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LIFE CYCLE COST ANALYSIS FOR SYSTEMS EQUIPPED WITH A HEAT PUMP

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Abstract: Selecting a suitable heating and cooling system for a building is critical, because it impacts its life cycle cost. The aim of the article is to obtain an answer on the optimal solution in terms of economic efficiency of heat pump heating and cooling systems, since the initial investment in these systems is higher, but the subsequent costs during the period of use are reduced. Cost savings in the operation of heat pump heating and cooling systems is directly related to lowering energy consumption and reducing greenhouse gas emissions. In this study the economic analysis was carried out using life cycle cost method. Economic parameters used in the study include 3.75% discount rate, 1% escalation price rate, 20 years lifespan and 0,2369 €/kWh electricity price.

Keywords: building, life cycle cost analysis, heat pump, economic efficiency, financial analysis, sensitivity analysis

1 INTRODUCTION

In the current context of global warming, EU leaders have endorsed the goal of achieving a climate-neutral Europe by 2050. This means the EU will drastically reduce its greenhouse gas emissions. According to Eurostat, energy used for heating and cooling accounts for the largest share of total energy consumption in the EU, at around 45%. Heating and cooling of buildings plays a crucial role in achieving the goal of a neutral transition of the European Union (Prada, Prada, Cristea, Popescu, Bungău, Aleya & Bungău, 2020).

Only 24% of the energy consumed by the European Union in 2020 comes from renewable energy sources. It is generally true that modern heating and cooling technologies involve a higher initial investment than conventional solutions but at the same time reduce annual costs during the operating period (Petrovi´c, Zhang, Eriksson & Wallhagen, 2021). As a result, research on the economic efficiency of heating and cooling systems equipped with heat pumps is perfectly in line with the current and future needs of sustainable development required by European directives.

To improve energy-saving and reduce the CO_2 footprint for the building sector, the European Union has decided that from 31 December 2020 all new buildings must comply with the nearly Zero-Energy Building (nZEB) standard. According to International Energy Agency (2013), the nZEB building means that the energy consumption for the building is close to 0. This can be achieved by improving the building envelope, using renewable energy and increasing the efficiency of the heating and cooling system (Ramesh, Prakash & Shukla,2010).

Cycle Cost Analysis (LCCA) is one of the methods that can be used to assess the economic feasibility of different energy systems used for heating and cooling in buildings (Wang, Yang, Hou, Tao & Dong, 2022). By using LCCA the most attractive option in terms of cost and economic efficiency can be obtained. According to NATO and RTO ("Code of Practice for Life Cycle Cost", 2009). LCCA is a powerful technique that supports the analytical processes by which managers can make the most cost-effective decisions about the options presented to them at different stages of the life cycle and at different levels of life cycle cost estimation. By using LCC analysis, all identified costs over the entire life cycle of a heating and cooling system are evaluated (Estevan & Schaefer, 2017).

2 METHODOLOGY

In this study the LCCA method was used to calculate the Net Present Value (NPV) of the total cost over the lifetime for three options for the heating and cooling system equipped with heat pump. The LCCA was performed by using Excel software and based on NIST Handbook (Kneifel & Webb, 2022). The costs identified for heat pump heating and cooling systems using air, water or ground as the primary source are shown in the figure 1.

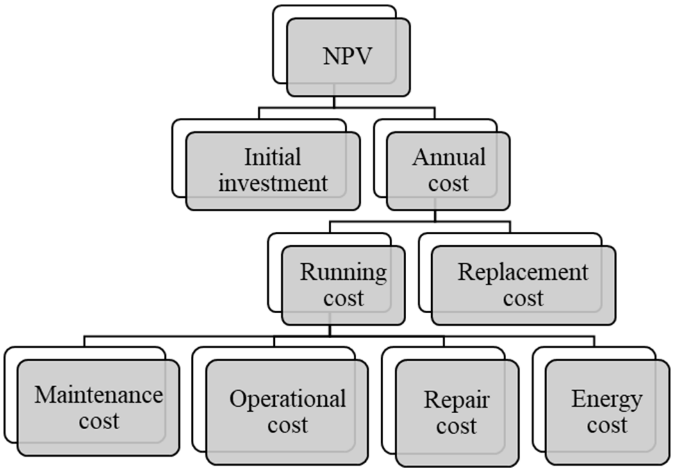

Figure 1. Cost classification in heat pump operation

The economic evaluation was carried out based on the sum of all costs involved in heating and air conditioning systems discounted to present value. According NIST Handbook, the general formula for LCC projects in buildings is shown below:

