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485

COOLING AND HEATING WITH GROUND SOURCE ENERGY

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Abstract: *Aims/purpose* – The purpose of this paper is to highlight the potential energy saving that could be achieved through the use of ground energy source heat pump systems (GSHPs) and other renewable energy sources for the heating and cooling of buildings. Exploitation of renewable energy sources and particularly ground heat in buildings can significantly contribute towards reducing dependency on fossil fuels.

Design/methodology/approach – The study focuses on the optimisation and improvement of the operating conditions of heat cycles and performances of direct expansion (DX) GSHP.

Place and duration of Study – Energy Research Institute (ERI), between July 2011 and November 2011.

Results/findings – It is concluded that the direct expansion of GSHPs are extendable to more comprehensive applications combined with the ground heat exchanger in foundation piles and the seasonal thermal energy storage from solar thermal collectors.

Originality/value – This study highlights the energy problem and possible savings that can be achieved through the use of the GSHP systems. This article discusses the principle of the ground source energy, varieties of GSHPs, and various developments.

Keywords: *Direct expansion GSHPs; Ground source; Development and evaluation of the system.*

Paper type Research paper

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INTRODUCTION

Renewable energy sources have one thing in common: they all existed before man appeared on this planet. Wind, wave, hydro, solar, geothermal and tidal power are all forces of nature and are mostly intermittent energy sources; geothermal power is the only consistent phenomenon. Geothermal renewable energy sources were probably the first to be fully utilised by man. Early civilisations tapped this heat to cook, fire clay pottery, create baths and spas and even heat their homes. Roman villas had under-floor heating from natural hot springs over 2000 years ago.

Shallow geothermal resources (<400 m depth by governmental definition in several countries) are omnipresent. Below 15–20 m depth, everything is geothermal. The temperature difference between determines the ground temperature; the ground and the fluid in the ground heat exchanger drives the heat transfer. The temperature field is governed by terrestrial heat flow and the local ground thermal conductivity structure (groundwater flow). In some countries, all energy stored in the form of heat beneath the earth surface is by definition perceived as geothermal energy (VDI, 1998). The same approach is used in North America. The ubiquitous heat content of shallow resources can be made accessible either by extraction of groundwater or, more frequently, by artificial circulation such as that in the borehole heat exchanger (BHE) system (Knoblich *et al.*, 1993). This means that the heat extraction occurs in most cases via pure conduction; no formation fluids are required. The most popular BHE heating system, with one or more boreholes typically 50–200 m deep, is a closed circuit, heat pump coupled system, ideally suited to supply heat to smaller, de-central objects such as single family or multi-family dwellings. The heat exchangers (mostly double U-tube plastic pipes in grouted boreholes) work efficiently in almost all kinds of geologic media (except in material with low thermal conductivity, such as dry sand or dry gravel). This means of tapping the ground as a shallow heat source comprises:

- Groundwater wells ("open" systems),
- Borehole heat exchangers (BHE),
- Horizontal heat exchanger pipes (including compact systems with trenches, spirals, etc.), and
- "Geo-structures" (foundation piles equipped with heat exchangers).

A common feature of these ground-coupled systems is a heat pump attached to a low-temperature heating system, such as floor panels/slab heating. These are termed "ground-source heat pumps" (GSHP) systems. In general, these systems can be tailored in a highly flexible way to meet locally varying demands. Experimental and theoretical investigations (field measurement campaigns and numerical model simulations) have been conducted over several years to elaborate a solid base for the design and for performance evaluation of BHE systems (NASA, 2009; Rybach and Eugster, 1997). In the 1980s, theoretical thermal analysis of BHE systems prevailed in Sweden (Claesson and Eskilson, 1988; Eskilson and Claesson, 1998) monitoring and simulation was done in Switzerland (Gilby and Hopkirk, 1985; Hopkirk *et al.*, 1988), and measurements of heat transport in the ground were made on a test site in Germany (Sanner, 1986).

