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ENERGY AND HOME COMFORT

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Abstract: In this paper we aim to make a comparison between three types of heat pumps: air–to–water, water–to–water, ground–to–water. We show that, from a construction point of view, the difference between the three types of heat pumps is the source from which the additional heat is extracted. We point out that the heat pump is the installation that transfers heat from a colder medium to a warmer medium. Most often, pumps extract heat from water, air or ground/geothermal sources and transfer it into the home via underfloor heating, radiators, etc. Any decision to install heat pump equipment must be carefully considered, taking into account all four elements (energy consumption, installation costs, existence of the chosen heat source and its accessibility) that influence the technical and economic efficiency and the proper functioning of the equipment.
Keywords: COP, SCOP, Air–to–water heat pump, Water–to–water heat pump, Ground–to–water heat pump, efficient investment

1. TOPICALITY OF THE THEME

In today's society it is necessary to find alternative sources of heating for both domestic consumers and public institutions and economic agents (SMEs, large companies, multinationals, etc.). In this regard, we propose to analyse three types of heat pumps that use green energy to heat buildings. In recent decades heat pump equipment has benefited from improvements brought about by new technologies. Today, developed countries and many developing countries are having to turn to alternative forms of energy production. This is largely due to: shortages of coal, natural gas, fossil fuels and energy from hydro and thermal power plants, energy from nuclear reactors, etc., and the need to achieve carbon neutrality by 2050. It should be noted that the demand for energy in both industrial and domestic sectors has been steadily increasing, leading to higher greenhouse gas emissions.

In 2019 greenhouse gas emissions in the European Union were 9.10% in industrial processes, 10.55% in agriculture, 3.32% in waste management and 77.01% in energy production [2]. The decision at company or household level to change the equipment owned (for which the energy source is difficult to access or has become expensive) to a new one using green energy is difficult. The lack of consistent comparative information or, on the contrary, the abundance of it leads to confusion and often to costly decisions that do not bring satisfaction and comfort. That is why we decided to look at this issue from multiple perspectives. The energy performance of the installation, the cost of the equipment, the cost and time of implementation as well as the cost of administration are just some of the aspects that need to be taken into account when deciding on a change of heat source. In order to have a more complete picture of what this means, we have proposed this techno–economic analysis covering heat pumps.

In this context we show that air, soil, water and ecosystem pollution is also caused by environmental accidents: Chernobyl and Fukushima, oil spills from the Gulf War or the British Petroleum accident in the Gulf of Mexico, the chemical industry, etc.

The Intergovernmental Panel on Climate Change [5,22] confirms that average global temperatures have risen significantly since the industrial revolution, and that 2000 has been the warmest year on record (according to the Intergovernmental Panel on Climate Change www.ipcc.ch/).

Global warming is motivating the European Union to promote action to protect the environment and make the most of renewable energy sources, found in abundance in the universe. Today, the use of clean energy helps to reduce greenhouse gas emissions and improve the quality of life of citizens. The use of green energy is provided for in the "European Green Pact" and aims to (Figure1):

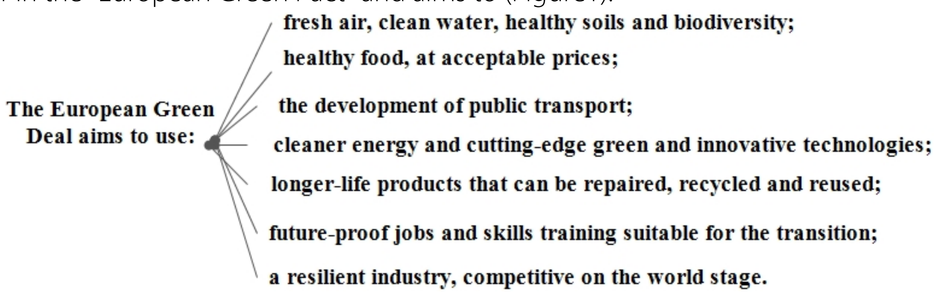

Figure 1. The European Green Deal

In this paper we present the use of heat supply equipment (heat pumps) and their effect on the environment.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

2. RESEARCH METHODOLOGY: AIM AND OBJECTIVES

The aim of the research is to show some of the alternative sources of heating buildings and their contribution to improving people's lives by reducing energy and fuel consumption. This is made possible by identifying the types of sources used to heat enclosed spaces.

