

Ground Source Heat Pump Design for Under Floor Heating System

***, ***83

November 29, 2021

1. Introduction

There are moves to displace fossil fuels from home heating and to replace it with a heating system based on sustainable energy. The driver for the move away from the use of fossil fuels is to reduce the CO₂ emissions to the atmosphere, which is a major cause of global warming. There are several sustainable energy sources that can be used to heat a home, such as: Solar panels, air source heat pumps, water source heat pumps and ground source heat pumps (GSHP).

The purpose of this report is to design a closed loop vertical GSHP system and to estimate its installed cost compared to an equivalent gas-fired central heating system. This report focuses only on space heating using an underfloor heating system.

2. Systems Description

The system description below is to be read in conjunction with the process schematic diagram in figure 1. A GSHP can provide heat to a house by collecting a significant amount of low-grade geothermal energy from the ground that is absorbed into borehole water circulating through pipes buried in the ground. A GSHP water system is divided to three cycles and each cycle is described below.

Borehole water cycle

The borehole water is pumped through the evaporator, where a small amount of heat (3°C temperature difference) is used to heat up and vapourised the refrigerant resulting in the borehole water temperature leaving the evaporator approximately three degrees cooler. The water is circulated to 15 - 150m deep boreholes to collect geothermal energy that has a constant ground temperature of 10°C. The borehole water from the ground is used to heat and vapourise the refrigerant in the evaporator. The return water temperature to the borehole is 7°C. A proportion of 25% Ethylene Glycol is to be added to the borehole water, which acts as antifreeze, to ensure the water in the pipes from and to the boreholes do not freeze in winter season or during upset condition when the borehole water cycle stops, and the refrigerant cycle keeps running (for evaporation temperature 0°C or less). The warmer the water, the more heat can be transferred to the house by the heat pump, therefore the pipes should be insulated to reduce heat loss. The borehole water system is a closed water system. Prior to starting-up the borehole water loop is to be pressurised between 2.75-3.5 bar and requires periodic top up to allow for any small losses that accumulate over a period (GSHPA, 2011). The borehole pipe size and length will depend on the amount of circulated water (evaporator capacity).

Refrigerant cycle

The heat source for heating the domestic water is the compressor. The compressor takes refrigerant gas from the evaporator, with a minimum of 5°C superheat, and compresses the gas. The compressed gas, leaving the compressor, has a maximum temperature in the region of 70°C to 85°C if using refrigerant R410a, R134a, R32, R1234yf (Araner, 2021). Refrigerant 134a is used in this design exercise. The hot refrigerant gas flows to the condenser where the heat is transferred counter currently through a plate exchanger to the domestic water flowing in under floor heating pipes. In the condenser, the refrigerant gas is cooled to its dew point, with at least several degrees of sub-cooling. The liquefied refrigerant from the condenser then flows via a Pressure Control Valve (PCV), where the pressure is dropped and the 2-phase fluid flows to an evaporator. The two-phase refrigerant is then vapourised in the evaporator by the borehole water and adds superheat before the gas flows to the compressor to ensure no liquid carry over to the compressor to prevent compressor damage.

Domestic water cycle

The heated domestic water from the condenser is distributed by a pump through the underfloor heating coils which heats the house. The maximum recommended water temperature leaving the condenser is 40°C for underfloor heating to avoid damage to the flooring. The cooled water is circulated back to the condenser to be heated. The capacity of the GSHP is based on heat loss from the house during minimum ambient conditions of -4°C and the design temperature of indoor comfort in the house is 25°C (Hawkins, 2011).