In the German test system at Schöffengrund-Schwalbach near Frankfurt/Main, a 50 m BHE was surrounded by a total of 9 monitoring boreholes at 2.5, 5 and 10 m distance and 50 m deep. Temperatures in each hole and at the BHE itself were measured with 24 sensors at 2 m vertical distance, resulting in a total of 240 observation locations in the underground. This layout allowed the investigation of the temperature distribution in the vicinity of the BHE. The influence from the surface is visible in the uppermost 10 m (approximately), as well as the temperature decrease around the BHE at the end of the heating season. Measurements from this system were used to validate a numerical model for convective and conductive heat transport in the ground (Bourna and Koppenol, 1984; Sanner *et al.*, 1996). Starting in 1986, an extensive measurement campaign has been performed at a commercially delivered BHE installation in Elgg near Zurich. The object of the campaign is a single, coaxial, 10 m long BHE in use since its installation in a single-family house. The BHE supplies a peak thermal power of about 70 W per m of length.

The ground temperature results are highly informative with respect to the long-term performance (Hellstrom *et al.*, 1997). Atmospheric influences are clearly visible in the depth range 0–15 m, and below 15 m, the geothermal heat flux dominates. The results show that in the near field around the BHE, the ground cools down in the first 2–3 years of operation. However, the temperature deficit decreases from year to year until a new stable thermal equilibrium is established between the BHE and the ground, at temperatures that are some 1–2 K lower than original measurements. Thus, a "thermal collapse" (i.e. a sudden drop of heat extraction efficiency) will not happen. After calibration of a numerical model with the data from the Elgg system, the extrapolation for an operation over a 30-year period, as well as the thermal recovery for 25 years following the end of the operation period, has been simulated. The temperature close to the BHE in winter drops quickly in the first years, only to stay more or less stable over the next years. In summertime, initial temperatures are not achieved again, but the temperature drop is decreasing from year to year (Knoblich *et al.*, 1993). After termination of the operation, a rapid thermal recovery can be seen in the first spring, followed by a slowing down of the recovery process due to the decreasing temperature gradients. In the numerical simulation, a complete recovery will occur only after an indefinitely long time period; nevertheless, the remaining temperature deficit 25 years after the operation ceases is only in the order of 0.1 K. The long-term reliability of BHE-equipped heat pump systems, along with economic and ecological incentives, led to rapid market penetration. This was accomplished by the development of design standards (e.g. VDI, 1998), and easy-to-use design tools (Hellstrom *et al.*, 1997).

HEAT PUMPS

Heat pumps work on a similar principle to domestic refrigerators, extracting heat from one source and transferring it to another. A key ingredient in the heat pump is the refrigerant in its coils, usually a substance called freon, which vaporises into a gas at a boiling point far lower than the 100°C that water requires to boil. When the refrigerant boils, it changes from a liquid to a gas, absorbing heat from its surroundings. As the refrigerant changes back into liquid form it gives up its heat to the surrounding atmosphere. An expansion valve and an electric compressor control this process of transformation from liquid to gas and back again.

The earth energy (EE) heat pump is one of the most efficient means available to provide space heating/cooling for homes and offices. It transfers the heat located immediately under the earth's surface (or in a body of water) into a building in winter, using the same principle as a refrigerator that extracts heat from food and rejects it into a kitchen. A heat pump takes heat from its source at low temperature and discharges it at a higher temperature, allowing the unit to supply more heat than the equivalent energy supplied to the heat pump. An earth energy system relies on the 51 per cent of solar energy that is absorbed by the land and water.

TERMINOLOGY

Due to the large demand for EE systems as cooling devices, the earth energy industry uses the term "ton" to describe a unit that will provide approximately 12,000 Btu of cooling capacity. On average, a typical 2,000 square-feet new residence would require a 4-ton unit for sufficient heat. Within the full swing of heat pump applications in Europe, ground-coupled heat pumps play a significant role. The development started around 1980 when the first BHE coupled heat pump systems were built in Germany and Switzerland. Following a larger number of new units installed during the oil price crises and a subsequent low (except for Switzerland), the number of new installations is again increasing in the 90s.

