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ECOLOGICAL AND ECONOMIC ANALYSIS OF A BUILDING HEATING SYSTEM THERMOMODERNIZATION EFFICIENCY

ANALIZA EKOLOGICZNA I EKONOMICZNA EFEKTYWNOŚCI TERMOMODERNIZACJI SYSTEMU GRZEWCZEGO BUDYNKU

Abstract

The paper presents a project of a building heating system thermomodernization. Currently, the building is not insulated which results in great heat losses and, consequently, high maintenance costs. The essential calculations performed by the Audytor OZC 4.8 Pro programme enable to estimate the range of a thermomodernization and payback period of thermomodernization. The report contains ecological analysis showing the annual reduction of the pollutants released into the atmosphere.

Keywords: thermomodernization, heat pump

Streszczenie

W artykule przedstawiono projekt termomodernizacji systemu grzewczego budynku. Aktualnie budynek nie jest ocieplany, co wiąże się z dużymi stratami cieplnymi, skutkującymi wysokimi kosztami ogrzewania. Wykorzystanie programu Audytor OZC 4.8 Pro umożliwiło określenie zakresu działań termomodernizacyjnych oraz wyznaczenie prostego okresu zwrotu nakładów inwestycyjnych. Analiza ekologiczna wykazuje roczne zmniejszenie emisji substancji zanieczyszczających.

Słowa kluczowe: termomodernizacja, pompa ciepła

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1. Introduction

Constant social and economic development in the world is associated with an increased demand for energy. Due to the increase in the cost of generating energy in a conventional manner, the limited resources of fossil fuels, as well as concerns about the environment, there has been a growth in interest in thermomodernization. Thermomodernization is an action that lowers the heat demand which results in the reduction of the maintenance costs [1]. Apart from the economic benefits, there is an important aspect of ecological effects that can be visible in the reduction of pollutants released into the atmosphere.

In general, thermomodernization includes insulation of walls and ceilings, doors and windows weatherstripping, adaptation of heating system to the reduced demand for heat, and the replacement of conventional energy sources with renewable ones [1].

2. Methodology and the Characteristics of the Research Object

In this paper, the Audytor OZC 4.8 Pro programme was used to determine the range of the thermomodernization and to select a heat pump with appropriate power.

The analyzed building is not insulated and it is heated by a coal stove. The heated area of the building equals 1171.6 m^2 and the volume equals 5340.3 m^3.

In order to perform the calculations in the Audytor OZC 4.8 Pro programme, the basic data concerning the location of the building, the thickness and kinds of materials of the walls and the dimensions of the rooms were entered. Another parameter that must be taken into account in the assessment was orientation relative to cardinal directions.

The defined barriers with thickness of the components were as follows:

- Exterior wall: plaster 1.5 cm, ceramic brick 75 cm, plaster 1.5 cm,
- Interior wall type 1: plaster 1.5 cm, ceramic brick 75 cm, plaster 1.5 cm,
- Interior wall type 2: plaster 1 cm, ceramic brick 38 cm, plaster 1 cm,
- Floor: terracotta 1 cm, concrete – 1900 22 cm,
- Ceiling: plaster 1.5 cm, reinforced concrete 22 cm,
- Roof: roofing paper 0.5 cm.

3. Thermomodernization

The first step to determine the range of the thermomodernization is to check whether the overall heat transfer coefficients (*U*-values) of the barriers fulfill the requirements included in the PN-EN ISO 6946 norm. The *U*-value is a measure of heat loss in an analyzed building element. The higher the *U* value, the worse the thermal performance of the building envelope.

Taking into account the thickness of the building materials *d*, characterized by a coefficient of thermal conductivity λ, the total thermal resistance R_T is calculated. Finally, the *U*-value is calculated as the reciprocal of the total thermal resistance of the building materials in the constructional element.

$$R = \frac{d}{\lambda}$$

where:

R – thermal resistance of a homogeneous layer [m^{2}K/W],
d – thickness of a layer [m],
λ – coefficient of thermal conductivity [W/mK].

$$R_T = R_{SI} + R_1 + R_2 + \ldots R_n + R_{SE}$$

where:

R_T – total thermal resistance [m^{2}K/W],
R_{SI} – the heat transfer resistance on the inner surface [m^{2}K/W],
$R_1, R_2, \ldots, R_n$ – the heat transfer resistances of particular layers [m^{2}K/W],
R_{SE} – the heat transfer resistance on the outer surface [m^{2}K/W].

$$U = \frac{1}{R_T}$$

where:

U – the heat transfer coefficient [W/m^{2}K],
R_T – the total thermal resistance [m^{2}K/W].