Process Schematic Diagram

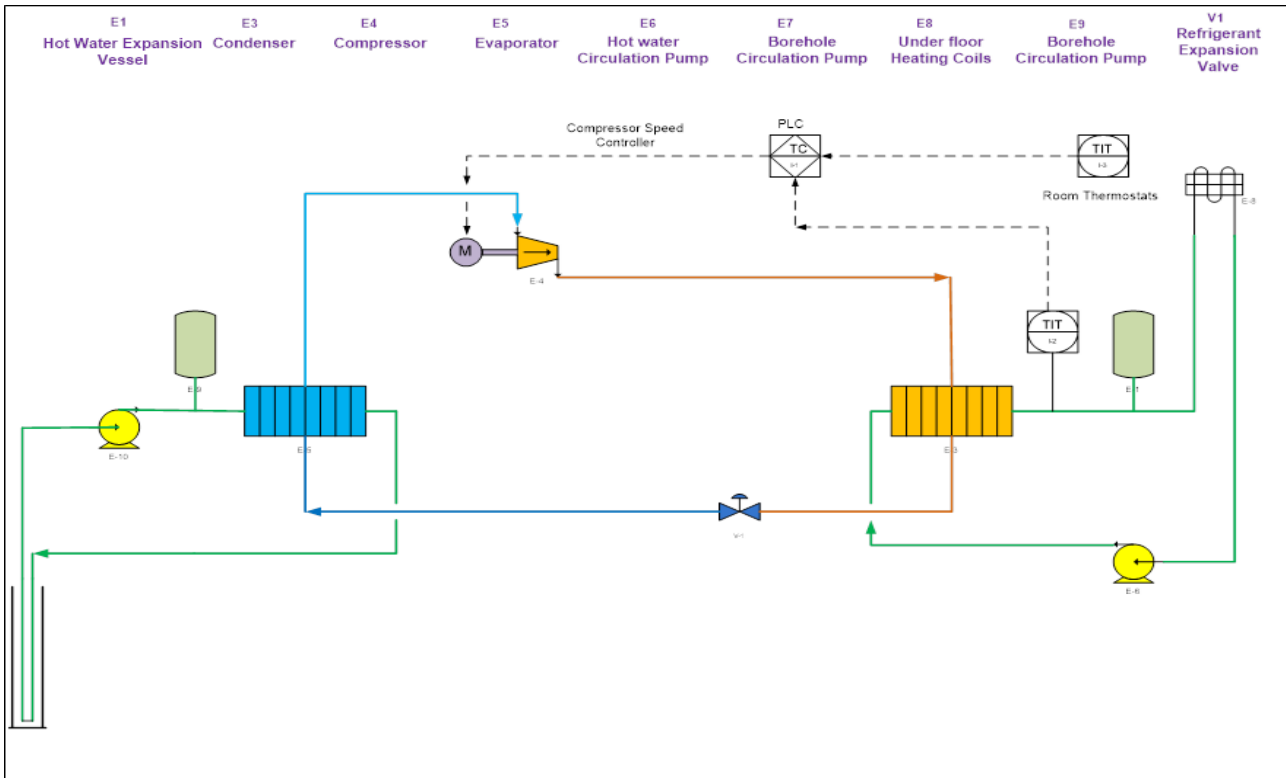


Figure 1. Simplified Process Schematic Diagram

3. Methodology

The methodology used to design the GSHP system in this report is described below.

1. Calculate the total design heat loss which was made up of heat loss from the house to the environment plus 0.35 air changes per hour (ASHRAE, 2021) during minimum ambient conditions of -4°C with the design temperature of indoor comfort in the house of 25°C (Hawkins, 2011). The total design heat loss calculated is the condenser capacity.
2. Select a refrigerant type. There are refrigerants that are environment friendly. However, for the purpose of this task, refrigerant R134a is selected.
3. Determine the evaporation temperature of the refrigerant to get the corresponding pressure for the compressor suction. The evaporation temperature selected was limited to firstly, the maximum borehole water inlet temperature to the evaporator which is 10°C ; secondly, the temperature approach in the evaporator plate heat exchanger ($4\text{--}5^{\circ}\text{C}$) and thirdly, 5°C superheat added to the refrigerant gas before entering the compressor. Standard MIS 3005, 2011 also stated that the “temperature of the thermal transfer fluid entering the heat pump shall be designed to be $>0^{\circ}\text{C}$ at all times for 20 years”. Therefore, the selected evaporation temperature was 1°C and the corresponding pressure was 303.7 kPa (The Chemours Company LC, 2018).
4. Determine the condensation temperature of the refrigerant to get the corresponding pressure from the refrigerant property table (The Chemours Company LC, 2018) and use the pressure as the compressor operating discharge pressure. The selection of condensation temperature was based on the required temperature for domestic water. The refrigerant condensation temperature should be between $50\text{--}60^{\circ}\text{C}$ to get gas temperature leaving the compressor to the condenser between $70\text{--}80^{\circ}\text{C}$ for hot water used for shower, washer and space heating using radiators. Since this design focuses only on space heating using underfloor heating, and there is a limitation of the maximum water temperature circulated through the underfloor coils, the condensation temperature was reduced and optimised to 40°C . As a result, the compressor power consumption was less, and the COP increased. The selected condensation temperature was 40°C resulting in 58°C refrigerant gas temperature leaving compressor to the condenser. The temperature of 58°C is high enough to heat the domestic water to 40°C which is the maximum recommended for underfloor heating to avoid

damage to the flooring (UFH1 Underfloorheating, 2021). It also gives a sufficient temperature approach in the condenser plate heat exchanger. The refrigerant was cooled in the condenser with a 5°C subcooling before entering the expansion valve. For the selected refrigerant condensation temperature of 40°C, the corresponding pressure was 1017.61 kPa (The Chemours Company LC, 2018).

