HEAT PUMP PRACTICE AND FUTURE OPPORTUNITIES IN EUROPE

Fogarassy, Csaba, PhD - Sandra Šlihte - Böröcz, Bakos, Mária, PhD

Authors: **Fogarassy, Csaba, PhD, Habil**, *Associate Professor, Director*
Clima Economic Analysing and Researching Centre
e-mail: fogarassy.csaba@gtk.szie.hu
Sandra Šlihte,
Riga Technical University
e-mail : sandra.slihte@gmail.com
Böröcz, Bakos, Mária, PhD, *Assistant Professor*
Clima Economic Analysing and Researching Centre
Institute of Regional Economics and Rural Development
Szent István University, Faculty of Economics and Social Sciences
2100 Gödöllő, Páter Károly u.1
Address: 2100 Gödöllő, P.O.Box. 303
e-mail: borocz.maria@gtk.szie.hu

Reviewers: Szűcs, István, *DSc, Professor*
Zsarnóczai, J. Sándor, *CSc, Associate Professor*

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Abstract

Geothermal energy is a renewable energy source stored beneath the earth's surface. It can be found everywhere all year around and technology like heat pumps is ready to meet the European market and has a potential to become a significant proportion of future heating and cooling systems.

Heat pump is an appliance that collects the heat from the ground, water or air and turns it into useful energy for heating or cooling a building. There are various types of systems that can be adapted to each case depending on needs and possibilities of a building. In this publication we are describing heat pump technology emphasizing the need to increase renewable energy sources in Europe and identifying opportunities to meet the growing need of it from a geothermal point of view.

The aim of the publication is to promote heat pump technology for heating and cooling for all types of buildings. The technology is simple but the process of finding the most suitable solution for each case can be complex. The efficiency and the payback time of heat pump depend on the electricity price, planning and installation quality. Bigger investment, required maintenance and a lack of experience can be a threat for the heat pump market. Description of advantages, disadvantages, problems and various types of solutions with examples is given are this publication. As an example a process of solar assisted ground source heat pump system for an office building in Hungary is analyzed.

Összefoglalás

A geotermikus energia nem más mint Földünk hője, megújuló energiaforrás, melynek semmiféle káros hatása nincsen. Felhasználása nem jár talaj, víz, vagy levegő szennyezéssel. Magyarország igen kivételes helyzetben van a geotermikus energia felhasználását illetően. A Kárpát- medence talaja üledékes, porózus kőzetből áll, mely igen jól vezeti a hőt, melynek köszönhetően a geotermikus energia kiválóan kinyerhető. Hazánkban a Föld belsejéből származó hőáram átlagosan 90-100 mW/m^2, mely a kontinentális átlag közel kétszeresét teszi ki, továbbá az egységnyi mélységnövekedéshez tartozó geotermikus gradiens átlagértéke nálunk 0,042-0,066 °C/m. Ezen geotermikus adottságainkból adódóan nálunk a 60 °C-t is eléri 1000 méter mélységben a réteghőmérséklet, sőt akár ezt meg is haladhatja. Hőszivattyú alkalmazásával ez a megújuló energia nagyon jól hasznosítható, akár kisebb méretű épületek esetében is a földbe elhelyezett szondák segítségével. A földbe vertikálisan vagy horizontálisan elhelyezett földszondák segítségével közel állandó hőmérsékletet tudnak a felszínre hozni, melyből a hőszivattyú segítségével melegvizet állíthatnak elő. A geotermikus energia felhasználása a jövő energiaigényének kielégítése szempontjából meghatározó szerepet fog betölteni, de mint minden erőforrás esetében ennél is meg kell valósuljon az erőforrásféleség ésszerű felhasználása, és védelme.

