Borehole Thermal Energy Storage System

The Borehole Thermal Energy Storage (BTES) system comprises a heat source, borehole thermal storage, and borehole heat exchangers (BHEs). Each BHE consists of a borehole filled with thermal grout and a U-tube that circulates a heat transfer fluid, typically water, along the vertical length of the borehole [1]. boreholes are typically drilled to depths ranging from 30 to 200 meters. However, research has explored much deeper boreholes to increase storage capacity while reducing the required number of boreholes. To minimize heat loss, insulation is installed underground to a depth determined by the soil and insulation properties. The charging temperature of the BTES system depends on the heat source [2]. Solar thermal collectors are commonly employed to provide heat at temperatures around 85-90°C, which is then used to charge the borehole storage [3].

The efficiency and effectiveness of a Borehole Thermal Energy Storage (BTES) system are influenced by numerous factors; Ground properties, such as thermal conductivity, thermal diffusivity, permeability, and undisturbed ground temperature, play a crucial role in determining the system's performance. Additionally, the design parameters of the system itself, including borehole depth and spacing, heat exchanger design, quality of borehole grouting, insulation around the boreholes, and pump efficiency, can significantly impact the system's operation. Other factors, such as the temperature difference between the ground and the heat transfer fluid, system load, and seasonal variations, also affect the system's performance. Furthermore, the geological conditions of the site, including soil types, and groundwater movement, can influence the system's effectiveness. The efficiency of the heat pumps used, as well as the maintenance and monitoring practices employed, also contribute to the overall performance. The scale and design of the district heating and cooling network determine how efficiently the stored heat can be distributed and utilized. Local climate conditions, such as ambient temperature and humidity, can also affect the system's efficiency and overall performance [4,5,6,7].

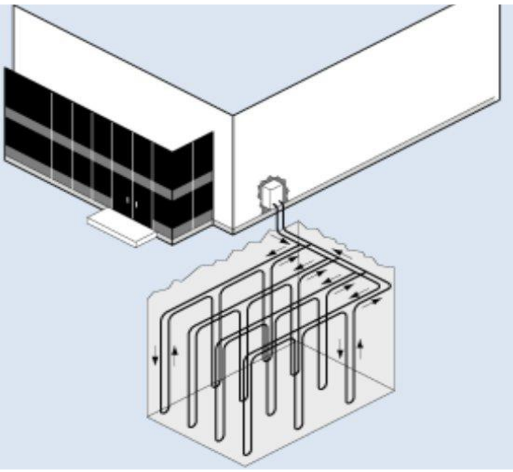


Figure 1vertical boreholes closed loop system.

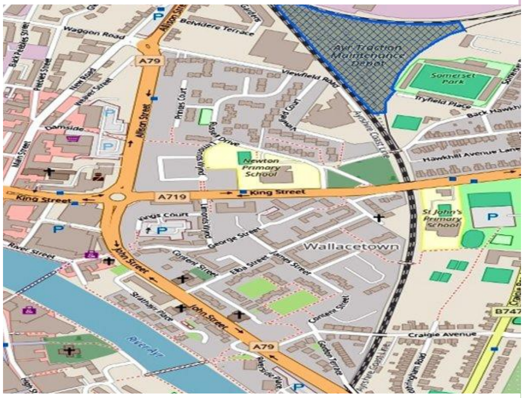


Figure 2:proposed boreholes location in Wallacetown.

The soil type in Wallacetown is carboniferous, with a thermal conductivity ranging from 1 to 2.5 W/m·K. Since the temperature of the fluid (water) is close to the ground temperature, thermal losses are considered negligible [8]. Referred to Halo project in Kilmarnock that will produce heat at rate of 2.1 GWh per year, equivalent to a steady rate of 239 kW, from a 2 km deep borehole. Extrapolation at a constant geothermal gradient would give a temperature of c. 69°C at 2 km depth. They suggested a smaller hole diameter (less than 0.75m) to figure out the best performance of this project considering local conditions and temperatures [9].

Thermal storage losses

Conduction Losses: Heat lost through the walls of the borehole due to conduction between the hot/cold fluid inside the borehole and the surrounding ground. This can be minimized by using high-quality insulation materials with low thermal conductivity around the borehole casing [10].

Heat Dispersion: Heat can dissipate into the surrounding ground if the ground has a lower thermal conductivity than the storage volume. This heat dispersion reduces storage efficiency. Locating multiple boreholes close together in an array can minimize dispersion by reducing the temperature gradient between the storage volume and surrounding ground [5].

