Cooling and heating with ground source energy

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Abstract

Purpose – The purpose of this paper is to describe how, in the recent attempts to stimulate alternative energy sources for heating and cooling of buildings, emphasis has been put on utilisation of the ambient energy from ground source heat pump systems (GSHPs) and other renewable energy sources.

Design/methodology/approach – Exploitation of renewable energy sources and particularly ground heat in buildings can significantly contribute towards reducing dependency on fossil fuels. This paper highlights the potential energy saving that could be achieved through use of ground energy source. It also focuses on the optimisation and improvement of the operation conditions of the heat cycles and performances of the direct expansion (DX) GSHP.

Findings – It is concluded that the direct expansion of GSHP 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 – The paper highlights the energy problem and the possible saving that can be achieved through the use of the GSHP systems and discusses the principle of the ground source energy, varieties of GSHPs, and various developments.

Keywords United Kingdom, Energy supply systems, Geothermal power, Ground source heat pump systems, Direct expansion GSHPs, Ground source, Development and evaluation of the system

Paper type Research paper

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 is the only consistent phenomenon. Geothermal renewable energy sources where 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 2,000 years ago.

Shallow geothermal resources (<400 metres depth by governmental definition in several countries) are omnipresent. Below 15-20 metres depth, everything is geothermal. Figure 1 show a summary of the soil thermal properties. The temperature difference between determine the ground temperature. The ground and the fluid in the ground heat exchanger drives the heat transfer so it is important to 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 form of heat beneath the earth surface is per 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 frequent, by artificial circulation like the borehole heat exchanger (BHE) system (Knoblich *et al.*, 1993). This means, the heat extraction occurs – in most cases – by pure conduction; there is no formation fluids required. The most popular BHE heating system with one of more boreholes typically 50-200 metres deep is a closed circuit, heat

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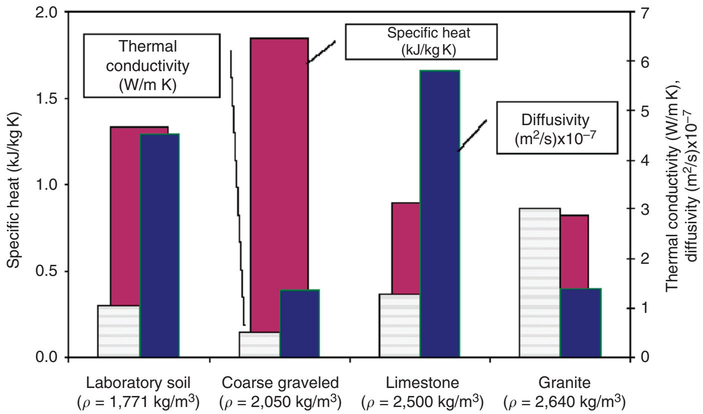
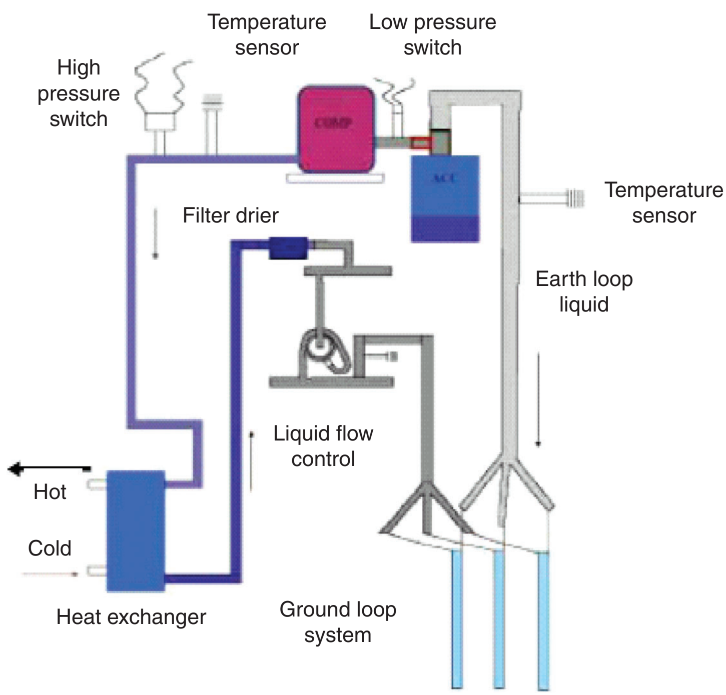