Introduction

Geothermal energy is generated in the core of Earth and is stored in rock or water. The temperature increases about 30 °C with each kilometre of drilling. This number depends on the geographical location, in Hungary it is 50 °C. Geothermal energy has a very promising future because unlike other renewable energy sources it is available all year around and is not dependent on the climate or weather changes. Geothermal energy can be used for heating, cooling, water heating and electricity generation. There are various methods of recovering geothermal energy and depending on available natural resources which are different in each country. Energy recovery can be applied in four areas: geothermal heat pumps, geothermal energy storage, direct uses and district heating. It can also be used for snow melting on roads and pavements. In countries where geothermal heated waters can be found such as Hungary, Germany, France, Italy it is possible to directly exploit ground water for district heating or other purposes. To find geothermal reservoirs research should be done which requires a large investment and can be one of obstacles for development of this field. In places where thermal waters can't be found energy can be reclaimed by using geothermal heat pumps. Temperature of the ground 10 – 100 m deep is a constant 5-25 °C all year around and it can be increased to a useful temperature of 40-55 °C for heating or 7-8 °C for cooling.

Discussion about using heat pumps

Heat pump is an appliance for heating, cooling and water heating which uses energy stored in the surrounding environment. In most European countries there is need for heating in winter and cooling in summer. Heat pumps are energy efficient and by using them it is possible to reduce greenhouse gas emissions. There are three different types of heat pumps: air, water and ground source heat pumps and the choice is dependent on household or industry needs. Air source heat pumps are efficient only in a warm climate (see about the renewable energy resource in detailed, Khalif, Abdussalam Ashour et al, 2010).

If the outside air is too cold, it can't provide needed temperatures to heat the building and requires back up heating. For example Danfoss and Toshiba air to water heat pumps the provide space heating to -20°C but at this temperature water heating is not possible anymore.

Heat pumps produce energy using clean renewable sources avoiding burning process which means that no gasses or toxic exhaust is produced. However there is need for external electrical energy to run compressors and pumps. From 1 input electricity unit the outcome is about 4 heat units, even if fossil fuel is used for power generation, there is an overall CO_2 emission reduction. But if the heat pump is combined with another renewable source for generation of electricity then heat energy is produced pollution free.

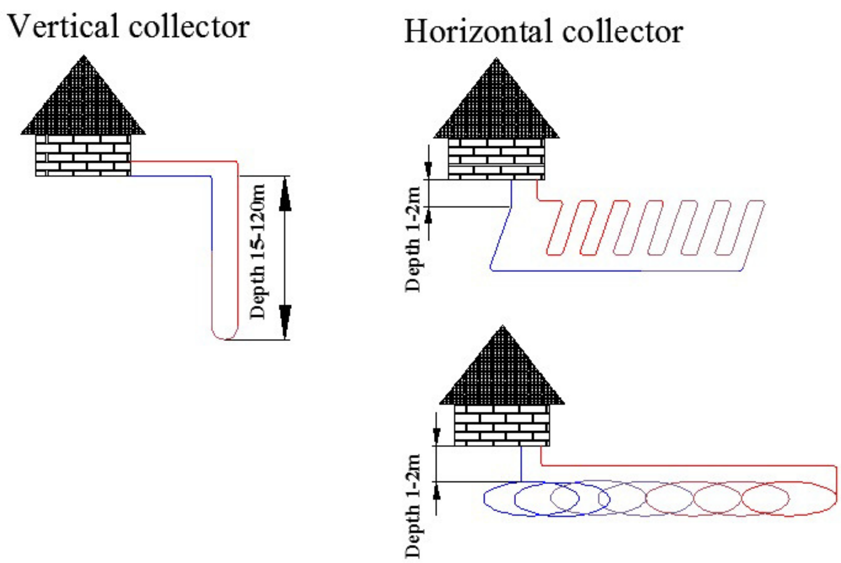
Water and Ground source heat pumps

Water source heat pumps can either produce heat either extract heat from the building and inject it to the water. The system can be opened or closed loop. Water is pumped from a well directly to the heat pump to recover its heat, and re-injected back using another well. Water quality is very important because it can damage the system. Closed loop water systems works the same as ground source the only difference is that collector is placed under the water - lake or river.

