Investigating the performance of Geothermal and Solar HVAC System

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ABSTRACT

Solar and geothermal energy are recognized for their good efficiency, safety, as well as ability to operate regardless of the weather. One of several applications wherein straight utilization of geothermal and solar energy is used is geothermal and solar pumps, and advancement in the augmentation of these renewable energy sources is needed for future improvement in this sector. The findings revealed that solar energy is much more viable than geothermal resources because solar energy has a lower initial investment than geothermal energy. Furthermore, the solar system involves a lower payback period, which means it is considered the most preferable system for the same operational life. Also, the expenditure of the solar system is more secure than in the case of geothermal power.

Keywords; Coefficient of Performance, Renewable Energy, Operating Life, Geothermal HVAC System, Solar System.

I. INTRODUCTION

There have been significant changes in the international energy sector, ranging from increased power to the expansion of renewable resources, as well as the generation of disturbance in the natural gas and oil markets. Government policy choices will define the shape of the upcoming power system throughout all fuels and so all regions (Seger, 2016). International energy industry demand increased by 2.2 percent in 2017, up from 1.2 percent a year ago year and above the ten-year average of 1.6 percent. The Organization for Economic Cooperation and Development (OECD), particularly the European Union, was the driving force behind this expansion. The usage of energy around the world is depicted in Figure 1 [15].

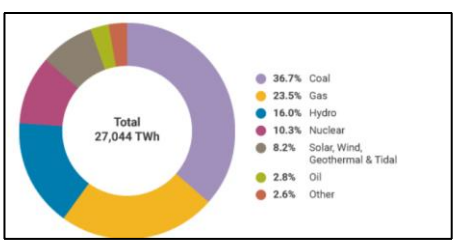

Figure 1: The global energy consumption [15].

According to [10], global energy demand is growing by one-third, yet two-thirds of the world's population in 2040 will be nations with the overall energy use of less than 100 GJ per capita. emission from energy use has been expected to rise by over 10% by 2040, instead of declining significantly.

The globe has also established carbon emission estimates and plans, including reducing carbon emissions by around 45 percent by 2040, which is about midway to completely eliminating carbon emissions from energy consumption [10].

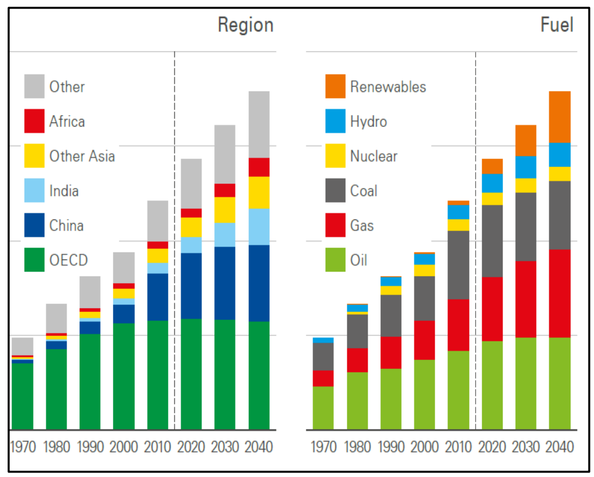

Figure 2: The demand for primary energy consumption [10].

Despite the huge amount of energy created by the globe, collecting this energy is extremely difficult because of the constant distribution of generated energy across the earth's surface.

The geothermal energy accumulation has a great concentration in certain areas, including the earth's tectonic plate boundaries. Tidal power is another renewable energy source, although it is also a restricted renewable energy supply. Despite the fact that the impact of global warming has increased significantly, and its effects including the swift variations in air temperature that have also increased, no major steps have been done. Because global warming is having such a negative impact on our environment, a remedy must be devised [13].

The efficacy of geothermal solar systems and HVAC adaption in residential buildings and their recent utilization in the

United Kingdom, as well as developed countries, will be studied and discussed in this paper. Furthermore, this paper will also evaluate the geothermal HVAC systems COP efficiency. A house in Bradford that will be used as a case study in order to design geothermal and solar HVAC systems depending on calculating heating load.

II. LITERATURE REVIEW

Fossil fuels usage is now considered a major concern due to its environmental effects and air pollution. The (IEA, 2016) observed that the warning and norms related to environmental protection have already increased since the consequences will affect the living quality and the patterns of energy consumption.

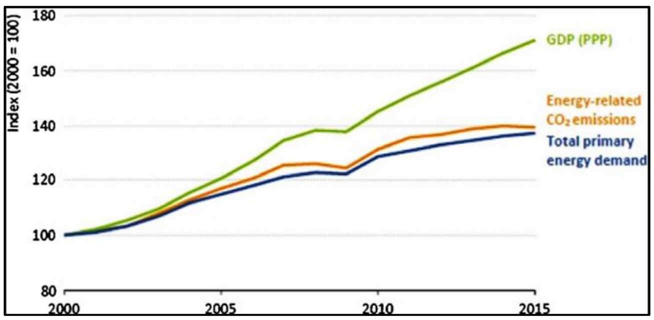

Figure 3: The changes in the energy demand, the global economic output, and the energy-related CO2 emissions (IEA, 2016)

Figure 3 shows the IEA's preliminary estimation for global carbon dioxides emissions in 2015, in which flattening carbon dioxides levels are shown. Several data show that there is a relation between growth and carbon dioxide emissions [17]. According to [11], a considerable percent of the emissions greenhouse gases have resulted from buildings. Also, the usage of fossil fuels significantly increases global warming, ecological consequences, and climate change.

A. Determining the efficiency of Geothermal energy systems (HVAC Systems).

Feasibly implementing geothermal energy is affected by some factors such as the system efficiency, resources, location, discount rate, demand, and yearly load [23]. The GHE has a great influence on the cost, thus, the GHE must have a certain size in accordance with demands expectations and ancillary systems [2]. A comparison between the conventional HVAC system and the geothermal HVAC system is presented in Figure 4.