AIRFLOW

EE units work efficiently because they provide a small temperature rise, but this means that the air coming through the register on the floor is not as hot as the air from a gas or oil furnace. A unit must heat more air to supply the same amount of heat to the houses, and duct sizes must be larger than those used for combustion furnaces to accommodate the higher CFM (cubic feet per minute) air flow. The major advantage of an EE system is that the heat obtained from the ground (via the condenser) is much greater than the electrical energy that is required to drive the various components of the system. The efficiency of a unit is the ratio of heat energy provided versus the electrical energy consumed to obtain that heat, and it is called its Coefficient of Performance (COP). EE units must exceed 3.0 (i.e. for every kilowatt of electricity needed to operate the system, the heat pump provides three kilowatts of heat energy).

SOIL TYPE

Loose dry soil traps air and is less effective for the heat transfer required in EE technology than moist packed soil. Each manufacturer provides specifications on the relative merits of soil type; low-conductive soil may require as much as 50 per cent more loop than a quality high-conductive soil.

VARIETIES OF HEAT PUMPS

Air conditioning systems are an example of an air-to-air heat pump. They are becoming increasingly prevalent, particularly because new cars are often fitted with air conditioning systems and people are beginning to ask for more controlled internal environments. However in the UK, the need for air conditioning is often a result of overheating because of unsatisfactory shading and poor natural ventilation. Every attempt should be made to design buildings that do not require air conditioning, because of the additional energy load required.

In addition to air-to-air heat pumps, there are air-to-water heat pumps and water-to-air systems. These can draw water from a well or pond and expel the used water to a discharge well. Because the source of heat is fairly constant (about 10°C) the heat pumps are more efficient than air-to-air systems. Water-to-water heat pumps are even more efficient, taking the energy from geothermal supplies, which are at a constant year-round temperature and transfer heat to approximately 53°C.

TYPES OF GEOTHERMAL SYSTEMS

There are a number of different methods to heat a building using geothermal energy:

- Groundwater GSHP, of which there are two variations: open loop and closed loop. An open loop groundwater GSHP supplies ground water directly to each heat pump and then returns the well water to the source. This system is normally not recommended because of fouling and corrosion concerns. The closed loop uses an isolation plate and frame heat exchanger between the ground water and the building water loop.

- Surface-water GSHP, which uses multiple heat exchangers made from spooled plastic pipe submerged in a body of surface water and connected to the building heat pumps.

- Ground heat exchanger GSHP, which relies on a ground-coupled heat exchanger installed either horizontally in trenches or as "U" tubes in vertical bores.

The heat exchangers are connected together in parallel, and run-outs are tied to the building's water loop. The selection of a particular design depends on the available land area. Table 1 provides the guidelines on the surface-area requirements for horizontal/vertical configurations. The decision to use any of the above systems depends on the results of geotechnical/hydrogeological investigations.

Table 1: Surface area requirements GSHP (sq metres)

Design	Horizontal	Vertical
2 pipes per trench	2000	3500
4 pipes per trench	1400	2400
6 pipes per trench	1400	2400

WATER DISCHARGE QUALITY

There are environmental regulations that govern how the water used in an open-loop system can be returned to the ground. A return well is acceptable, as long as the water is returned to the same aquifer or level of water table. A discharge pit is also acceptable, as long as certain conditions are followed.

Open water systems depend on a source of water that is adequate in temperature, flow rate and mineral content. EE units are rated under the national performance standard (CSA C446) based on their efficiency when the entering water temperature is 10°C (0°C for closed loop units), but this efficiency drops considerably if the temperature of water is lower when it comes from the lake or well. Each model has a specified flow rate of water that is required, and its efficiency drops if this rate is reduced. The CSA installation standard demands an official water well log to quantify a sustainable water yield. Water for open-loop systems must be free of many contaminants such as chlorides and metals, which can damage the heat exchanger of a unit.

SELECTING A GSHP

GSHPs are very similar to conventional heat pumps. Their specifications differ from conventional water-source heat pumps (WSHP) only in the following areas:

1. GSHPs operate over a very wide range of entering water temperatures

from source (ground), typically, 20°F to 110°F, whereas the conventional WSHP operates over a very narrow range (60 to 90°F). This requires the use of an extended-range heat pump to preserve the ability of the system to operate at low ground-water temperatures. Table 2 gives the typical temperature ranges for the water loop of GSHPs.