5. Using the result from step 1, the domestic water and the refrigerant required flowrates were calculated.
6. Using the results from step 5, and the enthalpy data from the refrigerant property table, the capacity of the evaporator and the compressor power consumption were calculated.
7. Using the results from step 1 and step 6, the coefficient of performance of the GSHP system was then calculated which is Q_c/W_{in} , where Q_c is useful heat liberated by the condenser and W_{in} is the compressor power.
8. Using the result from step 5, the domestic water pump was sized to provide 6 m head which was estimated based on the height between the floors which is 2.3 m, plus friction loss. The under-floor heating pipe was sized to ensure that the water flow in the pipes is turbulent (Reynold number > 2500) to get a better heat release to the house.
9. Using the evaporator capacity calculated in step 6, calculate the borehole water requirement.
10. Using the formula from MIS 3005, 2011, calculate the required borehole pipe length.

$L_b = G/g$, where:

L_b = the vertical borehole pipe length, m

G = Heat Pump evaporator capacity, kW

g = the specific heat power extraction from the ground (in W/m)

g value was taken from MCS 022, 2011 Ground Heat Exchanger Look-up Tables using 1800 FLEQ run hours for space heating. The minimum length of ground heat exchanger pipe in the active elements, L_p (in m), is determined according to the formula in MIS 3005, 2011 i.e.,

$L_p = L_b \times R_{pt}$, where R_{pt} is 2 for boreholes.

The depth and the number of boreholes could then be estimated.

11. The Hysys simulation was used to model the GSHP system for a comparison with the manual calculations performed. The Hysys process flow diagram is presented in Figure 7.
12. Using the data gathered in section 8.0, an economic analysis was undertaken.

4. Basis of Design

House

- The residence is a three-bedroom detached house in London with a small garden that has insufficient area for a horizontal trench system. It is well insulated, with two levels and a footprint of 8m x 10m with each ceiling level of 2.3m. The roof is 2m high at the apex. A sketch of the house is provided below:

