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Selected Issues of the Economic Analysis of a Heating System with the Direct Evaporation Heat Pump

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Summary. The article addresses the issues falling within the scope of the economic analysis of a detached building's heating system with a direct evaporation ground source heat pump installation. The paper was elaborated based on the data made available by the investment's contractor and the investor. The paper provides data on the investment expenditures and utility cost, calculations of the installation payback, internal return rate and the current net value.

Key words: heat pump, economic analysis, heating system, investment.

INTRODUCTION

During the modernization of the heating system, the investment profitability is an important issue, beside the ecological aspect, environmental aspect or meeting the heat demand [13, 22, 23]. From the investor's point of view this is the most important criterion in selecting the heating system [6, 7, 19], therefore the cost return period shall be given high priority [3, 10, 26]. Selecting the heating system with heat pumps requires significant investment expenditures [16, 17, 27]. Additionally, both the nature of using the system and the system's operation principle demand some electricity consumption [2, 12, 29]. Despite the above-mentioned aspects, heating systems using the heat pumps are getting more and more popular in the construction investments of service, industrial, accommodation facilities, and the aspects of their use are also being considered in terms of the logistics [4, 5,11, 20].

INVESTMENT EXPENDITURES TO DEVELOP A HEATING SYSTEM WITH THE DIRECT EVAPORATION HEAT PUMP

The installation under analysis was designed to supply for the central heating and heating the warm water in a manufacturing and office building of the total area of 826 m². The heated area within the building was 785 m². Based on the calculations, three direct evaporation heat pumps operating with 30 meter vertical heat exchanger were selected. The aggregate power of the devices was 52.05 kW. Five ground probes were entering each heat pump directly, without collector pipes [21, 24]. The designed receiving installation was composed of 35 ceiling and wall fan coil units of various power performance [1, 15]. Each device was equipped with a controller to set up the required temperature [18, 25]. The detailed technical analysis of the investment in question is described in [28].

Table 1 includes the expenditures on the investment consisting in the modernization of the heating system within the investment under analysis.

Table 1. The cost of the heating system in the investment under analysis

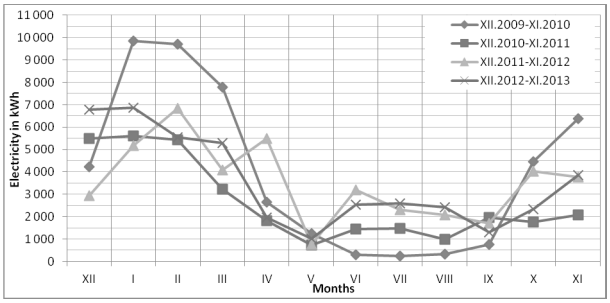
1	DXW 65 LGS heat pumps	PLN 60,000.00
2	Ground heat exchanger	PLN 150,000.00
3	Reflex PH1500 batch tank	PLN 4,800.00
4	Batch connection fittings	PLN 9,616.00
5	N200 pressure expansion vessel	PLN 583.10
6	Reflex SB200 warm water reservoir	PLN 2,442.30
7	Warm water installation connection fittings	PLN 1,450.00
8	DE40 warm water installation pressure expansion vessel	PLN 277.20
9	NG12 system's pressure expansion vessel	PLN 71.40
10	Wall and ceiling fan coil units	PLN 46,000.00
11	Geologic design	PLN 2,500.00
12	Hydraulic design	PLN 500.00
13	Supply installation in the engine room and labour	PLN 85,000.00
14	Supply installation of the fan coil units and labour	PLN 7,500.00

[Own elaboration]

The total investment cost of the heating installation under analysis was PLN 370,740.00

