Evaluation of Heat Enegry Savings After Renovation of a Standard 5-Storey Residential Building

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Abstract
The options for improving energy efficiency of a standard residential building built in 1960s were investigated and analyzed and the structure of the heat losses of the building prior to and after the thermal renovation was determined.
Thermal renovation of buildings leads to significant cost savings for space heating. Thus, the implementation of energy-efficient solutions for the analyzed building can lead to the following achievements: replacement of windows by more energy efficient ones leads to a reduction in heating energy consumption by 14,7%; insulation of external walls with bringing resistance to heat transfer to the normative values reduces heat losses by 40,4%; the most quantity of heat energy conservation (76,8%) is achieved by the integrated approach (external building envelope insulation, installation of energy efficient windows, refurbishment of the heating system).
Knowing the value of investments in energy saving measures, the payback period can be calculated as well as the optimal energy-saving solution can be determined.
The analysis and comparison of different energy saving solutions can be used to identify ways for further upgrading of buildings.
Key words: THERMAL RENOVATION, RESISTANCE TO HEAT TRANSFER, THERMAL INSULATION, ENERGY CONSERVATION, ENERGY EFFICIENCY

Residential buildings in Ukraine are one of the essential heat consumers during heating seasons. The majority of residential buildings are outdated and they don't meet the modern building's codes.

The vast majority of building's envelops in Ukraine has low resistances to heat transfer, which lead to significant losses of heat. The heat losses through the envelopes of old buildings are several times more than through the ones of modern buildings. The second, equally important reason for the high heat consumption is low energy efficiency of old heating systems. So, all the buildings constructed in accordance to the old building standards as well as a large number of buildings commissioned later must be renovated to reduce the heating energy demand. A significant rise in prices for energy resources observed lately makes the problem of energy saving in residential buildings particularly urgent.

A vast number of scientific works are devoted to the problem of the thermal renovation of residential buildings. The issues of energy performance of buildings are considered by Farenyuk G.G. [1]; Tabunschykov Y.A., Brodach M.M. [2, 3]; Gorshkov A.S. [4,5]; Samarin O.D. [6, 7] and others.

Along with addressing the problems of improving the efficiency of buildings equally important task is to choose the best solution to improve the energy efficiency of the buildings. It is necessary to carry out techno-economic analysis of the proposed solutions and choose the most appropriate one for the specific conditions.

The aim of the work consists in the development and techno-economic comparison of the energy-saving solutions for a typical 5-storey residential building, which does not meet the modern requirements for heat protection as well as determination of the structure of the building's heat losses before and after the implementation of thermal renovation.

Current trends in the operation of the existing building stocks aim at implementing of various energy saving measures. The objective of these measures is to reduce the heating costs of of the buildings. The feasibility of certain energy saving measures must be justified by the anticipated decrease in heating energy consumption and techno-economic calculations.

In practice, because of lack of funds, technical features of buildings or through some other reasons sometimes it is not possible to fulfill the full range of energy saving measures. This raises the problem of choosing the best options of energy saving solutions.

As a case study a 5-storey 70-apartments residential building is chosen. For initial data for the calculation of the energy performance of the building a report on the building energy audit performed by LLC "Ukraine ESCO" is used. The building is located in Kiev. The external walls of the building are made of ceramic bricks. The thickness of the brick walls is 370 mm. The walls are covered by lime-sand mortar 30 mm thick. The attic is unheated. The overlap between the top floor and attic consists of concrete slabs 300 mm thick, gravel insulation 150 mm thick, sand-cement mortar with thickness of 40 mm and slag insulation 40 mm thick. The basement is unheated. The design of the ceiling in the basement consists of 220 mm thick reinforced concrete slabs with cement-sand layer 20 mm thick. Estimated parameters of indoor and outdoor temperatures, duration of a heating period and the number of degree-days of the heating period [10] are given in Table 1. Geometric parameters of the building design are shown in Table 2. Thermal data and energy indicators are presented in Table 3. The energy indicators are defined in accordance with the methodology provided in [9].