2. GSHPs with the ground as a heat exchanger must be rated under ARI 330 or CSA 446 closed-loop conditions. GSHPs are to be rated under ARI 325 or CSA 446 open-loop conditions. Conventional heat pumps are rated under ARI 325 or CSA 656 conditions.

3. GSHPs usually use a thermal-expansion valve as opposed to the capillary expansion device used in WSHPs.

4. GSHPs typically encounter low suction temperatures and therefore need to be specified with low-temperature/pressure controls for freeze protection.

5. GSHPs usually employ larger liquid side and airside heat exchangers and insulated internal components to prevent internal condensation.

6. In conventional WSHPs, the insulation on the loop piping is not required because the loop temperatures are always maintained above 45°F. GSHP system piping will require insulation, and in some cases, antifreeze solutions will be required to prevent freeze up.

7. Specify copper heat exchangers for heat pumps on closed-loop ground source, groundwater, or surface-water applications. Use only cupronickel heat exchangers for open ground-water systems.

8. While calculating the loads for the ground-source heat pumps, it is necessary to perform the calculations with an hour-by-hour and month-by-month simulation programme because these calculations will be required to design the well field.

Horizontal design	Heating	Cooling
Ground heat exchanger	30-55	90-105
Surface water heat exchanger	30-45	80-95
Closed loop ground water	40-50	75-85
Open loop ground water	50-60	55-65

Table 2: Entering liquid temperatures for different system types (oF)

SELECTION AND PRE-INSTALLATION CONSIDERATIONS

The ground source heat pump (GSHP) system represents the natural evolution of a traditional water loop heat pump (WLHP) system. The GSHP system offers all the advantages of the WLHP system, combined with considerable reductions in building operating costs. The beauty of this system is that it can perform both heating and cooling without the use of separate boilers/furnaces and A/C systems.

A GSHP system does not create heat; it moves heat from one area to another. GSHP systems use the ground (earth, ground water, or surface water) as a heat sink in the summer and a heat source in the winter. This system is considered the most energy-efficient, environmentally safe, and cost-effective system available. Among the many components of a GSHP system, the most important is the heat pump itself.

GEOTHERMAL HEATING SYSTEMS

Geothermal energy is a natural resource, which can be used in conjunction with heat pumps to provide energy for heating and hot water. CO_2 emissions are much lower than gas-fired boilers or electric heating systems. Geothermal heating is more expensive to install initially than electrical- or gas-fired heating systems. However, it is cheaper to run, has lower maintenance costs, and is cleaner in use than other sources of heating.

THERMAL STORAGE

If off-peak electricity is used and the even distribution of hot water is desired, then it is worth considering a thermal store. The water, which is heated by the heat pump, can be stored in a large insulated tank at about 50°C and only used when needed. The thermal store can also link into solar water panels, providing an additional source of renewable energy. Thermal storage requirements will vary in size depending on house construction and insulation. The key to the diffusion of any innovation is the ability to reduce the associated uncertainty or risk. There are several diffusion attributes of a technology that help us identify its ability to overcome uncertainty and achieve potential adoption. The key attributes have been divided into five categories, presented below with our assessment of the status of GSHP relative to these attributes (Table 3).

APPLICATIONS FOR EARTH ENERGY

The decision to use geothermal heat pumps should be based on the results of geotechnical/ hydrogeological investigations. Sites may be encountered that are inappropriate for geothermal heat pumps. The geothermal heat-pump system is an all-electric system. A life-cycle analysis, using gas and electric rates, initial costs, maintenance costs, and replacement costs, must be conducted before selecting these systems. In locations with high electric rates and inexpensive gas, these systems may not be cost effective. The geothermal heat-pump concept is not a good candidate for buildings that are not expected to have heating loads. EE units can be used for the dehumidification of indoor swimming pool areas, where the unit can dehumidify the air and provide condensation control with a minimum of ventilation air. The heat recovered from the condensed moisture is then used for heating domestic/pool water or for space heating. EE systems are also used as heat recovery devices to recover heat from building exhaust air or from the wastewater of an industrial process. The recovered heat is then supplied at a higher temperature at which it can be more readily used for heating air or water.