Achieving this goal requires specific objectives, including:

- Identify the characteristics of the various types of heat pumps. We are particularly interested in clearly identifying the characteristics of heat pumps so as to show their contribution to space heating and explaining the techniques used. This information obtained from the literature will help us in our research and will contribute to the current state of knowledge on heat pump characteristics.
- Comparative analysis of implementation costs, administration costs and working techniques for heating buildings (enclosed spaces) with heat pumps. At national and international level there are several techniques for heating enclosed spaces and their operation depends on the sources used or the resources they consume. We would like to point out the beneficial effects of using these heating systems using renewable energy.

3. RESEARCH HYPOTHESES

The basis of the work is based on a series of hypotheses, such as:

- The use of heat pumps leads to positive economic effects.
- The use of heat pump heating technologies leads to protection of the air and the environment.
- Nowadays, the promotion/support of alternative (clean) technologies is a necessity for the population of Romania and therefore of the whole planet.

This work is a response to the current needs of the population of our country and beyond. The decision to purchase a heat pump is not a simple one, although at first glance it seems so, and we will explain why. The best possible implementation of these technologies and the possibility of purchasing them requires an improvement in the legislative framework, incentives for entrepreneurs who wish to invest in this field, as well as an 'increase in the quality' of providers of such services.

4. THE IMPORTANCE OF HEAT PUMP HEATING SYSTEMS

The effects of global warming as well as the ongoing Russia–Ukraine war, which has social, military and energy implications, are driving the need for technologies that reduce energy costs, energy consumption and carbon footprint. These technologies have both immediate and long–term effects in reducing the global impact of greenhouse gases and dependence on the use of natural gas, oil, coal or wood for heating.

In this context, we show that heat pumps heat air in enclosed spaces without burning fuel. They work much like air conditioners, except that heat pumps simply reverse the flow of refrigerant by capturing heat from outside and releasing it inside a building. Heat pumps are able to capture heat (when temperatures are very low) and deliver it to an indoor space. Heat pumps also have the ability to provide cooling or heating of the space depending on seasonal needs. These heating systems are very efficient because they transfer two to five times more energy than they consume. In this context, we show that the benefits are obvious both for the environment and for people's savings.

Today we are witnessing a growing public desire for efficient management of energy consumption, temperature and indoor comfort. Heat pump heating is increasingly adopted. This heating system was first implemented in milder climates (where the temperature does not drop below freezing for long periods) and is beginning to be used in other parts of the world (with wide temperature variations), including North America.

Of course, in order for these heat pumps to be used all over the world and to increase energy efficiency, their technology had to be developed.

For areas with high summer temperatures but cooler winters (e.g. Florida) homeowners use heat pumps because of their ability to save up to 40% on energy bills without sacrificing comfort. Heat pumps are also used to heat water in commercial and residential buildings. Heating water with heat pumps saves up to 75% energy (Figure2) compared to traditional water heating systems [24].

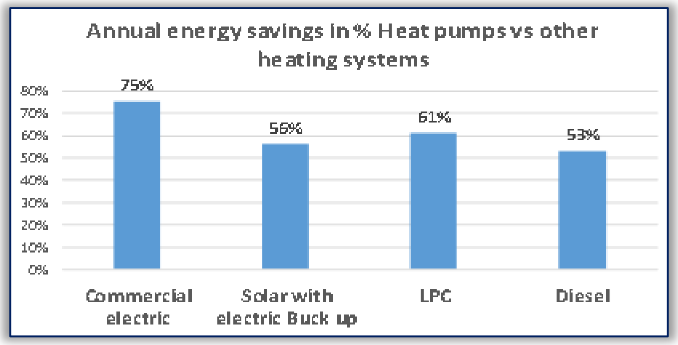

Figure 2. Heat pump saving energy
Source: Emerson Veermata Jijabai Technological Institute Case Study
www.emerson.com/en–in/news/corporate/emerson–teams–with–veermata

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Environmental protection and the need to reduce energy consumption are forcing us to be faster and smarter in the use of heat pumps and other current technologies [21]. Efforts to reduce greenhouse gases are now being made all over the world. This is being achieved by switching from fossil fuel heat–generating devices such as furnaces and boilers to efficient heat pumps. New legislation, incentives and tax breaks for the purchase, installation and commissioning of low–carbon technologies are needed to get people to use heat pumps.