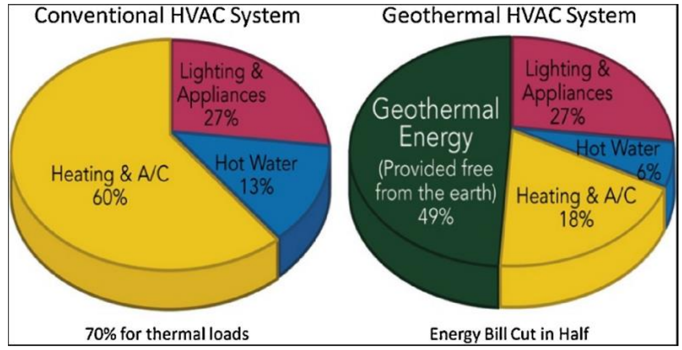

Figure 4: A comparison between the conventional HVAC system and the geothermal HVAC system [5].

Figure 4 shows that if geothermal energy is used in conjunction with a heating and cooling system, the energy bill might be cut in half. There are no CO, CO2, or hydrocarbon emissions in the atmosphere when geothermal systems are used [3]. Heat pump systems that use geothermal energy are among the most ecologically friendly, efficient, and cost-effective systems available. Approximately 70% of the energy consumed in a geothermal heat pump scheme comes from renewable sources on the ground. In comparison to gas and oil furnaces, geothermal systems are 48 percent and 75 percent more efficient, respectively [21].

B. The Configuration of Solar Heat Pump System

Solar heat pump systems, also known as SHPs, are systems that combine solar photovoltaic energy with heat pumps. Accordingly, the SHP system is a hybrid system. The collectors of solar thermal transfer the energy of the solar system into heat. Parallel and in series are the two main configurations for solar thermal collectors [6]. In terms of installation, design, and control, the parallel configuration is considered simpler than the series configuration. When radiation levels are high enough, is also more energy-efficient [12]. Covered or glazed solar thermal collectors, as well as uncovered or unglazed collectors, are categorized into two kinds. The covered collectors have two different types, namely, evacuated tubes and flat plate collectors. Collectors of flat plate typein tandem with a heat pump are the state of the art for domestic heating systems .[4]

C. COP for Geothermal HVAC Systems)

The rating of performance that gives a piece of information about the effectiveness of heat pump and air conditioner in transmitting heat compared to the amount of electricity used, is known as the Coefficient of Performance, COP. COP, on the other hand, informs us about how air conditioners or heat pumps perform this work by supplying the required power for the machine to transfer a specific amount of heat at a specific temperature [7].

A higher COP value means a more efficient heating system. The heat produced to electrical energy input ratio is referred to as a rating. In other words, it indicates the amount of home heating obtained based on the amount of electrical energy used by the system to calculate this heat. One significant distinction between COP and other efficiency labels is that COP does not require labeling on residential HVAC equipment. However, minimum standards are established for geothermal or air-source heat pumps with capacities greater than 5 tons, as shown in Table 1.

Table 1: The lowest cop efficiency standards for geothermal heat pumps [1].

Type of Product Type	EER	COP
Heat Pump of Double pipe Water-To-Air type	17.1 EER	3.6 COP
Single loop Heat Pump of Water-To-Air type	21.1 EER	4.1 COP
Double pipe Heat Pump of Water-To-Water type	16.1 EER	3.1 COP
Single pipe heat pump of Water-To-Water type	20.1 EER	3.5 COP
Heat Pump of DGX Geothermal type	16.0 EER	3.6 COP

Theoretically, the COP is a dimensionless rate because it associates and compares two factors of the same type. COP is a measurement of the amount of heat that a certain part of an HVAC machine is able to convey when given a specific amount of power or electrical contribution at a specific temperature.

$$COP = \frac{Power\ output\ (wattage)}{Power\ input\ (Wattage)} \qquad Eq.1$$

$$COP = \frac{Power\ Capacity\ (PTUs/Hr)}{Power\ input\ (Wattage)} \qquad Eq.2$$

For the loop or the water pump that is tinier than needed, the exclusion or inclusion of heat might raise the ground temperature above the standard test requirement, causing overall performance to suffer. Heat pumps based on geothermal mechanisms can reduce the consumption of energy and, accordingly, air pollution emissions will be reduced [25].

III. METHODOLOGY

A. Background

This chapter is a method for evaluating the benefits and drawbacks of utilizing solar and geothermal energy in HVAC heating systems in the United Kingdom. Also, an assessment of the solar and geothermal energy systems will be conducted in order to determine the best option regarding cost, efficiency, as well as long-term viability. Then the obtained heating loads are used to create a sustainable energy model that will improve the house's energy efficiency.

B. Case study

1. The selected house layout

The house is built on a land area of 13 meters wide by 15 meters long, with a constriction area of (12.7 m x 9 m), as can be seen in Figure 8. It is divided into two levels: the ground floor has two bedrooms and two bathrooms, as well as a reception area and a dining room with no partitions, and the second floor has a roof deck and multi-purpose rooms. The selected house to be studied in this work is shown in Figure 5, and its plane overview is shown in Figure 6.

Figure 5: The studied house.

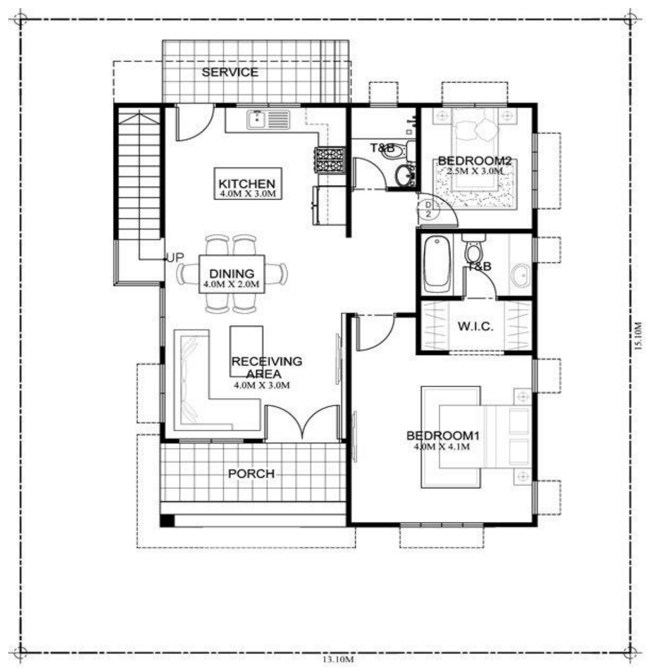

Figure 6: The studied house plane.