$$LCC = I + Repl - Rez + E + OMR \quad (1)$$

LCC =present value of life cycle cost for an alternative

I = present value of initial investment cost

Repl = present value of replacement cost

Rez = residual value

E = present value of energy cost

OMR = present value of operational, maintenance and repair cost.

All these costs are discounted to present value based on the discount rate and price escalation rate.

The heat pump heating and cooling system with the lowest LCC will be considered the economically optimal solution.

2.1 Initial investment

The initial investment cost for the heating and cooling system equipped with heat pump were obtained from companies in the region and based on the experience of the researcher. Initial investment costs include: the heat pump, hydraulic accessories for the heat pump, heating and cooling circuit elements, domestic hot water, primary source works, boreholes (if applicable), electrical panel accessories, installation and commissioning.

2.2 Replacement Cost

The replacement cost is the replacement investment value for an element of the heating and cooling system equipped with a heat pump. Considering a lifespan of 20 years and taking into account the standard SR EN 15459-1 regarding the lifespan of the elements of the heating and cooling system with heat pump, only the compressor must be replaced. Based on practical experience in the field of heat pumps we have identified the optimal time to replace the compressor as year 15 and the estimated value of the cost is 1000 EUR.

Before adding the replacement cost to the LCCA, it must be updated to the present value according to the following equation (Kneifel & Webb, 2022):

$$PV = F \cdot \frac{1}{(1+d)^t} \qquad (2)$$

where *d* is the discout rate, *t* is the specific year when the present value is calculated and *F* si the future amount occurring at the end of year *t*.

2.3 Operational, Maintenance and Repair Cost

Operational, Maintenance and Repair Cost (OMR) represents the cost for measures to preserve and restore the desired quality of the facility system and includes annual costs for routine repairs, preventive maintenance, consumable items, facility inspection, cleaning and minor adjustments.

The OMR cost represent 1% of the initial investment value excluding the drilling price for estimating the OMR cost for geothermal heat pump systems and 2% of the initial investment value for heat pump systems with air as the primary source. (Biglarian, Saidi & Abbaspour, 2919).

In the present study the OMR cost will be estimated as 2% of the initial investment value for all types of systems equipped with a heat pump. Before adding the OMR cost to the LCCA, it must be updated to the present value according to the following equation (Kneifel & Webb, 2022):

$$PV = A \cdot \frac{(1+d)^n - 1}{d * (1+d)^n} \qquad (3)$$

where *d* is the discout rate, *n* is the study period and *A* si the annual recurring OMR cost.

2.4 Energy Cost

The annual electrical energy used was simulated with a mathematical model based on Fuzzy Logic (Ban & Bungău, 2022) presented in 2021 at the INTER-ENG conference in Târgul Mureș. The mathematical model is based on four variables: the heat pump power, the secondary agent temperature, the heat pump coefficient of performance and the global thermal insulation coefficient of a building.

The electricity price was derivate by Eurostat and has a value of 0.2369 EUR with all taxes and levies included.

Before adding the energy cost to the LCCA, it must be updated to the present value according to the following equation (Kneifel & Webb, 2022):

$$PV = A \cdot \frac{1+d}{d-e} \left[1 - \left(\frac{1+e}{1+d}\right)^n\right] \qquad (4)$$

where *d* is the discout rate, *e* is the escaladation price for electricity, *n* is the study period and *A* si the annual recurring energy cost.

2.5 Parameters used in calculation

According to the Buildings Performance Institute Europe (BPIE) the real discount rate for countries in Europe is in the range of 1% and 7%. The reference value for the discount rate used in this study is equal to the monetary policy interest rate, set at 3.75% in May 2022, according to the National Bank of Romania. The higher the discount rate, the less attractive it becomes to invest in renewable energy systems for heating and cooling (Hermelink & de Jager, 2015).