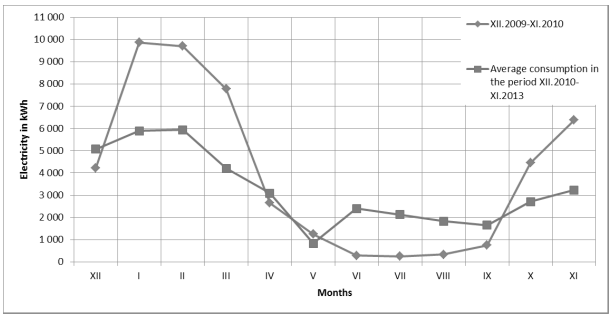
UTILITY COST OF THE INVESTMENT UNDER ANALYSIS

The utility cost analysis of the investment under analysis was based on the readings of the electricity consumption throughout the utility period of the installation with heat pumps and before their installation. The data were collected since December 2009, when the building was not insulated and only partially occupied. During that period the central heating was provided with oil radiator heaters powered with electricity, warm water was heated with instantaneous water heaters. Only the building's ground floor was heated, exclusive of one of the manufacturing halls. During that period, ten employees worked in the building eight hours a day. After the working hours ended, the electric heating was shut down. The usable and heated area was 252 m². The temperature within the building differed from the design temperatures for the rooms for such purposes. The rooms were heated to provide the temperature of 17–18 ºC and such actions were necessary to reduce the energy consumption bills. In the summer 2010 the decision was made to insulate the building and modernize the installation with heat pumps. The thermal modernization included installing new plastic windows and insulating the outer walls with mineral wool. In the autumn the modernization was completed and in December 2010 the area of 785 m² was heated with heat pumps. The receiving installation was designed to keep the temperature of 20 ºC in the office rooms, and the temperature of 18 ºC in the manufacturing halls. During the working hours, the temperature within the building was 22 ºC, reduced for the night to 18 ºC. From December 2009 to November 2010 both the usable and the heated areas were 252 m². Following the modernization, a separate meter was installed in the engine room, displaying the electricity consumption by the installation with three heat pumps. The data from the meters were recorded at the end of each month and the number of days between individual readings was irregular. During the period when the building was heated with electricity it was assumed that 400 kWh of electricity was consumed each month for utility purposes. The term "utility purposes" means the energy required to provide lighting and use of the electric devices. Diagram 1 presents the electricity consumption for heating and cooling purposes, divided into four years of the building's occupation.



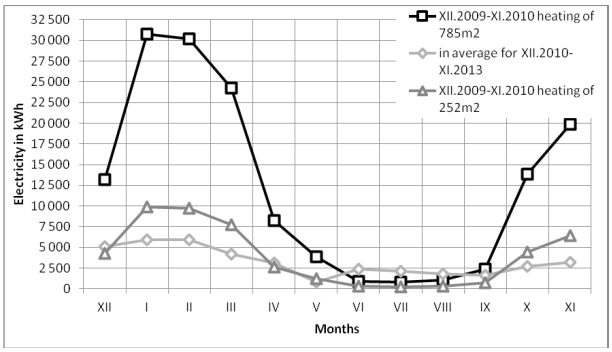
Diag. 1. Electricity consumption for the building's heating and cooling purposes [Own elaboration]

Diagram 2 provides graphic comparison of the electricity consumed for the above-mentioned purposes before the heating system's modernization and its average consumption following the modernization.



Diag. 2. Electricity consumption for heating purposes before modernization as well as the average electricity consumption by the heat pump installation [Own elaboration]

The above diagrams show that the electric heating of the area of 252 m² consumed significantly more electricity than heating the area of 785 m² with three heat pumps. One shall bear in mind that during the first year under analysis only 10 people worked in the building and the temperature inside the rooms was not comfortable. The next three years with the new heating system decreased the electricity consumption. The summer season, namely June, July and August, was the period during which the heat pumps were operating in the cooling mode. Therefore the power consumption was higher than in the first year of the analysis. The lowest electricity consumption for the three years when the heat pumps were operating was in May and reached 835 kWh. During that month, the installation was neither heating nor cooling the rooms. Only warm water was heated with the electric heater. The energy consumption in January 2009 was determined to be 4,235 kWh. Having analysed the trends of power consumption in winter it was concluded that the consumption diminished, probably due to the incorrect meter reading. The highest electricity consumption was in January and reached 9,865 kWh. The electric heating of the whole building would translate into three times the values of the power consumption readings. Such case was presented in diagram 3.



Diag. 3. Electricity consumption for heating purposes of the area of 785 m² [Own elaboration]

Table 2 presents the calculation of the cost of using the previous heating system. It was assumed that 1 kWh of the

electricity costs PLN 0.62. The analysis is divided by the cost incurred actually for heating 252 m² and that would have been incurred for heating 785 m².

Table 2. The cost of heating and cooling the rooms within the investment under analysis with electric power

Date	Monthly electricity consumption for heating purposes [kWh]	KWh per 1 m2 of the building	Heating cost for 252 m² [PLN]	Heating cost for 785 m² [PLN]
XII.2009	4 235	16.81	2 626	8 179
I.2010	9 865	39.15	6 116	19 053
II.2010	9 700	38.49	6 014	18 734
III.2010	7 780	30.87	4 824	15 026
IV.2010	2 650	10.52	1 643	5 118
V.2010	1 250	4.96	775	2 414
VI.2010	290	1.15	180	560
VII.2010	250	0.99	155	483
VIII.2010	335	1.33	208	647
IX.2010	750	2.98	465	1 449
X.2010	4 455	17.68	2 762	8 604
XI.2010	6 385	25.34	3 959	12 332

[Own elaboration]

Table 3 compares the cost of electric heating and the cost of heating the buildings with heat pumps of the aggregate power of 52 kW.

Table 3 compares the annual cost of the two heating systems. The annual heating cost for the building with the area of 252 m² to reach 18 ºC was PLN 29,725.90. In the case of heating the area of 785 m² to reach the same temperature, the cost would amount to PLN 92,598.54. The average annual cost of the electricity consumption required to supply the heat pumps installation during the three years amounted to PLN 24,168.63. That sum included the cost of heating and cooling the building of the area of 785 m². During the summer season, 6,351 kWh were required for cooling purposes, translating into the aggregate cost of PLN 3,937.62. To determine the savings from the system modernization, the cost of cooling with the heat pump installation for three months was excluded. Therefore, the total amount of the cost incurred exclusively for heating was PLN 20,231.01. The annual savings of heating the same area with electric heating system compared to heating with the heat pumps amounted to PLN 72,367.52.

