The Effect of Global Warming on BTES Systems

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ABSTRACT

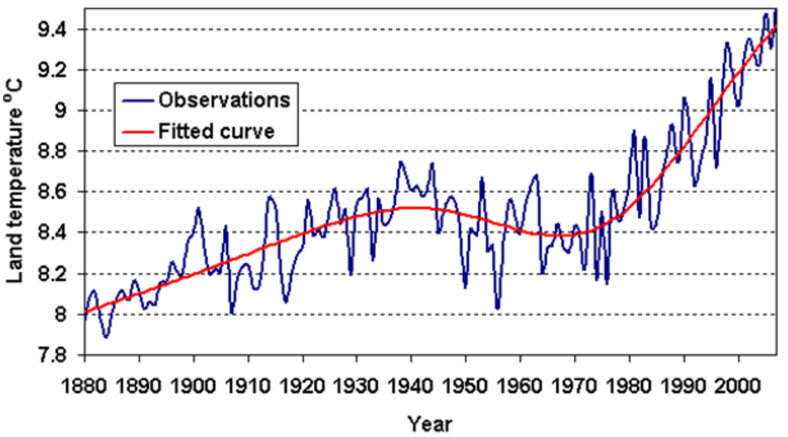
Global warming (GW) is linked to the use of conventional energy, mainly fossil fuels. There is a general understanding that the way to reduce GW is more efficient use of energy and increased use of renewable energy. Heating and cooling of buildings account for more than one third of the world's primary energy consumption. Using the ground as a heat/cold source means more sustainable heating and cooling. The ongoing GW means that heat is accumulating in air, ground and water. Since BTESs are using the ground as a source of heat and cold, such systems are affected by the increasing ground temperature. Thus, heat is more easily extracted and heating demand is reduced. The warmer ground means that it is more difficult to use the ground as a cold source, while the cooling demand increases. Here, the effect of GW on the performance of BTESs was analyzed for different GW.

1. Introduction

It is generally accepted that the global mean air temperature has increased since 1880. This phenomenon called Global Warming (GW) means that the ground temperature has increased as well. Fig1 shows the global land area temperature (air temperature over the continents) has been increasing of 1.4 °C between 1880 and 2007(NCDC, 2008).

The ground source heat pump (GSHP) system is used for both heating and cooling and is energy efficient and environmentally clean. In such systems, thermal energy is extracted and/or injected from/to the ground as a source or a sink for energy (John et al., 2005, Hepbasli, 2005 and Florides, 2008).

According to the fact that the heat transfer rate between two objects depends on the temperature difference between them, heat extraction from a warmer ground will be easier; while injecting heat into it is more difficult. The heating and cooling demand of a building is generally proportional to the mean air temperature (Durmayaz et al., 2000). Consequently, the ongoing global temperature increase affects both the heating and cooling demand of buildings. The overall objectives of this paper were to study how GW affects the heating and cooling demand of a certain building in combination with how GW affects a GSHP system. This was accomplished by calculating energy demand for a reference building. The total borehole length required for the GSHP system was also calculated. Both of these calculations were made for three different GW scenarios. Three global warming scenarios were studied. It was assumed that the land surface temperature was linearly changed since 1880 by 1.5, 3.0, and 4.5°C, Fig 2.



Figur 1 Global Land Area Temperature

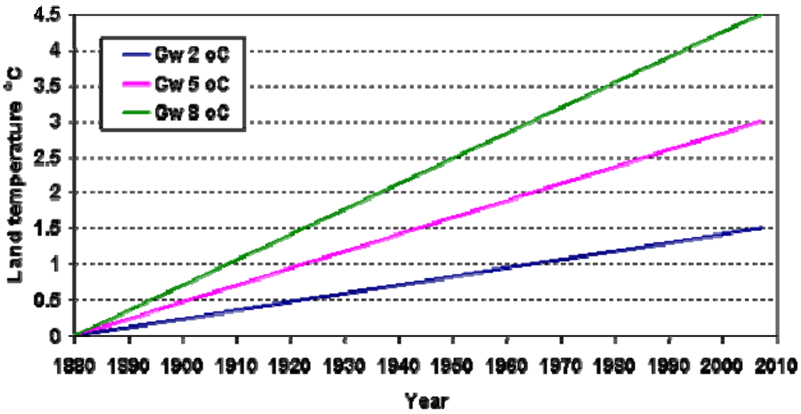


Figure 2. The three different GW scenarios used.

2. Determination of Ground Temperature Increase due to GW

In special cases, the heat conduction equation can be simplified to obtain the general heat conduction equation Eq (1) (Massoud, 2005):

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau} \qquad (1)$$

where T represents ground temperature and α thermal diffusivity of the ground. In our case (increasing ground surface temperature) the ground can be treated as a semi-infinite solid. Mathematically this is expressed as $0 \le x < \infty$, $-\infty < y < \infty$ and $-\infty < z < \infty$

The governing equation for a semi-infinite solid is the 1-D, x-direction (depth direction):

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau} \qquad (2)$$

The temperature of the ground is given by solving Eq. 2 numerically. Taking into account that Eq. 2 is linear, the superposition principle holds, and a constant temperature distribution may be added to any solution, i.e. the geothermal gradient can be added to the final solution (Winterberg, 1991). Fig 3 shows the temperature through the ground corresponding to GW equals to 0.0, 1.5, 3.0 and 4.5 °C. The following assumptions were used: Mean thermal conductivity of the ground λ=3 W/m.K, geothermal heat flow q=0.07 W/m^2 and volumetric heat capacity C=2.4 MJ/m^3.K.