2. Zones

The area of the studied house was 196.3 m^2 plot of land, with a construction area of 114.3 m^2 and two floors.

a) The ground floor

The ground floor has two bedrooms, two bathrooms, a reception area, and an open dining room without partitions. The ground floor of the studied house is divided into several zones, which are shown in Table 2.

Table 2: The ground floor zones.

Zone number	Area
Zone -1: Bed room 1	4 m × 4 m
Zone – 2 :Bed room 2	2.5 m × 3 m
Zone – 3 :Kitchen	4 m × 3 m
Zone – 4 :Dining	4 m × 2 m
Zone – 3 :Reserving area	4 m × 3 m
Zone – 4 :Bathroom 1	7 m × 2.5 m
Zone – 3 :Bathroom for master room	2 m × 1 m

b) The second floor

The second floor involves a roof deck and a multi-purpose room, and their area is provided in Table 3.

Table 3: The second-floor zones.

Zone number	Area
Zone -1: Multi-purpose room	12 m × 4 m
Zone – 2: Roof deck	8 m × 4 m

3. Temperatures

For the last five years, Figure 10 represents the outside temperature (°C) in Bradford. The maximum temperature is shown in orange, the minimum temperature is shown in dark blue, and the average temperature is shown in blue. It's worth noting that the information was gathered from [20].

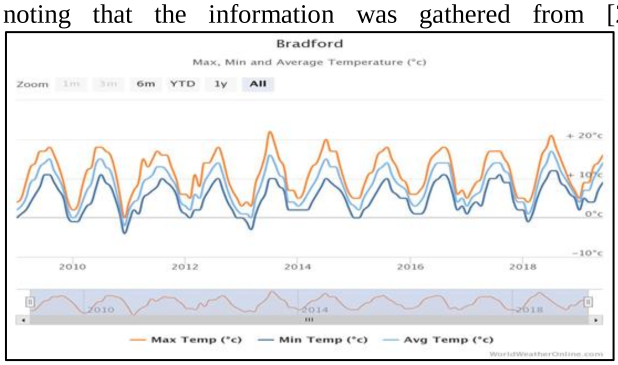

Figure 7: The maximum, minimum, and average outside temperature in Bradford [20].

C. HVAC calculations

The HVAC system and its proper sizing begin with considering the heating and cooling loads. The values determined by the calculation will guide the equipment selection and duct design to distribute the conditioned air in the house rooms. Calculations will have a significant effect on the costs of construction, as well as occupant comfort, operating energy efficiency, building efficiency, and indoor air quality. The air distribution mechanism is being designed to meet the expected cooling and heating loads of the entire residence. The term "right-sizing" refers to the process of selecting HVAC design and equipment.

D. Load Calculation:

1. Heat transfer over opaque surfaces

This is how heat is transferred properly. The rate of heat transfer thru an opaque surface, including doors, floor, walls, or roof is calculated as follows:

$$Q_{opaque} = U \times A \times CLTD \qquad Eq.3$$

Where:

- U represents the coefficient of the complete heat transfer.
- A represents the surface heat transfer area on the accustomed space side.
- CLTD represents the temperature modification of the cooling load.

2. Heat transfer over fenestration:

Heat is transferred over the transparent surface like a window, by conduction due to a temperature difference between the heat transfer and the window, and by the solar radiation from the window.

$$Q_{traus} = A_{unshaded} \times SHGf_{max} \times SC \times CLF \qquad Eq.4$$

Where:

- $A_{unshaded}$ represents the solar radiation-exposed area.
- SHGF represents the factor of the maximum Solar Heat Gain.
- SC represents the Shading Coefficient.
- CLF represents the Factor of the Cooling Load.

3. Heat transfer by infiltration:

Both latent and sensible components are present in heat transfer owing to penetration. Due to various penetration, the rate of sensible heat transference can be calculated by:

$$Q_{sinf}(T_o - T_i) = v_{\circ}\rho_{\circ}C_P(T_o - T_i) \qquad Eq.5$$

$$Q_{linf} = m_{\circ}h_{fg}(\omega_o - \omega_i) = v_{\circ}\rho_{\circ}h_{fg}(\omega_o - \omega_i)\ Eq.6$$

4. The method of infiltration rate by air change is:

$$V_{\circ} = (ACH).\frac{V}{3600} \qquad Eq.7$$

Where:

- ACH represents the air changes' number per hour.

- V represents the conditioned space is the gross volume (m^3).

The latent and sensible heat internal cooling load components due to occupants are both presents:

$$Q_{S_{occ}} = (no\ of\ peaple) \times (sen\ heat\ gain\ per\ person\ ) \times CLF \quad Eq. 8$$

$$Q_{l_{occ}} = (no\ of\ peaple) \times (letent\ heat\ gain\ per\ person\ ) \qquad Eq. 9$$

5. **Load due to lighting:**

The space that is conditioned receives more sensible heat as a result of lighting. Because the heat from the lighting system is transferred via both convection and radiation, the time lag is calculated using a cooling load factor. As a result, the following is a cooling load due to the lighting system:

$$Q_S = (installed\ wattege) \times (usage\ factor) \times (ballast\ factor) \times CLF\ Eq. 10$$

- For the fluorescent lights: the value of the ballast factor equals 1.25.