Ground source heat pumps can be used everywhere, the ground absorbs heat from the Sun and keeps it warm all year around not dependent on the weather. For ground source heat pumps closed loop collector systems are used. Heat collectors can be horizontal or vertical. A horizontal collector is placed one to two meters deep depending on the location. The deeper the collector is placed the more constant the ground temperature will be 24 hours a day, 12 months a year but the cost of installation will rise.

Fluid (usually water mixture with antifreeze) is circulating through closed loop pipe and collecting heat from the earth to heat the building using the heat pump. Energy is transferred to the heat pump via a heat exchanger. Ground collector consists of a continuous polyethylene pipe loop. The length of pipe depends on soil conditions, loop configuration, local climate and landscaping. The ground collector size has to be calculated so they can cover peak loads. Calculations are complicated and are made using computer software. Pipe layout should be designed thoughtful to reduce primary energy consumption of the pump. Types of collector are shown in Figure 1.

Figure 1: Collector types



Source: Drawing by Sandra Šlihte, 2010

Usually the area of a horizontal collector system has to be at least three to four times bigger than the heating/ cooling area. If available land area is not big enough vertical collectors are used. They require drilling boreholes with 100 – 150 mm diameter. The depth and number of drillings depend on required heating load. From every meter drilling it is possible to produce approximately 50 – 60 W heating. Usually one borehole is 15 – 120 m deep.

To describe the efficiency of Heat pumps two parameters are used. Coefficient of performance (COP) and is expressed as ratio of input energy and output energy. It depends on the temperature difference between heat source and heat sink. Seasonal performance factor (SPF) describes performance of the total system per one year

Heating and cooling cycle

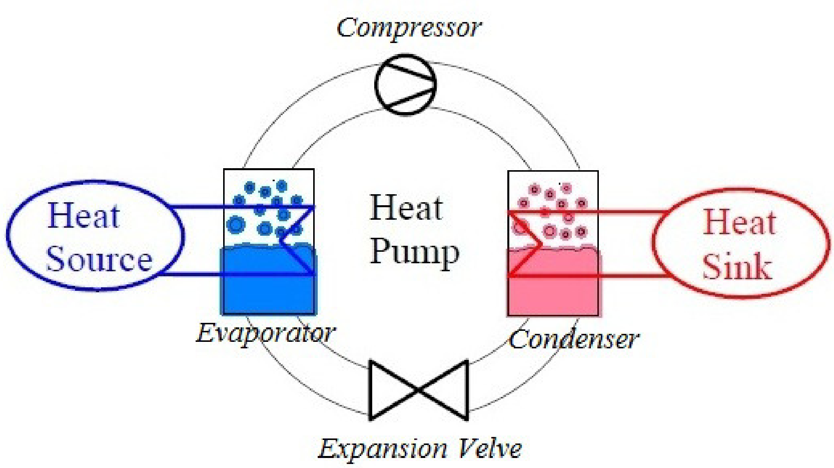
Geothermal heat pumps can be very efficiently used everywhere. The heat pump system consists of heat source, heat pump and distribution system. Figure 2 shows the operation of a heat pump.

The heat source warms up liquid that circulates in First loop. The liquid warms the refrigerant which is located within the close circuit of the heat pump. It boils and evaporates and is transferred to compressor where the pressure is increased thus increasing temperature of refrigerant which heats water in Second loop – households heating/cooling distribution system (Heat sink).

At the same time the heated refrigerant cools and condensates and the process starts all over again. Work fluid of heating/cooling system can be water or air. Refrigerants that are used in heat pumps (R 407C, R 404A, R 410A and others) work chlorine-free to avoid damage to the environment. By this cycle temperature can be increased to 40°C, maximum 55°C which limits choice of distribution system used in a building. Mostly underfloor heating systems are used; low temperature radiators or air systems also can provide needed temperatures.

The cooling cycle is reversed – heat is transferred from building to ground. By reversing valve refrigerant direction is changed and heat is pumped to First loop to give heat to ground or water. Or it can be used to heat domestic hot water.