HEATING AND COOLING

A GSHP extracts solar heat stored in the upper layers of the earth; the

Perceived Attribute	Description	GSHP Residential	GSHP Non-Residential
Relative advantage	The degree to which GSHP will perform better than any other space conditioning system.	Opportunity	Opportunity
Divisibility	Ability to try on a limited basis before full adoption.	Barrier	Neutral
Communicability	How well does the technology communicate benefits?	Barrier	Barrier
Compatibility	How closely does a GSHP system compare to conventional HVAC systems?	Barrier	Barrier
Complexity	How easy is it to understand both the benefits and features of the technology?	Barrier	Barrier

Table 3: Key attributes have been divided into five categories, presented with assessment of the status of GSHP relative to these attributes

heat is then delivered to a building. A re-circulating piping system connects the heat pump. The piping system adds or removes heat to the circulating water. GSHPs can reduce the energy required for space heating, cooling and service water-heating in commercial/institutional buildings by as much as 50 per cent (Figure 1). GSHPs replace the need for a boiler in winter by utilizing heat stored in the ground; this heat is upgraded by a vapour-compressor refrigeration cycle. In summer, heat from a building is rejected to the ground. This eliminates the need for a cooling tower or heat rejecter, and also lowers operating costs because the ground is cooler than the outdoor air.

RADIANT HEATING AND COOLING

There is an alternative source of heat beneath our feet. GSHPs are 380 per cent efficient, 75 per cent renewable and 100 per cent reliable. The land absorbs radiant energy from the sun, even on the darkest days (Figure 2). This is stored, every day, and all for free. Solar energy from above and geothermal heat from below maintains the subsurface UK ground temperature within a range of approximately 10^{o}C, even in winter. GSHPs tap this low-grade energy and turn it into usable heat through the simple principle of refrigeration – an idea recognised long ago.

As a guide to system sizing, the total heat transfer rate (combined radiation and convection) is about 11 W/m^{2}/^{o}C temperature difference for cooled ceilings and heated bare floors. This value drops to 6 W/m^{2}/^{o}C for heated ceilings and cooled floors. Floor coverings such as carpeting reduce the output of heated floors. Radiant systems are more energy-efficient than air-based systems. They require less parasitic energy (pump

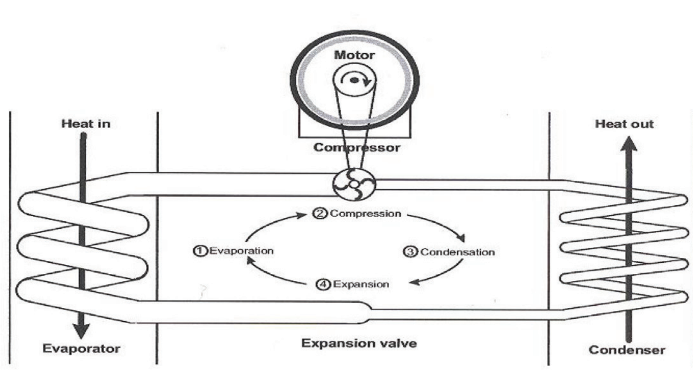

Figure 1:
Ground source heat pumps

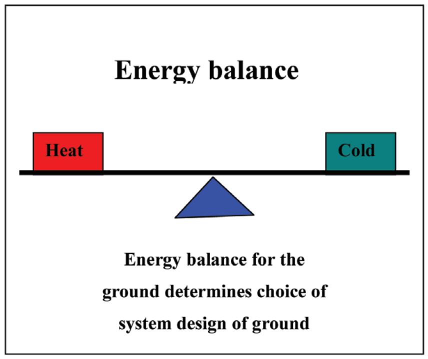

Figure 2: Energy balance for ground

and fan energy) to deliver heat. The low operating temperatures mean that boilers can operate more efficiently. Finally, because the walls are radiantly heated, the air temperature can be cooler to achieve the same level of comfort. These lower air temperatures result in lower heat losses to the outdoors (Table 4).

