Environment Protection Engineering

Vol. 34 2008 No. 1

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THE WORK OF A HEATING SYSTEM WITH RENEWABLE ENERGY SOURCES (RES) IN SCHOOL BUILDING

Excessive energy consumption in the building of our interest proves that it necessitates modernization. Based on the Thermal Modernization Act [5], the necessary works could be possible due to the financial support, called "thermomodernization premium", from the Thermomodernization Fund. During complex thermal modernization of the school building in Gródek nad Dunajcem (southern Poland), an old heating system was replaced with a new one whose operation being based on renewable sources of energy. Its design is described in [8]. This article presents the analysis of three-year (2004–2006) period of this system operation and its cost-effectiveness.

1. INTRODUCTION

The building of interest is a medium-size, four-storey (with a cellar) school building erected in Gródek nad Dunajcem, in southern Poland, in the 3-rd climate zone. Its total cubage and usable area reach 8594 m^3 and 2612 m^2, respectively.

The school erection was started in the middle of the 1990's. In the original project, the value of an overall heat-transfer coefficient did not meet national standards. A main heat source, i.e., coal-fired boiler, was inefficient and obsolete; moreover, its service was pretty expensive. This, in combination with poor thermal insulation of the building, was responsible for high energy consumption and high exploitation costs. Because of these economic and environmental circumstances the local authorities were forced to find a better, ecological and more efficient design. At their request the energy audit of the building was carried out [7] at AGH University of Science and Technology. It was based on the original design of the building, its careful inspection and on detailed computer calculations.

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2. THERMAL MODERNIZATION OF THE BUILDING

The audit revealed that the heat-transfer coefficient U for external walls did not meet the required standards. A natural, gravity ventilation system at school was installed according to the original design. In the winter, it allowed cold air to enter into the building. This air had to be heated which required high heat consumption. Heating installation was the traditional one, of ineffective control and fed with the heat from own local boiler.

The basic goals of the improvements were as follows: to achieve the maximum energy saving and to apply the renewable energy sources (RES) to heating purposes (central heating system and hot water for washing). The improvement in a thermal insulation of the building decreased a thermal energy consumption necessary for air heating from 1508 GJ to 923.9 GJ per year [7]. Consequently, due to modernization the thermal power demand of 150 kW was reduced to 99 kW. The thermal power demand for water heating amounted to 38 kW and the calculated annual thermal energy consumption for that purpose was 383 GJ.

3. MODERNIZATION OF THE HEATING SYSTEM

A total efficiency of the heating system η_0 before modernization was as low as 0.394 because of inefficient heat production, distribution and utilisation:

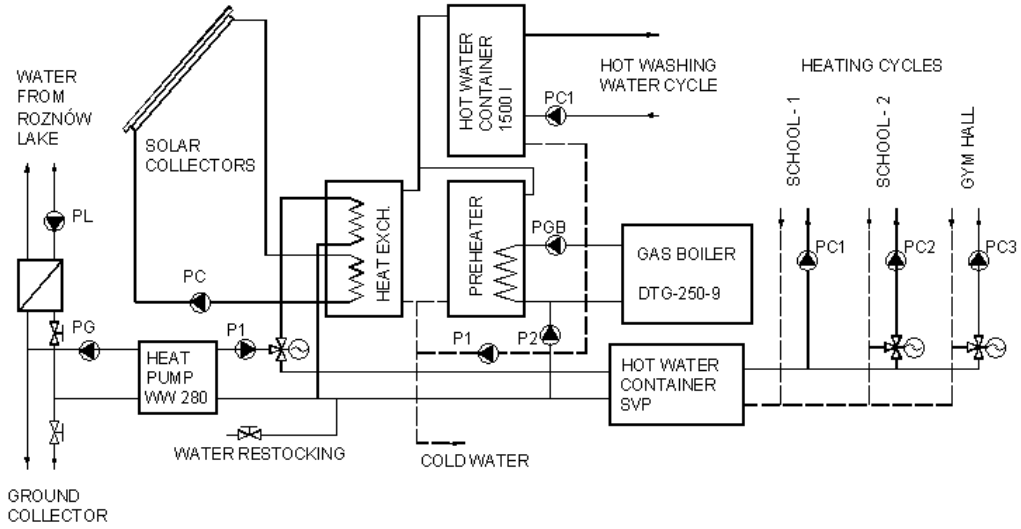
- Thermal energy production: $\eta_p = 0.5$.
- Heat distribution: $\eta_d = 0.95$.
- Adjustment: $\eta_a = 0.87$.
- Energy utilization: $\eta_u = 0.95$.
- Overall efficiency: $\eta_1 = \eta_p \cdot \eta_d \cdot \eta_a \cdot \eta_u = 0.39$.