Figure 2: Operating principle of heat pump



Source: Drawing by Sandra Šlihte, 2010

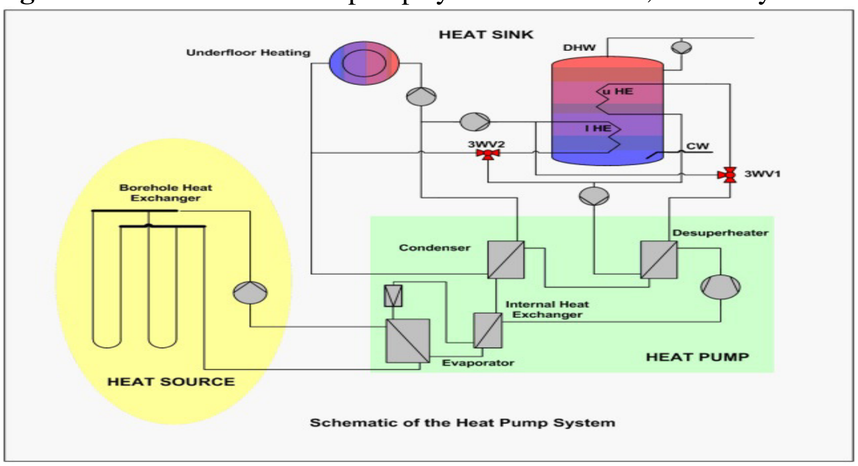
Water heating

Heat pumps also provide water heating all year around. If the temperature 30°C is enough for heating of the building, it is not enough for domestic hot water for comfort and health reasons. 20°C to 45°C is a perfect temperature for Lagionella bacteria to multiply, temperatures above 55°C should be provided. By increasing output temperatures the efficiency of heat pumps falls. It is also possible to heat using an external heating unit to heat water in separate tank.

The other option is use a Two-circuit heat pump (with desuperheater). In this system there is separate loop for water heating with desuperheater which uses superheated gases from the compressor. It is extra small heat exchanger and is placed on the outlet of the compressor before the condenser and provides water heating up to 70°C and uses waste heat from cooling to warm water in summer time which increases the efficiency of the heat pump. A Pilot-system of the Two-circuit heat pump was first installed in Dresden in 2003.[1] Distribution system of house is floor heating and 400 l domestic hot water tank.

Water can be heated by desuperheater or heat pump (condenser). Two heat exchangers are used for water heating – upper and lower switching them by three-way-valves, as illustrated in Figure 3. According to monitoring data in 2004 seasonal performance factor (SPF) was 3.64 which was improved by various actions later on. Figure 4 shows the ratio between productions of heat by heat pump condense and desuperheater. The reason the condenser supplies more heat in summer is that the system doesn't have a cooling mode.

Figure 3: Schematic of Heat pump system in Dresden, Germany



Source: FIZ-Karlsruhe, GroundMed 2009, Seventh Research Framework programme EU, 2004

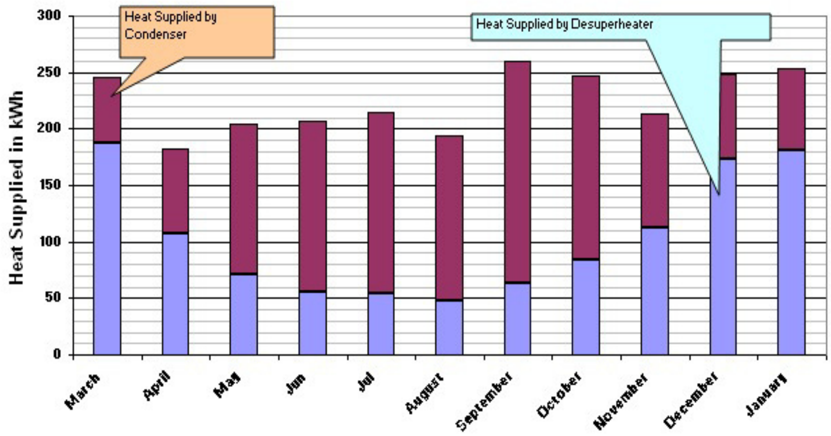
A possible solution for heating the water is to use solar system. Solar assisted heat pump systems can improve efficiency of heat pumps and reduce expenses. As an example, a ground source heat pump coupled with a 161 m² solar thermal for hot water in the summer was installed in retirement home 'Haus Rohrer Höhe' with 76 flats Stuttgart, Germany. In winter return water flow of the heating system is preheated by solar collectors.