HEAT DISTRIBUTION SYSTEM

The heat pump works by promoting the evaporation and condensation of a refrigerant to move heat from one place to another. A heat exchanger transfers heat from the water/antifreeze mixture in the ground loop to heat and evaporate refrigerants, changing them to a gaseous state. A compressor is then used to increase the pressure and raise the temperature at which the refrigerant condenses. This temperature is increased to approximately 40^{o}C. A condenser gives up heat to a hot water tank, which then feeds the distribution system. Features include: lower utility bills, less

Design loads	Capacity (kW)	Annual energy load (MWh)
Heat load winter	410	925
Heat load summer	160	50
Cool load winter	90	190
Cool load summer	330	305

Table 4: Design load and criteria

maintenance, no visible outdoor plant, reduction in emissions, and versatility of the system.

The closed loop portion of a ground source heat pump system consists of polyethylene pipe buried in the ground and charged with a water/antifreeze solution. Thermal energy is transferred from the earth to the fluid in the pipe, and is upgraded by passing to a water source heat pump. One 100 metres vertical closed loop borehole will typically deliver 14000 KWh of useful heating energy and 11000 KWh of useful cooling energy every year for life. For typical commercial building, early trials indicate annual HVAC energy consumption in the order of 75 kWh/m^2 compared with 156 kWh/m^2 "good practice target", and 316 kWh/m^2 typical consumptions published by the Department of the Environment in Energy Consumption Guide No.19 (DOE, 1998). Low energy consumption means associated lower CO_2 emissions than from conventional systems.

Energy savings of 40 per cent compared with air source heat pumps and by over 70 per cent compared to electric resistance heating are being achieved, and CO_2 emissions are reduced to 40 kg/m^2, less than half that associated with DOE typical HVAC design (EPA, 1993). With the heat source buried in the ground, the system is both invisible and silent. There is no need for boiler, flue, cooling tower, water treatment or associated plant rooms, and the total building resource content is reduced. At a depth of 7 to 7.5 metres, the earth's temperature will be constant at a temperature equal to the average mean ambient temperature throughout the year in any location, meaning that in winter, the temperature is higher than the air temperature, and in summer, it is lower than the air temperature, thereby providing higher efficiencies in both heating and cooling modes and ensuring a lower peak load throughout the year (Figure 3).

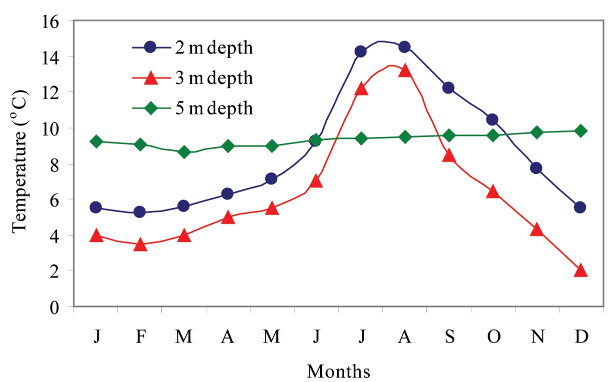

Figure 3: Ground temperatures throughout the year

This invention relates to a cooling and heating system, which operates on the absorption and phase change heat exchange principle. More particularly it relates to a continuous heat actuated, air cooled, double effect generator cycle, absorption system. In further aspects, this invention relates to a system constructed for use with an absorption refrigeration solution pair consisting of a nonvolatile absorbent and a highly volatile refrigerant, which is highly soluble in the absorbent. A disclosed refrigerant pair comprises ammonia as the refrigerant and sodium thiocyanate as the absorbent. An absorption cycle is disclosed using the thermo-physical properties of sodium thiocyanate/ammonia, absorption/refrigerant pair. Also disclosed is the construction and configuration of a reverse cycle air cooled double effect generator absorption refrigeration system for use with the sodium thiocyanate/ammonia refrigeration pair, as well as sub-compositions, subsystems and components that improve the system efficiency and reduce costs (SHTA, 1996; GEFF, 2009; Malin *et al.*, 2000).