As there were no data concerning doors and windows available, the maximum values were entered and they were not analyzed later. For that reason, its weatherstripping was not a part of this project.

Table 1

Comparison of the Umax-value form the PN-EN ISO 6946 norm with the current values

Kind of barrier	$U_{\max}$ [W/m^{2}K]	U [W/m^{2}K]
Exterior walls (temperature inside building >16°C)	0.3	0.847
Floor	0.45	0.449
Roof (temperature inside building > 16°C)	0.25	1.420
Windows (temperature inside building > 16°C)	1.8	1.8
Doors in exterior walls	2.6	2.6

According to the obtained results, it can be said that the roof and the external walls should be insulated, as the defined U-values exceed the values from the norm.

In both cases (the roof and the exterior walls), it was decided to perfrom the insulation by using a panel of mineral wool with the following specifications: thermal conductivity $\lambda = 0.045$ [W/mK], a density $\rho = 130$ [kg/m^3], and specific heat capacity $c_w = 0.75$ [kJ/kgK]. The main advantage of mineral wool is waterproofing and breathability, as well as, dimensional stability, elasticity and mechanical strength [2].

In order to choose the appropriate thickness of the mineral wool insulation of the roof, different thicknesses were taken into consideration. The minimal thickness that fulfills the requirements (the U-value lower than the U-value from the norm) was 14 [cm]. The other options of 16 and 18 [cm] were also examined. Thee variants presented in a table below have numbers 1, 2, 3. Assuming heating by coal, the annual savings resulting from the reduced demand for heat were calculated. Then, the payback time (SPBT) was found.

The roof area equals 584 [m^2] and it was assumed that the net calorific value of coal was 23 [MJ/kg] and its price was 720 [zł/t].

Table 2

The basic results of the roof thermomodernization

	Unit	Actual state	Variants		
			1	2	3
Thickness of the mineral wool d:	[m]		0.14	0.16	0.18
Growth in thermal resistance ΔR:	[m^{2}K/W]		3.333	3.810	4.286
Thermal resistance R_t:	[m^{2}K/W]	0.704	4.038	4.514	4.990
Overall heat transfer coefficient U:	[W/m^{2}K]	1.42	0.248	0.222	0.200
The unit price of mineral wool:	[zł/m^2]		100	103	106
The cost of improvement Nu:	[zł]		58400	60152	61904
Heat demand Q:	[GJ/year]	1679.27	1226.22	1216.70	1209.12
The amount of coal used for heating B:	[t/year]	73.01	53.31	52.90	52.57
The cost of heating K:	[zł/year]	52568.44	38386.13	38088.08	37850.67
Annual saving ΔK:	[zł/year]		14182.31	14480.36	14717.76
SPBT:	[years]		4.12	4.15	4.21

The same calculations were done in case of exterior walls. The total area of exterior walls (without the area of windows and doors) equals 800 [m^2]. The results of the payback period were similar, so it was decided to use the thickness layer of mineral wool.

Table 3

The Basic results of the exterior walls thermomodernization

	Unit	Actual state	Variants			
			1	2	3	4
Thickness of the mineral wool d:	[M]		0.1	0.12	0.14	0.16
Growth in thermal resistance ΔR:	[m^{2}K/W]		2.381	2.857	3.333	3.810
Thermal resistance R_t:	[m^{2}K/W]	1.181	3.562	4.038	4.514	4.990

cd. tab. 3

Overall heat transfer coefficient *U*:	[W/m²K]	0.847	0.281	0.248	0.222	0.200
The unit price of mineral wool:	[zł/m²]		94	97	100	103
The cost of improvement *Nu*:	[zł]		75200	77600	80000	82400
Heat demand *Q*:	[GJ/rok]	1226.22	778.09	756.70	739.82	726.18
The amount of coal used for heating *B*:	[zł/year]	53.31	33.83	32.90	32.17	31.57
The cost of heating *K*:	[zł/year]	38386.13	24357.46	23687.89	23159.63	22732.6
Annual saving Δ*K*:	[zł/year]		14028.66	14698.24	15226.5	15653.52
SPBT:	[years]		5.36	5.28	5.25	5.26

The obtained results indicate that there is a small difference in the payback time when various thicknesses of mineral wool are taken into consideration. Nevertheless, in both cases, the shortest payback time occurs when the mineral wool has a thickness of 14 cm. It is practical to buy the same thickness of mineral wool for both the roof and the exterior walls.

Thanks to the roof and exterior walls thermomodernization, the actual annual energy consumption is lower by more than 50 [%] and was reduced from 1680 [GJ/year] to 740 [GJ/year].

