Vol. 9, No 2/2020, 111-119

DOI: 10.17512/bozpe.2020.2.13

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Methodology for assessment of the cost effectiveness of simple energy efficient investments

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Abstract: The development of energy efficient buildings has been on the increase in recent years. This trend in architectural engineering reflects both the binding legal regulation and the rational approach of investors to the construction or refurbishment of buildings. When planning such an investment, it is necessary to scrutinize the underlying guidelines and the conditions in which the building will be developed, as well as its future useful life. Economic analysis of the effectiveness of investments in the building sector employs simple and discounted methods. Depending on the scope and complexity of envisaged construction work, it is possible to apply methods from both groups. However, simple methods should suffice for simple building projects, an example of which will be discussed in the article. Three variants of planned additional thermal insulation of external walls of a residential building will be presented. The results of our calculations showed that the payback period for such an investment would be too long, which is why it is recommended to combine the thermal insulation of outer walls with some broader measures so as to shorten the time needed to achieve a good return on investment ratio.

Keywords: cost effectiveness, energy efficient, thermal insulation

Please, quote this article as follows:

Szafranko E., Methodology for assessment of the cost effectiveness of simple energy efficient investments, BoZPE, Vol. 9, No 2/2020, 111-119, DOI: 10.17512/bozpe.2020.2.13

Introduction

Energy efficient buildings are steadily gaining increasing popularity among investors (Noailly, 2012; Kuckshinrichs et al., 2010). Several reasons are at play, such as the requirements set in building legal regulations in Poland and the European Union, or the users' awareness of costs incurred by using a building. Any investment in a building, be it the construction of a new building or major repairs and refurbishment of an existing one, should be carefully considered in terms of finances. This especially applies to energy efficient development projects. In order to assess the cost effectiveness of an investment, an analysis needs to be made in order to decide whether a given investment project will be profitable (Risholt & Berker, 2013). This can be done by comparing selected variants and calculating the duration of the period over which the invested capital will be returned by the savings obtained owing to the decreased demand for heating energy. The most effective investments are ones where the payback period is the shortest and the savings achieved are the highest (Diakaki et al., 2008, Diakakiet et al., 2010).

Beside erecting new buildings with a low demand for energy, it is possible to improve the thermal insulation of existing buildings. In line with the relevant literature (Gieseler et al., 2004; Martinaitis et al., 2007; Wilson et al., 2015), thermal improvement is the adaptation of buildings to the binding law and regulations concerning the external partitions and installations, especially heating installations (Gieseler et al., 2004). The biggest problems, due to high heat losses, occur in buildings constructed in the 20th century. This was when the regulations governing thermal insulation set very low thermal requirements. There were very high heat losses through partitions in those buildings, constructed with the use of traditional technologies (Wiren, 1983). The aim of thermal improvement is to increase the insulation of partitions and the air-tightness of a building. The measures taken aim at the improved insulation of partitions as well as the higher efficiency of heating and ventilation systems. They also include the additional insulation of external walls, roof, ceilings and ground flooring, replacement of window and door woodwork, replacement of heating sources, replacement of heating systems or refurbishment thereof, replacement of radiators or insulation of pipes, installation of thermostatic valves, refurbishment of mechanical ventilation and heat recuperation devices, or use of energy from renewable resources (Dylewski & Adamczyk, 2011; Weiner & Curtis, 1997; Navarro, 2002).

The most common solution applied in existing buildings is to insulate the external walls. This is dictated by a high percentage of heat loss through external walls from the total heat loss. This is in comparison with heat losses through other partitions in the buildings. Another reason is the evident decrease in demand for heat energy observed after the external walls of a given house were additionally insulated.

1. Methodology for making an assessment of the economic efficiency of an investment

There are numerous methods for performing an evaluation of the cost effectiveness of an investment. The literature suggests a division into static and dynamic approaches. The former are simple methods, and their distinguishing feature is that they do not involve the effect of time on an investment, in addition to which analyses include distinctly fewer data. Thus, someone who uses a static method will calculate the effectiveness of a planned investment excluding the question of the time value of money. An advantage of static methods is that they are easy and quick to implement, although in some cases the results might not be accurate enough. When more complex development projects are at play, it is better to employ dynamic methods, which are much more expanded and detailed. They include a discounting technique, which takes into account the time-related variability of data, and this means costs and future economic outcomes can be compared more accurately (Wilson et al., 2015; Patiño-Cambeiro et al., 2019).

The most popular static method is the Simply Payback Time (SPBT). It is employed to identify the time it will take for the inputs into an investment to be returned. It is a very simple and effective method, but it can only be applied to relatively simple investment projects. For instance, it is applied when doing energy auditing and evaluating energy-saving measures, as it allows one to compare in a simple manner the heat losses before and after thermal insulation. The following formula (1) serves to calculate a simple payback period (Faludi & Lepech, 2012):

$$SPBT = N/Z \tag{1}$$

where:
SPBT – simple payback period [years],
N – value of inputs needed to carry out the investment project [PLN],
Z – annual value of financial gains [PLN/year].

