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Estimation of the initial investment cost in systems equipped with heat pumps using regression analysis

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Abstract. The present research aims to obtain a mathematical model for estimating the costs involved in the initial investment for heat pump systems using the regression analysis. In the current economic context towards a climate-neutral Europe by 2050, heat pumps are becoming increasingly used in the buildings sector. As innovative and sustainable heat energy systems, they require a higher capital investment than conventional heating and cooling systems. Therefore, this study addresses the current needs by carrying out a comprehensive analysis of the costs involved in the initial investing in a heat pump system. Three regression analyses will be carried out to estimate the costs for air source heat pumps, ground source heat pumps and water source heat pumps respectively.

Keywords: heat pump, renewable energy, initial investment, regression analysis, estimation cost.

1. Introduction

In the current context of global warming, European Union leaders have established the goal of achieving a climate-neutral Europe by 2050. This means that EU will drastically reduce its greenhouse gas emissions. The Paris Agreement [1] from 2015 on climate change aims to limit global warming to no more than 2°C compared to pre-industrial times. This reduction involves the efficient use of fossil resources together with the widespread deployment of renewable energy technologies to decarbonise the electrical and thermal energy production [2].
According to Eurostat, energy used for heating and cooling accounts for the largest share of total energy consumption in the EU, around 45% [3]. Heating and cooling of buildings represent a significant energy saving potential and play a crucial role

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in achieving the goal of a transition to a neutral Europe [4]. EPBD [5] and EED [6] identified Heating, Ventilation, and Air Conditioning (HVAC) systems as the main solutions to increase renewable energy sharing and overall building energy efficiency. The selection of a high-efficiency HVAC system is critical for the construction sector. As a result, heat pump technology seems to be perfectly in line with the current and future needs of sustainable development required by European directives due to its hight efficiency and profitability [7].

A heat pump generates several times more heat than the energy input and uses renewable energy sources such as ground or ambient air [8]. Geothermal energy is one of the most complex renewable energy domain [9] with many possible applications such as ground source heat pump systems that have a high annual average efficiency and lower carbon emissions when compared with conventional systems [10].

Heat pump systems are viable solutions for heating, air conditioning and domestic hot water in the residential, commercial and industrial sectors. One of the main advantage of these systems is the possibility of generating both heating and cooling with the same device [11]. As it is presented on the European Heat Pump Association (EHPA) website, since 2009, increasingly heat pumps have been produced in Europe every year [12]. The sales development of heat pump market, despite the COVID-19 pandemic, indicates a continued strong market expansion for the heat pump industry in Europe. In 2020, a total of 1.62 million heat pump units were sold in 21 countries covered by the European Heat Pump Report 2020. This number represents an increase of 7.28% over 2019. Even though the notoriety of heat pumps is on an increasing trend, they account for only 5% of worldwide building heating demand at present [13].

From 2020, in Europe, standards for nearly zero energy buildings (NZEB) are mandatory. To meet these requirements, the building sector must consider optimising and making energy consumption more efficient [14]. The global economic context of the Covid-19 pandemic, in which a significant percentage of people opt to work from home, increases the importance of buildings. People spend a lot of time indoors, and the quality of life of each depends to a large extent on the thermal comfort inside buildings [15].

The initial investment in an HVAC is one of the major life-cycle cost items and is therefore a key element in the economic analysis of heating and air conditioning systems. In a recent study, Baç et al. [16] reviewed 23 studies on multiple methods of selecting HVAC systems. Considering this study, the capital cost was considered the most important selection decision. Two other essential parameters in the decision making were maintenance cost and thermal comfort.

Within this context, reducing greenhouse gas emissions through providing new renewable solutions for heating and cooling will act against global warming. In the process of transition towards lower carbon emissions, strategies must take into account not only the reduction of greenhouse gas emissions but also the sustainability of the strategies adopted [17]. Decarbonisation of thermal energy is a challenge. The use of heat pumps has been recognised as a key solution to address

this challenge worldwide, but a major reason affecting the replacement of fossil fuels with heat pumps is the high initial investment cost of these renewable systems [18].
A review of the available literature in the field of heat pump systems found a limited amount of data on the costs involved in implementing these systems, compared to the data identified for conventional gas or oil-fired systems.
Considering the important weight of constructions sector, as well as the global trends for sustainable and energy-saving environment, the topic addressed in this paper is actual and of great interest for builders, real estate developers and final user.

