Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2011, 27(99) z. 1 pp. 47–51

2011, 27(99) z. 1 s. 47–51

Ecological indicators of construction investment

Wskaźniki ekologiczne inwestycji budowlanej

Robert Dylewski[1], Janusz Adamczyk[2]

University of Zielona Góra, [1] Faculty of Mathematics, Computer Science and Econometrics
[2] Faculty of Economics and Management
Uniwersytet Zielonogórski, [1] Wydział Matematyki, Informatyki i Ekonometrii, [2] Wydział Ekonomii i Zarządzania
65-417 Zielona Góra, ul. Licealna 9, e-mail: R.Dylewski@wmie.uz.zgora.pl, J.Adamczyk@wez.uz.zgora.pl

Key words: environmental and economic evaluation, LCA, thermal insulation

Abstract
In Polish conditions, one of the types of investments which bring financial benefits for the investor and also reduce the load of the environment is thermal insulation. This article shows how to make an evaluation of sample of investment, which is the thermal insulation of the exterior boundary walls, from the financial side. Indicators to assess the investment in ecological terms, using life cycle assessment LCA are also proposed. An analysis of different options depending on the thermal insulation was made. Analysis includes: properties of the exterior boundary walls against thermal insulation, the type of thermal insulation and type of heat source in the building.

Słowa kluczowe: ocena ekonomiczna i ekologiczna, LCA, termoizolacja

Abstrakt
W warunkach polskich jednym z rodzajów inwestycji przynoszących korzyści finansowe dla inwestora, a zarazem zmniejszenie obciążenia środowiska jest termoizolacja. W artykule przedstawiono sposób oceny przykładowej inwestycji budowlanej, jaką jest termoizolacja przegród zewnętrznych budynku, od strony finansowej. Zaproponowano też wskaźniki do oceny inwestycji pod względem ekologicznym, z wykorzystaniem analizy cyklu życia LCA. Przeprowadzono analizę różnych wariantów termoizolacji w zależności od własności przegród zewnętrznych przed termoizolacją, rodzaju termoizolacji i rodzaju źródła ciepła w budynku.

Introduction

In the European Union including Poland topic related to the need of the increase of efficiency of energy use by end users is getting more and more often discussed. Largely, it's caused by made commitments in the Kyoto Protocol, but also by a number of action[1] taken within the Community to reduce the emission of greenhouse gas into the atmosphere. 5th April 2006 the European Parliament and the Council enacted the Directive 2006/32/EC on energy end-use and energy services. The Directive assumes that improving energy efficiency will enable the use of potential energy savings in an economically efficient way [1]. Energy Efficiency Action Plan was developed for improving energy efficiency and is implemented in art. 14 (2) of the Directive 2006/32/EC.

In EEAP two aims were defined:

- to achieve the indicative target for energy savings in accordance with the requirements of Directive 2006/32/EC, i.e. 9% of the five-year average (2001–2005) final energy consumption in 2016;
- achieving an intermediate target of 2% of the five-year average (2001–2005) final energy consumption in 2010 [2].

Assuming, that the typical residential buildings constructed today are characterized by a demand for usable energy for heating at 90–140 kWh/(m^2a) [3], the value of energy savings identified as indicative target for 2016 amounting to 53,432 GWh [2] average would be enough to heat over 464 million

[1] Zielona Księga, Biała Księga, Mapy Drogowe [4].

m^2 of residential floor space within a year. Comparison was made to illustrate the scale of energy savings associated with the final.

Analyzing the cost curve for greenhouse gas emission reductions for the Poland to 2030 – McKinsey's curve, it can be concluded that thermal modernization of existing commercial and residential buildings is one of the most economically and ecologically reasonable means of reducing those gases [4].

Meters of financial investments' evaluation

Financial investment is sequence of payment with known size and moment of occurrence. Negative payments represent investor's expenditures, while positive payments mean his income. Additionally, it was assumed that the first payment is expenditure and it occurrences at the time $t_0 = 0$ – time of starting investment. Thus, financial investment is a finite sequence of flow P_0, P_1, ..., P_n, where P_j is the flow at time t_j, $j = 0, 1, ..., n$, where $P_0 < 0$ and $P_n \neq 0$ [5].