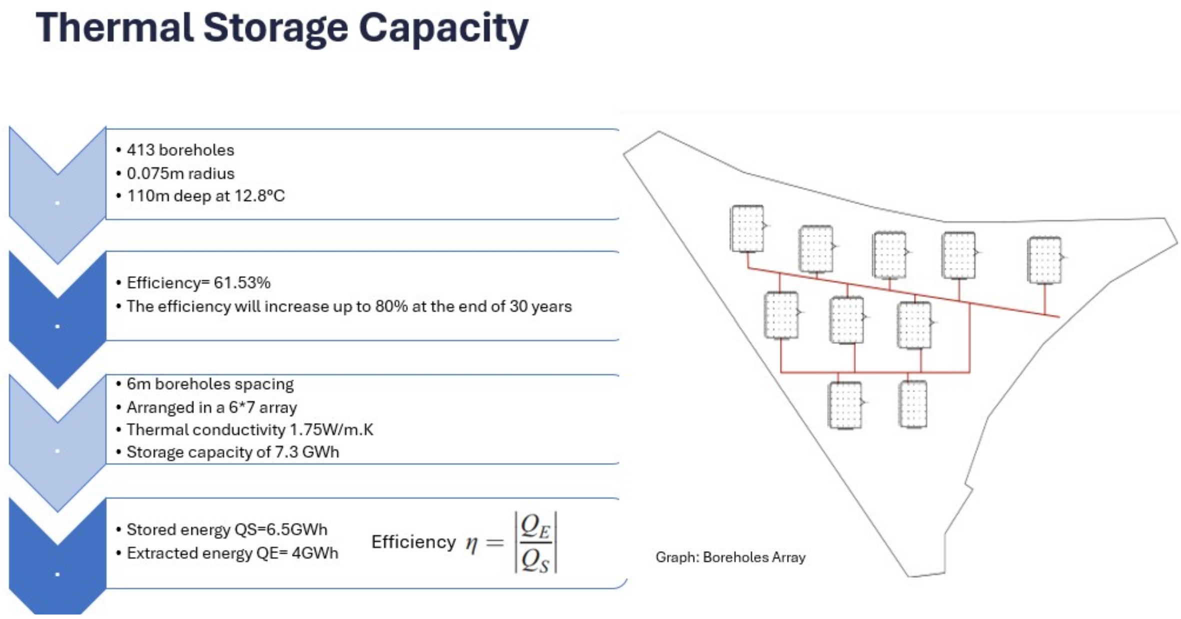
Temperature Gradient: Temperature gradients can develop along the length of the borehole, with the top being significantly warmer or cooler than the bottom. This temperature difference can lead to heat losses, as heat flows from the warmer regions to the cooler regions, reducing the overall storage efficiency [5].

Ground Losses: As mentioned, heat can be lost to the surrounding ground due to the temperature difference between the storage volume and the undisturbed ground temperature. These ground losses increase with higher storage temperatures and larger surface area of the borehole field [5].

System Inefficiencies: Other system inefficiencies, such as heat losses through the top insulation layer, can also contribute to the overall heat losses in borehole thermal energy storage systems [10].

Results

From the calculations of the storage magnitude, using a conservative estimate for the losses the following results were found from both excel and npro. The storage has 413boreholes,110m deep and can store 7.3GWh with efficiency of 61.5% that increases over time up to 80%. They are arranged in a 6*7 array for efficiency [11]. Other details for the storage are in the slide below.



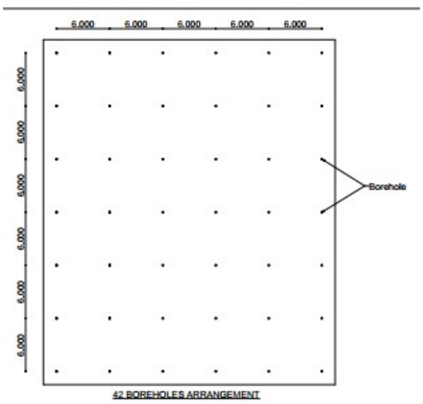


*Figure 3: boreholes Arrangement 6*7*

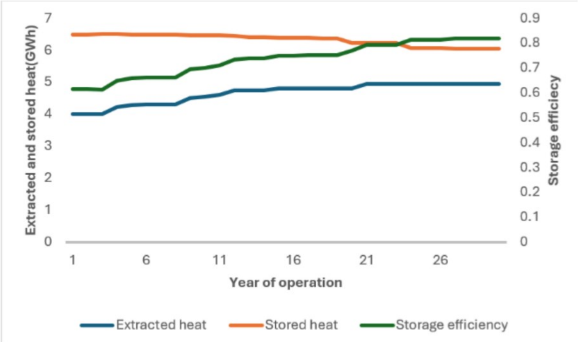


Figure 4: storage efficiency.

Graph 4 shows how both stored and extracted energy vary and the storage efficiency increase over time. “When excess energy is stored in the boreholes, it acts as insulation, which reduces future losses”.

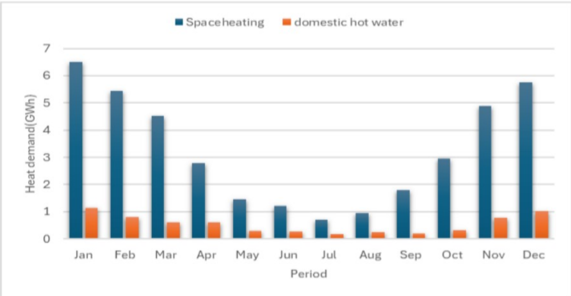


Figure 5:stored energy distribution.

Graph 5 demonstrate how the extracted energy from the storage will be distributed for both space heating and domestic hot water with over 85% of the energy to be used for space heating with the maximum extraction of 6.5GWh in January.

Formulas

Equation 1: velocity

$$v_1 = \sqrt{\frac{P_2 + pgy_2 - P_1 - pgy_1}{0.5p - 0.5p\left(\frac{A_1}{A_2}\right)^2}}$$

P: pressure, g: gravity,Y: distance, A: Area

Equation 2: stored heat

$$\dot{Q} = \dot{V}_f \rho_f C_f (T_{\text{in}} - T_{\text{out}})$$

V: Volume of the storage, C: specific heat capacity, ρ: density, Δt: temperature difference between the ground and the fluid(K)

Equation 3: Storage Volume

$$V = \frac{E_+}{\Delta T \cdot C}$$

E+: stored energy demand, C: specific heat capacity, Δt: temperature difference between the ground and the fluid(K)

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