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Original Research Article

TECHNICAL AND ECONOMIC ANALYSIS OF THE USE OF HEAT PUMPS IN A PUBLIC FACILITY

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A b s t r a c t

A heat pump uses natural energy from renewable sources such as air, ground or water. The pump, acquiring thermal energy from the environment (75%) and using electricity (25%), supplies it to the heated object. A heat pump-based system consists of a ground heat source (heat is taken from it), a heat pump unit and an upper heat source (heat is transferred to it). The refrigerant transfers heat from the lower heat source to the upper heat source.
The paper discusses types of heat pumps in terms of the use of the lower heat source. A technical and economic analysis was carried out on the basis of two types of heat pump: air-to-water and ground-to-water A comparative analysis of the results obtained results will allow a real assessment of the system's functioning.

Keywords: air-to-water heat pumps, ground-to-water heat pump, heat pumps, RES

1. INTRODUCTON

Energy efficiency and new renewable energy sources are one of the most important issue of the European Union (EU)'s strategy for sustainable growth. Renewable energy sources such as wind energy (wind farms), solar energy (farms and photovoltaic installations) and hydropower (hydroelectric power plants) are widely used in the world. Heat pumps are one of the most widespread sources of renewable energy in Europe [3]. Heat pumps are seen as a great opportunity to reach the EU target for a reliable, affordable and sustainable energy supply [17].

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According to Gupta [4], heat pumps are only efficient in well insulated buildings. Over80% of existing homes in the UK will still be standing in 2050. Heat pumps are a promising technology for heating (and cooling) domestic buildings that provide exceptionally high efficiencies compared with fossil fuel combustion. There are in the region of a billion heat pumps in use world-wide, but despite their maturity they are a relatively new technology to many regions [15].

According to Pollard & Berg [14], heat pump technology has been promoted as being highly energy efficient, but there is often conflicting advice on how best to operate a heat pump and variable information on how much electricity it will use. Heat pump performance is not a fixed factor and depends on:

- the indoor and outdoor temperatures when it is operating
- what additional energy use is involved, such as use of the defrost system
- system loading – performance will be reduced if the heat pump only operates in demanding conditions, such as being used to heat cold rooms on cold mornings.

The bottom source circuit medium receives heat energy from the ground, water or outside air and then transfers it to the refrigerant circuit. In the pump's evaporator, the warmer lower source refrigerant gives up heat to the colder refrigerant. The refrigerant evaporates, becoming a gas. The gas is compressed by the compressor making its pressure and temperature rise. The heat collected during evaporation and compression is transferred in the condenser to the building's central heating system. After leaving through the expansion valve, the condensed gas lowers its pressure and temperature and flows to the evaporator, where it again receives heat from the lower source circuit medium and the process repeats itself.

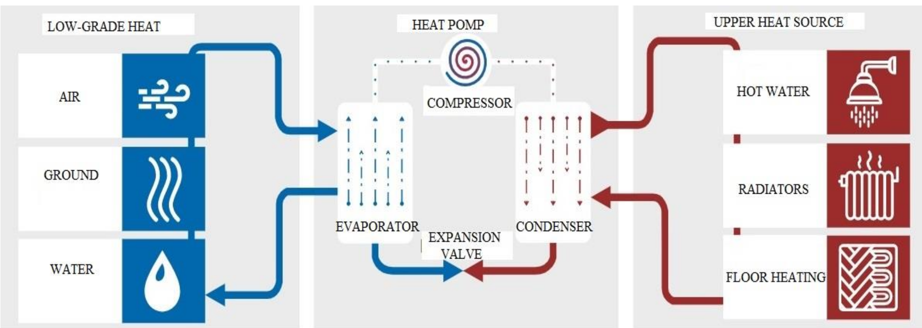

Fig. 1. Schematic diagram of the heat pump [5]

Carroll et all [2] indicate that heat pump performance is strongly influenced by ambient conditions of the heat pump, the installation, and the building characteristics. For this reason, their performance in real life can differ from those observed under laboratory conditions.

2. LOW – GRADE HEAT

2.1. Air source heat pumps

Air-to-water heat pumps can be divided into two types: monoblock and split. In a monoblock heat pump, all components-fan, evaporator, compressor, condenser, expansion valve-are a single unit [8].In addition, this pump can operate up to a supply temperature of 70°C, so they are a good solution when upgrading the heating system. An additional advantage of this pump is the use of natural refrigerant R290 (propane), which has a low GWP (Global Warming Potential) and is environmentally friendly. The monoblock pump has both indoor and outdoor versions. On the side of monoblocks is their design that extends their life[12]. The split air heat pump consists of two units: an outdoor unit and an indoor unit, which are connected by refrigerant pipes. The external unit contains components such as the fan, evaporator, compressor, and expansion valve. Most thermodynamic processes take place in this module. The indoor unit has a condenser, a 3-way valve, an electric booster heater and a hot water storage tank. Split heat pumps are easier to make, and this makes them much more widespread and less expensive [12].