- For the incandescent lamps: the value of the ballast factor equals 1.00.

- For the incandescent lamps: the value of the ballast factor equals 1.00.

- CLF: is an hours number function after turning on the lights.

6. **Internal loads resulted from appliances and equipment:**

The equipment and appliances in the conditioned space may add both latent and sensible loads. Convection and/or radiation, once again, maybe the sensible load. Internal sensible load resulting from the equipment and appliances is calculated as follows:

$$Q_{Lapp} = (installed\ wattage) \times (latent\ heat\ fraction) \quad Eq. 11$$

$$Q_{Sapp} = (installed\ wattage) \times (usage\ factor) \times CLF \quad Eq. 12$$

Where:

- Both the installed wattage and usage factor depend on tools or appliance sort.

- CLF represents values availability in the tables forms in ASHARE handbooks.

E. ASHRAE Standards

ASHRAE standards serve as a reference point for performance criteria as they evolve measurement and testing procedures. That demonstrates the HVAC industry's acceptable value. It is a set of rules and criteria for participants and engineers that is followed when designing and maintaining building environments, with an emphasis on construction systems, air quality, energy efficiency, sustainability, as well as refrigeration.

IV. Geothermal HVAC Heat Pump Design

A. Design methodology

The following steps are involved in designing a geothermal heating system: a) the heat load determination for the chosen home; b) determining the needed temperature of the pipe that meets the load; and c) estimating the depth, spacing, and size of the geothermal tubes.

B. The temperature of the pipe

The estimation of the lowest temperature of the surface of the system's pipes to meet the heating load of the house is calculated by the following equation [18]:

$$\frac{q}{A} = 0.472\left[\left(\frac{1.8\,T_p + 492}{100}\right)^4 - \left(\frac{1.8\,AUST + 492}{100}\right)^4\right] + 2.186\,\left(T_p - T_0\right)^{1.32}$$

Where:

- q represents the house’s heating load (855.43 kW)
- A represents the area of the floor (196.3 m^2)
- T_p represents the temperature of geothermal pipes surface (°C)
- $AUST$ represents the average temperature of the house’s unheated surfaces (15 C) [18].
- T_0 represents the temperature of the inside air temperature (18.3°C)

C. The temperature of the internal surface

An equation was proposed by [9] to be used in determining the internal surface temperature (IST):

$$IST = IDT - (0.0291 \times 3.6 \times U \times \Delta T)$$

Where:

- IST represents the internal surface temperature.
- IDT, represents the inside design temperature [60°C], assuming that there is no temperature degradation through pipes, the IDT is considered equal to the surface temperature of the geothermal pipes (T_p).
- U represents the coefficient of heat transfer losses [4.26 W/m^2. °C]
- ΔT represents the temperature difference outside and inside [10°C] according to [9].

$IST = 60 - (0.0291 \times 3.6 \times 4.26 \times 10) = 55.5\ C$

D. Total tube length of a geothermal system

According to [9], the total pipes’ length needed for heating the house is:

$$L = \frac{Q \times \ln\left[\left(8\left(\frac{H}{d}\right)^2 - 1\right) + 4\left(\frac{H}{d}\right)\sqrt{4\left(\frac{H}{d}\right)^2 - 1}\right]}{4\pi\, k\, (LMTD)}$$

- Q represents the heating load that is covered by geothermal source [W],
- L represents the geothermal heating pipes total length [m],
- H represents the height between the pipe location in Earth and ground surface [50 m],
- d, represents the pipes outside diameter [0.05m] "assumption",
- k: Earths' thermal conductivity [4.26 W/m°C],

$LMTD$= Log-mean-temperature-difference [°C], which is calculated by the following equation:

$$LMTD = \frac{T_{W,in} - T_{W,out}}{\ln \frac{T_{W,in} - T_s}{T_{W,out} - T_s}}$$

Where:

- $T_{W,in}$, represents the temperature of the water inlet [110°C] to the geothermal system (assumption).
- $T_{W,out}$, represents the temperature of the water outlet [80°C] from the geothermal system (assumption).
- T_s represents the pipes' surface temperature, also known as the floor temperature [60°C]

$$LMTD = \frac{110 - 80}{\ln \frac{110 - 60}{80 - 60}} = 32.74°\text{C}$$

By introducing the hybrid network, including geothermal and boiler, to ensure that the designed heating system is practical and reliable, the heat duty to and of the geothermal and the boiler, respectively, is used in determining the pipes' length Figure 8 shows the hybrid system design (the geothermal and boiler heat pump)

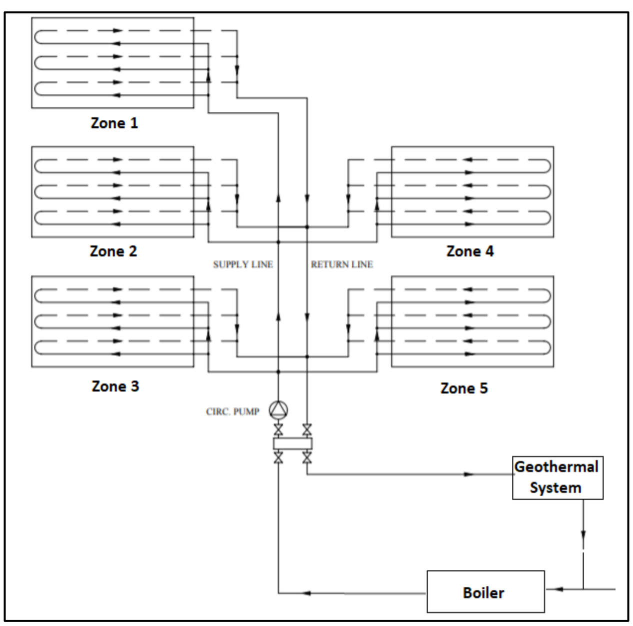

Figure 8: the hybrid system design (the geothermal and boiler heat pump)

Various percentages of heating load will be taken, and pipe lengths are calculated as follows:

$$L = \frac{Q \times \ln\left[\left(8\left(\frac{50}{0.05}\right)^2 - 1\right) + 4\left(\frac{50}{0.05}\right)\sqrt{4\left(\frac{50}{0.05}\right)^2 - 1}\right]}{4\pi\, (4.26)\, (32.74)}$$

$$L = \frac{Q \times \ln\left[\left(8\left(\frac{50}{0.05}\right)^2 - 1\right) + 4\left(\frac{50}{0.05}\right)\sqrt{4\left(\frac{50}{0.05}\right)^2 - 1}\right]}{4\pi\, (4.26)\, (32.74)}$$

$$L = 9.46 \times 10^{-3}\, Q$$

Figure 9 shows the results.