The primary meter used to evaluate the investment decision is the net value of present investment, defined as *NPV* (Net Present Value). *NPV* is the sum of discounted outlays and incomes of investments at moment $t_0 = 0$ and set interest rate r. In case of long-term investments, where unit of time is a year (r is then annual interest rate), model of exponential interest rate is usually used (compound capitalization) and then the net, present value is given by [5]:

$$NPV = \sum_{j=0}^{n} P_j (1+r)^{-t_j} \quad \text{[PLN]} \tag{1}$$

Investment for set r rate is profitable if the value of NPV is non-negative. When comparing two investments (because of this indicator), better is the one that has a higher NPV.

Net present value is an absolute meter of investment evaluation, and it essentially depends on the scale of investment. When comparing of investments of different lengths of investment period (investment time horizon) and significantly different expenditures, it is better to use a relative meter of profitability or internal rate of repayment (do not depend on the scale of investment).

Another meter, expressed in units of time, the payback period of investment (also called the discounted payback period). Period of return means the shortest period of $[0, T]$ for which the net, present value of all payments from this period is greater than or equal to 0. For the convenience repayment period is identified with the moment of the final T [5]:

$$T = \min\left\{ t_k : \sum_{j=0}^{k} P_j (1+r)^{-t_j} \geq 0 \right\} \quad \text{[years]} \tag{2}$$

If for the entire investment period the net present value is negative ($NPV < 0$), we say that the investment does not pay up (pay-back period T does not exist). When comparing two investments (due to the indicator) better investment is the one which has a smaller T. If the payment P_{k+1} is a result of a cumulative income evenly distributed over the period $(t_k, t_{k+1}]$, then the value of T can be determined more precisely (than for the full year) by approximation of linear function of *NPV* in the between (t_k, t_{k+1}).

In the rest of this article, the investments will be considered with the same time horizon, similar expenditures occurring only at the time t_0 and income in times t_1, ..., t_n, so only the *NPV* indicators and T will be taken into account, the discounted repayment period for such investments is clearly defined (if $NPV \geq 0$).

Ecological indicators of investment

The investment can be assessed not only in financial terms. In many cases, it is reasonable to examine the impact of investments on the environment. For the environmental assessment of investment, the technique of Life Cycle Assessment LCA can be used. LCA values are expressed in the so-called ecopoints [Pt] (value of 1 Pt is equal to 10^3 units of annual environmental load per one inhabitant of Europe).

To the financial metrics similarly can be defined the ecological one, while expenditures will be associated with an additional burden on the environment as a result of realization of investments and income with the reduction of environmental load. In addition, we assume that the value of environmental burdens (in Pt) do not change at discounted over time (ecological interest rate is equal to 0).

Ecological net present value of NPV_E can be defined by:

$$NPV_E = \sum_{j=0}^{n} E_j \quad \text{[Pt]} \tag{3}$$

where: $E_j < 0$ means the amount of increase of burden on environment because of the investment in year $(t_j, t_{j+1}]$, and $E_j > 0$ amount of decrease of burden on environment because of investment in year $(t_j, t_{j+1}]$.

Of course, the investment is profitable in terms of ecological (generate decrease of burden on environment) if the value of NPV_E is non-negative. Comparing two investment (due to this indicator), better is the one which has greater value of NPV_E.

You can also specify the ecological meter expressed in units of time. An ecological repayment period can be defined as the shortest period [0, T_E], for which ecological, net present value of all flows E_j from this time is greater or equal 0:

$$T_E = \min\left\{ t_k : \sum_{j=0}^{k} E_j \geq 0 \right\} \text{ [years]} \tag{4}$$

According to T, if $NPV_E < 0$, then ecological period of repayment T_E doesn't exist (investment doesn't payback for ecological reasons). When comparing two investments (due to this factor) as better is considered an investment which has lower T_E.

Flows in the construction investment involving thermal insulation of the exterior boundary walls of the building

An example of construction investment may be the thermal insulation of the exterior boundary walls. Financial expenditures in this investment are taken only in moment $t_0 = 0$ and depends of the gauge of thermal insulation layer, costs of used material and costs of implementation of thermal insulation. Income is a result of decrease of building's energy requirements for heating and in consequence of decrease of heating cost according to building without thermal insulation. It occurs at times $t_1, \ldots, t_n$. Details of determination of financial flow can be found in [6].