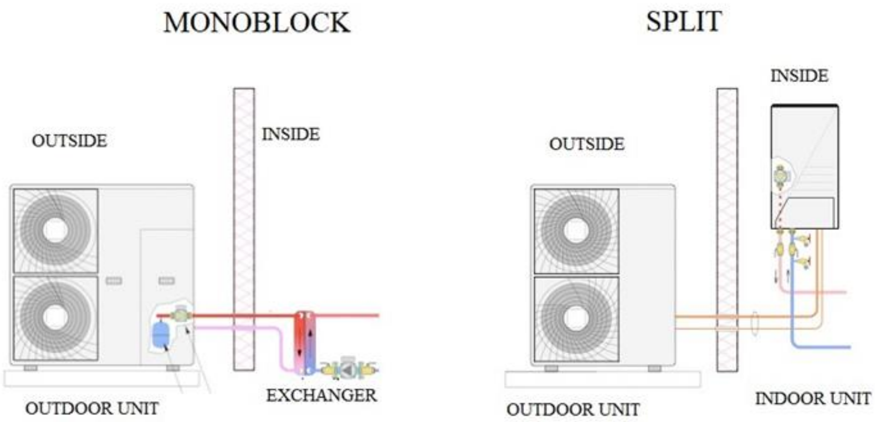

Fig.2. Monoblock and split pump diagram [4]

2.2. Ground source heat pumps

The ground has favourable properties for storing heat through solar radiation energy, so it provides a stable temperature level for the lower heat source. Below the ground's frost zone, the temperature remains at 6 - 13°C throughout the year. In the second half of the heating season, thanks to the increasing intensity of solar radiation and precipitation, the thermal regeneration of the ground takes place until the next heating season. Ground heat pumps can be divided according to the type of exchanger: horizontal and vertical. Horizontal exchangers are inserted into trenches below the ground frost zone. Vertical exchangers are placed in boreholes that reach depths of 100m. In the boreholes or trenches, manifolds filled with a medium with a low freezing point, such as a solution of glycol and water, are placed [7]. Vertical collectors are located at a greater depth, and thus have a higher and more stable heat source temperature. Comparing them with horizontal collectors, they need a much smaller plot area.

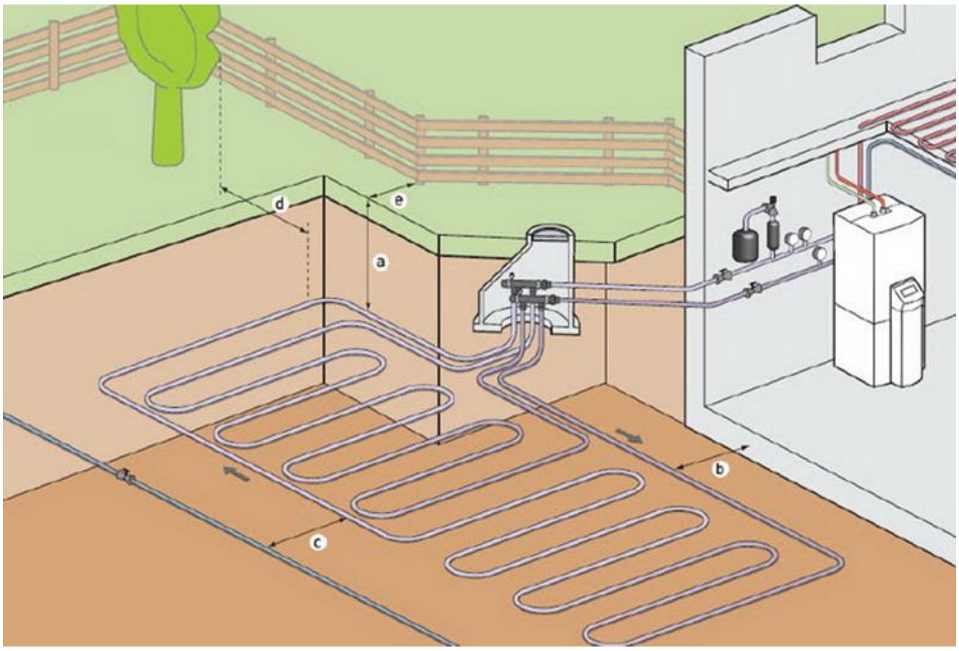

Fig. 3. Horizontal collector should be made with such requirements as: "a" - depth of pipe laying min. 20 cm below the ground freezing point, so about 1.2÷1.7 m depending on the climatic zone of the country, "b" - distance from the foundations of the building 1.5 m, "c" - distance from water and sewer connections 1.5 m, "d" - distance from the outer edge of the tree crown 0.5 m, "e" - distance from the foundation of the fence 1.0 m [8]