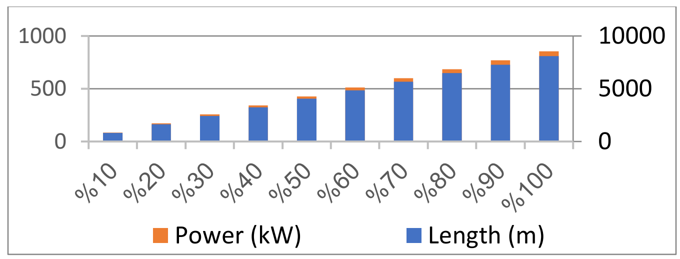

Figure 9: Geothermal heating system optimization results at different percentages of the geothermal power participation

Figure 9 shows that the total tube length must be increased to increase the participation of geothermal power. The main factor, which enhance the transferring process of heat was the surface area increment. As a result, there is a direct correlation between power participation and tube length. Also, as the layout expands, the surface area (heat exchange area) increases, and both more geothermal power participation and geothermal power are generated.

E. The Design of geothermal heat pump

The working fluid amount (water) in the network, is calculated as follows:

$$\dot{m} = \frac{Q}{C_P\, \Delta T}$$

Where:

- $\dot{m}$ represents the water mass flow rate (kg/s)
- Q represents the systems' heat duty (855.43 kW)
- C_P represents the water-specific heat (4.182 kJ/kg.K)
- ΔT represents the difference in temperature between the outlet and inlet water (30K)

$$\dot{m} = \frac{855.43}{(4.382)(30)} = 6.51\ kg/s$$

The water volumetric flow rate can be calculated using the formula below:

$$\dot{Q} = \frac{\dot{m}}{\rho}$$

$$\dot{Q} = \frac{6.51}{1000} = 0.00651\ m^3/s$$

The following equation gives the equation for a pump general design:

The following is a formula for calculating the pump's head:

$$P_1 + \frac{1}{2}\rho\, u_1^2 + \rho\, g\, z_1 + \Delta P_p = P_2 + \frac{1}{2}\rho\, u_2^2 + \rho\, g\, z_2 + \Delta P_{Losses}$$

Where:

- P_1 represents pump inlet pressure (Pa),
- P_2 represents the geothermal pipe network pressure (Pa),
- ρ, represents water density at average temperature (kg/m^3).
- g represents the acceleration of gravity (9.81m/s^2),
- u_1 *and* u_2 represent water velocity inside the tube (m/s),
- z_1 represents pump elevation (m),
- z_2 represents geothermal network elevation (m),
- ΔP_p represents pump differential pressure (Pa),
- Δ the process represents pressure losses resulting from minor and major losses (Pa).

After simplification, the equation for designing a pump is:

$$\Delta P_p = \Delta P_{Losses}$$

The following formula can be used to calculate the pressure difference caused by losses in a pipe network:

$$\Delta P_{Losses} = \Delta P_{L,major} + \Delta P_{L,minor}$$

$$\Delta P_{Losses} = \frac{f\, u^2 L}{2D} + \frac{\sum K_{L,i}\ u^2}{2}$$

Where:

- f represents dimensionless pipe friction factor that is estimated from Moody chart, knowing tube material relative roughness and Reynolds number.
- L represents the total length of the geothermal tube (m).
- $K_{L,i}$, represents the dimensionless factor of minor losses that is presented for every single loss type. Only U- bend will be considered in this project.
- D represents the tube's internal diameter (0.05m).

The system's working velocity can be calculated by:

$$u = \frac{4\,\dot{Q}}{\pi\, D^2}$$

Where:

$\dot{Q}$, represents water flow inside the network (0.00651 m^3/s).

$$u = \frac{4\ (0.00651)}{\pi\ (0.05)^2} = 3.32\ m/s$$

The following formula is used for Reynolds number (Re) estimation:

$$Re = \frac{D\ u\ \rho}{\mu}$$

Where:

- μ, represents the fluid dynamic viscosity (water) ($8.90\ \times\ 10^{-4}$)Pa.s

$$Re = \frac{(0.05)(3.32)(1000)}{8.90 \times 10^{-4}} = 1.865 \times\ 10^5\ (Turbulant\ flow)$$

To reduce corrosion and improve heat transfer, copper was chosen as the tube manufacturing material. The steel has a 0.0015-millimeter absolute roughness. Absolute roughness is divided by tube diameter to calculate relative roughness. As a result, the tube's relative roughness is:

$$e_r = \frac{e}{D} = \frac{0.0015}{50} = 0.00003$$

Based on both, friction factor and Reynolds number, the relative roughness can be estimated as follows:

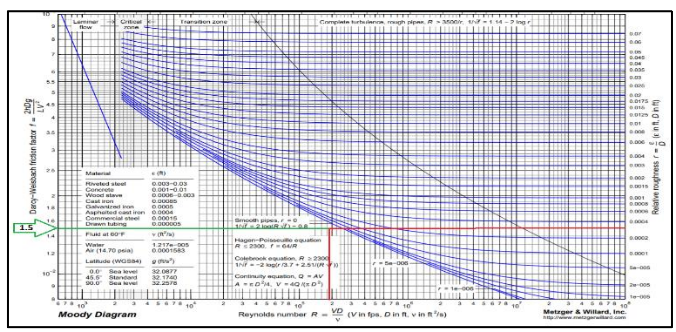

Figure 10: Determining relative roughness for geothermal pipe network.