The energy price escalation rate has been estimated based on available historical data and has a value of 1%.

The study period of the heating and cooling system is 20 years and the residual value is not taken into account for this study.

3 CASE STUDY

In the study, a two-story single- family house was used for the case study (Figure 2).

Figure 2. The case study building

The house, constructed in 2014, is located in north-west of Romania and has a total floor area of 171.8 m^2 (Figure 3). The building is well-insulated and has a global thermal insulation coefficient of 0.334. The energy system consists of 8 kW ground source heat pump with two borehole of 90 m each. Heating and cooling are done by Thermally Activating of the Building Structure (TABS) and therefore the temperature of the secondary agent is below 35°C. The ventilation is provided by a 95% efficient Passivhaus certified heat recovery system. The real heat pump system coefficient of performance (COP) after one year of monitoring is around 4.4.

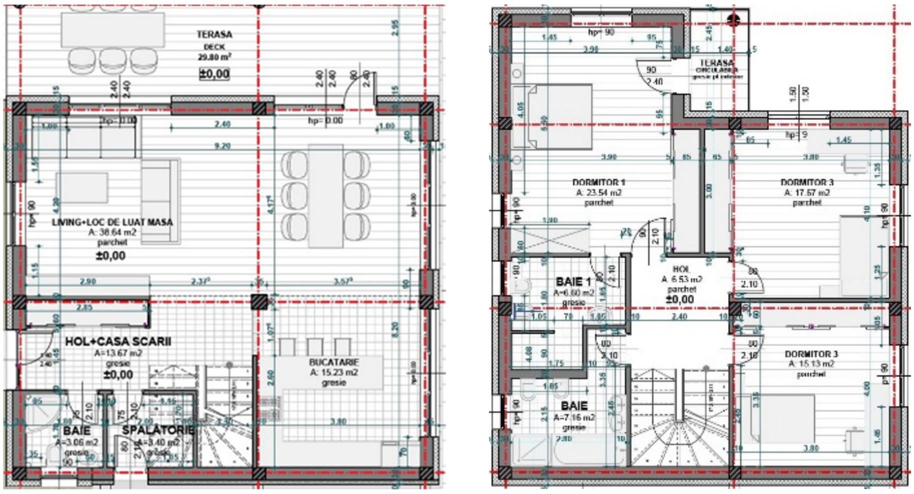

Figure 3. Ground and floor plan
Source: SC Poliart SRL

Three different scenarios were developed, for the reference building, depending on the renewable energy source of the heat pump:

I. 8 kW air source heat pump system
II. 8 kW ground source heat pump system
III. 8 kW water source heat pump system

Table 1 present the input data for the LCCA for the three alternatives system.

Table 1. Input data

	AIR source	GROUND source	WATER source
Initial investment (€)	12,750€	14,486€	16,780€
OMR percentage (%)	2 %		
COP	4	4.6	4.7
Annual electricity consumption (kwh)	6.57 MWh	5.5 MWh	4.79 MWh
Replacement cost (€) /year	Compressor - 1000€ / year 15		
Discount rate (%)	3.75%		
Price escalation rate (%)	1%		
Electricity price (€/kWh)	0.2369 €/kWh		
Lifespan (years)	20 years		

4 RESULTS

The economic performance of each solution was investigated and compared over a 20-year period. Table 2 provides the costs, including initial investment accounting for heating and cooling system with heat pump, OMR cost, replacement cost and energy cost, for each design solution. The initial investment is based on Romania market 2022 prices. The annual OMR cost is estimated to be 2% of the initial investment. It is assumed that, within the calculation period of the study, there is only one replacement cost for each design option. In the year 15 the compressor must be replaced. Energy price is calculated as the product of the estimated annual consumption and the reference electricity price. The energy cost is calculated as the product of the estimated annual consumption and the reference electricity price. The reference electricity price for the present study was set at 0.2369 €/kWh and the estimated energy consumption is based on fuzzy logic.