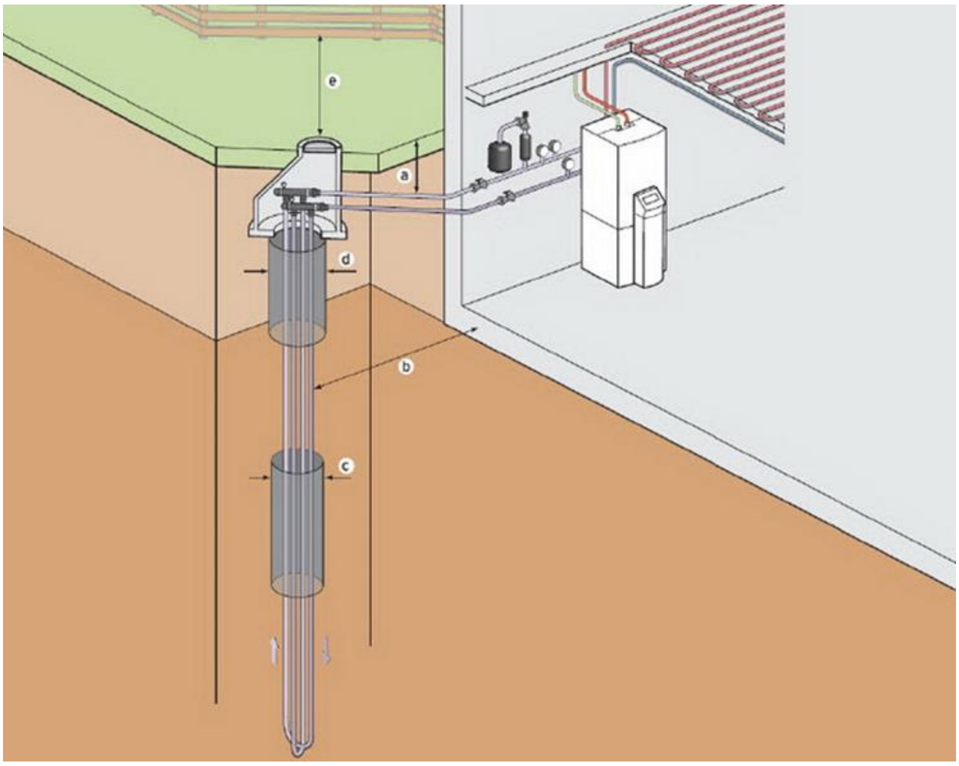

Fig. 4. Vertical probes should be made with such requirements as: "a" - supply/return with a slope in the direction from the heat pump to the ground probe, in sandy soil laid at a depth of about 1 m; collector vent at the heat pump, "b" - the minimum distance from the foundation of the building should be 2 m, "c" and "d"- lining pipe, used for loose material, with a length of about 6-20 m, diameter of about 17 cm, "e" - distance from the foundation of the fence 1.0 m [9]

2.3. Water heat pumps

Water heat pumps use energy from groundwater, surface water or sea water to transfer heat to the heated building. The pump works most efficiently when there is a pond, river or lake near the house [11]. This arrangement provides the lowest installation costs. If we do not have direct access to a pond, river or lake then two wells are drilled for wells. The first of these is a water intake well, from which water is drawn. A pump then extracts heat from it and transfers it to the building [8]. The second discharge well receives the cooled liquid back into the ground. The advantage of a water heat pump with in a system with wells is high efficiency.