2. Methods

The economic analysis conduct by this article is based on collection relevant data from 106 residential and commercial buildings equipped with heat pump heating and air conditioning systems. The obtained data were structured in an Excel file according to the following parameters: year of project implementation, building data, system type, heat pump data and initial cost of the heat pump system.
From the 106 systems studied, 35 systems are equipped with air-to-water heat pumps, 43 of them are equipped with ground source heat pumps and the remaining 28 systems are equipped with water-to-water heat pumps. The figure (Fig.1.) below summarises the proportion of each heat pump system type studied.
For a more rigorous analysis we have divided the initial investment costs into the following categories: heat pump, hydraulic accessories, heating and/or air-conditioning circuit elements, electrical panel and accessories, elements required for domestic hot water preparation, work on the primary heat source, installation and commissioning of the heat pump (Fig. 2.). Hydraulic accessories for the heat pump include the buffer tank and the electrical resistance. The heating and air-conditioning circuit components include sensors, circulation pumps, mixing valve, dampers, pipes and fittings.

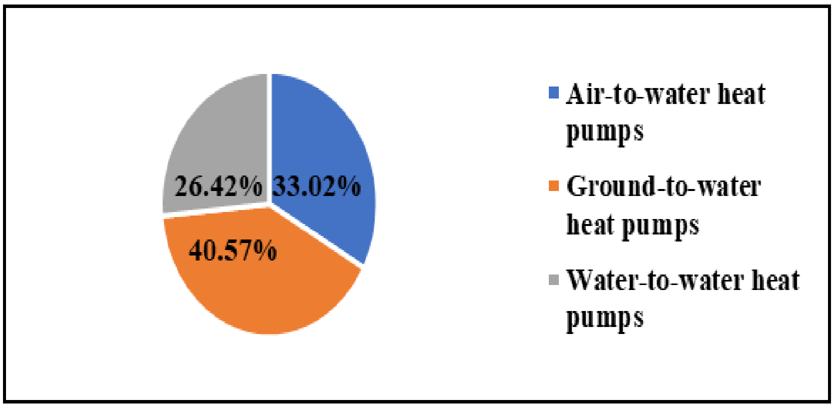

Fig. 1. Types of heat pumps studied.

Fig. 2. Cost categories for the investment in a heat pump system.

From 106 systems equipped with renewable systems 84.91% have a heat demand below 50 kW, 9.43% have a heat demand for heating between 50 kW and 100 kW and only 5.66% have a heat demand above 100 kW. As a result, the representative sector of the study will be for systems below 50 kW because we have more accurate data available.

Kavanaugh et al. [19] was among the first to address a cost breakdown for geothermal heat pump systems. The result of the study was an average cost of $8,997 for heat pump systems using ground as the primary source. A large and representative study is carried out in 2010 by Blum et al. [20] that studied more than 1100 ground-water heat pump systems with vertical collectors installed for private households in the southern part of Germany. The analysed data suggest that the average system is represented by new single-family house with a heating demand of 11 +/-3 kW and a heating area of about 190 +/-57 m^2. The system is usually used for domestic hot water and heating and has two boreholes with a total length of 180 +/-90 m. According to the study the average cost for such a system equipped with a geothermal heat pump is € 23,460. In the case study 51% of the cost is represented by the borehole (€11,997) and the remaining 49% by the heat pump system (€11,649).

After obtaining a relevant data base with information about the costs related to heat pump system, we will develop a mathematical model to estimate those costs. The mathematical model will be based on simple and multiple regression analysis. According to Woinaroschy and Iordache [21] a strength of regression analysis lies in the open and interpretable relationship between exogenous and response variables. On the other hand, the weaknesses of regression analysis include sensitivity to outliers and the assumption that the errors are independent and follow a normal distribution with zero mean and constant variance.
According to the literature review [22] we have identified two correlations between thermal power *P* (*KW*) and initial cost *C (EUR)* of heat pump systems, one for air source heat pump and one for ground source heat pump. Equation (1) represents the correlation between the thermal power and the cost for geothermal heat pump system, where the heat pump capacity is below 1.7 MW. Equation (2) represents the correlation between the thermal power and the cost for air source heat pump system, where the heat pump capacity is below 1 MW.