Table 1. Estimated parameters of indoor and outdoor temperatures, duration of a heating period and the heating degree-days number

Climate-related figures during heating period	Units	Value
temperature of internal air	°C	20
temperature of outdoor air	°C	-22
duration of a heating period	day	187
the average outdoor temperature over the heating period	°C	-1.1
estimated heating degree-day number	°C· day	3750

Table 2. Geometric data of the residential building

Building components	Units	Value
Total area of the external envelope of the building, including:	m^2	3855.8
walls	m^2	1973.5
windows and balcony doors	m^2	486.1
front doors	m^2	12
top floor ceiling (unheated attic)	m^2	692.1
basement ceiling (unheated basement)	m^2	692.1

heated area	m^2	3460.5
the coefficient of glazing of the building facades		0.19
compactness index of the building	m^{-1}	0.44

Table 3. Resistance to heat transfer of buiding's components and energy performance of the apartament block before implementation of energy saving measures

Titles	Units	Value
Adjusted resistance to heat transfer of the external envelope:		
walls	$m^2 \cdot K/W$	0.68
windows and balcony doors	$m^2 \cdot K/W$	0.32
front doors	$m^2 \cdot K/W$	0.25
top floor ceiling (unheated attic)	$m^2 \cdot K/W$	1.22
floor/basement ceiling (unheated cellar)	$m^2 \cdot K/W$	0.46
Calculated annual specific energy need for space heating of the building	$kW \cdot h/m^2 \cdot a$	189.4
Energy performance class		F

From Table 3 it is seen that the annual specific energy need for space heating of the building consists 189.4 $kW \cdot h/m^2 \cdot a$ which is significant in comparison with the corresponding values of modern energy efficient buildings.

Let's consider the different options for energy efficiency improvements and define the building's costs for space heating when implementing such measures. The results of calculation of the energy performance of the building in the case of the implementation of energy efficient measures are given in Table 4. The calculation methodology used is presented in [9, 12]. It is assumed that the thermal isolation of the elements of the building envelope allows to increase the resistance to heat transfer to the standard values [9], namely, resistance of external wall reaches 3.3 $m^2 \cdot K/W$, basement ceiling – 3.75 $m^2 \cdot K/W$, top floor ceiling – 4.95 $m^2 \cdot K/W$, front doors – 0.5 $m^2 \cdot K/W$. The resistance to heat transfer of installed new energy efficient windows corresponds to 0.75 $m^2 \cdot K/W$. The refurbishment of the heating system consists in installation of an automated modern heating substation and equipment of heating radiators with thermostat valves.

Table 4. The results of determination of energy performance of the building in the case of the implementation of energy efficient options

Energy efficient options	Expected annual heating energy consumption, $kW \cdot h/a$	Expected specific annual heating energy consumption, $kW \cdot h/m^2 \cdot a$	Energy performance class	The relative reduction in heat demand compared to the existimg state of the building, %
Thermal insulation of external walls	390632.7	112.9	F	40.4
Thermal insulation of the basement ceiling	601275.3	173.7	F	8.3
Thermal insulation of the top floor ceiling	637892.9	184.3	F	2.7
Thermal insulation of the external walls, top floor ceiling, basement ceiling and front doors	316181.0	91.4	E	51.8
Replacement of the windows by more energy efficient ones	559274.5	161.6	F	14.7
Thermal insulation of the external walls, top floor ceiling, basement ceiling, front doors and replacement of windows	220024,6	63.6	D	66.4

Thermal insulation of the external walls, top floor ceiling, basement ceiling and front doors and replacement of windows and refurbishment of the heating system	152195.9	43.98091	B	76.779

So, the largest economy of heat energy (approximately 77%) is achieved with an integrated approach (external envelope insulation, installing energy efficient windows, the installation of an automated modern heating substation and equipment of heating radiators with thermostat valves). Replacement of the windows by the more energy efficient ones results in reduction of heat energy need by 14.7%. Increased resistance to heat transfer of the exterior walls can save up to 40.4% of thermal energy. The small savings due to the top floor ceiling insulation (about 3%) is due to the fact that the ceiling of the building has been already warmed to some extent although the heat resistance did not reach the standard value. It is seen that even by insulating the external envelope of the building only D energy performance class can be achieved, whereas by the additional refurbishment of the heating system B energy performance class can be reached.

Costs needed for the space heating of the building are representad in Table 5. Heat energy tariffs were taken from [11].