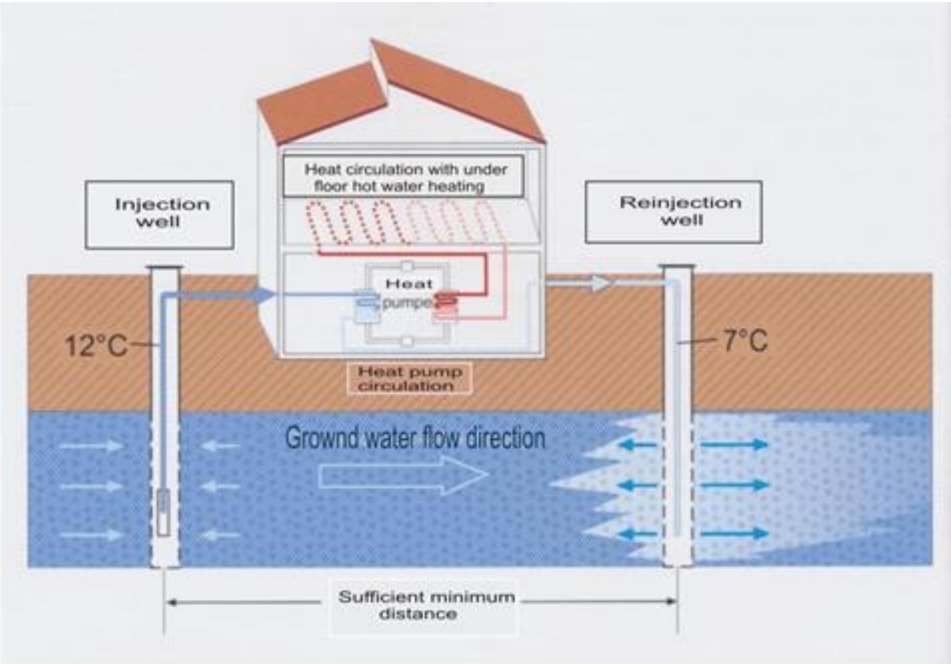

Fig. 5. Water heat pump [12]

3. MATERIALS AND METHODS

3.1. Site description

The paper presents a newly designed building in which various heating systems were alternatively considered: ground water and air-to-water heat pumps. The building will be located at 4 Szwajcarska Street in Zielona Gora, Lubuskie Province. The visualization of the building is shown at fig. 6 and 7.

Fig. 6. Visualization of an animal shelter, author: E.Pobudejska

Fig. 7. Visualization of an animal shelter, author: E.Pobudejska

It is a detached, two-story and non-basement building with very good thermal insulation. The building is located in climate zone II. The usable area for heating is 1039.0m^2, the designed heat load is 39.6kW. The analysis aims to present technical solutions for the application of air-to-water and ground-to-water heat pumps in a non-residential building.

3.2. Analytical methods

The article aims to choose the most favourable solution in terms of operating costs and capital expenditures for type of heat pump for the object under consideration. For this purpose, the applied calculation is based on a program from a pump manufacturer called stiebeleltron. The following is a comparison of two types of heat pumps.

4. RESULTS AND DISCUSSION

In this chapter the monoblock air-to-water and ground-to-water heat pump has been described. These pumps are characterised by a high proportion of power for heat at low outside temperature. They have low electricity requirements. All properties have been shown in tables 1-4.

Table 1. Pump air-to-water used to calculate the lower heat source [15]

Producer	STIEBEL-ELTRON
Type of pump	2x WPL 47
Bivalent point	-14.6°C
Share of heat pump power	79.4%
Share of heat pump coverage	99.8%
Normative outdoor temperature	-18.0°C

Table 2. Heat pump with horizontal heat exchanger used for bottom heat source calculations, Energeoprogram

Producer	STIEBEL-ELTRON
Type of pump	WPF 52 55,83 kW
Coolingpower- thermalefficiency	44.22 kW
Temperature difference in the lower heat source circuit	3°C

Heat pumps at maximum heating capacity of the building show a high energy efficiency class, which is presented in table 3.

Table 3. Selected components of the lower source system

Name	Element	Quantity
Distributor	WellGeo New Brado	1 pcs.
Exchanger	Horizontal meander M40	11 pcs..
- Length of a single section		296m
- Number of sections		11 pcs.
Factor	Propylene liquid concentrate for the preparation of a solution with a crystallizationtemperature -20°C	1479.00kg
Run pipe	HDPE100 Ø90 PN10	30m
Distribution pipe	Not applicable for horizontal exchanger	

In table 4 the selection of components of the lower heat source system, along with the necessary amount for the selected system to heat the building has been shown. The table shows the required design calculations for the selected system. The optimum flow rates and velocities for the circuit are described.