Figure 1. Measured thermal properties for different soils

pump coupled system, ideally suited to supply heat to smaller, de-central objects like single family or multifamily dwellings (Figure 2). The heat exchangers (mostly double U-tube plastic pipes in grouted boreholes) work efficiently in nearly all kinds of geologic media (except in material with low-thermal conductivity like dry sand or dry gravel). This means to tap the ground as a shallow heat source comprise:

- groundwater wells ("open" systems);
- BHEs;



Note: Typical BHE length = 100 m

Figure 2. Typical application of a borehole heat exchanger (BHE) heat pump system in a central European home

- 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 like floor panels/slab heating. They are all termed "ground-source heat pumps" (GSHPs) systems (see Appendix). 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 (National Aeronautics and Space Administration (NASA), 2009; Rybach and Eugster, 1997). While 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-metre BHE was surrounded by a total of nine monitoring boreholes at 2.5, 5, and ten-metre distance, also 50-metres deep. Temperatures in each hole and at the BHE itself were measured with 24 sensors at two metres vertical distance, resulting in a total of 240 observation locations in the underground. This layout allowed investigating the temperature distribution in the vicinity of the BHE. The influence from the surface is visible in the uppermost approximately ten metres (Figure 1), 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 campaigns is a single, coaxial, ten-metre long BHE in use since its installation in a single-family house. The BHE supplies a peak thermal power of about 70 W/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 metres, and below 15 metres, the geothermal heat flux dominates. The results show that in the near field around the BHE, the ground coils down in the first two to three years of operation. However, the temperature deficit decreases from year to year until a new stable thermal equilibrium is established between BHE and ground, at temperatures that are some 1-2 K lower than originally. Thus, a "thermal collapse" (i.e. 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. 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 is stopped, 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.

An earth energy (EE) heat pump is one of the most efficient means available to provide space heating/cooling for homes and offices (Figure 3). 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 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 EE system relies on the 51 per cent of solar energy that is absorbed by the land and water (NASA, 2009).

Terminology

Due to the large demand for EE as cooling devices, the EE 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 four-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

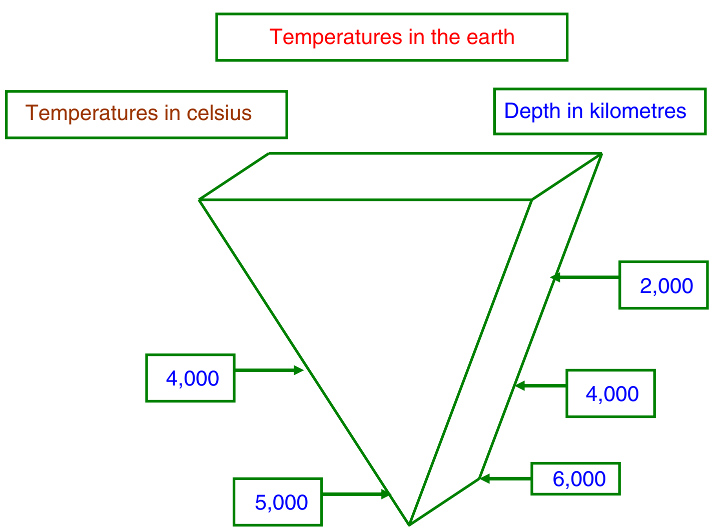


Figure 3.
Earth energy budget

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 1990s.

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 cubic feet per minute (CFM) 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 v. 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 3 kW 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.

Auxiliary heat

When the outdoor air temperature drops below the design balance point, the EE unit cannot meet the full heating demand inside the house (for units sized to 100 per cent of heat loss, this is not an issue). The difference in heat demand is provided by the supplementary or auxiliary heat source, usually an electric resistance element positioned in the unit's plenum. Like a baseboard heater, the COP of this auxiliary heater is 1.0; so excessive use of backup heat decreases the overall efficiency of the system and increases operating costs for the homeowner.

Balance point

The outdoor temperature at which an EE system can fully satisfy the indoor heating requirement is referred to as the balance point, and is usually -10°C in most regions of North Europe. At outdoor air temperatures above this balance point, the unit cycles on and off to satisfy the demand for heat indoors. At temperatures below this point, the unit runs almost continuously, and also turns on the auxiliary heater (called second stage heat) to meet the demand.

Heat transfer fluids

Closed-loop units can circulate any approved fluid inside the pipe, depending on the performance characteristics desired. Each manufacturer must specify which fluids are acceptable to any particular unit, with the most common being denatured ethanol or methanol (the latter is not approved for use).

