TECHNICAL AND ECONOMIC ANALYSIS OF THERMAL MODERNISATION PROCESS OF A DETACHED HOUSE

[1]Ewa Zarzeka-Raczkowska, [2]Andrzej Raczkowski, [2]Piotr Pomorski

[1]Pope John Paul II State School Higher Education in Biala Podlaska,
Department of Engineering Sciences, Department of Civil Engineering
Sidorska St. 95/97, 21-500 Biała Podlaska, Poland
e-mail: e.zarzeka-raczkowska@pollub.pl,
[2]Collegium Mazovia Innowacyjna Szkoła Wyższa w Siedlcach
Sokołowska St. 161, 08-110 Siedlce,
e-mail: araczkowski@mazovia.edu.pl,

Summary:
The aim of this paper is to analyse the cost-effectiveness of thermal modernisation of a detached house, making use of different technologies. In order to reduce heat losses three thermo-modernisation options are considered. In the first option the exterior walls are insulated with 10 cm thick Styrofoam and the roof is insulated with 15 cm thick mineral wool. This produces the following heat transfer coefficients: for the exterior wall U = 0.213 W/(m^{2}K) and for the roof U = 0.214 W/(m^{2}K). In the second option, additionally to the wall and roof insulation, the windows whose heat transfer coefficient is U=0.9W/(m^{2}K) are replaced. In the third option all the work as in the second option is done and a new, state-of-the-art boiler of the 93 % efficiency is installed.
The heat calculations for the thermal modernization of the detached house are performed with the computer program PURMO OZC v 4.80b. To cost the thermo-modernisation works the computer program Norma Pro v 4.03 – pricelist for the April-July quarter 2013 is used.
The thermal modernization of the existing detached house encompassing insulating external barriers, replacing old windows with new tighter ones and installing a new more efficient boiler resulted in a considerable reduction of the heat demand coefficient (EA) and allowed classifying the house as energy-efficient.
The scope of the thermo-modernisation in the three options increases as well as the costs incurred. The third option is twice as expensive as the first one, yet the payback period is similar - approximately nine years. The most profitable is the third option of thermo-modernisation because in a twenty-year period the owner can save about 41324 PLN as compared to the costs incurred currently.

Keywords: thermo-modernisation, mechanical ventilation, recuperation

Introduction

In recent years the rising costs of maintaining and operating a residential building, together with increasingly restrictive regulations in residential construction as well as growing environmental awareness of Polish society have all forced designers, investors and occupants to apply technologies which will enable to achieve the most cost-effective and energy-saving building solutions.

The value which assesses the building in energy-consumption terms is the coefficient of seasonal heat demand (EA). This value enabled to create energy-consumption classification of buildings (Table 1) (Sas-Micuń 2006).

Tab. 1. Energy-consumption classification of buildings (www.termoexpert.com.pl)

Type	**Residential Building**	**Coefficient EA [kWh/m2 year]**
A	Highly energy-efficient	20 - 45
B	Energy-efficient	45 - 80
C	Medium energy-efficient	80 - 100
D	Medium energy-intensive	100 - 150
E	Energy-intensive	150 - 250
F	Highly energy-intensive	over 250

In order to improve the energy-efficiency of a building, i.e. to limit the amount of energy supplied mainly by heating, ventilation and hot water systems, which entails the reduction of maintenance costs, it is advisable to thermo-modernize the building and to carry out its energy audit.

Thermo-modernisation lies in refurbishing a building in such a way as to reduce its consumption of energy needed to maintain constant pleasant living temperature and the consumption of energy needed to heat water as well as preventing exterior walls from freezing and enhancing the look of the building (Bogacki M., Osicki 2011, Dreger 2006).