Each pipe (N) is assumed to have only two bends for minor losses. The following diagram depicts the energy losses due to major and minor losses:

$$\Delta P_{Losses} = \frac{1.5\ (3.32)^2 L}{2(0.05)} + \frac{(2N_p)(0.35)\ (3.32)^2}{2}$$

$$\Delta P_{Losses} = \frac{1.5\ (3.32)^2 L}{2(0.05)} + \frac{(2N_p)(0.35)\ (3.32)^2}{2}$$

$$\Delta P_{Losses} = 165.3\ L + \ 3.86\ N_p$$

The following is a simplified version of the pump equation:

$$\Delta P_p = 165.3\, L + \ 3.86\, N_p$$

This equation can be used to estimate flow rate, head, and pump pressure. Table 4 shows the results.

Table 4: The characteristics of the pump at different percentages of geothermal usage.

Pump #	Geothermal %	L_{total}	N_{total}	ΔP_p (kPa)	Pump head (m)	Pump flow (m^3/hr)
1	10%	810	54	134.07	13.67	23.4
2	20%	1619	108	268.14	27.33	23.4
3	30%	2429	162	402.20	41.00	23.4
4	40%	3238	216	536.27	54.67	23.4
5	50%	4048	270	670.34	68.33	23.4

Due to the length of the tubes, Table 4 shows the pressure drop and pump head for each layout. The second pump, with a 20 percent geothermal power participation, is clearly the one that was chosen. The pressure difference, pump head, flow rate, installation cost, and running and maintenance costs are all important factors to consider when choosing a pump.

Figure 11 depicts the Neptuno® pump's performance curve, which is appropriate for pumps 1 and 2. It should be noted that the manufacturer's specifications for Pump 1 are not met, whereas Pump 2 is available with a VPT 3000 rpm and a 146 mm impeller. The pump's efficiency is roughly 60%. Pump 2 has a net positive suction head (NPSH) of 2.9 m and consumes 2.9 kW (3.9 hp).

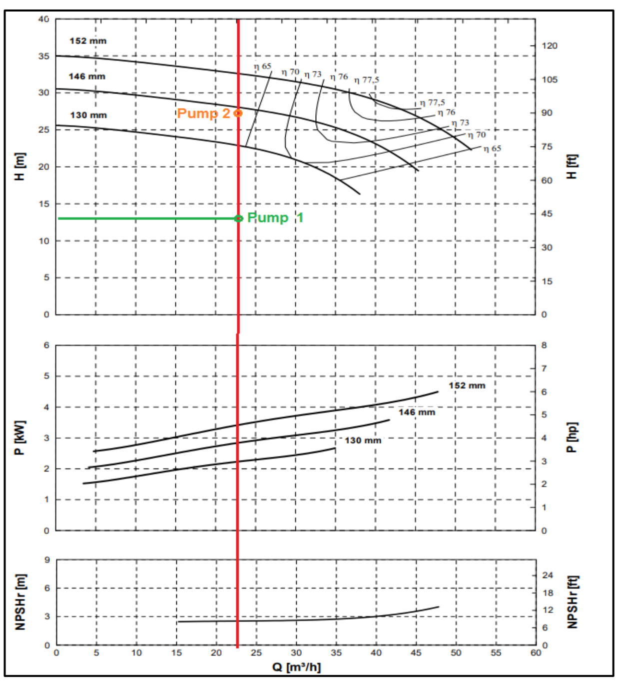

Figure 11: Neptuno® Vertical Turbine Pumps (VTP) – 3000 rpm performance chart displaying a collection of two pumps, Pump 1 and 2.

The second pump is chosen due to the previously mentioned factors. Figure 11 shows a comparison between pump 1 and pump 2. The same rate of flow and net-positive-suction-head (NPSH) is considered in this comparison. The head graph shows the corresponding values for both pumps. Due to the head graph, no pump meets pump 1 specifications, however, if one pump does, it is expected to have a propeller speed and a low efficiency. At the needed NPSH and rate of flow, Pump 2 matches to proper speed and efficiency. It has a 60% efficiency rating, a 146 mm propeller, and a 3000 rpm speed.

V. The Design of Solar HVAC System

A typical solar system HVAC heating structure is shown in Figure 12.

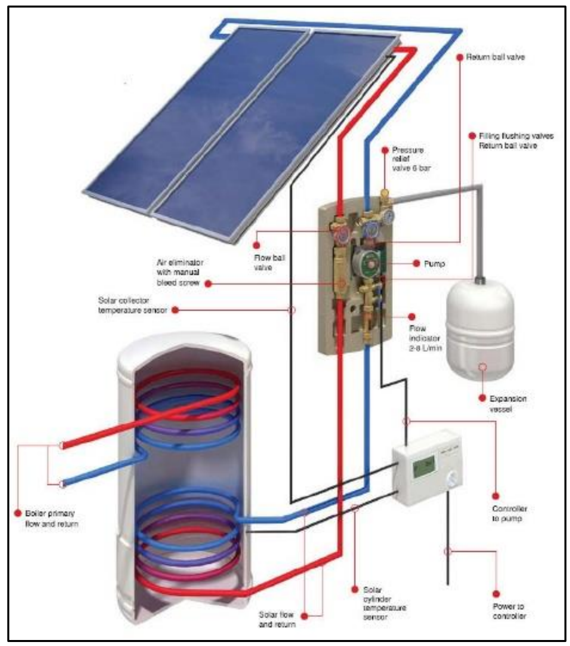

Figure 12: Typical solar heating system [16].