Taking into account the environmental reasons in thermal insulations' investment, the expenditures (increase of environmental burden) connected to production of thermo-insulation material. Income (decrease of environmental burden) occurs in phase of using the building, because of decrease of energy used to heat the building. Ecological indicators depends on type of insulating material, gauge of thermal insulation layer, dividing wall properties without thermal insulation and used heat source. Details of determining of ecological flows can be found in [7].

Indicators of exemplary options of thermal insulation

At this point, the financial and ecological indicators for exemplary options of thermal insulation are set, depending on the type of dividing exterior wall, used type of heat source and type of insulating material. The following are the necessary data to determine financial and ecological flows in investment.

The analysis was performed for three types of construction materials used to build the exterior boundary walls:

(P1) blocks of cellular concrete ACC (density 400 kg/m^3) with a gauge of 24 cm and thermal conductivity indicator equal to 0.10 W/mK, (R_o = 2.40 m^{2}K/W, U_o = 0.39 W/m^{2}K);

(P2) breeze blocks MAX with a gauge of 29 cm and thermal conductivity indicator 0.21 W/mK, (R_o = 1.38 m^{2}K/W, U_o = 0.65 W/m^{2}K);

(P3) sand-lime blocks (silicate) with a gauge of 24 cm and thermal conductivity indicator 0.46 W/mK, (R_o = 0.52 m^{2}K/W, U_o = 1.45 W/m^{2}K).

The parameter R_o means thermal resistance of homogeneous layer of construct material and U_o – heat transfer coefficient of division without thermal insulation layer. According to PN-EN ISO 6946 norm, the resistance of heat diffusion on interior surface R_{si} = 0.13 m^{2}K/W and the resistance of heat interception on exterior surface R_{se} = 0.04 m^{2}K/W.

The three types of heat source were selected for analysis:

(E1) coal boiler, G_o = 11.25 PLN K/W (= 130 $\cdot 10^{-6} \cdot 24 \cdot 3605$), costs for heating 130 PLN/MWh, (an efficiency of boiler 80%, calorific value of the fuel 29 MJ/kg and price 795 PLN/t);

(E2) natural gas boiler, G_o = 20.76 PLN K/W (= $240 \cdot 10^{-6} \cdot 24 \cdot 3605$), costs for heating 240 PLN/MWh, (efficiency of boiler 90%, calorific value of the fuel 31 MJ/m^3 and price 1.80 PLN/m^3);

(E3) electric boiler, G_o = 37.20 PLN K/W (= $430 \cdot 10^{-6} \cdot 24 \cdot 3605$), costs for heating 430 PLN/MWh, (price of electrical energy 0.43 PLN/kWh).

The G_o parameter means an annual cost of heating, relative to 1 m^2 of selected surface of division. The number Sd = 3605 degree days[2] (the average for Poland for years 1980–2004 [8]) was adopted.

For thermal insulation following isolating materials were chosen:

(I1) styrofoam, λ = 0.032 W/mK (density about 14 kg/m^3), cost 156.00 PLN/m^3 (for gauge 10 cm);

(I2) mineral wool, λ = 0.035 W/mK (density 90 kg/m^3), cost 381.90 PLN/m^3 (for gauge 10 cm);

[2] Number of degree days of heating season is a quantitative indicator of the demand for energy for heating houses and public buildings, which is determined on the basis of climatic data for a selected place. It is calculated when the temperature of the air (outside) during the whole day is lower than the set up base temperature.

Table 1. Net present values NPV [PLN/m^2] of thermal insulation investment [source: author's own research]
Tabela 1. Wartości bieżące netto NPV [zł/m^2] inwestycji termoizolacyjnej [źródło: opracowanie własne]

Type of dividing wall	Heat source	Thermal insulating material					
		I1		I2		I3	
		d_N	d_{opt}	d_N	d_{opt}	d_N	d_{opt}
P1	E1	–9.28	10.10	–16.06	–12.27	–11.64	6.96
	E2	12.19	70.04	5.41	27.28	7.68	59.05
	E3	49.31	178.88	42.53	115.80	41.09	166.46
P2	E1	52.08	71.45	37.25	38.49	49.44	64.46
	E2	129.37	187.22	116.69	137.68	126.73	174.91
	E3	262.99	391.00	254.02	322.71	260.35	385.72
P3	E1	250.59	269.97	228.98	230.22	245.59	264.19
	E2	499.65	557.50	480.18	501.19	492.50	548.55
	E3	930.20	1 059.77	914.45	983.14	919.34	1 044.71

(I3) ekofiber, $\lambda = 0.041$ W/mK (density 60 kg/m^3), cost 150.00 PLN/m^3.