INVESTMENT'S PROFITABILITY ASSESSMENT

The investment's profitability assessment compared to the previously applied electric heating methodology was performed with the following economic performance assessment [8, 9]:

- SPBT – simply pay back time method;
- NPV – net present value method;
- IRR – internal rate of return method.

The direct pay back time of the expenditures incurred (SPBT) was defined with the time required to have the cash expenditures on the investment paid back (equation 1) [14].

$$SPBT = I/Z \text{ [years]}, \quad (1)$$

where:
I – is the amount of the investment expenditures [PLN];
Z – is the annual gross profit [PLN].

This is the difference between the electricity consumption cost of the heat pump installation compared to the electric heating cost.

The net present value (NPV) is the total of the discounted values, maintaining a fixed interest rate of the revenues and expenditures throughout the investment. NPV is calculated as follows (equation 2) [14]:

$$NPV = \sum_{t=0}^{N} \frac{CF_t^*}{(1+r)^t} \text{ [-]}. \quad (2)$$

Table 3. Summary of the electricity consumption cost in the two heating installations for the area of the investment under analysis

Date	Average monthly electricity consumption by the installation with heat pumps [kWh]	Cost of heating with the heat pump installation [PLN]	Heating cost of the electricity for 252 m2 [PLN]	Difference from the modified heating system [PLN]	Heating cost of the electricity for 785 m2 [PLN]	Difference from the modified heating system [PLN]
XII.2009	5 070	3 143.61	2 626	-518	8 179	5 035.66
I.2010	5 887	3 650.15	6 116	2 466	19 053	15 402.61
II.2010	5 943	3 684.45	6 014	2 330	18 734	15 049.63
III.2010	4 201	2 604.83	4 824	2 219	15 026	12 421.07
IV.2010	3 094	1 918.49	1 643	-275	5 118	3 199.59
V.2010	835	517.70	775	257	2 414	1 896.49
VI.2010	2 399.67	1 487.79	180	-1308	560	-927.70
VII.2010	2 123.67	1 316.67	155	-1 162	483	-833.84
VIII.2010	1 827.67	1 133.15	208	-925	647	-486.15
IX.2010	1 655.67	1 026.51	465	-562	1 449	422.00
X.2010	2 709.33	1 679.79	2 762	1 082	8 604	6 924.37
XI.2010	3 234.67	2 005.49	3 959	1 953	12 332	10 326.17
	TOTAL	**24 168.63**	**29 725.90**	**5 557.27**	**92 598.54**	**68 429.90**

[Own elaboration]

where:
CF^*_t – expected profit on the investment in the year t [PLN];
r – discount rate [%].

The cashflow was defined as the difference in the electricity consumption cost resulting from the heating system modernization. For the analysis' purposes, the discount rate was assumed to be 4%, while the simulation period was 30 years.

The internal rate of return (IRR) constitutes the investment's profitability ration assuming that the net present value is zero [14]. The amount of the investment expenditures was estimated by decreasing the actual investment cost with the cost of purchasing and installing the wall and ceiling fan coil units. This was made, because the receiving installation constitutes a component of each heating system and its cost needs to be incurred irrespectively of the heating system selected. The results of the economic analysis were gathered in table 4.

Table 4. Economic analysis result

Coefficient	Result
SPBT	4 years
NPV	361 416.82
IRR	0.07212

[Own elaboration]

CONCLUSIONS

The heating system installation with heat pumps is deemed to be profitable when the pay back time of the cost incurred does not exceed five years. According to that condition, the investment under analysis is profitable, and the investment's cost pay back time is four years. The total cost including the bottom heat source development, purchase of the heat pump units and fan coil units, as well as the labour cost totalled with the amount of PLN 370,740.00. If the previous heating system was maintained for the whole building, the annual utility cost would amount to PLN 92,598.54. The choice of the heating system using the heat pumps with the additional cooling mode during the summer season translated into the annual savings of PLN 68,429.90.

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WYBRANE ASPEKTY ANALIZY EKONOMICZNEJ SYSTEMU GRZEWCZEGO Z ZASTOSOWANIEM POMP CIEPŁA BEZPOŚREDNIEGO ODPAROWANIA

Streszczenie: Artykuł dotyczy zagadnień z zakresu analizy ekonomicznej systemu ogrzewania budynku wolnostojącego instalacją z gruntowymi pompami ciepła bezpośredniego odparowania. Praca zrealizowana została w oparciu o dane udostępnione przez wykonawcę opisanej inwestycji oraz inwestora. W opracowaniu zawarto dane dotyczące nakładów inwestycyjnych i kosztów eksploatacji, przeprowadzono obliczenia czasu zwrotu instalacji, wewnętrzną stopę zwrotu i bieżącą wartość netto.
Słowa kluczowe: pompa ciepła, analiza ekonomiczna, system grzewczy, inwestycja.