Heat losses in a building bring about a number of unfavourable phenomena for the building itself as well as its occupants. One of them is insufficiently heated rooms. According to the regulation PN-82/B-02403 the pleasant living temperature for rooms should be 20^0C. Occupants, to reduce building maintenance costs, significantly lower the temperature even down to 15^oC - 17^oC. This, apparently, reduces the costs but dramatically diminishes thermal comfort. Another threat is overheating of rooms, which may derive from an inadequate heating system in the building. The old, over-exploited and badly chosen interior heating system, without the possibility of adjusting the heat supply results in heat surplus. This may lead to frequent airing of rooms and unreasonably high heat loss. This, in turn, leads to unjustified costs incurred by the occupant to heat the premises.

Far more heat energy needs to be supplied to maintain the desired temperature in older buildings than in new buildings. This requires supplying far more fuel. In Poland the most popular fuel sources are coal, oil and natural gas. Prices of these fuels are independent of the occupant and strictly dependent on the political and economic situation. As a result, an underheated building makes the occupant cover considerable costs to buy energy.

An acute problem of inadequately insulated house is the problem of freezing walls in winter time. On the internal surface of a cold building wall moisture turns up. This is an ideal environment for fungi and mold to spread, which is hazardous to human health. Damp barriers and moisture penetrated walls result in a significant drop in heat accumulation by construction materials used for facades. This leads to the deterioration of wall surfaces and manifests itself by water stains and peeling off plaster (Norwisz 2006).

Thermal modernisation of a building consists in insulating walls, roofs and ceilings, replacing windows and doors, upgrading or replacing the heating system, upgrading the ventilation and water heating system as well as using renewable energy sources.

The most beneficial in thermal modernisation is performing all the possible refurbishment works simultaneously. The profitability of each operation is presented in Table 1.

Thermal modernisation is a fairly costly operation. In Poland investors planning to modernise thermally their houses can seek financial support. Pursuant to the Thermo-modernisation and Refurbishment Support Act dated 21.11.2008 (Dz. U. Nr 223, poz. 1459) investors may receive financial support with a view to repaying part of the thermo-modernisation loan on several conditions, one of them being the reduction of building energy consumption (Dylewski, Adamczyk 2008).

The document required to obtain a thermo-modernisation loan is a building energy audit. This document is an analysis of thermo-modernisation solutions trying to find the best technical and economic solution for the building, which will minimize the maintenance and operational costs as well as reducing the energy consumption. In other words, the investment must be cost-effective, whereas the repaid loan cannot be higher than the savings generated through the thermo-modernisation.

Tab. 2. Cost-effectiveness of thermo-modernisation works - www.muratordom.pl

Thermo-modernisation work type	Approximate savings compared to before modernisation [%]	Approximate payback period [years]
Roof and ceiling over attic insulation	5 – 15	6 – 8
Wall insulation	10 – 20	8 – 12
Ceiling over basement insulation	2 – 5	10 – 20
Window replacement	10 – 15	15 - 25
Heating installation upgrade	10 – 20	4 – 8
Boiler room automatisation	5 – 10	3 – 5
Boiler replacement	10 – 20	8 – 12

The correct energy audit is performed in order to indicate the best technological solution to the investor or prospective occupant and to enable a conscious choice of employing the best thermo-modernisation method for the building in question.

Methods

The detached house is situated in Siedlce in Sokołowska Street. It was erected in 1985. It is a two-storey house with a basement and an unusable attic. The area which needs to be heated is 372.5 square metres. The building was constructed using traditional building methods. Three-layered exterior walls have the heat transfer coefficient of U = 0.39 W/ (m^2K), the ceiling under the unheated attic has the heat transfer coefficient of U = 0.5 W/ (m^2K), and the wooden-frame double-glazed windows have that of U = 2.6 W/ (m^2K).

Numerous heating calculations were carried out for the building. Their aim was to evaluate the annual maintenance cost of this detached house before modernization and to analyse the cost-effectiveness of thermo-modernisation in three different options (Dylewski, Adamczyk 2008, Koczyk et al. 2005).

In the first option the exterior walls are insulated with 10 cm thick Styrofoam and the roof is insulated with 15 cm thick mineral wool. This produces the following heat transfer coefficients: for the exterior wall U = 0.213 W/ (m^2K) and for the roof U = 0.214 W/ (m^2K) (Wysocki 2007).