$$C_{GSHP} = 2485 \cdot P^{0.6094}, \quad P < 1.7MW \tag{1}$$

$$C_{ASHP} = 1168 \cdot P^{0.8364}, \quad P < 1MW \tag{2}$$

Excel programming environment was used to estimate the initial costs of heat pump systems. In general, multiple regression has the following mathematical formula (3):

$$Y = \beta_0 + \beta_1 \cdot X_1 + \cdots + \beta_n \cdot X_n + \varepsilon \tag{3}$$

Where:

Y	dependent variable
$X_1, \dots, X_n$	independent variables
β_0	intercept
$\beta_1, \dots, \beta_n$	coefficients
ε	error

For the most accurate estimation we will divide the studied systems according to the renewable energy source into: air-water systems, ground-water systems and water-water systems.

3. Results

3.1. Initial investment related to the 106 heat pump systems studied

The collection of data on the initial investment in air-to-water heat pump systems showed that 64% of the initial investment is represented by the heat pump itself, about 13% is represented by the elements needed to produce domestic hot water and 8% is represented by the heating and cooling circuit elements. Only 1% of the investment value is directed towards the primary source works (Fig.3).

The study of the 24 systems equipped with ground-to-water heat pumps with vertical borehole showed that 39% of the initial investment is represented by the heat pump itself, 23% by the price of the borehole and almost 11% the work on the primary source (Fig.3). Passive cooling represents less than 1% of the investment value as only 2 systems out of the 25 studied have this equipment. On the other hand, an analysis of the 19 systems equipped with ground-to-water heat pumps with horizontal borehole showed that 55% of the investment value is represented by the heat pump itself and 15% is the price of the primary source work (Fig.3).

An evaluation of the 28 systems equipped with water-to-water heat pumps showed that 43% of the initial investment is represented by the heat pump itself and about 22% is the price of the borehole (Fig.3).

The average cost per kW and the standard deviation obtained from the analysis of the 106 heat pump systems is shown in the table below (Table 1).

Table 1. Average cost for heat pump system per kW and standard deviation

System	Average cost per kW (EUR)	Standard deviation
Air source heat pump system	802	210.23
Ground source heat pump system	1044	247.16
Water source heat pump system	1059	379.27

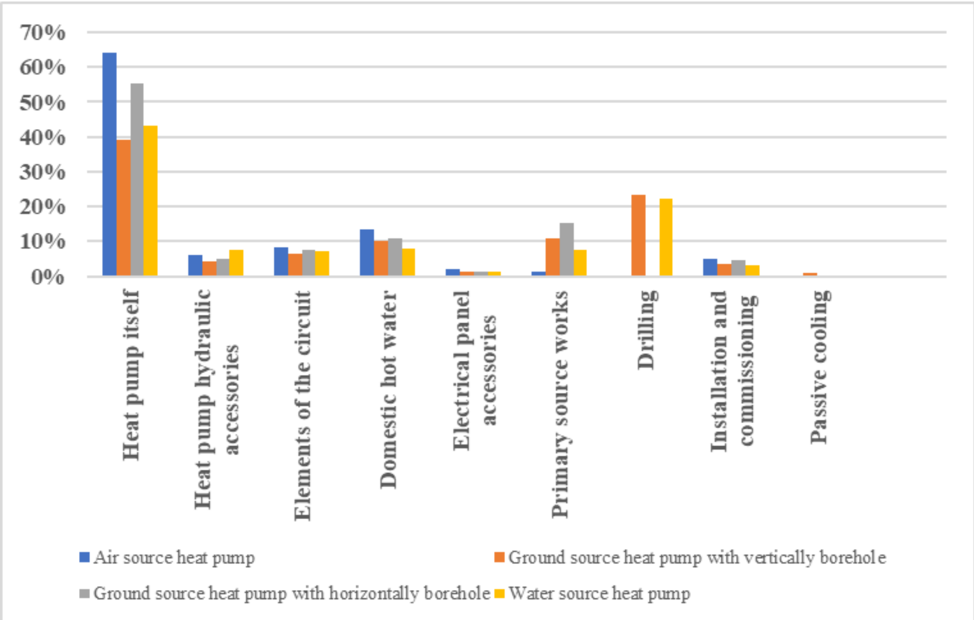

Fig. 3. Percentage distribution of initial investment for the heat pump systems studied.