Loop depth

EE technology relies on stable underground (or underwater) temperature to function efficiently. In most cases, the deeper the loop is buried, the more efficient it will be.

A vertical borehole is the most efficient configuration, but this type of digging can be very expensive.

Loop length

The longer the amount of piping used in an outdoor loop, the more heat that can be extracted from the ground (or water) for transfer to the house. Installing fewer loops than specified by the manufacturer will result in lower indoor temperature, and more strain on the system as it operates longer to compensate for the demand. However, excessive piping can also create a different set of problems, as well as additional cost. Each manufacturer provides specifications for the amount of pipe required. As a broad rule of thumb, an EE system requires 400 feet of horizontal loop or 300 feet of vertical loop to provide heat for each ton of unit size.

Loop spacing

The greater the distance between buried loops, the higher the efficiency. Industry guidelines suggest that there should be three metres (ten feet) between sections of buried loop, in order to allow the pipe to collect heat from the surrounding earth without interference from the neighbouring loop. This spacing can be reduced under certain conditions.

Loop configuration

Closed loops generally are installed either in a vertical or in a horizontal configuration, depending on the land available and a number of other factors. EE ground pipe comes in two common diameters: 0.75 and 1.25 inches. Two coiled loops (commonly called the Svec Spiral and the Slinky) require less trenching than conventional straight pipe. As a result, the lower trenching costs and the savings in property disruption offset the higher cost of the coiled pipe.

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, which 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 transferring heat to about 53°C.

Because heat pumps do not produce very high temperatures, they work best when heating well-insulated houses, which are designed to be heated by low-temperature systems. Traditional radiators, which are oversized, will give a larger area to dissipate heat and so work at lower surface temperatures. Under floor water-based heating systems are ideal as they work on the radiant heating principle which creates a comfortable environment at a lower temperature.

The heating loads for a house will vary considerable over the year. At the coldest time of the year, the energy requirements will be greatest. If the design to these levels of maximum load, the heat pumps size can get very big, and as a result costly. It is thought best to design the heat pumps to only cover about 50-70 per cent of the annual heating demand, and where demand peaks over a smaller period, to provide supplementary direct electrical heating (or alternatives) to meet this demand.

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 I 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.

Water discharge quality

There are environmental regulations, which 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 nation 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

Table I.
Surface area requirements GSHP

Design	Horizontal (square metres)	Vertical (square metres)
Two pipes per trench	2,000	3,500
Four pipes per trench	1,400	2,400
Six pipes per trench	1,400	2,400

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 (WSHPs) only in the following areas:

(1) GSHPs operate over a very wide range of entering water temperatures from source (ground), typically, 20-110°F, whereas the conventional WSHP operates over a very narrow range (60-90°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 II 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 GSHPs, 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.

Selection and pre-installation considerations

The 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

Table II. Entering liquid temperatures for different system types

Horizontal design	Heating (°F)	Cooling (°F)
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

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 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.

Heat pump accessories and controls

Considerations for heat pump:

- Heat pumps, whether water or ground source, should not be used to handle large outdoor air loads. These outdoor air loads should be handled through separate A/C units, preferably with heat-recovery capabilities and conditioned outdoor air ducted to each heat pump.
- Heat pump sizing is very critical. It does not need to oversize heat pumps. In general, size at no <95 per cent for adequate latent-heat capacity. Do not size >125 per cent of the zone peak sensible-cooling load unless the heat pump has multi-speed fan/compressor and automatic means of adjusting flow.
- Pay special attention to the specifications for the on/off automatic valve in the source water-supply connection to the heat pump, which is interlocked with the compressor to permit compressor operation only after it is fully open. Though seemingly a small component in the overall system, this is prone to frequent failures if it is not of good quality. Its failure will lead to expensive compressor failures.
- Heat pump schedules must include the minimum acceptable COP for heating performance and energy efficiency ratio (EER) for the cooling performance to take advantage of the most efficient heat pumps available on the market.

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.

The temperature of the earth under two metres of the surface is a fairly constant 10°C throughout the year. At a depth of about a 100 metres, the temperature of any water or rock is at about 12°C throughout the year. The heat stored at this depth comes largely from the sun, the earth acting as a large solar collector. For very deep wells, in excess of about 170 metres, there is an added component of heat from the core of the earth. As an approximation, one can add 3°C of heat gain for every 100 metres of depth drilled into the earth.