4. Selection of the heat pump

Due to an investor suggestion, only the brine/water and water/water heat pumps were taken into consideration. In the first one, the energy accumulated in the ground can be captured by a horizontal or vertical heat exchanger [3]. As there is not enough area, the option with the horizontal heat exchanger was rejected. Using the Ochsner technical specification [4], the brine/water and the water/water heat pumps were compared. The pumps that provide the appropriate heat demand are water/water OWWP 96 and two pumps brine/water (OSWP 56) (cascade connection).

The total heat load considering the heat load calculated in the Audytor OZC 4.8 Pro programme and the heat load for the hot water preparation equals 125 192 [kWh/year].

Considering this value, efficiency of heating by the coal stove (0, 61), the real heat load for generating heat by the coal stove was calculated. Then, assuming the net coal calorific value of 6.4 [kWh/kg], its price 720 [zł/t], and the service charge 2000 [zł/month] the annual operating cost was determined. It is equal to 48107.80 [zł/year].

Similar calculations were done to compare two types of heat pumps. Power consumption includes the power needed for heating and for preparing hot water. The electricity price was assumed as 0.6 [zł/kWh].

Table 4

Comparison of the OWWP 96 and OSWP 56 heat pumps

	Unit	Heat pump Ochsner OWWP 96	Heat pumps 2x Ochsner OSWP 56
Heat demand	[kWh/year]	125192	125192
Coefficient of Performance	–	4.1	3.2
Power consumption	[kWh/year]	41528	50841
Annual operating cost	[zł/year]	24916.8	30504.6
Annual saving in comparison with the coal stove	[zł/year]	23191	17603.2
The cost of buying	[zł]	148222	349524
SPBT	[year]	6.4	19.8

It can be seen that the cost of buying the heat pump water/water OWWP 96 is more than 2 times lower than in case of heat pumps brine/water OSWP 56 in a cascade connection. What is more, the coefficient of performance of OWWP 96 is higher and the payback time is more than 3 times lower than in case of OSWP 56.

5. Economic analysis

The total cost of thermomodernization was calculated as a sum of the costs of exterior walls and roof thermomorednization, the costs of exchange of the actual heaters for the heaters adapted to the new operating parameters and the costs of buying and installing the heat pump. The total cost of thermomodernization equals 313497 [zł]. Thanks to this action, the annual cost of heating was lowered from 76568.44 [zł] to 24916.8 [zł]. The payback period of the whole enterprise is about 6 years.

$$SPBT = \frac{313497}{76568.44 - 24916.8} = 6.1\,[\text{year}]$$

6. Ecological analysis

The best way to estimate the ecological effect is to calculate the reduction of the emissions of pollutants into the atmosphere. Currently, each year, 33.48 [t/year] of coal is used in the coal stove to heat the building. In order to calculate the reduction of the emissions, it was necessary to determine the amount of the pollutants released during the production of electricity in the power plant. As the annual heat pump energy consumption equals 41528 [kWh/year] it was calculated that 19.12 [t] of coal has to be used to generate electricity. The table below shows that the thermomodernization contributes significantly to the reduction of pollutants released into the atmosphere.

Table 5

Emission of pollutants released to the atmosphere in [kg/year]

	Coal stove (before thermomodernization)	Power plant (electricity for the heat pump. after thermomodernization)	The difference
SO_2	803.52	458.88	344.64
NO_2	73.66	19.12	54.54
CO	1506.6	860.4	646.2
CO_2	61938	38240	23698
dust	334.8	191.2	143.6

7. Conclusions

The first step of the thermomodernization concerns building insulation. Thanks to this action, by using 14cm–mineral wool, the actual annual energy consumption is lowered by more than 50 [%] from 1680 [GJ/year] to 740 [GJ/year] and the payback period is shorter than 5,5 year. The second one concerns the selection of a heat pump. The Ochsner pump chosen is OWWP 96, as it has the payback time more than 3 times lower than the OSWP 56. The thermomodernization results in a decrease of the annual cost of heating from 76568.44 [zł] to 24916.8 [zł] with the payback time of about 6 years. Apart from the economical benefits, there is an important ecological aspect present. The emissions of the pollutants into the atmosphere is reduced significantly. There is a reduction of 23698 [kg/year] of carbon dioxide released into the atmosphere which is especially important as the carbon dioxide is one of the greenhouse gases.

To sum up, it can be said that the action of thermomodernization is reasonable, as the payback time period found to be short. What is more, better barriers insulation and the use of a heat pump as an energy source will increase thermal comfort in rooms and it will add to the value of the building.

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