As shown in Figure 5 heat from solar collectors and the heat pump is stored in two 5 m^3 buffer tanks of water so that it can be used anytime required and also an electric heater is used as a backup system in peak loads or when the sun is not shining.

Solar systems are not cheap in this case it cost € 70 700 and can be used only when sun is shining. Expenses also were for the heat pump with installation € 69 100, duct with piping € 150 600, electric boiler with installation € 68 800. The system works with SPF 3.0. It is low because of engineering problems and mistakes made during the planning process.

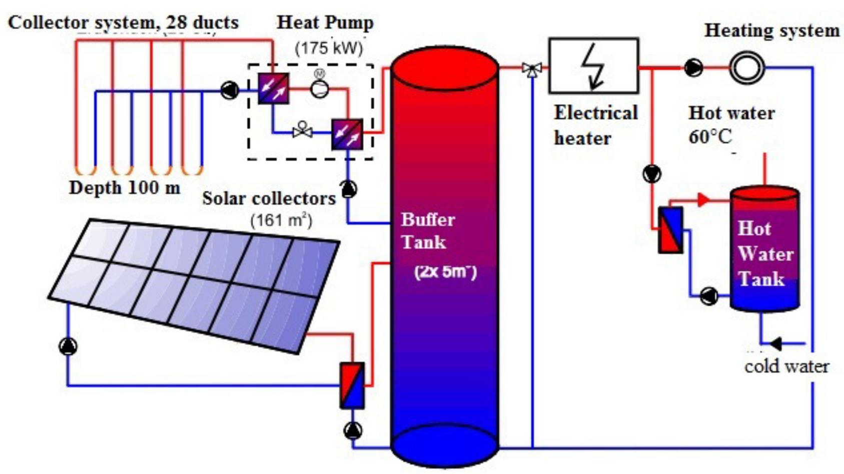
[1] FIZ-Karlsruhe 2009, Seventh Research Framework Programme EU, viewed 21st March, 2011, < www.groundmed.eu/hp_best_practice_database/database/513>

Figure 4: Hot water generation in year 2004



Source: FIZ-Karlsruhe, GroundMed 2009, Seventh Research Framework programme EU, 2004

Figure 5: Schematic of solar assisted heat pump system Stuttgart, Germany



Source: European Commission, ManageEnergy, Integrated energy concept at "Röhrer Höhe", featuring heat pump and solar thermal system City of Stuttgart, Germany, 2007

Heat pump costs and market opportunities

Price of fossil fuel have grown during last ten years and likely that will keep rising in the future what means that it is necessary to look for alternative energy resources. Every new system requires an investment. Cost of installing a new heat pump system can be up to twice the cost of a gas boiler with extra air conditioning. Cost of heat pump systems consists of field costs (surface exploration, drilling and else) and system costs (heat pump unit, pipe, engineer calculations, design and installation costs).

Installation cost depends on type of system, running cost depends on primary energy fuel type and price. According to Ground Source Heat Pump Best Practice Database for the single family building it can be € 12 000 – 20 000, for example € 13 000 for 238 m^2 big house in

Estonia, € 12 000 for 160 m^2 in Sweden and 16 000 for 190 m^2 house in France. Experience shows that average payback time of heat pump systems is 10-15 years as it reduces energy costs by 50% or more. Heat pumps last 20 to 30 years.

However just installing the system can be not enough, usually to provide required temperature for heating water in domestic heat systems is 80-90°C warm but geothermal heat pumps can increase the temperature of the fluid only to 40-55°C it means that the building has to be very well isolated and can require energy efficiency measures. That is why heat pumps are mostly installed in new buildings.