A. The rate of water flow rate in the system

The working water amount in the system can be calculated depending on the following equation:

$$\dot{m} = \frac{Q}{C_P\, \Delta T}$$

Where:

- Q represents the heat duty, and equals 855.43 kW,
- C_P represents the water-specific heat, and equals 4.182 (kJ/kg.K),
- $\dot{m}$ refers to water mass flow rate (kg/s),

- ΔT *represents* Inlet/Outlet water temperature differences and equals (30K).

Therefore:

$$\dot{m} = \frac{855.43}{(4.382)(30)}$$

$$\dot{m} = 6.51\ kg/s$$

Now, the volumetric water flow rate can be calculated from the following equation:

$$\dot{Q} = \frac{\dot{m}}{\rho}$$

$$\dot{Q} = \frac{6.51}{1000}$$

$$\dot{Q} = 0.00651\ m^3/s$$

After that, the water flow rate per day can be calculated a shown below:

$$\dot{Q} = 0.00651 \frac{m^3}{s} \times 3600\ \frac{s}{hr} \times 24 \frac{hr}{day}$$

$$\dot{Q} = 562.5 \frac{m^3}{day}$$

B. The solar intensity in Bradford

The value of the average intensity of solar in February 2019 was 6.3 kWh/m^2.day [24].

Furthermore, both thermal and solar efficiencies should be considered to find the actual solar flux in the studied area (Bradford):

$$\dot{Q}_{net} = \eta_{solar}\ \eta_{thermal}\ \dot{Q}_{solar}$$

Between 55 and 65 percent of solar collectors, efficiency is achieved. During the winter, the efficiency is estimated to be around 55%. Water heating with an insulated solar heat pump has a thermal efficiency of 85% [8]. The net solar flux, based on these assumptions, is:

$$\dot{Q}_{net} = 0.55\ (0.85)(6.3) = 2.95\ kW/hr$$

C. The area of the solar collectors

The following equation is used to calculate the solar collector area:

$$A = \frac{\dot{Q}_{heating}}{\dot{Q}_{net}}$$

Where:

A refers to the area of the solar collector.

$\dot{Q}_{net}$ refers to the net heat flux (kW/m^2),

$\dot{}_{Cheating}$ $r$efers to the needed heating power portion from the solar collector (kW).

To make it easier to compare the two systems, the collector area can be obtained using the covered energy percentage from the geothermal systems. Based on the geothermal system's heat pump, twenty percent of the entire heat duty ($\dot{Q}_{heating}$ = 171.09 kW) was chosen.

$$A = \frac{171.09}{2.95} = 58.1\ m^2$$

This area value will be used to obtain the maximum possible solar collectors' number to be fixed on the house's roof. The unit dimensions should be provided before determining the solar units number. Figure 13 shows the solar collector that was chosen:

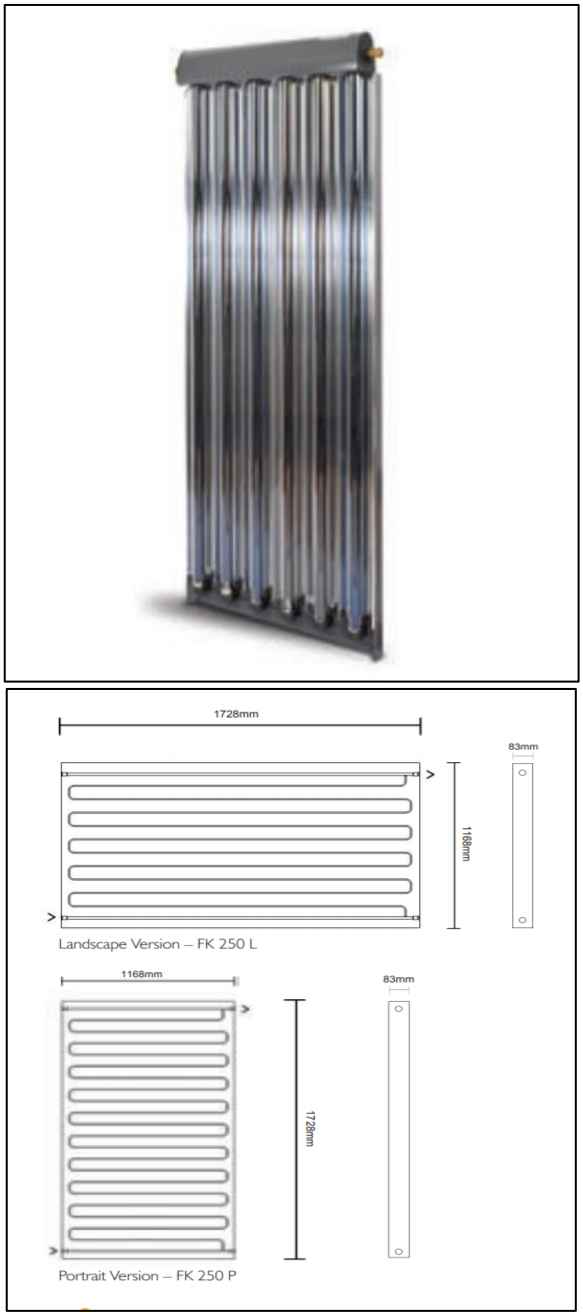

Figure 13: The chosen solar heater collector's size [22].

The selected size of the solar heater collector was chosen based on the amount of available roof space that is exposed to sunlight. The area of a single collector is approximately 2 m^2, with 6 tubes of 1.7 meters for each unit. The roof's total area will be calculated using the diagram below.

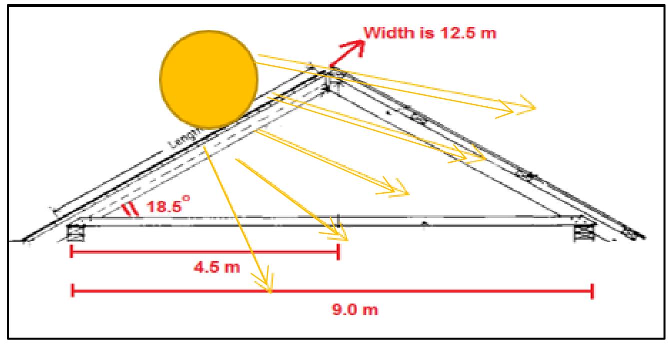

Figure 14: The total area of the studied house's roof.