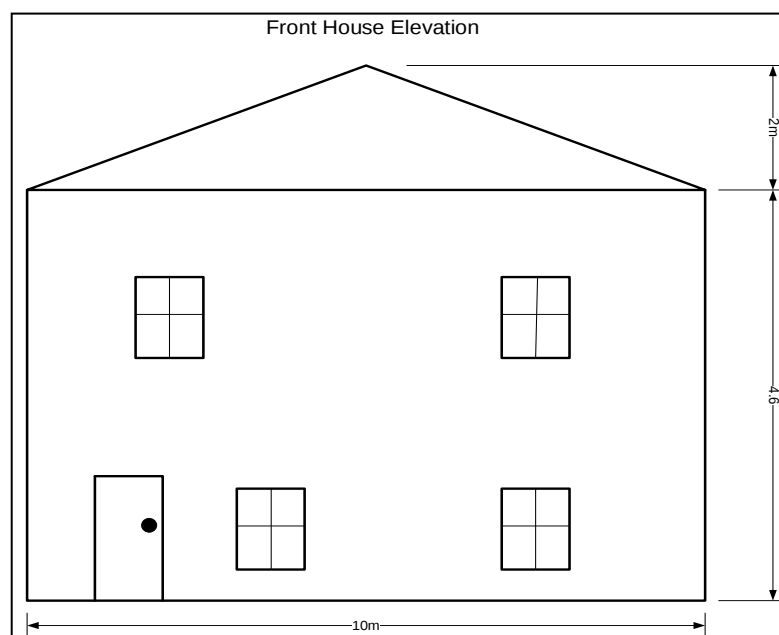


Figure 2. House front view

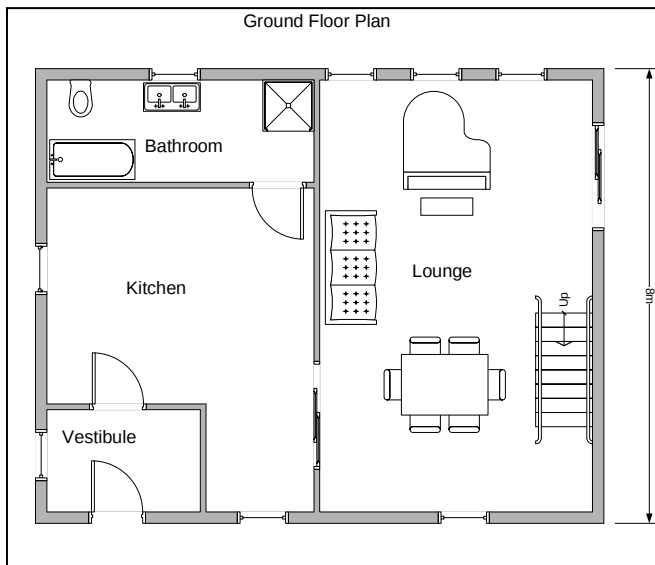


Figure 3a. Ground Floor Plan

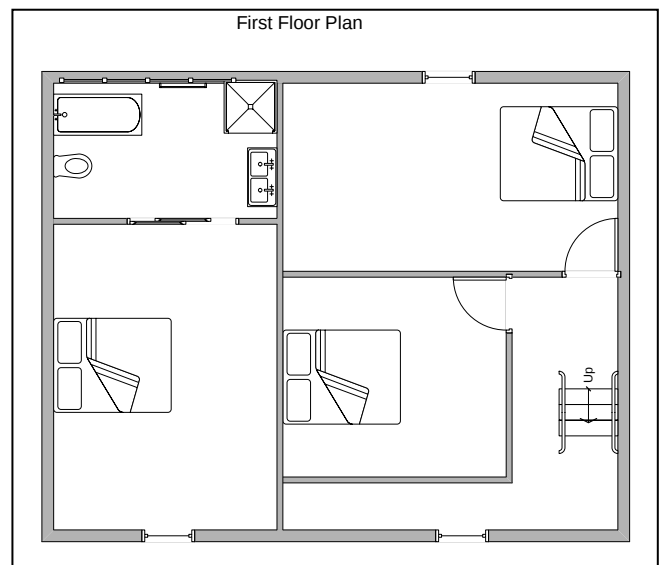


Figure 3b. First Floor Plan

- **Insulation**

It is assumed that the house is provided with double glazing and all potential areas of heat loss are heavily insulated. This includes all walls, loft, and floors below the underfloor heating. The exterior walls are a combination of double brick with 100mm phenolic foam insulation in the cavity. The loft is insulated with 100mm of fibre insulation. The floor is insulated with 50mm of polyurethane insulation. It is assumed that the exterior walls are 20% double glazed windows and the overall heat transfer coefficient for the roof and ground floor that are sufficiently insulated to have the same U value as the walls i.e., $0.343 \text{ W/m}^2\text{K}$ (Combustion Research Cooperation, 2021). The U value of the double-glazed windows is $0.7 \text{ W/m}^2\text{K}$ (Combustion Research Cooperation, 2021).

GSHE

- A closed loop vertical heat exchanger.
- 130mm borehole diameter; single U-tube; 32mm OD SDR-11, PE100 pipe with thermal conductivity = 0.420 W/m/K ; 52mm pipe centre-pipe centre shank spacing; 25% Mono Ethylene Glycol thermal transfer fluid; $Re > 2500$ in the borehole active elements; thermally enhanced grout with thermal conductivity = 2.4 W/m/K Assumptions result in borehole thermal resistance = 0.1 m.K/W at 10°C mean ground temp. and 2.5 W/m/K average ground thermal conductivity (MCS 022, 2008).
- The borehole water temperature to the evaporator is 10°C and leaving the borehole at a temperature of 7°C .
- The borehole pipes on the surface to and from the house are to be insulated to reduce the heat loss.
- Vertical borehole heat exchanger with pipe diameters 20mm and larger shall have a minimum pressure rating of 16 bar (GSHPA, 2011).

GSHP

- Refrigerant used is R134A.
- The selected evaporation temperature (T_e) is 1°C and the selected condensation temperature (T_c) is 40°C .
- The refrigerant gas enters the compressor with a 5°C superheat.
- The refrigerant liquid leaves the condenser with a 5°C subcooling.

Underfloor heating

- The target room temperature in all rooms is 25°C (Hawkins, 2011).
- The minimum ambient air temperature is -4°C (Hawkins, 2011).
- The maximum water temperature circulated to the underfloor heating pipes is 40°C to prevent damaging the floor (UFH1 Underfloorheating, 2021).
- The return water to the condenser is 28°C .

5. Calculations

Heat Loss Calculations

The total design heat loss is based on a minimum ambient condition of -4°C and the design temperature of indoor comfort in the house of 25°C (Hawkins, 2011) plus 0.35 air changes per hour (ASHRAE, 2021).

	U, W/m ² .K	A, m ²	dT, °C	Q, W
Front walls	0.343	0.8 x (2 x 10 x 4.6)	29	732.1
Side walls	0.343	0.8 x (2 x 8 x 4.6)	29	585.7
Windows	0.7	(2 x (8 + 10) x 4.6)	29	672.3
Floors	0.343	(2 x 10 x 8)	29	1591.5
Roof	0.343	[(2 x 5 x 2) + (2 x 8 x 5.3830)]	29	1055.7
Heat Loss - 1				4637.3
Air volume in the house, m ³	10 x 4.6 x 8 = 368			
Average air density @8C, kJ/ kg	1			
Calculated mass of air, kg	456.32			
Air changes per hour	0.35			
Heat Loss - 2	1286.6 W			
Total heat loss + 10%	6.5 kW (6.5 kJ/s).			

