

The optimum, as noted, is that TRM_j, in which $NPVR_j$ (Y_j) is the maximum, namely, TRV_{III}. This means that the maximum economic effect will be in the case of the simultaneous application of four TRM (Table 3). It should be noted that the optimization carried out is complete, despite the fact that the total amount of TRM in the selected 3 TRM is $2^3 = 8$, and the required amount of TRM is N = 3, that is, the presented method gave the opportunity to reduce the amount of TRM near 3 times.

The specific profit from the introduction of energy-saving technologies during the period of their operation is over 60 thousands UAH.

Conclusions and practical significance

1. In case of number n of "simple" TRM it is not necessary to consider the whole complete set of TRV, which includes in the sum of 2^n variants, but only n "aggregate", methodically determined variants.
2. Using of ASC is enable the design of energy-saving heating systems in the buildings.
3. SSPO system, although have a payback period that exceeds the regulatory (14.8 years), is also attractive, because it provides energy savings of about 15 % at relatively low capital costs.

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ТЕРМОРЕНОВАЦІЯ СИСТЕМИ ОПАЛЕННЯ ЖИТЛОВОГО БУДИНКУ

Важливим пріоритетним завданням економічної політики України є дбайливе використання енергоносіїв. В країні ведеться широкомасштабна політика в галузі енергоощадності, а завдання енергоощадності є комплексними та охоплюють як законодавчу базу, так і технічні інновації. Безперечно, в результаті термонагрівання енергетичні потреби системи опалення будуть зменшуватися. Для досягнення максимального ефекту необхідно визначити економічно доцільний рівень теплозахисту опалювальних систем, який повинен бути оптимальним як у теплотехніці, так і в економічному плані. Одним із ефективних способів зменшення енергозатрат на потреби народного господарства є проведення термомодернізації систем теплопостачання. У статті наведено економічні показники термореноваційних заходів під час реконструкції системи опалення житлового будинку. Під час реконструкції системи опалення порівнювали такі термореноваційні заходи: встановлення повітряного сонячного колектора, реконструкція системи опалення, встановлення системи сонячного повітряного опалення.

Зокрема, у повітряному каналі вздовж руху теплоносія встановлено турбулятори потоку, виготовлені з листової сталі у вигляді кругового крученого коноїда із селективним покриттям.

Визначено затрати коштів на реалізацію вказаних термореноваційних заходів, а також економію енергоресурсів за рахунок їх впровадження та економічний ефект у грошовому еквіваленті. Визначено показники економічної ефективності згідно з новітньою методикою United Nation Industrial Development Organization, namely: "SimplePayBackTime", "Net Present Value Ratio", "Internal Rate of Return". Проаналізовано сукупну дію вказаних термореноваційних заходів згідно із зазначеною методикою.

Ключові слова: енергоощадність; система сонячного повітряного опалення; повітряний сонячний колектор; термореноваційні заходи; термомодернізація; енергоаудит.