Table 2. Costs

	AIR sauce	GROUND source	WATER source
Initial investment	10,140€	14,486€	18,094€
OMR cost	3,543€	4,026€	4,663€
Replacement cost	576€	576€	576€
Energy cost	23,760€	19,891€	17,506€

The cumulative chart (see Figure 4) for LCC is presenting the cumulative net present value for the entire 20-year study period, for all three design options assuming a discount rate of 3,755 and a price escalation rate of 1%. As can be seen in the figure below, the system equipped with an air source pump represents the lowest initial investment, but in terms of economic efficiency at the end of the study period it is the least efficient solution. Based on the LCC analysis the most economically profitable solution is the ground source heat pump.

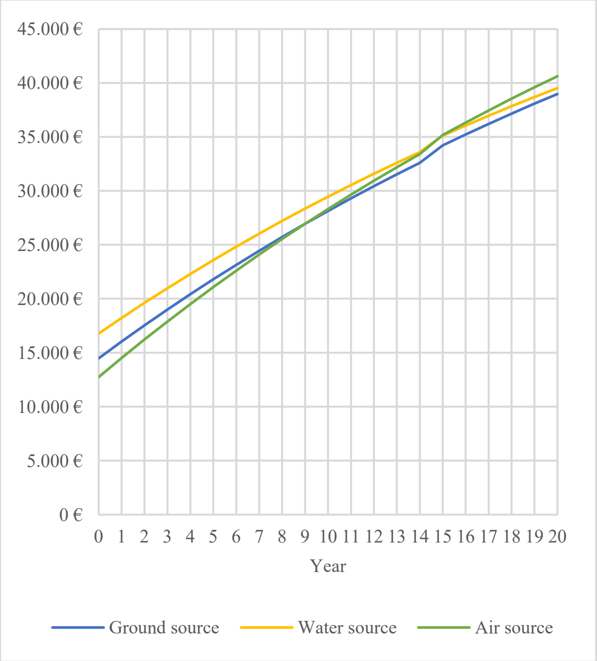

Figure 4. The cumulative net present value

The results in Figure 5 present the total LCC by cost category for the three solutions for heating and cooling system with heat pump. The energy cost represents the major part of the total LCC for all three alternatives. Initial investment for air source system represents 32% of the total LCC, for ground source system represent 37% of the total LCC and for water source system represent 43% of the total LCC. Following the analysis, the ground source heating and cooling system recorded the lowest LCC value, being considered the economically optimal variant. However, it should be taken into account that the three design options have close values and an uncertainty analysis of the reference parameters for the LCC model is necessary.

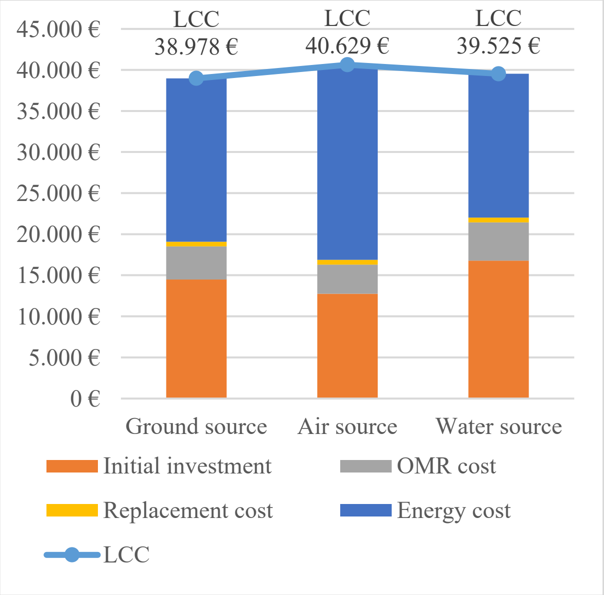

Figure 5. LCC for air, ground and water source heat pump system

The LCCA represent estimation of the future costs of heating and cooling system and therefore include many uncertainties. One possible solution to remove uncertainty is to investigate several scenarios. In the present study the uncertainty was reduced by selecting several discount rates and by varying the electricity price.

4.1 *The influence of varying discount rate*

Figure 6 present the total LCC by using different discount rates (3%, 5%, 7% and 3.75%) for the three design options. When the discount rate increases from 3% to 7% the total LCC decreases by 21% for air source heat pump, by 19% for ground source heat pump and by 18% for water source heat pump.