The market for heat pumps has grown since 2005 and reached 584 649 units sold in 2008 in Austria, Finland, France, Germany, Italy, Norway, Switzerland and the UK. The global crisis did not leave the heat pump market untouched and number of units sold decreased in 2009 and 2010. The Swedish Heat Pump association has researched the market, heat pumps are installed in 77% on single family houses, 15% in cottages, 3% multifamily houses, 3% commercial premises and 2% other.

European Union policy towards geothermal energy

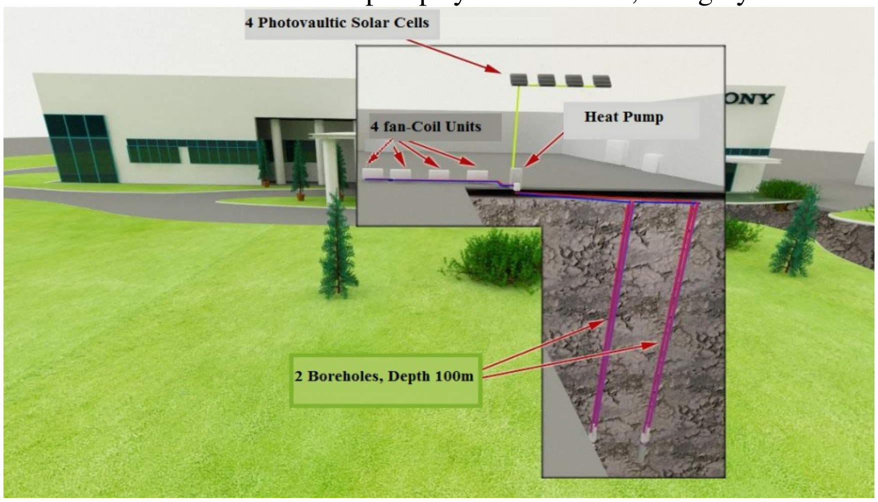
The requirement of EU Directive 2009/28/EC is to increase Renewable source for heating and cooling to 20.2% in 2020, with biomass representing 17.2%, heat pumps from aerothermal energy 1.6%, solar thermal energy 1.2% and only 1.3% geothermal energy. This number doesn't show the potential of geothermal energy and heat pumps. Also it is only mentioned in the Energy Performance of Buildings Directive that use of alternative source technology like heat pumps should be considered in new buildings with a surface area above 1,000 m².

The technology is ready to market, secure, reliable, energy efficient and meets all the requirements for sustainability but does not get enough political attention. The problem of development of the market can be the higher investment cost of geothermal applications, lack of knowledge, experience, undeveloped institution and financial support. The system can be complicated and requires skills, knowledge, and experienced engineers and technicians to run it successful. There are a lot of positive examples for heat pump installations already. Research supported by the European Union about ground source Heat pumps and "Ground Source Heat Pump Best Practice Database" has made information available for more than 90 heat pump installations.

CASE STUDY: Heat pump system for SONY office building in Gödöllő, Hungary

Solar assisted ground source heat pump system is installed to heat and cool 100 m^2 office building in Gödöllő. The collector system is two 100 m deep boreholes with a heat exchanger in depth 15 m. System is assisted by four solar photovoltaic cells for electricity generation to run the pump. System is shown in Picture 1.

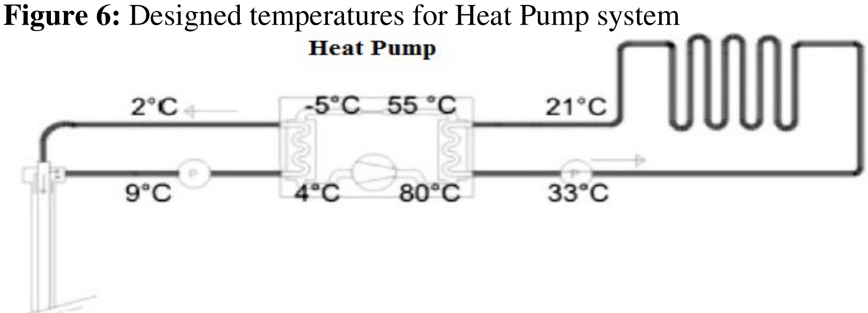
Picture 1: Solar assisted heat pump system Gödöllő, Hungary



Source: SONY projekt, 2009

The buildings heating system consists of four series connected fan-coils – the heat exchanging unit in which water is circulated and heated or cooled air is transferred to room by fan.