3.2. Estimation of the initial investment in heat pump systems

To estimate the cost of air source heat pump systems, multiple regression analysis was used with two independent variables, namely: the thermal requirement for heating and air conditioning option. The heat demand is a scalar variable and the cooling is a nominal variable that can take the value 0 if the system is not provided with cooling equipment or 1 otherwise. The regression equation for estimating the initial investment cost for heating and air-conditioning systems equipped with air source heat pumps have the mathematical formula (4):

$$\hat{Y} = 2787 + 517.95 \cdot X_1 + 4245 \cdot X_2 \quad (4)$$

Where,

$\hat{Y}$ estimated variable

X_1 independent variable - installed capacity (kW)

X_2 independent variable, - air conditioning option

Three independent variables were used in the regression analysis for ground source heat pump system cost estimation, namely: the thermal requirement for heating, total borehole depth (for vertical boreholes only) and air conditioning option. Heat requirement and borehole depth are scalar variables and air conditioning is a nominal variable that can take the value 0 if the system is not provided with cooling equipment or 1 otherwise. The regression equation for estimating the initial investment cost for heating and air-conditioning systems equipped with ground source heat pumps have the mathematical formula (5):

$$\hat{Y} = 4686.04 + 490.42 \cdot X_1 + 1487.77 \cdot X_2 + 22.38 \cdot X_3 \quad (5)$$

Where,

$\hat{Y}$ estimated variable

X_1 independent variable - installed capacity (kW)

X_2 independent variable, - borehole deep (m)

X_3 independent variable, - air conditioning option

Only one independent variable was used in the regression analysis for water source heat pump system cost estimation, namely the heat demand for heating, which is a scalar variable. The regression equation for estimating the initial investment cost for heating and air-conditioning systems equipped with water source heat pumps have the mathematical formula (6):

$$\hat{Y} = 14554.03 + 442.5054 \cdot X \quad (6)$$

Where,

$\widehat{Y}$ estimated variable

X_1 independent variable - installed capacity (kW)

3.3. Validation of the model

Fig.4. and Fig.5. show the correlation between the initial investment cost and the estimated cost for the three type of heat pump analysed (air source, ground source and water source). The one-sided critical probability of the Fischer test and the two-sided probabilities of the Student test corresponding to the coefficients of the regression analysis are all below the significance limit of 5%, which confirms the validity of the proposed regression models.

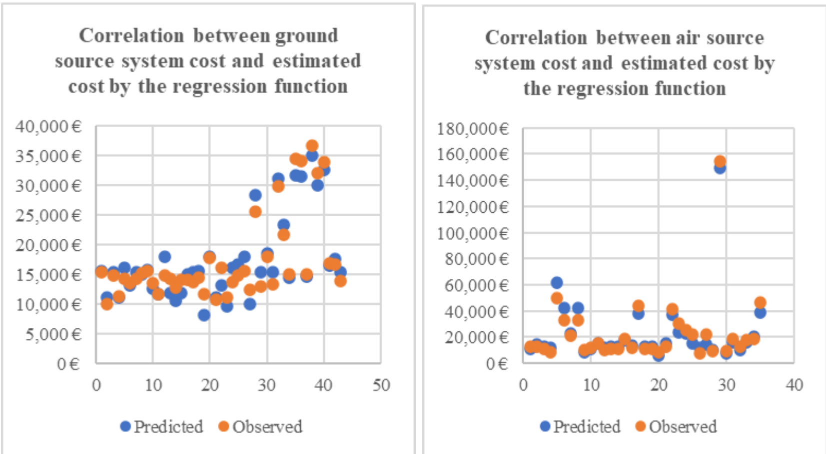

Fig. 4. Correlation between predicted and observed value for air and ground source heat pump.