In the second option, additionally to the wall and roof insulation, the windows whose heat-transfer coefficient is U=0.9W/ (m^2K) are replaced.

In the third option all the work as in the second option is done and a new, state-of-the-art boiler of the 93 % efficiency is installed.

The calculations were performed taking the following into consideration: convection heating system, low building tightness, location in the third climatic zone for which the predicted outdoor temperature is that of -20^{o}C in winter time. Average annual temperature for the building location is t=7,6^{o}C. The data for the calculations came from the actinometric weather station in Mikołajki.

All the calculations were carried out in compliance with the Polish regulations:

PN-EN ISO 6946 Construction components and building elements. Heat resistance and heat transfer coefficient. Calculation method.

PN-EN 12831:2006 Heating installations in buildings. Calculation method of design heat load.

PN-B-02025: Calculation of the seasonal heat demand for single-family and multi-family residential buildings.

The heat calculations for the thermal modernization of the detached house were performed with the computer program PURMO OZC v 4.80b. To cost the thermo-modernisation works the computer program Norma Pro v 4.03 – pricelist for the April-July quarter 2013 was used.

Results and discussion

The calculations allowed determining the design heat load for the building, the seasonal heat demand EA indicator and investment costs for each thermo-modernisation option. The results are presented in Table 3.

Tab. 3. Results of the building heat load F_{h1}, seasonal heat demand EA indicator and investment costs

Building state	**Present state**	**1st Option**	**2nd Option**	**3rd Option**
Investment costs PLN	-	16511.18	25188.73	32017.08
Heat load $F_{h1,}$ [W]	19610	17722	16330	16330
Seasonal heat demand EA indicator, [kWh/(m²*year)]	88.3	72.3	65.1	65.1
Annual heating maintenance costs PLN	10022.42	8213.71	7388.10	6355.35

The enhancement of external barrier insulation in the first and second options resulted in a considerable reduction of design heat load respectively by 9.6% and 12.7 %. It also resulted in the reduction of the seasonal heat demand EA indicator respectively by 18.1% and 26.3% and the reduction of annual heat maintenance costs by respectively 19.0% and 26.3% compared to the maintenance costs of the building in the present state.

The values of the seasonal heat demand EA indicator and the annual heat maintenance costs are directly proportional to each other; therefore their decrease is the same. The replacement of the heat source in the third option does not influence the further reduction of the design heat load and the seasonal heat demand EA indicator because it does not affect the heat loss values, yet it brings about the reduction in fuel consumption. Therefore, it directly reduces the annual heat maintenance costs by 36.6% as compared to the maintenance costs of the building in the present state. (Figure 1)