A closed loop system takes the heat gained from the bedrock itself. In a vertical system a borehole of a diameter of about 150 mm is drilled, depth varies between 32 and 180 metres but will depend on the energy requirements. Multiple boreholes can be drilled. A pair of pipes with a special U-bend assembly at the bottom is inserted into the borehole and the void between pipe and hole backfilled with a special grout solution so that the pipe is in close contact with the rock strata or earth. Fluid (referred to as "brine") is then circulated through this loop and is heated up by the bedrock. Different rock types will give different results. In some cases a number of boreholes will be made (e.g. over a car park) to provide sufficient energy for the heat pump supply. If the ground is not suitable, horizontal loops can be laid or even trench filled "slinky" loops, which are very simple to install. However, trench filled systems and horizontal systems require much more ground than vertical systems. If one has a pond or lake nearby then can lay a closed loop at the base of the pond (it needs to be about two metres deep), or simply extract the water directly out of the lake at low level and re-distribute it elsewhere in the lake.

Heat pumps can be cheaper to operate than other heating systems because, by tapping into free heat in the outdoor air, ground, or water supply, they give back more energy – in the form of heat – than the equivalent amount of electrical energy they consume. For example, in heating mode, a highly efficient heat pump could extract energy from the earth and transfer it into a building. For every 1 kWh of electrical energy used to drive the heat pump, around 3-4 kWh of thermal energy will be produced. In cooling mode, the heat pump works in reverse and heat can be extracted from a building and dissipated into the earth. Heat pumps which work in a heating mode are given a "COP" calculated by dividing the input kWh into the output kWh. This will give a COP figure, which varies with the input temperature and is the ratio of energy in to energy out. In cooling mode, the ratio is called the "EER". The higher the EER and COP ratios, the more efficient the unit. Geothermal/GSHPs are self-contained systems. The heat pump unit is housed entirely within the building and connected to the outside-buried ground loop.

Thermal storage

If the use off-peak electricity and want to ensure the even distribution of hot water, 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 uncertainty or risk associated with the innovation. There are several diffusion attributes of a technology that help us identify the technology's ability to overcome uncertainty and achieve potential adoption. The key attributes have been divided into five categories, presented in Table III with our assessment of the status of GSHP relative to these attributes.

Applications for EE

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. These systems may not be cost effective in locations with high-electric rates and inexpensive gas. 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.

Efficient heating performance makes EE a good choice for the heating and cooling of commercial and institutional buildings, such as offices, stores, hospitals, hotels, apartment buildings, schools, restaurants, and penitentiaries. EE systems can heat water or heat/cool the interior space by transferring heat from the ground outside, but they can also transfer heat within buildings with a heat-producing central core. The technology can move heat from the core to perimeter zones where it is required, thereby simultaneously cooling the core and heating the perimeter.

Heating and cooling

A GSHP extracts solar heat stored in the upper layers of the earth; the 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 4). GSHPs replace the need for

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

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

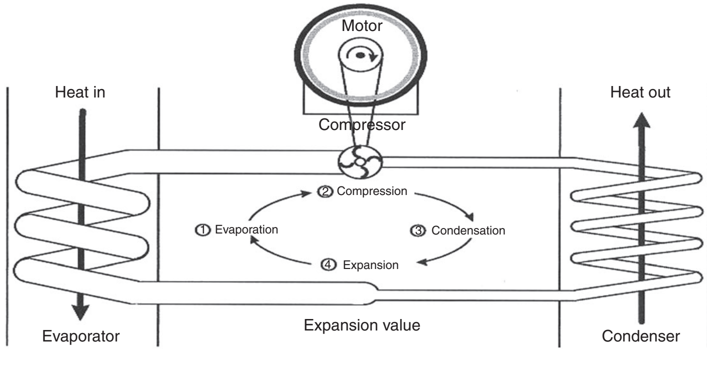


Figure 4. Ground source heat pumps

a boiler in winter by utilising 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.