When using the SPBT method for evaluation of energy efficient investments in the building sector, it is advisable to remember that the annual gains are the savings an investor will obtain. It is equally important to ensure that the given investment project should have the shortest possible payback period, that is the lowest SPBT value. The analyzed investment can only then be said to be cost effective.

Another highly popular method is the Simple Rate of Return on investment inputs, which is calculated from the formula (2) (Knapp & Jester, 2001):

$$R = (Z + A)/K \tag{2}$$

where:
R – simple rate of return of investment outlays,
Z – net profit,
A – depreciation,
K – total investment inputs.

Another static technique for the evaluation of the cost effectiveness of an investment is the comparative analysis of costs. This approach is applied when one of several potential variant conditions for the performance of a given project is to be chosen. It is usually assumed that one year is a time unit in the calculations. The outcome is the selection of the best variant of an investment with the same final outcomes but different costs. The costs can be divided into operating and capital expenses, which are composed of calculated profit and depreciation. Thus, it is recommended to choose the option that would require the least inputs but would satisfy the requirements set for the project (Landsberg & Stewart, 1980; Knapp & Jester, 2001).

Dynamic methods, known as discounted methods, are more complicated but lead to more precise results. Investors planning bigger development projects prefer this approach for an assessment of cost effectiveness because discounted methods take into account the timeline of the implementation of an investment project, variability of costs and gains, and they include interest calculations. To be able to employ dynamic methods, one needs such information as:

- the time interval taken for the calculations (n),
- the discount rate (r), and
- the net cash flow.

The time period assumed for the calculations spans the time needed to complete the investment and to pay back the loan taken to finance it. It is extremely difficult and often impossible to determine precisely the discount rate, which comprises the predicted inflation rate, risk free rates and a premium for the risk of completing the project. The net cash flow, which provides very important information, consists of several factors. The cash flow volumes are determined according to the costs and revenues during each year of the investment as well as the expenditure on fixed and current assets (Navarro & Sanchez, 2002).

Discounting means taking into account changes in the value of money over time. To calculate the current worth of inputs, it needs to be discounted using the dependence of prices on the interest rate. The future value of the capital will equal ((3) and (4)) (Malatji et al., 2013; Knapp & Jester, 2001):

$$FVn = (1 + r)n \cdot PV \tag{3}$$

$$PV = FVn/(1 + r)n \tag{4}$$

where:
PV – present value,
FV – future value,
n – year in the time period of the investment,
r – discount rate.

One of the discount methods is the Net Present Value approach. It enables the user to determine the current value of expenditures and gains related to the analyzed investment. The computed value corresponds to the sum of net cash flows discounted separately for each year over the entire period of the investment. If this value equals or exceeds zero, then the investment can be said to be cost effective. This also means that a higher value derived from the calculations will be the basis for generating a higher profit. When the NPV value is less than zero, the gains will be lower than the outlays, and the investment will be unprofitable. The formula for the calculation of the Net Present Value (5) is given below (Malatji et al., 2013):

$$NPV = \Sigma NCF_{mt} = o \cdot (1+ r) - t \tag{5}$$

where:
NPV – Net Present Value,
NCF_t – value of net cash flows in consecutive years of the time period included in the calculations,
r – discount rate,
n – number of intervals in the life cycle of the investment,
t – the consecutive year in the time period taken for the calculations.

The aim of the article is to show the advantages of simple methods of assessing energy-saving investments and to propose an approach to the assessment of simple investment solutions.

2. Case study

The case study involved a detached residential house, which was approved for habitation in 2005. The house was built with the use of traditional technology. The basic parameters of the building, such as floor space and cubic size, are shown in Table 1. The data concerning heat transfer through partitions are collated in Table 2.

Table 1. The basic parameters of the analysed building (*own study*)

1	Building area	222.6 m^2
2	Usable area of the building	216.2 m^2
3	The surface of the external walls of the building	261.7 m^2
4	The area of windows and doors	62.3 m^2
5	The area of windows and doors in external walls	52.5 m^2
6	Cubic size	1019.8 m^3

Table 2. The data concerning heat transfer (*own study*)

No	Partition	U	Compliance with applicable regulations as of:		
		W/(m^2 K)	1.02.2014	1.01.2017	1.01.2021
1	External wall	0.375	no	no	no
2	Structural internal wall	1.61	no	no	no
3	Partition wall	2.04	no	no	o
4	Ground flooring	0.325	no	no	no
5	Ground floor ceiling	0.899	yes	yes	yes
6	Roof	0.294	no	no	no
7	Window joinery	1.7	yes	no	no
8	Exterior doors	1.6	yes	no	no
9	Interior doors	2.0	no	no	no
10	Garage door	2.0	no	no	no

This data proves that the partitions in the building do not have good insulation parameters. A possible solution that would lower the demand for heating and result in lower costs could be an investment intended to improve the thermal efficiency of the building partitions. In this case, due to the large surface area as well as an evident difference between actual and required coefficients of the heat transfer through partitions, the best option was to improve the insulation of the roof and external walls. Three variants were analysed (Tables 3-5).