As a result of the roof rigid structure, the slope of solar collectors is clearly a constraint, as shown in Figure 18. Because of the Azimuth angle, it may be a better slope. The inclined roof length can be calculated using the sine rule:

$$L = \frac{4.5}{\cos 18.5} = 4.75\ m$$

Consequently, the roof net area is:

$$A_{roof} = 4.75\ m \times 12.5\ m$$
$$Aroof = 59.4\ m$$

The calculated roof area is larger than the area of the solar panel, which means that there is sufficient room for a solar collector. There are 42 units in total. As a result, there are a total of 252 tubes. Furthermore, the total length of the tube is around 430 m.

VI. Comparison Between Geothermal and Solar HVAC Systems

The comparison aims to assess the economic benefits of the two systems when used as hybrid systems together with gas heat pump systems. The following specifications and assumptions are used to determine the cost and the profit of the two systems:

1. As shown in Table 5, the using gas cost index that is used in heating water is 45 pence/230L:

*Table **5**: the using gas cost index that is used in heating water in the UK per square meter of the house [14].*

	Degree-days	Annual space heat demand	Cost for heating
Newcastle	2,400	10,368 kWh	£363
London	2,100	9,072 kWh	£318
Plymouth	1,900	8,208 kWh	£287

Note: The average gas heating cost is £32.3/year/m ^{2} [14].

2. For solar systems, a 10% maintenance cost is assumed, while for geothermal systems, a 5% cost is assumed.
3. Both systems have a 25-year life expectancy.
4. According to the Office for National Statistics, gas price inflation in the UK equals 9.3% [19].

A. Geothermal system financial analysis

Today's prices for heat pumps and pipelines are used for calculating the geothermal system capital cost. The bill of quantities for a geothermal system is presented in Table 6.

*Table **6**: The geothermal system bill of quantities (BOQ).*

Item	Unit Price	Amount	Total cost
Copper pipes with 2 inch diameter	£8.33/m [1]	1619 m	£13,486.3
Heat pump (Neptuno® - VTP30)[2]	$4830 + 144(Q)^{0.9}$	Q = 6.51 L/s	£5,607.3
Sub Total			£19,093.6
Installation cost (10%)	10% of capital cost		£1,909.4
Total cost			£21,003

While Table 7 presents the geothermal energy cash flow based on the values above.

*Table **7**: Calculations of geothermal system cash flow.*

Year	Capital cost (£)	Operating cost (£/year)	Revenue (£/year)	Cumulative Balance (£)
0	-21003.00	0.00	0.00	-21,003.00
1	0.00	-210.03	737.69	-20,475.34
2	0.00	-229.56	806.30	-19,898.61
5	0.00	-299.75	1052.82	-17,826.18
10	0.00	-467.59	1642.31	-12,870.61
15	0.00	-729.40	2561.86	-5,140.34
16	0.00	-797.23	2800.12	-3,137.45
17	0.00	-871.37	3060.53	-9,48.29
18	0.00	-952.41	3345.16	1,444.46
19	0.00	-1040.98	3656.26	4,059.73
20	0.00	-1137.80	3996.29	6,918.22
25	0.00	-1774.86	6233.87	25,728.54

B. Solar system financial analysis

The solar system capital cost can be estimated using today's prices for solar collectors and operating pumps. The bill of quantities of a geothermal system is shown in Table 8.

Table 8: Solar system bill of quantities (BOQ)

Item	Unit Price	Amount	Total cost
Solar collector	£286/m²	58.1 m	£10,806.6
Heat pump (Neptuno® - VTP30)[1]	£1250 / pump		£2,500
Sub Total			£13,306.6
Installation cost (10%)	10% of capital cost		£1330.7
Total cost			£14,637.3

Table 8 presents that the BOQ for a solar system that releases annual cost savings equals 7,376.9 £.

The annual cost saving, M_{save}, in the first year can be determined for 20% saving as below:

$$M_{save} = (20\%)\frac{£32.3}{m^2} \times 114.3\ m^2$$

$$M_{save} = £7{,}376.9$$

Related to the above values the cash flow of using geothermal energy is presented in Table 9.

Table 9: Calculations of cash flow of the solar system

Year	Capital cost (£)	Operating cost (£/year)	Revenue (£/year)	Cumulative Balance (£)
0	-14637.26	0.00	0.00	-14,637.26
1	0.00	-146.37	737.69	-14,045.94
2	0.00	-159.99	806.30	-13,399.63
5	0.00	-208.90	1052.82	-11,077.18
10	0.00	-325.87	1642.31	-5,523.77
11	0.00	-356.17	1795.05	-4,084.89
12	0.00	-389.30	1961.98	-2,512.21
13	0.00	-425.50	2144.45	-793.26
14	0.00	-465.07	2343.88	1,085.55
15	0.00	-508.33	2561.86	3,139.09
20	0.00	-792.94	3996.29	16,652.41
25	0.00	-1236.93	6233.87	37,732.02

VII. CONCLUSION

The geothermal heating system design was achieved depending on estimating the selected house heat load, determining the required temperature of pipes to meet the estimated load, and obtaining the required depth, spaces, as well as size of the geothermal tubes. The heat load for the chosen house was determined during the design of the geothermal heating system. The optimal participation of geothermal power equals 50%, which is not ideal because of the high-pressure drop those results in significant energy losses. Because of the solar system's location, the water pump is smaller than the pump in a geothermal system. Moreover, the results showed that solar energy is more effective than geothermal energy because solar energy has a lower capital cost than geothermal energy.

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