This caused high fuel consumption used for heating, which in combination with thermal losses contributed greatly to high operating costs. In the energy audit, we proposed to replace the traditional and obsolete coal-gas boiler with ecological one. As a main source of thermal energy a heat pump was applied. After modernizing the heating system the efficiency of its elements increased as follows [3], [8]:

- Thermal energy production – an average COP of the heat pump [6]: $\eta_p = 4.0$.
- Heat distribution: $\eta_d = 1.0$.
- Adjustment: $\eta_a = 0.95$.
- Energy utilization: $\eta_u = 0.95$.
- Overall efficiency: $\eta_1 = \eta_p \cdot \eta_d \cdot \eta_a \cdot \eta_u = 3.61$.

As an additional heat source (for hot water) solar collectors were proposed. In order to meet the maximum power consumption (for example, during frosty winters), a gas boiler was used. After the modernization, the heating system efficiency increased to 3.61 [2], [7]. A total cost of the thermal modernization of the building

and the installation of the ecological heating system with heat pump was 462 734 zł. This new heating system of the school building is presented in the figure.



Schematic diagram of the heating system [8]

4. THE ANALYSIS OF HEATING COSTS

The efficiency of investments of the modernized system depends significantly on the annual exploitation costs. This is connected with the type of the fuel applied and other costs. For more detailed analysis, a short calculation of annual operating costs (thermal energy for heating and hot water purposes) for different fuels, i.e., gas, oil, coal, electricity and heat pump, was made. In our analysis, the market prices of energy in July 2006 were accepted. All the prices include VAT (22%). Electricity cost was calculated based on the Enion S.A. scale of charges [4], tariff C22B for heat pump and electric heating. It was assumed that electric energy would be consumed in equal proportions in day/night cycle, which gave a unit cost of 0.3056 zł/kW. C11 tariff was assumed for other cases. In C11 tariff (energy + distribution), a unit cost was 0.3908 zł/kWh. Gas price is set by KSG gas company according to W-3 tariff [3]. The prices of coal and oil were assumed based on the offers of local sellers. For the modernized system there were also assumed the breaks in heating during the day ($w = 0.95$) and during the week ($w = 0.95$).

4.1. COST OF HEATING BEFORE THE MODERNIZATION, COAL BOILER

Fuel (coal) consumption:

- Calorific value of the coal: H_u = 24 MJ/kg.
- Total efficiency of the heating system: η_o = 0.39.
- Unit cost of coal: C_{cu} = 0.48 zł/kg.
- Total annual thermal energy consumption: Q = 1892.1 GJ/year.

Annual fuel (coal) consumption: M = 200 095 kg.
Cost of the coal for central heating system and hot water:
$C_{e1} = C_{cu} \cdot m_1$ = 96 046 zł/year.
Cost of electricity for circulating pump (1 kW):
C_{e2} = 2 182 zł/year.
Standing costs (service staff, repairs):
C_{e3} = 14 400 + 3000 = 17 400 zł/year.

Total cost: $C_e = C_{e1} + C_{e2} + C_{e3}$ = 115 628 zł/year.