Table 1 - Heat Loss Calculation

Condenser Heat and Mass Balance

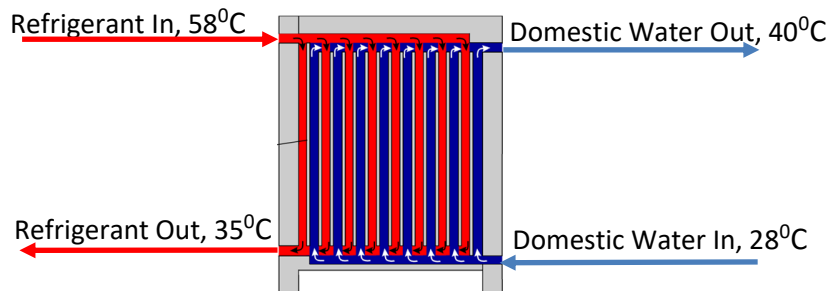


Figure 4 - Condenser

Domestic water circulation rate calculation

$$Q = m \times C_p \times \delta T. \text{ Heat capacity of water at } 34^\circ\text{C average temperature is } 4.18 \text{ kJ/kg.K}$$

$$6.5 \text{ kJ/s} = m \times 4.18 \text{ kJ/kg.K} \times (40-28)^\circ\text{K}$$

$$m = 0.13 \text{ kg/s}$$

Refrigerant circulation rate calculation

$$Q = m (h_2 - h_1) = 6.5 \text{ kJ/s}$$

$$h_2 = \text{Enthalpy at inlet condenser @1017.61 kPa, } 58^\circ\text{C}$$

$$= 440 \text{ kJ/kg (The Chemours Company LC, 2018).}$$

$$h_1 = \text{Enthalpy at outlet condenser @1017.61, } 35^\circ\text{C}$$

$$= 248 \text{ kJ/kg (The Chemours Company LC, 2018).}$$

$$m = 0.034 \text{ kg/s}$$

Under Floor Heating pipe sizing

The flow in the pipes should be relatively slow but still in the turbulent region. Choosing a line velocity of 0.5 m/s, the pipe size would be:

$$A = Q/V$$

$$= (0.11 \text{ kg/s} / 1000 \text{ kg/m}^3) / (0.5 \text{ m/s})$$

$$= 2.2 \times 10^{-4} \text{ m}^2, \text{ which gives a pipe diameter of } 16.7 \text{ mm.}$$

Check for turbulence:

$$Re = \rho \times V \times D / \mu$$

$$= 1000 \times 0.5 \times 0.016 / 0.001$$

$$= 8,000. \text{ The flow is turbulent}$$

Piping of 16 mm N.B. would be used.



Figure 5 – Under Floor Heating

Evaporator Heat and Mass balance

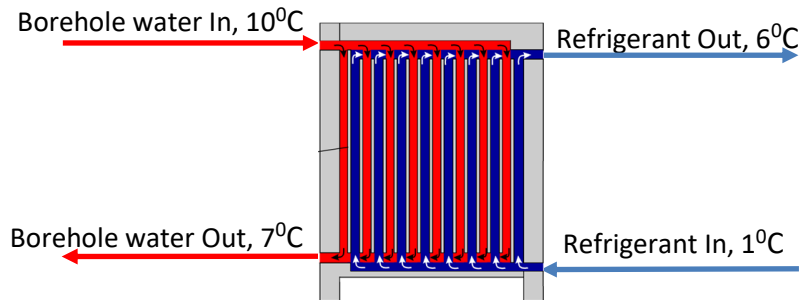


Figure 6 - Evaporator

Based on Standard MIS 3005, 2008, the maximum power extracted from the ground (i.e., the heat pump evaporator capacity) is

$$\begin{aligned} G &= \text{Heat Pump capacity} \times 1000 \times (1 - (1/7)) \text{ for electrical} \\ &= 6.5 \times (1 - (1/7)) \\ &= 5.57 \text{ kW} \end{aligned}$$

Evaporator capacity calculation

$$\begin{aligned} Q &= m \times (h_2 - h_1) \\ h_2 &= \text{Enthalpy at inlet evaporator @303.7 kPa, 1°C} \\ &= 248 \text{ kJ/kg (The Chemours Company LC, 2019).} \\ h_1 &= \text{Enthalpy at outlet evaporator @303.7 kPa, 6°C} \\ &= 403.4 \text{ kJ/kg (The Chemours Company LC, 2019).} \\ m &= 0.034 \text{ kg/s} \end{aligned}$$

$$\begin{aligned} Q &= 0.034 \text{ kg/s} \times (403.4 - 248) \text{ kJ/kg} \\ &= 5.28 \text{ kW which is aligned with the standard, i.e., less than 5.57 kW.} \end{aligned}$$