So increased comfort, lower costs, energy savings and greater environmental responsibility are driving more and more households and businesses to install heat pumps. According to the EIA's Annual Energy Outlook 2018, commercial space heating and cooling accounts for 30% of CO_2 emissions and 38% for residential buildings; water heating accounts for 15% of CO_2 emissions.

Of particular importance is the fact that heat pumps do not use fossil fuels such as coal, wood or methane gas for space and water heating. Heat pumps therefore heat the spaces of buildings, produce domestic hot water and do not emit carbon dioxide (CO_2) or other pollutants into the atmosphere.

5. COMPARATIVE ANALYSIS OF WORKING TECHNIQUES FOR HEATING BUILDINGS (ENCLOSED SPACES) WITH HEAT PUMPS

Implementation of measures to reduce carbon dioxide emissions and dependence on fossil fuels are the issues addressed in this theme. It should be recalled that at global level there are numerous international treaties, such as the United Nations Framework Convention on Climate Change, the Kyoto Protocol and the Paris Agreement, which aim to reduce global greenhouse gas emissions. In this context, most advanced countries have set targets to achieve carbon neutrality by 2050 [3,10–14,21]. In this context, heat pumps are much more efficient than traditional heating systems and use electricity to move heat from one place to another.

Heat pumps work (Figure3) on the principle of a refrigerator or air conditioner [19]. The explanation is that the appliances pump heat from outside into an indoor space at an energy cost. For hot days it can go into reverse mode and pump heat from the air in the house to the outside.

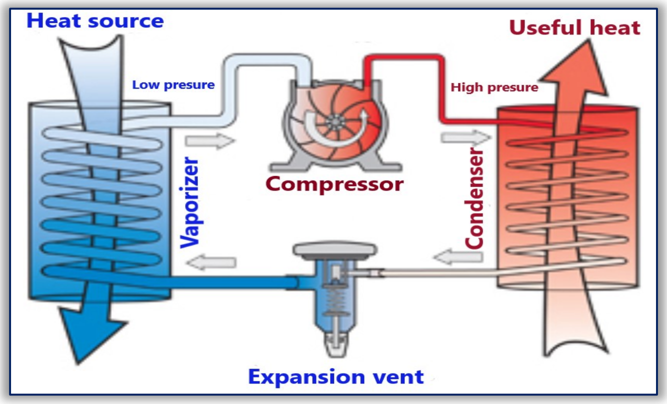

Figure 3. How a heat pump works in heating mode
Processed after www.heatpumpcentre.org/en/aboutheatpumps/Sidor/default.aspx

These heat pumps are effective for heating and cooling enclosed spaces (rooms). When the temperature drops below 20 degrees, the best cold climate heat pumps are even more energy efficient than fossil fuel stoves and power plants. This is confirmed by millions of people (building owners) in Norway, Finland and Sweden [15].

— Air–water heat pumps

These heat pumps provide efficient heating and cooling when used in a moderate climate. Studies show that air–water heat pumps can provide up to 5 times (depends on the required temperature on the heating circuit) more heat energy than the electricity they consume.

This type of outdoor air source heat pump offers efficient energy savings and low carbon dioxide emissions. The heat is taken from outside through an outdoor unit (Figure4) where the refrigerant circulates in a closed pipe system, transferring heat from the source to the indoor unit. The criteria by which heat is transferred can be simplified as follows (figure 5).

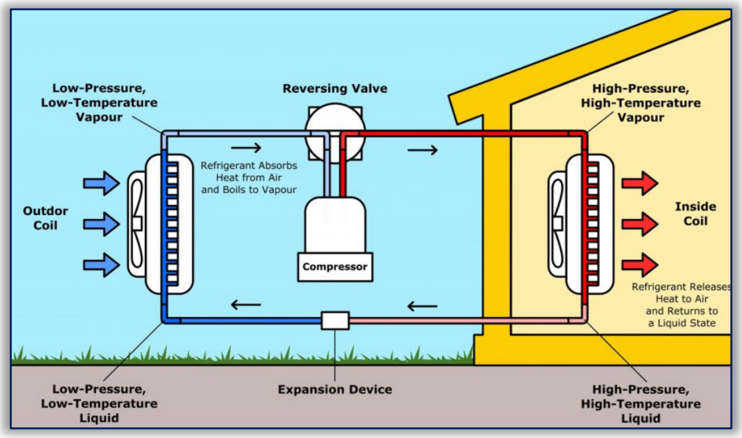

Figure 4. Air–water heat pump
Source: www.despre–energie.ro/wp–content/uploads/2020/11/Foto3–1024x721.jpg