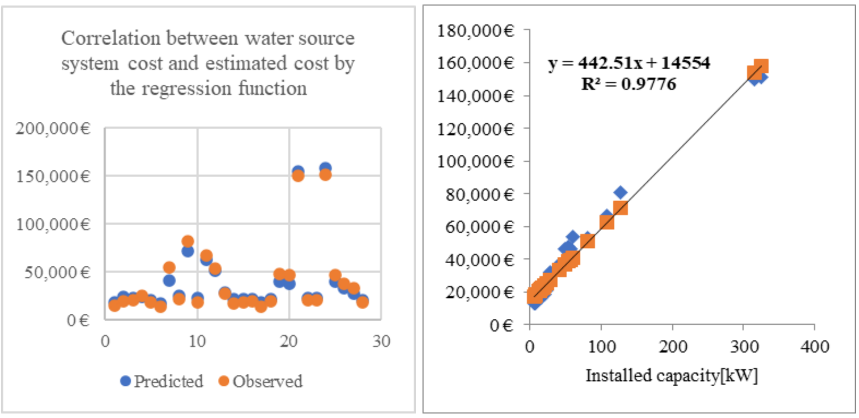

Fig. 5. Correlation between predicted and observed value for water source heat pump.

4. Discussion

Air source heat pump system have the lowest average price per kW, 802 EUR and water source heat pump have the highest average price per kW, 1059 EUR (Table 1). Even if the average price per kW is close in the case of ground source heat pump and water source heat pump (there is a percentage difference of only 1.5%) there is a considerable difference in terms of standard deviation. Ground source heat pump have a deviation of about 247 EUR while water source heat pump has a deviation of about 379 EUR, which in percentage terms represents a 53% increase. After the analysis we can conclude with 95% probability that the average price per kW for air source heat pumps is between 592 EUR -1012 EUR, the average price per kW for ground source heat pumps is between 797 EUR -1291 EUR and the average price per kW for water source heat pumps is between 680 EUR -1438 EUR. According to Fig. 6 most air source heat pumps are in the cost range of 907 EUR – 1,012 EUR and only 14.3% of the systems analysed have an average price per kW above this range. If we refer to ground source heat pumps (Fig.7) most systems are in the cost range of 1,044 EUR – 1,168 EUR and 23.3% of the systems analysed have an average price per kW above this range. Fig. 8 shows us that most water source heat pumps are in the cost range of 869 EUR – 1,059 EUR, but 46.4.3% of the systems analysed have an average price per kW above this range.