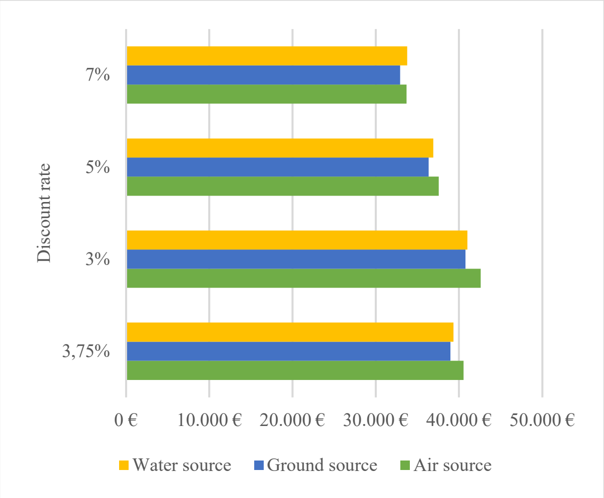

Figure 6. LCC including different discount rates

4.2 *The influence of varying electricity price*

When analyzing the influence of varying electricity price there were assumed four possible evolutions for the price, namely: 0% decrease, 10% increase, 25% increase and 50% increase (Figure 7). The result show that energy price will have an evident impact on the total LCC. Increasing the electricity price by 50% means an increase in the total LCC cost by 29% for air-source systems, 25% for ground-source systems and 22% for water-source systems. It is obvious that the increase in electricity price influences the system with the highest energy consumption.

Increasing the reference price of electricity by 25% or more makes the water heat pump system the economically optimal solution.

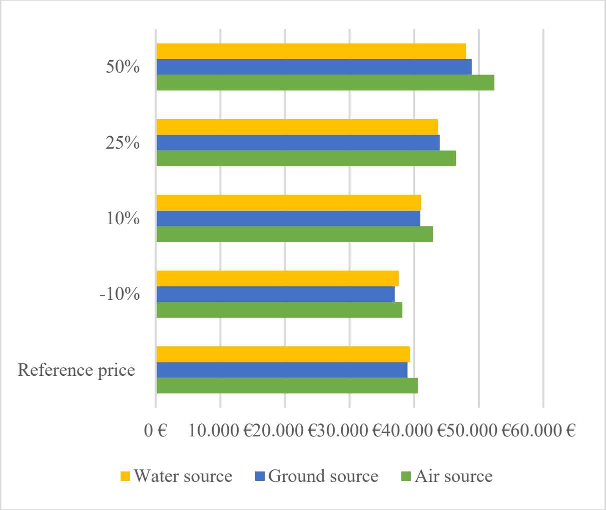

Figure 7. LCC including different price for electricity

5 DISCUSSION

This study evaluates the lifetime costs of heat pump heating and cooling systems. The aim is to obtain an answer on the economic efficiency of heat pump heating and cooling systems, as the initial investment in these systems is higher compared to conventional systems, but the subsequent costs over the period of use are reduced. The study has presented different LCC solution for each design solution influenced by the parameters used in the study.

From the investigations of the costs involved in the LCC analysis it can be seen that the share of the energy cost and the initial investment are significant high and have the greatest influence on the final LCC cost. Another observation is that fluctuations in the discount rate have an impact on all costs except the initial investment. Increasing the discount rate has the effect of decreasing the present value of the other costs, only the initial investment remains constant.

In our study the best economically solution is the ground source heat pump system, which has the lowest LCC value assuming 3.75% discount rate, 1% escalation price rate and 0.2369 €/kWh electricity price. The economic analysis showed that the LCC value for the ground source heat pump system is 1% lower compared to water source heat pump system and 4% lower compared to air source heat pump system.

Given the very small differences in the economic indicators evaluated, a sensitivity analysis is considered appropriate. Sensitivity analysis aims to measure the impact of total LCC if we change one or more key parameters. The key parameters on which the sensitivity analysis is based are the discount rate and the electricity price. Thus, the proposed values for the discount rate are 3%, 5% and 7%, and for the electricity price a scenario of a 10% decrease in the electricity price and three scenarios of a 10%, 25% and 50% increase in the electricity price are proposed.