Borehole water flow rate calculation

For a heat exchange of 5.28kW and a water temperature delta of 3°C, the mass flowrate of the borehole water is:

$$\begin{aligned} m &= Q / (C_p \times \Delta T) \\ &= 5.28 / (4.319 \times 3) \\ &= 0.41 \text{ kg/s} \end{aligned}$$

Borehole HE length calculation

$$L_b = G/g$$

Where:

$$\begin{aligned} L_b &= \text{the vertical borehole pipe length, m} \\ G &= \text{Heat Pump evaporator capacity, kW} \\ g &= \text{the specific heat power extraction from the ground (in W/m)} \\ &= 39 \text{ W, for 1800 FLEQ run hours (MCS 022, 2008)} \\ L_b &= 5280/39 = 135 \text{ m} \end{aligned}$$

The estimated number of boreholes is two, each at 70 meters deep.

The minimum length of ground heat exchanger pipe in the active elements, L_p (in m), is determined according to the formula (MIS 3005, 2011):

$$\begin{aligned} L_p &= L_b \times R_{pt}; \text{ where } R_{pt} \text{ is 2 for boreholes.} \\ &= 135 \times 2 \\ &= 270 \text{ m} \end{aligned}$$

Borehole water pump power assessment

The borehole pump power requirement should be < 2.5% of the heat pump thermal output (MIS 3005, 2011). The maximum required pump power is $2.5\% \times 6.5 \text{ kW} = 0.1625 \text{ kW}$.

Domestic water pump power assessment

$$P_{s(kW)} = m \times g \times h / (3.6 \times 10^6 \times \eta)$$

Where;

$P_{s(kW)}$ = shaft power (kW)

m = mass flow (kg/h), 0.13 kg/s = 468 kg/h

g = [acceleration of gravity](#) (9.81 m/s²)

h = differential head (m), 6 m

η = pump efficiency, 0.75

$$P_{s(kW)} = 0.01 \text{ kW}$$

Refrigerant Compressor Power Assessment

$$\text{Compressor power consumption} = m \times (h_2 - h_1) / \eta$$

Where:

m = refrigerant mass flowrate in kg/s = 0.034 kg/s

h_2 = Enthalpy at inlet condenser @1017.61 kPa, 58°C
= 440 kJ/kg (The Chemours Company LC, 2018).

h_1 = Enthalpy at outlet evaporator @303.7 kPa, 6°C
= 403.4 kJ/kg (The Chemours Company LC, 2018).

Adiabatic efficiency, η = 0.75

$$\text{Compressor power} = 1.24 \text{ kW}$$

Coefficient of performance (COP) calculations

$$\text{COP} = Q_c / W_{in}$$

Where,

COP = Coefficient of Performance

Q_c = Useful heat liberated by the condenser

W_{in} = Compressor power

$$\text{COP} = 6.5 / 1.24 = 5.24$$

6. Results

The summary of the results from the calculations in section 5 is tabulated in Table 2 below.

Description	Results
Total heat loss from the house to the environment	6.5 kW
Condenser capacity	6.5 kW
Domestic water flowrate	0.13 kg/s
UFH pipe diameter	16 mm
UFH pump power consumption	0.01 kW
Refrigerant flowrate	0.034 kg/s
Evaporator capacity	5.28 kW
Compressor power consumption	1.24 kW
Borehole water flowrate	0.41 kg/s
Borehole water pump power consumption	0.1625 kW (max)
Vertical borehole pipe length	135 m
Estimated number of boreholes	2, each at 70 meters deep
COP	5.24

Table 2 – Summary Table

The GSHP system was also simulated using Hysys software for a comparison and the results are close to the manual calculations performed in this design report.