Parameter λ is a thermal conductivity factor of thermal insulating material. Data connected to thermal insulating materials were taken from [9] and [10].

The calculations assume a real annual interest rate $r = 5\%$ and real increase of cost of heating $s = 3\%$. Term of using thermal insulation took $n = 30$ years. Cost of making thermal insulation is equal to 30 PLN/m^2.

The study involved a residential building with garage located next to Zielona Góra with area of floor space equal to 156.1 m^2 and with exterior walls surface equal to 158.7 m^2 (cubature of the building is 390 m^3).

Calculations were performed for two cases of thermal insulation gauge: d_N (the gauge of the thermal insulation layer is chosen to give thermal conductivity factor U isolated dividing wall equal to $U = 0.30$ W/m^{2}K), according to Regulation of the Minister of Infrastructure dated 6th November 2008 changing the regulation in technical conditions which should be granted by the building and their localization, Coll. Laws 2008 No 201, pos. 1238 with later amendments and d_{opt} (gauge of thermal insulation is so selected to obtain maximum value of NPV, for e.g. [11, 6]). Values of NPV and NPV_E were designated in connection to 1 m^2 of dividing wall surface.

Table 1 shows designated financial, net present values of NPV (w PLN/m^2). It can be noticed that for each variant we obtain NPV at gauge d_{opt} greater than at d_N, for some variants even a few times, for e.g. variant P1/E3/I1. It's noticeable that investment is not always profitable. If dividing wall without additional thermal insulating layer has good thermal conductivity factor, thermal insulating material is relatively expensive and costs of obtaining the heat are relatively low, for e.g. variant P1/E1/I2, value of NPV obtained negative.

In table 2 the periods of repayment T (in years) for selected variants of thermal insulation are set. In case, when $NPV < 0$, investment does not pay off in period of 30 years (sign "–" in table). Note that if the dividing wall is without thermal insulating layer and has thermal conductivity factor much differing from norm (e.g. P3), then repayment of investment is just after a few years.

Table 2. Periods of repayment T [years] of thermal insulating investment [source: author's own research]
Tabela 2. Okresy zwrotu T [lata] inwestycji termoizolacyjnej [źródło: opracowanie własne]

Type of dividing wall	Heat source	Thermal insulating material					
		I1		I2		I3	
		d_N	d_{opt}	d_N	d_{opt}	d_N	d_{opt}
P1	E1	–	24	–	–	–	26
	E2	21	13	26	21	24	14
	E3	11	8	13	12	12	9
P2	E1	11	12	16	18	12	13
	E2	6	7	9	10	7	8
	E3	4	5	5	7	4	5
P3	E1	4	5	6	7	4	5
	E2	2	3	3	4	3	3
	E3	2	2	2	3	2	2

This section shows the ecological indicators for thermal insulating investment. Table 3 contains the results of ecological net present value (in Pt/m^2). Each of considerate option the investment is profitable from ecological point of view (decrease the environmental burden, $NPV_E > 0$). Just like in the financial evaluation, for each variant we obtain NPV_E at gauge d_{opt} greater than at d_N, for some variants even a few times greater.

In table 4 designated ecological periods of repayment (in years) were shown. Notice that for analyzed variants the period of repayment is at

Table 3. Ecological net present value NPV_E [Pt/m^2] of thermal insulating investment [source: author's own research]
Tabela 3. Ekologiczne wartości bieżące NPV_E [Pt/m^2] inwestycji termoizolacyjnej [źródło: opracowanie własne]