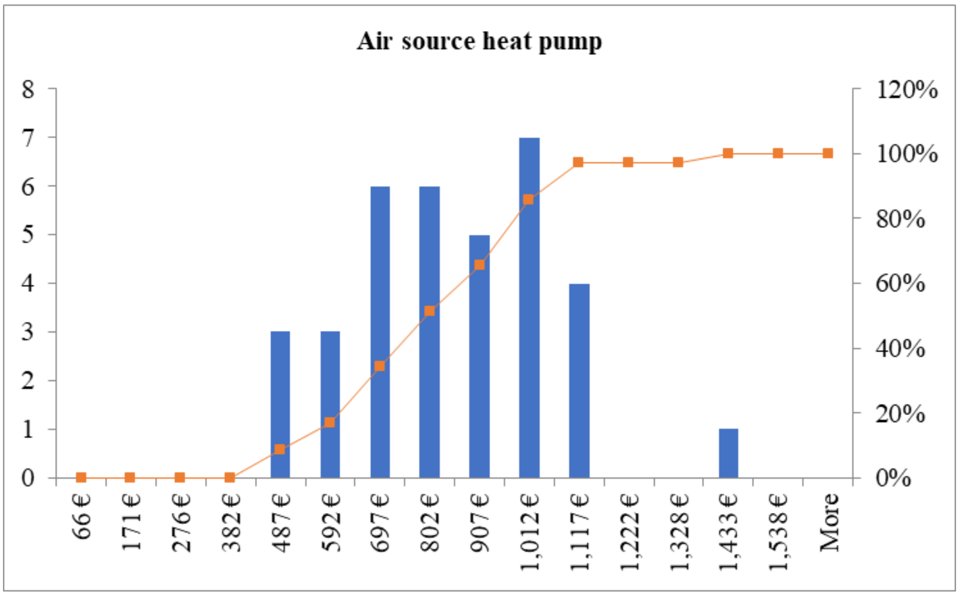

Fig. 6. Histogram for the average price per kW of air source heat pumps

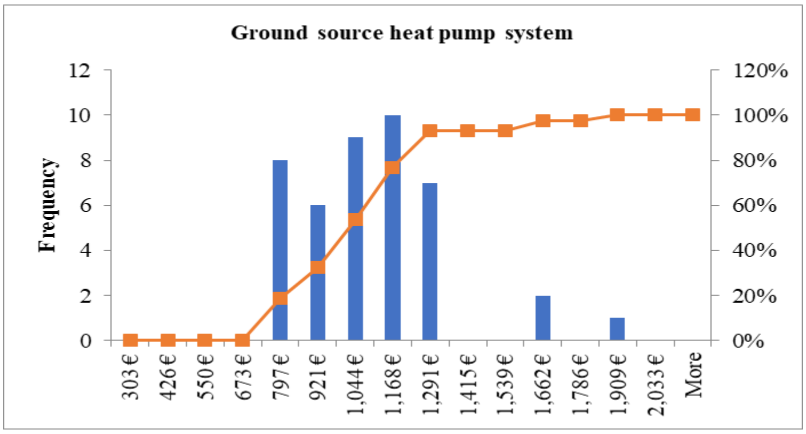

Fig. 7. Histogram for the average price per kW of ground source heat pumps

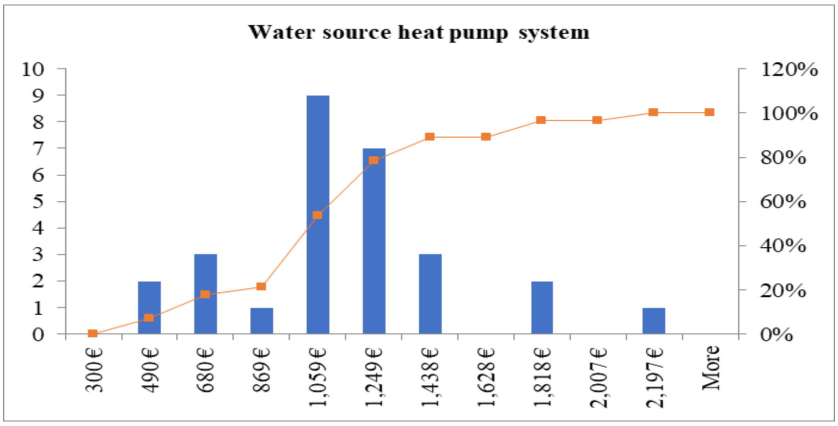

Fig. 8. Histogram for the average price per kW of water source heat pumps

As a result of obtaining different average prices per kW depending on the source of the heat pump, a different mathematical model is chosen for each type of heat pump. According to the three mathematical models obtained, the relationship between the coefficients and the estimated variable is positive, since all coefficients are greater than 0. From the regression summary (Table 2) we can state that:

- 96% of the variation in the initial investment cost for air source heat pump system is due to the thermal requirement and the choice of air conditioning equipment.
- 94% of the variation in the initial investment cost for ground heat pump system is due to the thermal requirement, the depth of the borehole and the choice of air conditioning equipment.
- 97% of the variation of the initial investment cost for water source heat pump system is due to the thermal requirement.

Based on these findings we can show that these three models can be successfully used in economic analysis.

Table 2. Regression analysis summary for air, ground and water source heat pump

Regression Statistics	Air source heat pump	Ground source heat pump	Water source heat pump
Multiple R	0.982884246	0.969863077	0.988742
R Square	0.966061441	0.940634388	0.97761
Adjusted R Square	0.963940281	0.936067802	0.976749
Standard Error	4882.028331	1810.945429	5507.73
Observations	35	43	28

5. Conclusion

The goal of achieving a climate-neutral Europe by 2050 is supported by the adoption of heat pumps. These innovative systems are essential for reducing the energy consumption and emissions, but also for improving the energy efficiency of buildings. In this context, the importance of the costs involved in the implementation of systems equipped with heat pumps becomes of great interest.

The first part of the study makes a detailed analysis of a number of 106 heat pump systems in terms of the costs involved for the initial investment. As a result, we conclude that the average cost for air source heat pump system is 802 ± 210 EUR/kW, for ground source heat pump system is 1,044 ± 247 EUR/kW and for water source heat pump system is 1,059 ± 379.

The second part of the study proposed three mathematical model for estimating the initial investment for implementing heat pump system using regression anallysis. All three model where validated and we conclude that all models can be successfully used in economic analysis.

As a future research direction, we consider this cost estimation for heat pump systems very useful and as a starting point for medium- and long-term economic analyses, such as life cycle cost analysis.

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