Table 5. The expected reduction in heating costs by the implementation of energy efficient solutions

Energy efficient option	The annual heating energy consumption, kW·h/a	The annual heating energy consumption, Gcal	The cost of the building's space heating over a heating period , UAN.	The reduction in costs of the building's space heating compared with the initial state, UAN.
Existing state of the building	655430.9	563.67	370455.47	0
Thermal insulation of external walls	390632.7	335.94	220793.21	149673.26
Thermal insulation of the basement ceiling	601275.3	517.10	339858.80	30607.67
Thermal insulation of the top floor ceiling	637892.9	548.59	360555.29	9911.18
Thermal insulation of the external walls, top floor ceiling, basement ceiling and front doors	316181.0	271.92	178716.70	191749.77
Replacement of the windows by more energy efficient ones	559274.5	480.97	316112.72	54353.75
Thermal insulation of the external walls, top floor ceiling, basement ceiling and front doors and replacement of windows	220024.6	189.22	124362.95	246103.52
Thermal insulation of the external walls, top floor ceiling, basement ceiling, front doors, replacement of windows and refurbishment of the heating system	152195.9	130.89	86026.14	284440.33

From Table 5 it is seen that the comprehensive implementation of energy efficient measures (thermal insulation of the external walls, top floor ceiling, basement ceiling and front doors and replacement of windows and refurbishment of the heating system) will save on space heating to 284440.33 UAN yearly. But it is understood that the comprehensive upgrade also requires major investments in comparison with the introduction of partial energy efficient measures (wall insulation, replacement of windows, etc.).

In practice, because of lack of money, homeowners often perform partial thermal renovation of buildings (for example, only insulation of exterior walls or replacement of windows by the more energy-efficient ones). This raises the problem of choosing the best solution for investments in energy efficient projects. To choose the most appropriate option techno-economic analysis must be carried out and the payback time of each measure must be evaluated.

Let's also consider the structure of the building heat losses before the implementation of energy saving measures and after implementation the ones (refurbishment of the heating sytem and increase of heat transfer resistance of external envelope to the required level). The calculation results are given in Table. 6.

Table 6. The structure of the building heat losses

State of the building	Heat losses, % from total losses					
	through front doors	through external walls	through top floor ceiling	through basement ceiling	through windows	due to the heating of ventilation and infiltration air
The initial state of the building	0.6	37.5	6.5	19.4	19,6	16.4
The building after the implementation of thermal renovation (insulation of the external envelope; refurbishment of the heating system)	0.7	17.9	4.2	5.5	29.0	42.7

As can be seen from Table 6, the distribution of heat losses largely depends on the level of energy efficiency of the building. Thus, prior to the implementation of thermal renovation of the building the most significant heat losses occur through the external walls (37.5%). After the implementation of the energy efficient measures heat losses attributable to heating of air due to ventilation and infiltration becomes the most significant (42.7%). It should be noted that the rate of air echange is not changed and remains at the level that meets regulatory requirements. Therefore, reducing the losses of heat attributable to the heating of the ventilation air and further improvement of energy efficiency of the building is possible by increasing the sealing of the building envelope and use of heat recuperation in mechanical ventilation systems.

Conclusions

The analysis of solutions of thermal renovation of the residential building of a typical design defined the following.

1. Thus, the largest economy of heating energy (up to 76.8%) is achieved by the implementation of an integrated approach (external envelope insulation, installing energy efficient windows, the refurbishment of the heating system). The replacement of windows by the more energy efficient ones results in reduction of heating energy needs only by 14,7%. Insulation of exterior envelope and bringing the value of resistance to heat transfer to normative values allows to reduce heat losses up to 40.4%.

2. The heating costs in comparison to the original state of the building are reduced by 149673 UAN with provision of thermal insulation of walls; by 54354 UAN in the case of replacement of the windows by the more energy efficient ones and by 284440 UAN by implementation of an integrated approach to the building thermal renovation, namely, installation of the building envelope insulation, replacement of the windows by the more energy efficient ones and refurbishment of the heating system.

3. Knowing the value of investments in energy saving measures, the payback period can be calculated and the optimal energy-saving solutions can be determined.

4. The distribution of heat losses largely depends on the level of energy efficiency of the building. Thus, prior the implementation of thermal renovation of the building the most significant heat losses occur through the external walls (37.5%). After the implementation of the energy efficient measures heat losses attributable to heating of ventilation air becomes the most significant (42.7%). It should be noted that the rate of air echange is not changed and remains at the level that meets regulatory requirements. Therefore, reducing the losses of heat attributable to the heating of the ventilation air and further improvement of energy efficiency of the

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