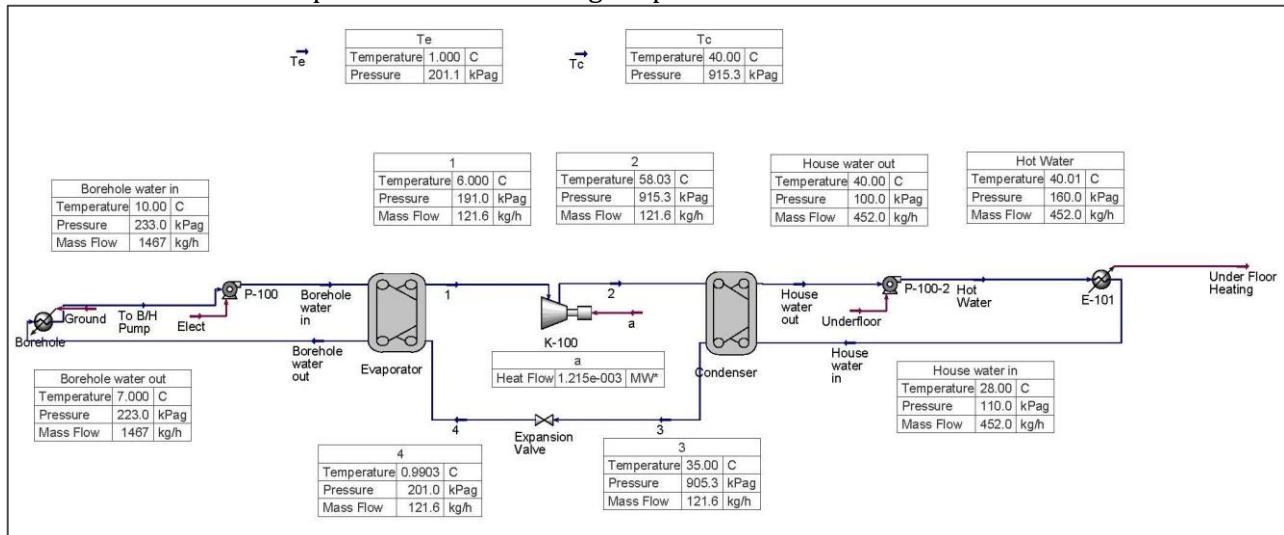


Figure 7 -Hysys Process Flow Diagram

7. Control Philosophy

The control philosophy described herein is a simple system whereby the target room temperature of the lounge is set at 25°C. The thermostat that measures the temperature sends a signal to the variable speed drive on the compressor. The programmed logic controller will increase the speed of the compressor, thereby increasing the flow of gas in the loop and sending more heat into the domestic water system, until the target set point is reached. The compressor will then act on a gap controller where the compressor will stop once the temperature has reached 25°C and restart when the temperature drops to 24°C.

For the type of house described and shown in the report, a more complex control system would likely be used. There are several potential options for the control system. One that would work would be to have a thermostat in each room. The water from the condenser would be pumped, via a centrifugal pump, at a constant flow rate. The target temperature leaving the condenser would be 40°C which is the maximum recommended for underfloor heating to avoid damage to the flooring. This temperature would be detected and transmitted to the speed controller on the compressor. There would be a thermostat in each room with a set-point in the programmed logic controller. Each thermostat would be independently set. If heating to a particular room wasn't required the temperature would be set at 5°C, for example. Each thermostat would send a signal to an electrically operated flow control valve situated in the offtake from the flow header. The flow control valve would operate to send hot water to the room until the target temperature was reached. It would then operate under gap control to ensure that the house was heated in optimally. Each thermostat would be provided with a timer, to ensure that rooms were only heated when required. The water from the heated rooms would flow to the return header where it would flow to the condenser to be heated.

8. Cost Estimate

Description	Number of units	Unit Price £	Total Cost	Remarks
Borehole	2	£5000	£10,000	IMS Heat Pump, 2019
Pipe to and from the borehole, buried	Borehole Depth 70m			Included in borehole costs
Borehole Pump	1	£500		Included in borehole costs
6.5kW GSHP	1	£6500	£6500	Boiler Guide, 2021. £1000 per kW
Underfloor Heating Retrofit cost	160m ²	£50/m ²	£8000	Homebuilding & Renovation, 2021
Total Cost (inc. installation & commissioning)			£24,500	

Table 3 – Cost Estimate

The overall effective cost of a heating system is a combination of Capital Expenditure (CAPEX) and Operating Expenditure (OPEX). The CAPEX represents the initial capital outlay for the installation of a heating system and the OPEX represents costs of energy use, and maintenance.

The cost of the heat pump, refer to the table 3 above, amounted to £24,500. This included a sizeable amount for the drilling of two boreholes for the water to the evaporator. A horizontal trenched system would have been cheaper but the premise for this study was that the house was in London and had a small garden that was not suited to a trenched geothermal heating system. The cost for a gas boiler and associated radiators would be less than that for a heat pump and it's estimated to be approximately £4000, for a 3 bedroomed house in London, the price includes a London premium (Household quotes, 2021). The difference between the installation costs for a GSHP and a gas-fired central heating system, in London is approximately £20,500. The cost of retrofitting a GSHP is clearly factors more expensive than a gas-fired system.