Table 3. Data on heat transfer in the case of thermal insulation in variant I (*own study*)

No	Layer of partition	d	λ	R	U_c
		m	W/(mK)	$(m^2K)W$	$W/(m^2K)$
	Outside			0.04	0.215
1	Plaster or lime-lime finish	0.015	0.82	0.018	
2	Styrofoam	0.15	0.04	3.750	
3	Solid ceramic brick	0.25	0.77	0.325	
4	Plaster or lime-lime finish	0.015	0.82	0.018	
	Inside			0.14	

Table 4. Data on heat transfer in the case of thermal insulation in variant II (*own study*)

No	Layer of partition	d	λ	R	U_c
		m	W/(mK)	$(m^2K)W$	$W/(m^2K)$
	Outside			0.04	0.169
1	Plaster or lime-lime finish	0.015	0.82	0.018	
2	Styrofoam	0.20	0.04	5.00	
3	Solid ceramic brick	0.25	0.77	0.325	
4	Plaster or lime-lime finish	0.015	0.82	0.018	
	Inside			0.13	

Table 5. Data on heat transfer in the case of thermal insulation in variant III (*own study*)

No	Layer of partition	d	λ	R	U_c
		m	W/(mK)	$(m^2K)W$	$W/(m^2K)$
	Outside			0.04	0.143
1	Plaster or lime-lime finish	0.015	0.82	0.018	
2	Styrofoam	0.20	0.033	6.061	
3	Solid ceramic brick	0.25	0.77	0.325	
4	Plaster or lime-lime finish	0.015	0.82	0.018	
	Inside			0.14	

The calculations were carried out according to a simple method, which allows the user to compute a simple period of the return of the inputs. Table 6 presents the calculations and the results of the performed analysis.

Table 6. Calculations and results (*own study*)

Coefficients	Variant I	Variant II	Variant III
Heat transfer coefficient after thermal works	0.215 W/(m^{2}K)	0.169 W/(m^{2}K)	0.143 W/(m^{2}K)
Change the value of the factor ΔU	ΔU = 0.159 W/(m^{2}K)	ΔU = 0.205 W/(m^{2}K)	ΔU = 0.231 W/(m^{2}K)
Reducing heat loss ΔQ	ΔQ = 0.159 W/(m^{2}K) · (20°C – 2°C) · 5568 h · 209.2 m^2/1000 = 3333 kWh	ΔQ = 0.205 W/(m^{2}K) · (20°C – 2°C) · 5568 h · 209.2 m^2/1000 = 4298 kWh	ΔQ = 0.231 W/(m^{2}K) · (20°C – 2°C) · 5568 h · 209.2 m^2/1000 = 4843 kWh
The value of savings (O) (in PLN)	O = 0.25 PLN/kWh · 1,7 · 3333 kWh = 1416	O = 0.25 PLN/kWh · 1,7 · 4298 kWh = 1826	O = 0.25 PLN/kWh · 1,7 · 4843 kWh = 2058
Spending on investment (in PLN)	42912.20	46445.35	46959.99
Co-financing from the “Clean Air” program (in PLN)	12873.66	13933.61	14087.95
Payback period	SPBT = (42912.20 PLN-12873.66 PLN)/ 1419 PLN/year = 21.2 years	SPBT = (46445.35 PLN-13933.61 PLN)/ 1826 PLN/year = 17.8 years	SPBT = (46959.99 PLN-14087.95 PLN) /2057 PLN/year = 15.9 years

Conclusions

The results prove that the investment project described in variant III, despite the highest outlays, is most profitable. The payback period calculated during the analysis was nearly 16 years, which is 5 years less than that for variant I. With high investment inputs, the co-financing is also higher, as it is calculated as a percentage of the value of the investment project. Although the shortest payback period is relatively long, it is still recommendable to combine the improvement of the thermal efficiency of external walls with other measures, which could ensure better results and a payback period of less than 10 years.

Summary

When planning energy efficient investments, the economic aspect turns out to be one of the major issues. Such investments should be as profitable as possible, and when selecting a specific solution the decision is supported by at least one of many methods applied to evaluate the cost effectiveness of an investment project. The choice of a specific method depends on the category and type of planned works. Concerning the thermal improvement of buildings, it is possible to employ simple methods. They will generate the most important data, such as profit or pay-

back period. However, it should be noted that not every energy saving investment is profitable. Projects where the inputs would be returned after decades do not make sense because of the high probability that the insulating material would lose its properties or the installation would cease to function properly over such a long time. In the case of more complex investments, it is recommended to apply dynamic methods, which in these situations will produce more reliable results. Dynamic methods take into account time-related changes in values of the investment factors, and this allows the user to make a more in-depth analysis. It is also worth remembering that not every building needs energy saving improvements, as in some cases the change and future savings will be negligible. Comparison of costs of different projects, as in the case presented herein, should also include the possibility of receiving co-financing from government programmes dedicated to energy efficiency improvement. The example presented in the article shows how to easily evaluate energy-saving investments. The result obtained in the case study confirms that from an economic point of view it is better to carry out larger complex investments as the level of benefits are more encouraging for investors.

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Rozporządzenie Ministra Transportu, Budownictwa i Gospodarki Morskiej z dnia 5 lipca 2013 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie.

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