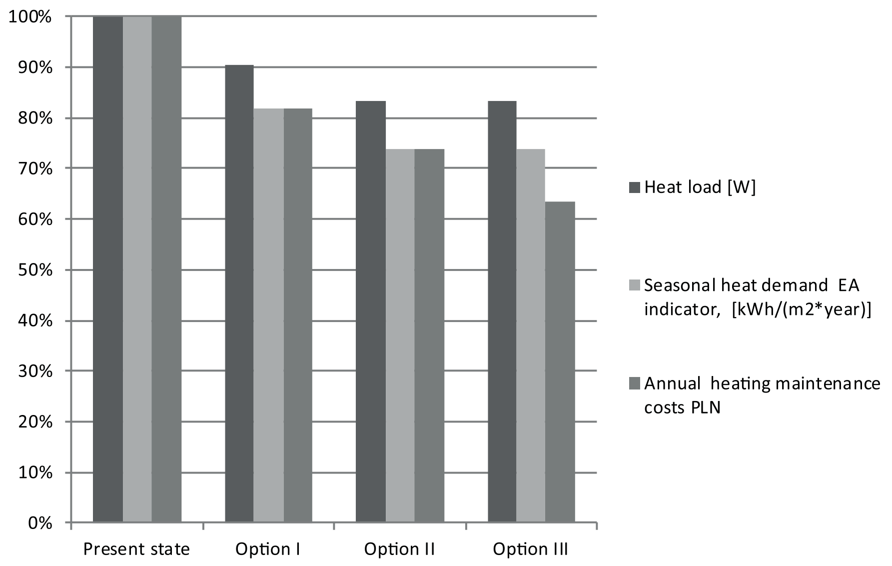

Fig. 1. Reduction in design heat load, seasonal heat demand EA indicator and heat maintenance costs.

On the basis of the calculated seasonal heat demand EA indicator which is 88.3 kWh/ (m^2year), the house in Siedlce has been classified as medium energy-efficient. The first and second thermo-modernisation options reduced the seasonal heat demand EA indicator respectively down to 72,3 kWh/ (m^2year) and 65,1 kWh/ (m^2year), which meant that the building could be classified as energy-efficient (Figure 2).

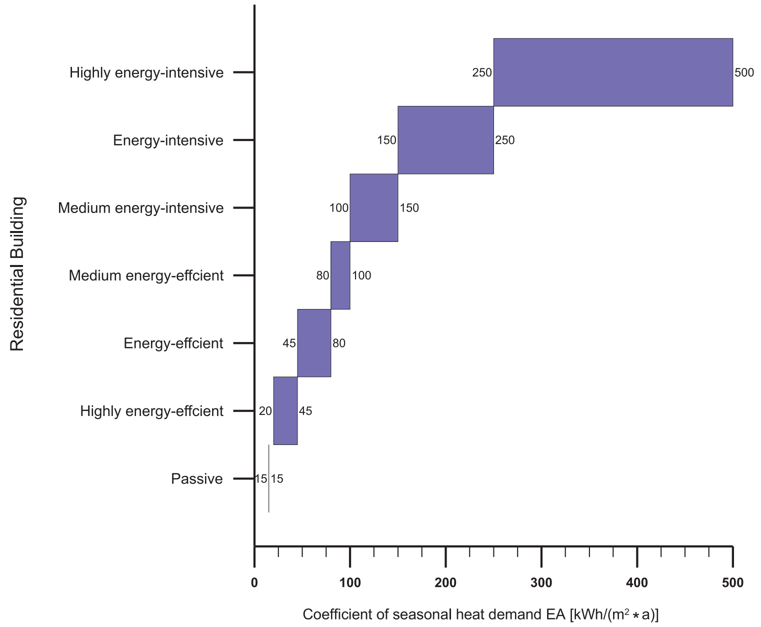

Fig. 2. Energy classification of buildings including the house in Siedlce

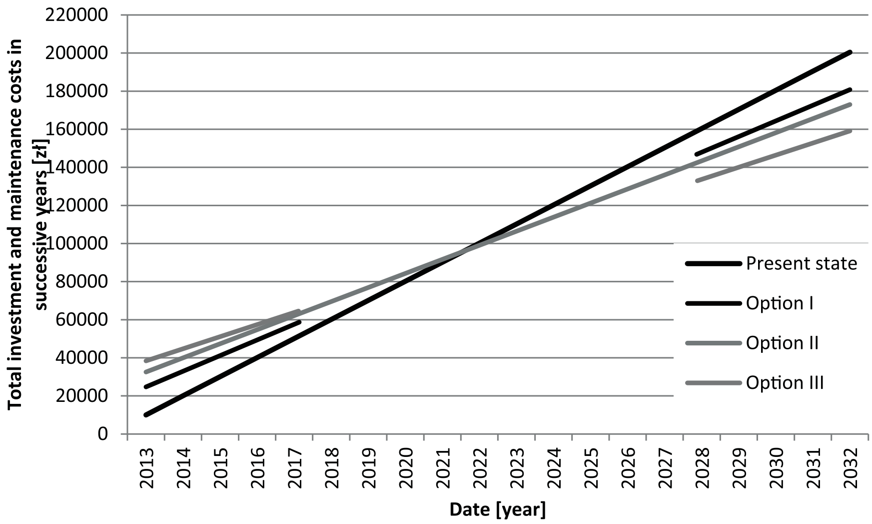

Fig. 3. Total investment and maintenance costs in successive years for the three modernisation options