Type of dividing wall	Heat source	Thermal insulating material					
		I1		I2		I3	
		d_N	d_{opt}	d_N	d_{opt}	d_N	d_{opt}
P1	E1	4.26	11.24	4.23	7.26	4.43	11.59
	E2	2.62	7.77	2.59	6.08	2.79	8.53
	E3	10.56	35.56	10.53	30.34	10.73	36.22
P2	E1	16.73	23.70	16.59	19.62	17.09	23.80
	E2	10.54	15.68	10.40	13.96	10.90	16.62
	E3	42.56	67.50	42.42	62.30	42.92	69.66
P3	E1	56.27	63.25	56.10	59.13	56.80	63.96
	E2	35.28	40.42	35.11	38.67	35.81	41.85
	E3	141.34	166.34	141.17	161.05	141.87	167.35

most 4 year, it means that decrease of environmental burden made by the building in using phase balances the increase of environmental burden which was made because of production process of thermal insulating material which is at least 4 years.

Table 4. Ecological periods of repayment T_E [years] of thermal insulating investment [source: author's own research]
Tabela 4. Ekologiczne okresy zwrotu T_E [lata] inwestycji termoizolacyjnej [źródło: opracowanie własne]

Type of dividing wall	Heat source	Thermal insulating material					
		I1		I2		I3	
		d_N	d_{opt}	d_N	d_{opt}	d_N	d_{opt}
P1	E1	1	2	2	2	0	0
	E2	2	4	2	4	0	0
	E3	1	2	1	2	0	0
P2	E1	1	2	1	1	0	0
	E2	1	3	1	2	0	0
	E3	1	1	1	1	0	0
P3	E1	1	1	1	1	0	0
	E2	1	2	1	1	0	0
	E3	1	1	1	1	0	0

For ecofiber (I3) ecological repayment period was 0 because production of this material cause decrease of environmental burden through the use of recycled newspaper to his production.

Conclusions

At the evaluation of construction investment financial aspect and impact of this investment on environment should be taken. Investment involving thermal insulation of exterior boundary walls proves to be very profitable from ecological point of view. Admittedly, the production of thermal insulating material cause increase of environmental burden (excluding ekofiber), but in phase of using the building, the ecological advantages which are taken from decrease of energy requirements to heat are a few times greater and ecological repayment of investment is just after a few years. It is worth to choose the optimal gauge of thermal insulation which in all analyzed variants appeared to be greater than required by the regulation in case for technical conditions, which the building and their location should grant. Then the financial and ecological benefits are even greater.

References

1. Dyrektywy 2006/32/WE Parlamentu Europejskiego i Rady z dnia 5 kwietnia 2006 r. w sprawie efektywności końcowego wykorzystania energii i usług energetycznych. Dziennik Urzędowy Unii Europejskiej.
2. Krajowy Plan Działań dotyczący efektywności energetycznej 2007. Ministerstwo Gospodarki, Warszawa 2007.
3. KWIATKOWSKI J., RUCIŃSKA J., WISZNIEWSKI A.: Analiza dostosowania różnych budynków do standardu budynku energooszczędnego. Energia i Budynek 09(40), 2010, 6–12.
4. ŻMIJEWSKI K., SOKOŁOWSKI M.M.: Efektywnie o energetyce (cz. 1). Energia i Budynek 07(38), 2010, 12–15.
5. PODGÓRSKA M., KLIMKOWSKA J.: Matematyka finansowa. Wyd. Naukowe PWN, Warszawa 2005.
6. DYLEWSKI R, ADAMCZYK J.: Management of Thermal Energy in Buildings by Selecting Heat Sources and Choosing the Optimal Thermal-insulation Thickness. Management 12(1), 2008, 255–266.
7. DYLEWSKI R., ADAMCZYK J.: Ocena korzyści termoizolacji. Ekonomika i Organizacja Przedsiębiorstwa 723(4), 2010, 142–152.
8. GIKAS A, KEENAN R.: Statistical aspects of the energy economy in 2004. Eurostat. Environment and Energy 5, 2006.
9. LASKOWSKI P, OKOŁOWSKA A.: Ciepło na przyszłość. Materiały na dom energooszczędny. Murator 2, 2010, 85–91.
10. www.icmarket.pl (Imarket – materiały budowlane).
11. LASKOWSKI L.: Ochrona cieplna i charakterystyka energetyczna budynku. Of. Wyd. Politechniki Warszawskiej, Warszawa 2005.

Recenzent:
dr hab. inż. Zbigniew Matuszak, prof. AM
Akademia Morska w Szczecinie