With reference to the OPEX, on average the annual cost saving of a GSHP over a gas fired system is approximately £225. This figure doesn't account for the recent very steep rises in the price of gas. This would likely create the cost difference further in favour of a GSHP. It is expected that the increased electricity cost that the GSHP system would experience would likely not compensate for the larger gas price increase. It is expected that the average dual fuelled home would pay around £1277, in the winter 2021 and the year 2022 (BBC News, 2021). Should the electricity price remain the same, the GSHP to a 28-kW gas-fired system differential would increase to approximately £300 per annum. If it is assumed that the annual or biannual servicing cost for the systems is similar then based on an annual differential of £300 on OPEX, it will take approximately 68 years for the GSHP system to equal the cost of the gas-fired system. It should be noted that the UK government Renewal Heat Incentive (RHI) has been severely reduced in England. The RHI returned money to the user based on the energy use. The more energy used for a heat pump system or other renewable energy system; the more money returned to the user. The UK Government has stated their intention to increase the price of gas and to reduce the cost of electricity to encourage people to switch to green energy.

9. CONCLUSIONS

The conclusion from this report is that the installation of a GSHP system has a far greater CAPEX than an equivalent gas fired central heating system. However, the OPEX for the GSHP is much lower than the equivalent gas fired central heating system.

10. References

- 'Araner' (2021) *The best refrigerant for Heat Pump Systems*. [Online] Available from: <https://www.araner.com/blog/best-refrigerant-for-heat-pump>. [Accessed: 18 November 2021].
- 'BBC News' (2021) *Why are gas prices so high and what is happening to fuel bills?*. [Online] Available from: <http://www.bbc.co.uk/news/business-58090533> [Accessed: 22 November 2021].
- 'Boiler Guide' (2021) *Which are the Best Ground Source Heat Pumps?*. [Online] Available from: <https://www.boilerguide.co.uk/ground-source/best-ground-source-heat-pump-manufacturers>. [Accessed: 18 November 2021].
- 'Combustion Research Cooperation' (2021) *U-Values for common materials*. [Online] Available from: [https://www.combustionresearch.com/U-Values for common materials.html](https://www.combustionresearch.com/U-Values%20for%20common%20materials.html). [Accessed: 18 November 2021].
- 'GSHPA Association' (2011) *Closed-loop Vertical Borehole Design, Installation & Materials Standards Issue 1.0*. [Online] Available from: [https://www.gshp.org.uk/pdf/GSHPA Vertical Borehole Standard.pdf](https://www.gshp.org.uk/pdf/GSHPA%20Vertical%20Borehole%20Standard.pdf). [Accessed: 18 October 2021].
- Hawkins, G. (2011) *Rules of Thumb Guidelines for Building Services*, BSRIA. Available at: [https://www.bsria.com/uk/product/Ln3Q4B/rules of thumb 5th edition bg 92011 a15d25e1/](https://www.bsria.com/uk/product/Ln3Q4B/rules%20of%20thumb%205th%20edition%20bg%2092011%20a15d25e1/) (Accessed: 18 November 2021).
- 'Homebuilding & Renovating' (2021) *How much does underfloor heating cost*. [Online] Available from: <https://www.homebuilding.co.uk/advice/underfloor-heating-guide#section-how-much-does-underfloor-heating-cost>. [Accessed: 22 November 2021].
- 'Household Quotes' (2021) *How Much To Install Central Heating*. [Online] Available from: <https://householdquotes.co.uk/how-much-to-install-central-heating/>. [Accessed: 22 November 2021].
- 'IMS Heat Pumps' (2019) *Ground source heat pump borehole cost*. [Online] Available from: <https://www.imsheatpumps.co.uk/blog/ground-source-heat-pump-borehole-cost/>. [Accessed: 18 November 2021].
- 'MCS 022' (2008) *Ground Heat Exchanger Look-up Tables*. [Online] Available from: [https://www.gshp.org.uk/pdf/MIS 3005 Ground loop sizing tables.pdf](https://www.gshp.org.uk/pdf/MIS%203005%20Ground%20loop%20sizing%20tables.pdf). [Accessed: 18 November 2021].
- 'The Chemours Company LC' (2018) *Freon 134a Thermodynamic Properties*. [Online] Available from: <https://www.freon.com/en/-/media/files/freon/freon-134a-si-thermodynamic-properties.pdf>. [Accessed: 18 November 2021].
- 'The Microgeneration Installation Standard 3005' (2011) *Requirements for MCS Contractors Undertaking the Supply, Design, Installation, Set To Work, Commissioning And Handover Of Microgeneration Heat Pump System Issue 5.0*. [Online] Available from: [https://www.gshp.org.uk/pdf/MIS 3005 Heat Pump Systems.pdf](https://www.gshp.org.uk/pdf/MIS%203005%20Heat%20Pump%20Systems.pdf). [Accessed: 18 November 2021].
- 'UFH1 Underfloorheating' (2021) *Floor surface temperatures when fitting underfloor heating*. [Online] Available from: [https://underfloorheating1.co.uk/blog/article/Floor surface temperatures when fitting underfloor heating](https://underfloorheating1.co.uk/blog/article/Floor%20surface%20temperatures%20when%20fitting%20underfloor%20heating). [Accessed: 18 October 2021].