To complete the above information, we show that heat pumps using outside air as a heat source work on the principle of vapour conversion and transfer heat from the air from one place to another in exactly the same way as a refrigerator system. We emphasise that air at a temperature above absolute zero always contains little heat and many of these heat pumps manage to extract heat even at temperatures as low as –20 degrees C.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

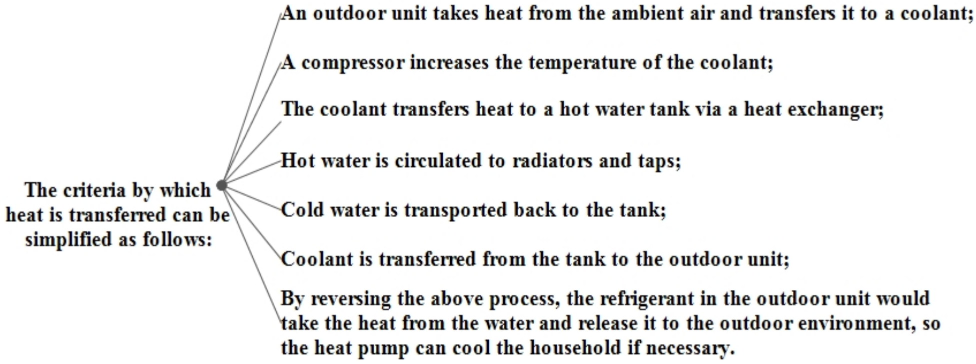

Figure 5. How heat pump work

To complete the above information, we show that heat pumps using outside air as a heat source work on the principle of vapour conversion and transfer heat from the air from one place to another in exactly the same way as a refrigerator system. We emphasise that air at a temperature above absolute zero always contains little heat and many of these heat pumps manage to extract heat even at temperatures as low as –20 degrees C.

Heat pump systems with a heat source taken from the outside air consist of four major components (Figure 6) [19] that allow the refrigerant to change from a liquid to a gaseous state:

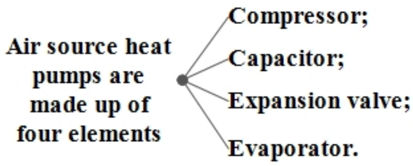

Figure 6. Heat pump components

The performance measurement of heat pumps is analysed using a Coefficient of Performance (COP) (equation 1) which can record different values, values that relate to the units of heat that are produced using one unit of energy.

$$COP_{HP} = \frac{\text{Thermal energy delivered [kw]}}{\text{Electricity used [kw]}} \tag{1}$$

At the same time we have to pay attention to another coefficient, the SCOP (seasonal coefficient of performance or average performance over the year), which is not as visible as the COP. The SCOP provides information closer to what the energy performance of the heat pump will be over a longer period of time. From this point of view we will see that pumps with a higher COP declared by the manufacturer (real but which can only be reached under certain conditions) will have a lower SCOP and those with a somewhat more modest COP in a SCOP assessment will "become" much more efficient. From this point of view it is easy to see that for most heat pumps the only energy performance factor that is offered to customers is the COP. Also, the advantages of using heat pumps with outdoor air as the heat source are environmental and economic. From an environmental point of view these heat pumps do not affect the environment because the heat they use for operation is extracted from the air and is continuously regenerated, although they need electricity to operate the system.

This type of system requires no ongoing maintenance, operates smoothly after installation and is cheaper to install than ground source heat pumps because it requires no excavation. Heat pumps using outdoor air source heat energy can be less efficient than ground source heat pumps and their performance can be adversely affected by low temperatures, and they usually need longer time and larger radiant surfaces to heat interiors.

We can say that this type of air–to–water heat pump is the way of the future in terms of green and clean heating systems. The benefits are visible within a year after the investment has been made.