Table 4. Calculations for the selected lower source installation

Name	Value	Unit
Flow rate in the run-of-river pipe:	13.80	[m^3/h]
Velocity in the runway pipe:	0.77	[m/s]
Flow in the exchanger pipe:	1.25	[m3/h]
Speed in the exchanger pipe:	0.35	[m/s]
Required ground area for the horizontal exchanger:	2 602.00	[m^2]
The capacity of the liquid solution water charge:	3 410.00	[dm^3]
The amount of bottom source factor:	1 479.00	[kg]
Calculated resistance in the lower source installation:	47.33	[kPa]

4.3. Ground-to-water heat pump with vertical exchanger

Calculations for the selection of the lower heat source vertical collector are shown in tables 5-7. This include heat pumps at maximum heating capacity of the building shows high energy efficiency class (table 5), the selection of components of the lower heat source system, along with the necessary amount for the selected system to heat the building under study (table 6) and the required design calculations for the selected system are shown. The optimum flow rates and velocities for the circuit are described (table 7).

Table. 5 Pump used in the calculation of the lower heat source

Producer	STIEBEL-ELTRON
Type of pump	WPF 52 55.83 kW
Cooling power- thermal efficiency	44.22 kW
Temperature difference in the lower heat source circuit	3°C

Table 6. Selected components of the lower source system

Name	Element	Quantity
Distributor	WellGeo New Brado	1 pcs.
Exchanger	Vertical 440 (4 pipes with a diameter of 40)	10 pcs..
Length of a single section		111m
Number of sections		10 pcs.
Factor	Propylene liquid concentrate for the preparation of a solution with a crystallisation temperature -20°C	2844.0 kg
Run pipe	HDPE100 Ø90 PN10	30m
Distribution pipe	Distribution pipe HDPE 100 50 PN10	1500m

Table 7. Calculations for the selected lower source installation

Name	Value	Unit
Flow rate in the run-of-river pipe:	13.80	[m^3/h]
Velocity in the runway pipe:	0.77	[m/s]
Flow in the exchanger pipe:	1.33	[m^3/h]
Speed in the exchanger pipe:	0.21	[m/s]
Total active length of the vertical exchanger:	1 106.00	[m]
The capacity of the liquid solution water charge:	6 560.00	[dm^3]
The amount of bottom source factor:	2 844.00	[kg]
Calculated resistance in the lower source installation:	36.39	[kPa]

5. EVALUATION OF ECONOMIC EFFICIENCY

Many authors indicate reasonable investments in renewable energy sources in the case of public utility facilities since the payback period is well smaller than the life span of the technology [1, 16]. In order to calculate the energy prices for the heating system in the building, energy suppliers's current prices were applied (tab 8-10).

Table 8. Prices of fuel, energy carriers

Type of heating system	SCOP	The amount of kWh per unit	The cost of the energy carrier [gr/kWh]	The cost of 1 kWh of heat [gr/kWh]
Air-to-water, underfloor heating - 35 ^{0}C	4.32	1.00	292.8	67.8
Ground-to-water underfloor heating - 35 ^{0}C	4.93	1.00	292.8	59.4

Table 9. Operating costs in the variants analysed

Investment options	Annual cost [zl/year]
Heat pump air-to-water underfloor heating - 35 deg. C (SCOP = 4.32)	39770
Heat pump ground-to-water underfloor heating - 35 deg. C (SCOP = 4.93)	34850

Table 10. Payback period of the investment in the analysed variants

Type of heating system	Total investment costs [zl]	Annual cost [zl/year]	Investment payback time [years]
Air-to-water	302038	39770	5,0
Ground-to-water, horizontal collector	318074	34850	8,3
Ground-to-water, vertical collector	345020	34850	13,7

6. CONCLUSIONS

The investment costs of the installation and use of a heat pump show significant differences depending on the lower heat source.

After analysing two types of heat pumps, it was decided to choose an air-to-water pump, primarily due to investment costs and limited land area, an air-to-water pump was chosen. To limit the space, a monoblock was located on the roof of the building. The choice of air-to-water and ground-to-water heat pumps is influenced by the size of the plot on which the building is located, the type of soil, the climate zone and the financial costs incurred. Air-to-water heat pumps are a more popular and less expensive solution, there is no need for additional soil testing, excavation for collectors, or expensive drilling.

When comparing air with ground source heat pump in terms of operation and maintenance costs, the ground source heat pump is superior to the air source heat pump. The decision in choosing a ground source heat pump may be discouraged by the more expensive cost of the investment, technological installation and the sacrifice of a significant area of the investor's plot.

Economically and energetically, ground-to-water heat pumps are more efficient and economical. The ground temperature is fairly constant throughout the year, so these pumps can heat a building more efficiently at extremely low outdoor temperatures. It is an efficient way to heat a building that provides low operating costs, low heat loss and stable operation regardless of the outside temperature.

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