The analysis of the aggregated investment and maintenance costs in the successive years (on condition that energy prices and efficiency of the existing solutions do not change) showed that the payback period for the first and third options is nine years, while for the second option is ten years. In a twenty-year period the third option will prove to be the most profitable as it will give 41324 PLN in savings (Figure 3).

Conclusions

The house in Siedlce in the present state has been classified as medium energy- efficient. The scope of thermo-modernisation works in the second option significantly reduces the value of seasonal heat demand EA indicator and as a result, the house meets the criterion of being energy-efficient. Further heat reduction is feasible through the improvement of the ventilation system and central heating system by means of automatisation.

The scope of the thermo-modernisation in the three options increases as well as the costs incurred. Despite the costs increase, the third option is twice as expensive as the first one, yet the payback period for all options is similar - approximately nine years. The most profitable is the third option of thermo-modernisation because in a twenty-year period the owner can save about 41324 PLN as compared to the costs incurred currently.

References:

1. Bogacki M., Osicki A. (2011), Termomodernizacja w świetle dyrektywy o charakterystyce energetycznej budynku. Fundacja na rzecz Efektywnego Wykorzystania Energii. Katowice.
2. Dreger M. (2006), Właściwa grubość izolacji, Materiały Budowlane, No 3, 7-8.
3. Dylewski R., Adamczyk J. (2008), Wpływ kosztów ogrzewania na dobór termoizolacji, Ciepłownictwo, Ogrzewnictwo, Wentylacja, No 6, 20-24.
4. Koczyk H., Antoniewicz B., Basińska M., Górka A., Makowska-Hess R., (2005), Ogrzewnicwo praktyczne- projektowanie, montaż, eksploatacja, Wyd. Systherm Serwis, Poznań.
5. PN-B-02025:2001 Obliczanie sezonowego zapotrzebowania na ciepło do ogrzewania budynków mieszkalnych i zamieszkania zbiorowego.
6. PN-EN 12831:2006 Nowa metoda obliczania projektowego obciążenia cieplnego.
7. PN-EN ISO 6946 Komponenty budowlane i elementy budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczania.
8. Praca zbiorowa pod redakcją dr hab. inż. Jana Norwisza (2006), Termomodernizacja budynków dla poprawy jakości środowiska. Narodowa Agencja Poszanowania Energii, Gliwice.
9. Rozporządzenie Ministra Infrastruktury z 6 listopada 2008r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie.
10. Rozporządzenie Ministra Infrastruktury z dnia 15 styczna 2002 roku w sprawie szczegółowego zakresu i formy audytu energetycznego (Dz. U. Nr 12, Poz. 114).
11. Rozporządzenie Ministra Infrastruktury z dnia 17 marca 2009 roku w sprawie szczegółowego zakresu i formy audytu energetycznego oraz części audytu remontowego, wzorów kart audytów, a takŜe algorytmu oceny opłacalności przedsięwzięcia termomodernizacyjnego.

12. Rozporządzenie Ministra Infrastrukturyz 12 kwietnia 2002r. w sprawie warunków technicznych, jakim powinny odpowiadaćbudynki i ich usytuowanie (Dz. U. 2002 nr, 75 poz.690).
13. Sas-Micuń A. (2006), System oceny energetycznej budynków – proponowane rozwiązania prawne. Materiały Budowlane 1/2006.
14. Ustawa z dnia 21.11.2008 r. o wspieraniu termomodernizacji i remontów (Dz. U. Nr 223, poz. 1459, z późn. zm.)
15. Wysocki K. (2007), Docieplanie budynków, Wyd. „KaBe", Krosno.