— Water–to–water heat pumps

Hydrothermal heat pumps have a high thermal efficiency of the heat source compared to heat pumps with an outdoor air heat source [1,7,24]. Therefore,

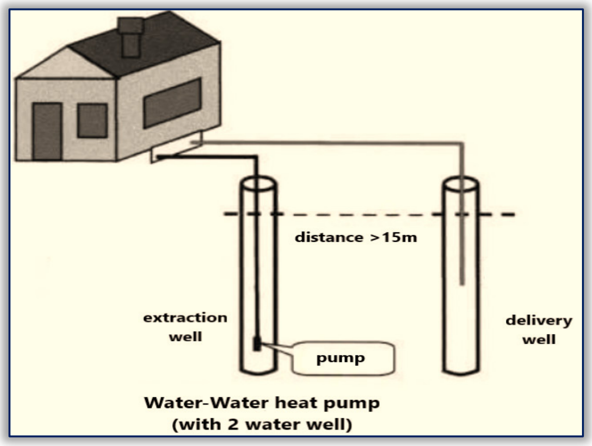

Figure 7. Water–water heat pump
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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

water–to–water heat pumps mainly use groundwater as a heat source (Figure 7). But the heat supply in this case is unstable because it depends on the amount of groundwater available [8,9,23], minimum 2 m^3/hour recirculation flow. We stress that water–to–water heat pumps require high initial investment costs.

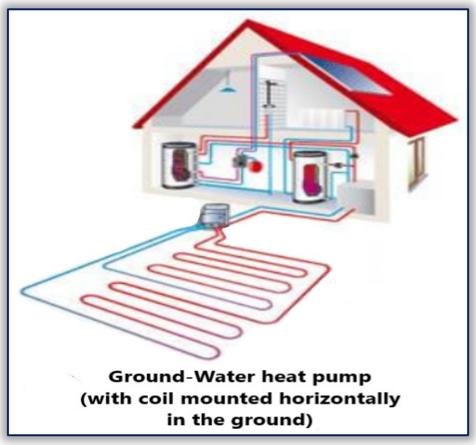
These heat pumps have the ability to operate as both a heating and cooling system. Their operation involves transferring heat from a medium where it is readily available to a medium that can accept it. A water–to–water heating system can extract heat from a low–temperature water source and deliver that heat to a higher temperature water stream. The heat source can be groundwater, water from a lake/pond, cooling water from an industrial process, or even process water that needs to be cooled before use. This technology has come into increasing use in the last decade and is suitable for floor heating and radiators. For space heating applications, water–to–water heat pumps typically extract heat from groundwater. This is because the ground temperature a few feet below the surface is considerably higher than the outside temperature during most of the winter. In some situations, the outside air temperature can be close to zero or below zero, while the ground temperature at a depth of 2 metres below the earth's surface is 7 – 10 degrees Celsius. So the higher the temperature of the heat source, the higher the capacity and efficiency of the heat pump [16]. These heat pumps are efficient and do not need additional heat when properly sized.

The water–to–water heat pump involves two important factors:

- "open loop" (water–to–water) – there must be a source of water (pond, lake or at least 2 wells) near the building that can supply the heat pump while it is running. It takes 10 – 15 litres of water per minute from the source to get 12,000 Btu/h (British Termal Unit, 1 Btu/h = 1055J = 0,293W). If the water source does not have this capacity the water pump will stop due to low pressure;
- "closed loop" (ground–water) – circulating water or a mixture of water and antifreeze through a closed loop of piping inserted several metres below ground level. The heat extracted by cooling the water circulates through the loop buried in the ground at a lower temperature than the surrounding soil. The heat migrates from the ground through the pipe wall into the cold fluid. The fluid carries the heat back to the heat pump, where it is extracted again in a standard refrigeration process. The cooled water flows back into the loop buried in the ground to repeat the process. The pipe loops start and end at the heat pump. This method eliminates potential water quality and quantity deficiencies associated with open loop systems.

— Ground–to–water (geothermal) heat pumps

These heat pump systems use an environmentally friendly technology [4,6] that can replace traditional heating and cooling systems in various buildings and reduce CO2 emissions. These heat pumps use the ground as a heat source (Figure8) for heating and as a radiator for cooling.