4.2. COST OF GAS HEATING AFTER THERMAL MODERNIZATION

Fuel (gas) consumption:
- Calorific value of gas: H_u = 35.50 MJ/m^3.
- Total efficiency of the heating system: η_1 = 0.86.
- Total annual thermal energy consumption (from audit): Q = 1307.2 GJ.

Total annual fuel (gas) consumption M = 38 642 m^3.
Total cost of the gas for central heating system and hot water:
C_{e1} = 48 788 zł/year.
Cost of electricity for circulating pump:
C_{e2} = 2 182 zł/year.
Standing costs (service staff, repairs):
C_{e3} = 9 600 zł/year.

Total cost of gas heating: $C_e = C_{e1} + C_{e2} + C_{e3}$ = 60 570 zł/year.

4.3. COST OF OIL HEATING AFTER THERMAL MODERNIZATION

Fuel (oil) consumption:
- Calorific value of the oil: H_u = 42.6 MJ/kg.
- Total efficiency of the heating system: η_1 = 0.85.
- Total annual thermal energy consumption (from audit): Q = 1307.2 GJ.

Total annual fuel (oil) consumption M = 32 580 kg.
Unit cost of the fuel (EKOTERM PLUS oil): C_o = 2.48 zł/kg.
Total cost of the oil for central heating system and hot water:
$C_{e1} = m_1 \cdot C_o$ = 32 580 · 2.48 = 80 798 zł/year.

Cost of electricity for circulating pump:
C_{e2} = 2082 + 44 + 56 = 2 182 zł/year.
Standing costs (service staff, repairs):
C_{e3} = 8100 + 1500 = 9 600 zł/year.

Total cost of oil heating: $C_e = C_{e1} + C_{e2} + C_{e3}$ = 92 580 zł/year.

4.4. COST OF ELECTRIC HEATING AFTER THERMAL MODERNIZATION

Electric energy consumption:
- Total efficiency of the heating system: η_1 = 0.98.
- Total annual thermal energy consumption (from audit): Q = 1307.2 GJ = 363 111 kWh.

Total annual electric energy consumption: M = 334 400 kWh.
Cost of electric energy (C22B tariff, 50%/50% day/night) with standing costs:
C_{e1} = 116 102 zł/year.
Cost of electric energy for circulating pump:
C_{e2} = 1 726 zł//year.
Other costs (service, repairs):
C_{e3} = 1000 zł/year.

Total annual cost of electric heating: $C_e = C_{e1} + C_{e2} + C_{e3}$ = 118 828 zł/year.

4.5. TOTAL COST OF HEATING AFTER THE MODERNIZATION, COAL BOILER

Innovative construction of retort coal-fired boiler with stoker, operated by a reduced service staff, was applied.
Fuel (coal) consumption:
- Calorific value of the coal: H_u = 24 MJ/kg.
- Total efficiency of the heating system: η_1 = 0.65.
- Total annual thermal energy consumption: Q = 1307.2 GJ/year.

Total annual fuel (coal) consumption M = 70 210 kg.
Cost of the coal for central heating system and hot water:
C_{e1} = 33 700 zł/year.
Cost of electric energy for circulating pump and stoker motor:
C_{e2} = 3 094 zł/year.
Other costs (service staff and repairs):
C_{e3} = 10 100 zł/year.

Total annual cost of heating: $C_e = C_{e1} + C_{e2} + C_{e3}$ = 46 894 zł/year.

4.6. COST OF HEATING AFTER THERMAL MODERNIZATION, HEAT PUMP

Electric energy consumption:

• Total efficiency of the heating system (from audit): $\eta_1 = 3.61$.

• Total annual thermal energy consumption (from audit): Q = 1307.2 GJ = 363 111 kWh.

Total annual electric energy consumption M = 90 778 kWh.

Cost of the electric energy (C22B tariff, 50%/50% day/night) for central heating system and hot water:

C_{e1} = 31 814 zł/year.

Cost of electric energy for circulating pump and borehole pump:

C_{e2} = 4 316 zł/year.