Water-to-air heat pumps are typically installed throughout a building with ductwork serving only the immediate zone; a two-pipe water distribution system conveys water to and from the ground-source heat exchanger. The heat exchanger field consists of a grid of vertical boreholes with plastic U-tube heat exchangers connected in parallel. Simultaneous heating and cooling can occur throughout the building, as individual heat pumps, controlled by zone thermostats, can operate in heating or cooling mode as required. Unlike conventional boiler/cooling tower type WLHPs, the heat pumps used in GSHP applications are generally designed to operate at lower inlet water temperature. GSHP are also more efficient than conventional heat pumps, with higher COPs and EERs. Because there are lower water temperatures in the two-pipe loop, piping needs to be insulated to prevent sweating; in addition, a larger circulation pump is needed because the units are slightly larger in the perimeter zones requiring larger flows. GSHPs reduce energy use and hence atmospheric emissions. Conventional boilers and their associated emissions are eliminated, since no supplementary form of energy is usually required. Typically, single packaged heat pump units have no field refrigerant connections and thus have significantly lower refrigerant leakage compared to central chiller systems. GSHP units have life spans of 20 years or more. The two-pipe water-loop system typically used allows for unit placement changes to accommodate new tenants or changes in building use. The plastic piping used in the heat exchanger should last as long as the building itself. When the system is disassembled, attention must be given to the removal and recycling of the HCFC or HFC refrigerants used in the heat pumps themselves and the antifreeze solution typically used in the ground heat exchanger.

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 sun, even on the darkest days (Figure 5). 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°C – even in winter. GSHPs tap this low-grade energy and turn it into usable heat through the simple principle refrigeration – an idea recognised as long ago.

Conventional radiators have been used for many years to heat buildings. The radiators are located around the building perimeter. Because of the small surface area of the radiators, they must be operated at a high temperature to deliver sufficient heat. Modern systems are different in that they cover a large area of floor or ceiling and

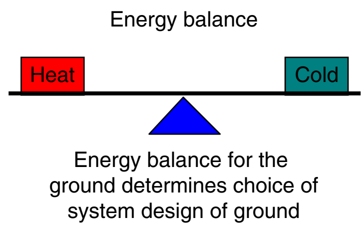


Figure 5.
Energy balance for ground

operate at temperatures much closer to room air temperature, approximately 15°C in cooling mode and 35-50°C in heating mode. The system cannot be operated at lower temperatures in cooling mode without the risk of condensation (Figure 6). The small temperature difference means that about 30-50 per cent of the ceiling or almost the entire floor area must be available as heat transfer surface. Ventilation air is provided by a small-dedicated ductwork system and works particularly well with displacement ventilation concepts. Several companies have developed metal radiant panels that can be ceiling mounted, either attached directly to the ceiling or as part of a T-bar suspended ceiling. For floor systems, flexible plastic piping is embedded in the concrete floor or in gypsum topping on a wooden sub-floor. Ceiling mounted systems are usually best for combined heating and cooling systems. Floor systems are best for heating-only systems (provided the floor is not covered with heavy carpets). The amount of heat transfer depends on the direction of heat flow. Air in contact with a cooled ceiling panel will naturally fall as it is cooled increasing the movement of air over the panel. Conversely, air in contact with a warm ceiling will stratify at the ceiling and have low convective heat transfer. As a guide to system sizing, the total heat transfer rate (combined radiation and convection) is about 11 $W/m^2/°C$ temperature difference for cooled ceilings and heated bare floors. This value drops to 6 $W/m^2/°C$ 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 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 IV).

Heat distribution system

The heat pump works by promoting the evaporation and condensation of a refrigerant to move heat from one place to another (Figure 6). 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

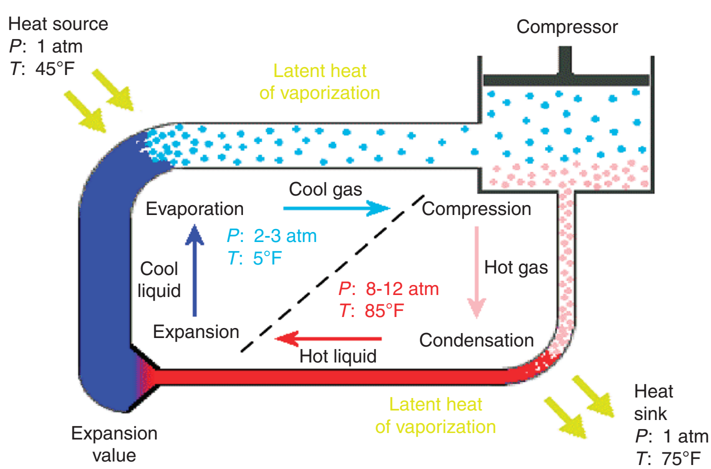


Figure 6.
Heat pump works by promoting the evaporation and condensation of a refrigerant

the pressure and raise the temperature at which the refrigerant condenses. This temperature is increased to approximately 40°C. A condenser gives up heat to a hot water tank, which then feeds the distribution system. Features include: lower utility bills, less maintenance, no visible outdoor plant, reduction in emissions, and versatility of system.