The lowest LCC values are obtained for the 7% discount rate and the 10% electricity price decrease. The lower the discount rate and the higher the price of electricity, the less economical the air source heat pump system is. For high electricity prices, a price increase of more than 25%, the economically optimal solution is the water source heat pump system.

5.1 Future investigations

In considering the similar results obtained for the three proposed heating and cooling solutions, respectively their difficult evaluation in terms of economic returns, we propose two future research directions.

A first research direction would be the investigation of an office building with a usable surface of more than 300 m2, with a heating and cooling system thermal power of more than 15 kW.

A second research direction is the comparative analysis of the heat pump systems in the present study with conventional gas and electric systems.

6 CONCLUSIONS

The goal of this study is to compare, through LCCA, three types of heat pump solution for a single-family house. On the basis of the comparative analysis of the three heating and cooling system equipped with air, ground and water heat pump, taking into account economic criteria, it appears that for the case study building a more advantageous solution is the ground source heat pump.

Since it is difficult to estimate the parameters due to high uncertainties in the medium and long term, sensitivity analysis is used to evaluate the LCC. The sensitivity analysis partially confirms the result obtained before. The economically optimal option remains the ground source heat pump system as long as the price of electricity does not go above 0.296 €/kWh. Above this value and given a discount rate of between 3% and 7% the optimal option from an economic point of view becomes the water source heat pump system.

Regardless of the chosen scenario, the least advantageous option is the heating and cooling solution with air source heat pump. The only scenario where the air source heat pump system is economically competitive is for a shorter lifespan of less than 10 years.

This research can be adopted for other residential houses with similar technical specifications and considering similar climatic conditions

BIBLIOGRAPHY

Ban, A., Bungău, C. (2022). A Fuzzy Mathematical Model to Estimate the Energy Cost for Heat Pump System. In: Moldovan, L., Gligor, A. (eds) The 15th International Conference Interdisciplinarity in Engineering. Inter-Eng 2021. Lecture Notes in Networks and Systems, vol 386. Springer, Cham. https://doi.org/10.1007/978-3-030-93817-8_70

Biglarian, H., Saidi, M., Abbaspour, M., (2019). Economic and environmental assessment of a solar-assisted ground source heat pump system in a heating-dominated climate, *International Journal of Environmental Science and Technology*,16:3091–3098 https://doi.org/10.1007/s13762-018-1673-3

Code of Practice for Life Cycle Costing, (2009). North Atlantic Treaty Organization and Research and Technology Organization

Estevan, H., & Schaefer, B., (2017). Life Cycle Costing State of the art report, ICLEI – Local Governments for Sustainability, European Secretariat

Eurostat. (2022, May 20) Data Explorer, Electricity price for household consumer, https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_204/default/table?lang=en

IEA. (2013). Global Status Report for Buildings and Construction; IEA: Paris, France

Kneifel, J., & Webb, J., (2022). Life cycle costing manual for the Federal Energy management Program, NIST Handbook

Hermelink H., de Jager D., (2015). Evaluating Our Future: The crucial role of discount rates in European Commission energy system modelling, The European Council for an Energy Efficient Economy, Suedia

Petrovi´c, B.; Zhang, X.; Eriksson, O.; Wallhagen, M., (2021). Life Cycle Cost Analysis of a Single-Family House in Sweden, *Buildings*, 11, 215. https://doi.org/10.3390/buildings11050215

Prada, M., Prada, I.F., Cristea, M., Popescu, D., Bungau, C., Aleya, L., Bungau, C.C., (2020). New solutions to reduce greenhouse gas emissions through energy efficiency of buildings of special importance – Hospitals. Science of the Total Environment, 718, ID 137466 https://doi.org/10.1016/j.scitotenv.2020.137446

Ramesh, T.; Prakash, R.; Shukla, K.K., (2010). Life cycle energy analysis of buildings: An overview. Energy Build., 42, 1592–1600

Wang, Y.; Yang, X.; Hou, Q.; Tao, J.; Dong, J., (2022). Quantitative Study on the Life-Cycle Carbon Emissions of a Nearly Zero Energy Building in the Severe Cold Zones of China. Sustainability, 14, 1448. https://doi.org/su14031448