The heat pump has operated reliably and its performance appears to be at least as good as its specification (Breembroek, 1998; Breembroek and Lazáro, 1998; Van De Venn, 1999; Sanner, 1999; Rybach and Wilhelm, 1999; Anderson, 1998; Eklöf and Gehlin, 1996). The system has a measured annual performance factor of 3.16. The occupants are pleased with the comfort levels achieved and find the system quiet and unobtrusive. The heat pump is mounted in a cupboard under the stairs and does not reduce the useful space in the house, and there are no visible signs of the installation externally (no flue, vents, etc.). The ground source heat pump system is responsible for lower CO_2 emissions than alternative heating systems (the emission figures for an all-electric system and oil- or gas-fired boilers are given in Table 4). For example, compared with a gas-condensing boiler, the heat pump system resulted in 15 per cent lower CO_2 emissions (assuming a CO_2 emission factor for electricity of 0.46 kg/kWh). When compared with a new oil-fired boiler system or an all-electric system, the emissions of CO_2 are cut by over 40 per cent and nearly 60 per cent respectively. Annual fuel costs are based on the fuel prices and are about 10 per cent higher than those for a gas condensing boiler and about 20 per cent higher than for a new regular oil boiler, but servicing costs are likely to be lower. Running costs are substantially cheaper than for an all-electric heating system. At present, suitable products are not readily available in the UK, so the heat pump had to be imported. This had some drawbacks, e.g. limited documentation in English and possible difficulty in obtaining spare parts. The controller supplied with the heat pump was not designed for use with an Economy 7-type tariff structure.

There is, however, potential to improve the operation of the system by scheduling more of the space and water heating duty during the reduced tariff period. The performance of the heat pump system could also be improved by eliminating unnecessary running of the integral distribution pump. It is estimated that reducing the running time of this pump, which currently runs virtually continuously, would increase the overall performance factor to 3.43. This would improve both the economics and the environmental performance of the system. More generally, there is still potential for improvement in the performance of heat pumps, and seasonal efficiencies for ground source heat pumps of 4.0 are already being achieved. It is also likely that unit costs will fall as production volumes increase (Sanner, 1995; Rybach and Hopkirk, 1995; Omer, 2008a; Omer, 2008b; Omer, 2008c; Omer, 2009). By comparison, there is little scope to further improve the efficiency of gas- or oil-fired boilers.

CONCLUSIONS

The installation and operation of a geothermal system may be affected by various factors. These factors include, but are not limited to, the field size, the hydrology of the site, the thermal conductivity and thermal diffusivity of the rock formation, the number of wells, the distribution pattern of the wells, the drilled depth of each well, and the building load profiles. The performance of the heat pump system could also be improved by eliminating unnecessary running of the integral distribution pump. This would improve both the economics and the environmental performance of the system. The results of soil properties investigation have also demonstrated that the moisture content of the soil has a significant effect on its thermal properties. When water replaces the air between particles it reduces the contact resistance. Consequently, the thermal conductivity varied from 0.25 W/m/K for dry soil to 2.5 W/m/K for wet soil.

However, the thermal conductivity was relatively constant above a specific moisture threshold. In fact, where the water table is high and cooling loads are moderate, the moisture content is unlikely to drop below the critical level. In Nottingham, where the present study was conducted, soils are likely to be damp for much of the time. Hence, thermal instability is unlikely to be a problem. Nevertheless, when heat is extracted, there will be a migration of moisture by diffusion towards the heat exchanger and hence the thermal conductivity will increase.

BIOGRAPHY

Abdeen Mustafa Omer (BSc, MSc, PhD) is a qualified Mechanical Engineer with a proven track record within the water industry and renewable energy technologies. He graduated from the University of El Menoufia, Egypt, with a BSc in Mechanical Engineering. His previous experience involved being a member of the research team at the National Council for Research/Energy Research Institute in Sudan and working director of research and development for National Water Equipment Manufacturing Co. Ltd., Sudan. He was listed in the WHO'S WHO in the World in 2005, 2006, 2007 and 2010. He has published over 200 papers in peer-reviewed journals, 50 review articles, 5 books and 50 chapters in books.

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