Because GSHPs raise the temperature to approximately 40°C they are most suitable for under floor heating systems, which require temperatures of 30-35°C, as opposed to conventional boiler systems, which require higher temperatures of 60-80°C. GSHPs can also be combined with radiator space heating systems and with domestic hot water systems. However, top-up heating would be required in both cases in order to achieve temperatures high enough for these systems. Some systems can also be used for cooling in the summer. Geothermal heat pumps are the most energy efficient, environmentally clean, and cost effective space conditioning systems available according to the Environmental Protection Agency in the USA. Ground source geothermal heating and cooling is a renewable resource, using the earth's energy storage capability. The earth absorbs 47 per cent of the suns energy amounting to 500 times more energy than mankind needs every year.

The closed loop portion of a GSHP 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 WSHP. One 100 metres vertical closed loop borehole will typically deliver 14,000 kWh of useful heating energy and 11,000 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 (Environmental Protection Agency (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 7-7.5 metres the earths temperature will be constant at a temperature equal to the average mean ambient temperature throughout the year in any location meaning temperature in winter higher than the air temperature, and in summer lower than air temperature thereby providing higher efficiencies in both heating and cooling modes and ensuring a lower peak load throughout the year (Figure 7).

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 IV.
Design load and criteria

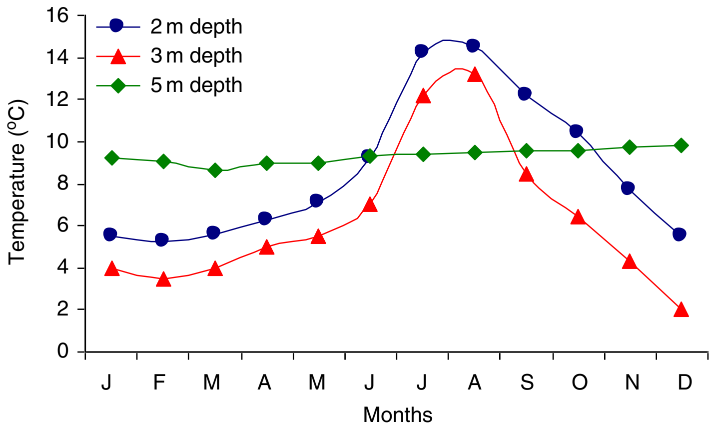


Figure 7.
Ground temperatures throughout the year

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 is ammonia as the refrigerant and sodium thiocyanate as the absorbent. An absorption cycle is disclosed using the thermophysical 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, sub-systems and components that improve the system efficiency and reduce cost (E Source Inc, 1996; GeoExchange in Federal Facilities (GEFF), 2009; Malin and Alex, 2000).

There is unlikely to be a potentially larger mitigating effect on greenhouse gas emissions and the resulting global warming impact of buildings from any other current, market available single technology, than from GSHPs. Over its first year of operation, the GSHP system has provided 91.7 per cent of the total heating requirement of the building and 55.3 per cent of the domestic water-heating requirement, although only sized to meet half the design heating load. 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 GSHP 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 IV). 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, 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 GSHPs 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-c, 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.

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Nomenclature

ACH	Air changes per hour
GSHP	Ground source heat pump
HRV	Heat recovery ventilator
DC	Direct current
HSPF	Heating season performance factor
SEER	Seasonal energy efficiency ratio
Btu	British thermal unit
EER	Energy efficiency rating
DX	Direct expansion
GS	Ground source
EPA	Environmental Protection Agency
HVAC	Heating, ventilating and air conditioning
DETR	Department of the Environment Transport and the Regions
DTI	Department of Trade and Industry
AFUE	Annual fuel utilisation efficiency rating
ARI	The Air-Conditioning and Refrigeration Institute
COP	Coefficient of performance (%)
GHP	Geothermal heat pump
GL	Ground loop
GSHP	Ground source heat pump
HP	Heat pump
N	Air change per hour (ACH) (h^{-1})
P	Pressure (Pa) (kPa)
Q	Heat (thermal energy) (J)
Q_c	Capacity (thermal power) (W)

About the author

Abdeen Mustafa Omer is an Associate Researcher at the Energy Research Institute (ERI), University of Nottingham, UK. He obtained his PhD degree in the Built Environment and his

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