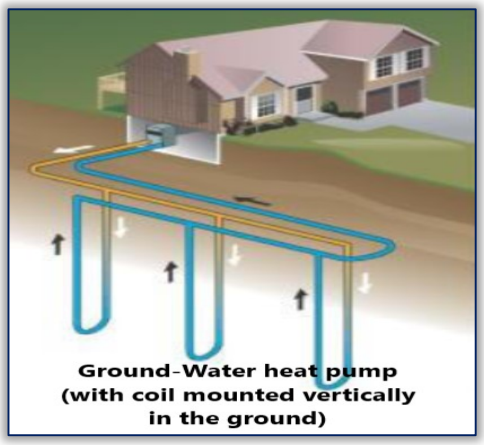


Figure 8. Ground–water heat pump
Processed after www.termocasa.ro/images/sys–termo/pompa_de_caldura_foraj.jpg

Geothermal heat pumps are quieter than air–to–water heat pumps, are durable, require little maintenance and do not depend on outdoor air temperature. From an economic point of view, the government can intervene with certain incentives to buy heat pumps, and households can reduce carbon emissions by reducing fossil fuel consumption.

— COP and SCOP of heat pumps, implementation and administration costs

A comparative analysis of the COP (Coefficient Of Performance) of heat pumps shows quite large differences between air–to–water, water–to–water and ground–to–water heat pumps. These differences arise from the fact that each energy source used has a lower (outdoor air) or higher (water, ground) thermal stability and hence differences in efficiency. At the same time if we consider the SCOP (Seasonal Coefficient Of Performance) of

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

heat pumps things change quite a lot. If the COP takes into account the performance of the heat pump under certain conditions of outdoor temperature as energy source and indoor temperature that can be provided, the SCOP takes into account the same criteria but considering the whole heating season.

However, if we analyse the difficulty of implementation, the time required for implementation, the costs involved and the operating energy costs, we will see that the highest COP does not always come with the simplest or most affordable (table.1) solution [27].

In order to have the possibility to make a comparison as close as possible to reality, we have chosen a building with a useful surface of 150 sqm, medium insulation, indoor temperature 21^{0}C, climate zone IV (Suceava). Heating is done with classic radiators and underfloor heating and the required temperature per lap is 50^{0}C. Estimated number of operating hours per heating season: 1800 hours (between 1200 and 1800 operating hours depending on the area of the country, 1200 hours for warm areas, for example Constanta and 1800 hours for cold areas, for example Suceava).

For this reason we have proposed a heat pump comparison that takes into account all the aspects involved in the decision to install a particular type of heat pump:

- The primary energy source is the first decision to be made and involves an analysis of its affordability. If the building has sufficient surrounding land and is permanently exposed to solar radiation, it is possible to implement a ground–to–water or water–to–water solution. If the building does not have enough land for a soil–water solution, a water–water solution can be implemented, but here 2 medium or deep wells are needed to provide a minimum flow of water per minute and a minimum distance of 15 metres between wells to avoid recirculating water from the same underground spring. The last option is the air–water solution and is usually chosen when the land area is small.
- Implementation costs (15% – 25% of the equipment value) and administration costs (table 2) depending on the type of heat pump. We choose the most affordable (cheapest) version of equipment [27], (for all three types of pumps) from the same supplier, which has in its portfolio all the types of heat pumps we want to compare.

The comparison between heat pumps has 2 levels:

- Economic with strict reference to the equipment costs (table.1) and energy costs (table.2) of the heat pump per heating season;
- Technical which takes into account the technical capabilities of the heat pump, the type of electrical connection required, the outdoor space available for heat capture and the heat demand. At the same time, the temperature required per tour of the heat medium depending on the heating solution (floor, fan coil or radiators), the geographical area where the equipment is installed, the orientation of the building and the terrain are also important. All the aspects listed above must be taken into account for the choice of equipment and optimal installation.

Table 1. Types of heat pumps, purchase and installation costs

Detailed costs	Comments	Ground–water heat pump (coil horizontally)	Ground–water heat pump (coil vertically)	Comments	Water–water heat pump	Air–water heat pump
Heat pump power	–	6kw	6kw	–	6kw	8kw
Cost of equipment (euro)	–	8500	8500	–	8500	6500
Installation costs 15% of equipment value (euro)	–	1275	1275	–	1275	975
Material and installation cost other than those related to the heat pump (euro)	2x250 ml pipe required buried 1.5–2 m deep	2000	–	water well drilling 2x 30 m x 70 euro/ml	4200	–
	laying the pipe in the ground	3000	–	pipe 150 ml well x 4 euro	600	–
	required 2x75 ml pipe buried vertically at 75 m depth	–	600	–	–	–
	vertical drilling for pipe installation 2x 75 m x 30 euro/ml	–	4500	–	–	–
Total initial investment (euro)	–	14775	14875	–	14575	7475