Figure 6: Designed temperatures for Heat Pump system



Source: SONY project, 2009

Figure 6 shows designed temperatures. Borehole collector system collects heat source with temperature 9°C which is increased by compressor to 80°C. Recovered by the heat exchanger temperatures up to 33°C are produced and transferred to fan-coils for heating. Internal loop return water temperature is 21°C, ΔT=12°C. External loop return water temperature is 2°C.
To analyze how the system works monitoring was carried out. Results of minimal, maximal and average temperatures are shown in Table 1.

Temperatures are closed to design ones. The difference between heat pump minimal and maximal temperature is because the compressing process of the heat pump doesn't happen constantly. Measurements for temperatures were made every 10 minutes. Electricity analysis shows that during 24 hour period heat pump works with interval 17 – 25 min. Very high temperatures above 23.4°C are provided in the room.

Table 1: Measured temperatures in the office building in Gödöllő

		Min T °C	Max T °C	Average T °C
Water supply temperature (Heat Pump out)		24.93	36.98	27.72
Water return temperature (Heat Pump in)		24.93	30.12	26.73
ΔT		0.14	8.02	0.98
Ground temperature 16 m deep	*1*	11.04	22.73	15.18
	2	8.18	23.81	17.05
Fan-coils in		24.92	37.50	27.72
Fan-coils out		24.76	30.12	26.74
Air temperature in the room		23.40	25.00	24.29

Source: Measured data, 2009

In one year consumption of energy was 12679.2 MJ (Heat pump 10368 MJ, circulation pump 1728 MJ, fan-coil units 583.2). By using a traditional heating system with boiler and climate control this number could be 4.6 times bigger which saves about 45236 kg carbon emissions and € 135 708 in one year. This is a successful project.

Cost of the heat pump system was € 13 868 (1 drilling of 100 m deep borehole in Hungary costs € 2190). The system works without problems and provides heating and cooling, just by changing a position of a switch. Also using a fan coil units gives the possibility to control indoor temperature easily providing comfort in the room.

Proposals and conclusion

It is obvious that for creating a sustainable future energy we will be required look for renewable energy sources considering environmental, technical and the economic aspects. Geothermal energy meets all the requirements but it is not enough, it needs political support to develop.

Targets of the EU Directive 2009/28/EC are to increase renewable sources but it does not reflect the possibilities of geothermal energy. This publication shows how the heat pump systems can be engineered and installed everywhere.

Heat pump systems reduce energy consumption as well as being an energy efficient appliance which require good heat insulation; they can be planned and installed only by professionals providing work placements. Geothermal energy is an economical way to reduce CO_2 emissions leaving good impact on environment.

The SWOT analysis of heat pump systems is shown in Table 2. We conclude that there are very good conditions in Hungary to use heat pump systems for heating and cooling but the installation costs are relatively high. This problem can be solved with a support of the government by giving subsidies to install these systems.

Table 2: SWOT Analysis for Heat pumps:

Strengths	**Weaknesses**
Energy efficient; Renewable source which can be found everywhere all year around not dependent on weather; Can be used for heating and cooling;	Requires primary energy source – electricity; High installation cost; Not easy to retrofit; Provides only 45 – 55 °C temperature for heat supplier; Slow to respond – cannot heat up and cool down building quickly;
Opportunities	**Threats**
Good for new buildings or refurbishments; Advantages of heat pumps gives an opportunity to become main heating/cooling source;	Reliant on grid of electricity; Is not supported enough by political governments; Requires qualification and knowledge to install efficient systems.

Source: Our own analysis

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