Standing costs (service, repairs and other):

C_{e3} = 2700 + 1000 zł/year.

Total annual cost of heating: $C_e = C_{e1} + C_{e2} + C_{e3} = 40\ 330$ zł/year.

On the basis of the calculations presented the total costs of heating by different fuels can easily be compared. A sharp rise in gas and oil prices in recent years is responsible for very high operating costs of heating systems.

5. ENVIRONMENTAL EFFECTS OF MODERNIZATION

The technologies that are based on renewable energy sources are environmentally friendly. First of all they allow greenhouse effect to be reduced. For the school in Gródek a short analysis of the effect of its modernization was carried out [8]. Total annual gas emission after modernization and for old heating system is shown in the table.

Table

Annual emission of pollutants [1] from the school in Gródek nad Dunajcem

Emission [kg/year]	SO_2 (7.8 kg/MWh)[1]	NO_x (3.2/MWh)[1]	CO_2 (937 kg/MWh)[1]	Dust (1.1 kg/MWh)[1]
Coal boiler-room [1]	2 832	1162	340 235	399
Heat pump[2]	639	262	76 765	90

[1] – NFOŚiGW data [1].

[2] – Effects of the electric energy production necessary for heat pump operation.

Environmentally friendly effects of the modernization of interest are very important in such recreational and tourist areas as Gródek. They can improve significantly local environment condition.

6. ENERGY CONSUMPTION IN THE MODERNIZED HEATING SYSTEM

After modernization the boiler-room operation is based on electric energy and gas. The energy consumed is measured by gasmeter and electricity meter. Gas is used only for heating purposes, while electric energy is supplied to different devices.

On the basis of the information obtained from the book-keeper in school it was assumed that annual electric energy consumption in 2004–2006 amounted to 60 MWh. Heat pump was working for six months each year, while in the second six months all energy has been consumed for non-heating purposes. A calculated consumption of electric energy for heat pump was 33 MWh annually. Based on the invoices for electric energy it was possible to calculate the cost of energy consumed by heat pump, which was 15056 zł/year. The readings of a gasmeter allowed annual gas consumption for central heating and water heating to be determined on the level of 3800 Nm^3, which gave a total cost of 5661 zł/year. Moreover, in a cost account, one person of service staff paid on a part-time basis should be taken into account. This gives the cost of 2700 zł per year. Total cost is 23417 zł/year. Overall operating cost will be known after the detailed analysis of the gasmeter and electricity meter readings.

A greater reduction of operating cost is possible after applying a computer monitoring and control of the system. This can reduce the energy consumption by about 5–10%. Also, a service staff cost can be reduced.

7. CONCLUSIONS

Due to thermal modernization of the school building heat losses were reduced. Thermal energy consumption decreased from 1508 GJ to 923.9 GJ per year. Higher efficiency of the heating system allowed us to cut down both the energy consumption and the exploitation cost of the system. The application of renewable energy sources has a positive impact on local environment limiting the air pollution. The results obtained testify to a high economic efficiency of the design applied.

LITERATURE

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SYSTEM GRZEWCZY Z WYKORZYSTANIEM ODNAWIALNYCH ŹRÓDEŁ ENERGII (OŹE) W BUDYNKU SZKOLNYM

Ponadnormatywne zużycie energii w budynku szkoły jest wskazaniem do przeprowadzenia jego modernizacji. Na mocy Ustawy o Wspieraniu Przedsięwzięć Termomodernizacyjnych [5] można po wykonaniu niezbędnych robót, uzyskać wsparcie finansowe, zwane *premią termomodernizacyjną*, z Funduszu Termomodernizacyjnego. Podczas kompleksowej termomodernizacji budynku szkoły w Gródku nad Dunajcem zmodernizowano system grzewczy. Zastosowano w nim odnawialne źródła energii (OŹE). Koncepcja tej inwestycji została przedstawiona w pracy [8]. W niniejszym artykule zaprezentowano analizę eksploatacji nowego systemu grzewczego w latach 2004–2006.