Source: Processed after www.trust–expert.ro/ rezultate–configurator–pompa–caldura–130–150mp/

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Table 2. Technical details and consumption of heat pumps

Technical details	Comments	Ground–water heat pump (coil horizontally)	Ground–water heat pump (coil vertically)	Water–water heat pump	Air–water heat pump
Heat pump power	–	6kw	6kw	6kw	8kw
Mains supply	–	400 V	400 V	400 V	230 V
Noise level	–	26 db	26 db	26 db	37 db
Minimum outdoor temperature	–	-40^0 C	-40^0 C	-40^0 C	-20^0 C
Maximum lap temperature at the installation	–	$+70^0$ C	$+70^0$ C	$+70^0$ C	$+58^0$ C
Indoor temperature	–	21^0 C	21^0 C	21^0 C	21^0 C
Energy consumption per heating season (Kwh)	–	2450	2450	2450	3600
Energy consumption per heating season of the recirculation pump (Kwh)	operating hours per season are 1800 and we are considering a 1Kw recirculating pump	1800	1800	1800	0
Total energy consumption per heating season (Kwh)	–	4250	4250	4250	3600

Source: Processed after www.trust–expert.ro/ rezultate–configurator–pompa–caldura–130–150mp/

If the dwelling is located in a geographical area where minimum temperatures of -20^0C are rarely reached and the space available for the installation of the heat pump is limited, the air–to–water option should be chosen. If temperatures of -20^0C and even lower are common, this solution can no longer be chosen and the ground–to–water or water–to–water option will be chosen even if there is a limitation on the outdoor space available for installation. In this case the ground–water version with 2 vertical wells can be chosen to compensate for the lack of space for a surface mounting with horizontally mounted heat trapping pipes. At the same time we can also point out a very important aspect related to this equipment, namely the noise level produced in operation which is below <30 db (40 db – library, 30 db – whispering, 10 db – breathing).

Another very important aspect is the energy consumption of heat pumps. If we make a comparison and consider only the consumption of the equipment, we can see an advantage in the case of water–to–water or ground–to–water pumps, but this does not take into account the consumption of the water or heat pump/circulating pump that facilitates heat transfer from water or ground.

6. CONCLUSIONS

The author concludes that heat pumps are an efficient investment for our home. This is because heat pumps offer sustainability (they use a renewable energy source), comfort (no fossil fuel supply required) and independence (independence from heat distributors). Of course, there are also some disadvantages such as the cost of implementation (table.1) and administration (table.2). Heat pumps are much more expensive than traditional heating solutions and installation is a little more difficult depending on the solution chosen. There are differences between the heat pump variant chosen versus the heat demand and outdoor temperatures during the cold season. Depending on the heat demand it is possible that the equipment needed will require the electrical connection of the house to be changed from 230V to 400V which again increases the cost of installing the heat pump. Depending on how the heat is distributed in the dwelling (radiators, underfloor heating, fan convectors) it is possible that the maximum temperature that the equipment can supply is sufficient (see air–to–water pump with maximum $+58^0$C) or that a higher temperature is needed (water–to–water or ground–to–water with $+70^0$C). This aspect must be taken into account if it is a new dwelling and everything is being sized from scratch or it is a change of heating source with the existing indoor heating system being maintained.

These heat pumps are an efficient solution for heating buildings if we choose the right solution. By using these heat pumps you will reduce the cost of heating your home by up to 60%. The environmental impact will be minimised (heat pumps need little energy to operate); renewable sources (air, water, soil) heat buildings at minimum cost. The strengths of these three types of heat pumps are that they are a beneficial alternative both financially (low long–term costs over an average lifetime of at least 15 years) and in terms of the comfort they offer.

Therefore, heat pump heating systems offer ideal conditions for heating your home in the most cost–effective way, using energy from the ground, air or water and not polluting the environment. Heat pumps can also provide domestic hot water all year round, which is not considered in this paper. Heat pump systems are generally very quiet, fully automated and do not require regular maintenance. Heat pumps are the most modern heating technology available today and their use only brings economic, environmental and why not psychological benefits.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Acknowledgment

This paper has been financially supported within the project entitled "DECIDE–Development through entrepreneurial education and innovative doctoral and postdoctoral research", project code POCU/380/6/13/125031, project co–financed from the European Social Fund through the 2014–2020 Operational Program Human Capital.

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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN–L 1584 – 2665