Considering ground surface temperature is equivalent to zero, we can calculate the mean ground temperature changes due to GW instead of calculating ground temperature itself, e.g. considering the previous assumption the mean change of ground temperature down to 100 m depth due to GW=3 °C equals to 1.44 °C. Fig 4 shows mean change of ground temperature due to GW.

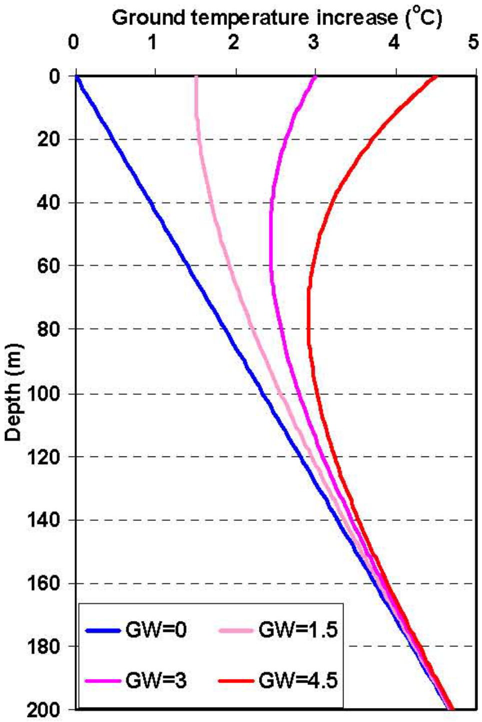


Fig. 3. Ground temperature increase and mean change until 100 m at different global warming. Assumed λ=3 W/m.K, q=0.07 W/m², C=2.4 MJ/m³.k.

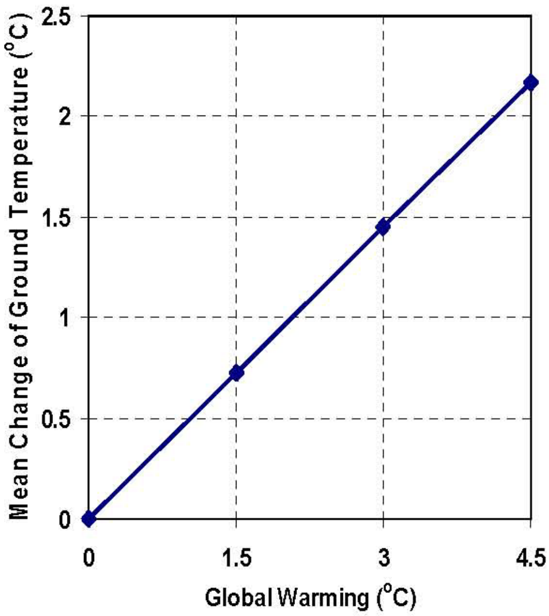


Fig. 4. Mean change of ground temperature due to GW down to 100 m depth. λ=3W/m.K, C=2.4 MJ/m³.K, q=0.07 W/m²

3. Heating and Cooling Demand Change Due to GW

By using the Degree-Hours (DH) Method, the effect of GW on the heating/cooling demand of a building can be determined. The total number of heating degree-hours (DHh) for the complete heating season can be expressed as (Durmayaz et al., 2000 and Guttman et al., 1992)

$$DHh = \sum_{j=1}^{N} (T_i - T_o)_j \qquad when\ is \quad T_o \le T_b \qquad (3)$$

While for cooling (DHc)

$$DHc = \sum_{j=1}^{K} (T_o - T_i)_j \qquad when\ is \quad T_o \ge T_b \qquad (4)$$

Where T_b is the base temperature and T_i represents the indoor design temperature, T_o is the hourly ambient air temperature measured at a meteorology station, N is the number of hours providing the condition of $T_o \le T_b$ in a heating season while K is the number of hours providing the condition of $T_o \ge T_b$ in a cooling season. From long records of measurements and experience, the indoor temperature is designed to be maintained at 20 (Durmayaz et al., 2000) and 23 °C (Sekhar, 2005) in heating and cooling season, respectively. Taking into consideration the fact cooling and heating days have been found to be represented by base levels of 24 and 15 °C, respectively, (Durmayaz et al., 2000 and Kadioglu et al., 1999).

The seasonal outdoor air temperature in the chosen region is assumed as a sinusoidal curve from -3 to 29 °C, so that, the seasonal fluctuation of air temperature would be expressed by Eq. 5:

$$T(t) = T_a + \Delta T_a \cdot \cos\left[\frac{2\pi \cdot t}{8760}\right] \qquad (5)$$

Where T_a is mean ambient air temperature, ΔT_a is amplitude of temperature variation and t represents time during the year. Fig 5 shows the temperature variation during an entire year in chosen area. In this case, by using the Eq.3 and Eq.4, the total number of heating DH by the areas $A_{12341}+A_{56785}$ and the corresponding cooling DH by the area A_{abcdea}, see fig 5. These areas are calculated by integrating Eq.6; consequently, to calculate A_{12341}:

$$A_{12341} = \int_0^c \left(T_i - T(t)\right) \cdot dt \qquad (6)$$

Where c is the time providing the condition of $T(t) \leq T_b$

The heating/cooling demand of a building is caused by the heat transfer through building envelope and ventilation. Let us assume that the seasonal average air exchange rates per hour is I (1/h); the roof, outside wall, glazing and floor areas is A (m^2) thermal transmittance of the building envelope U (W/m^2 K), volumetric heat capacity of air $(\rho c_p)_{air}$ (J/kg.K) and the total volume of the building is V, m^3.

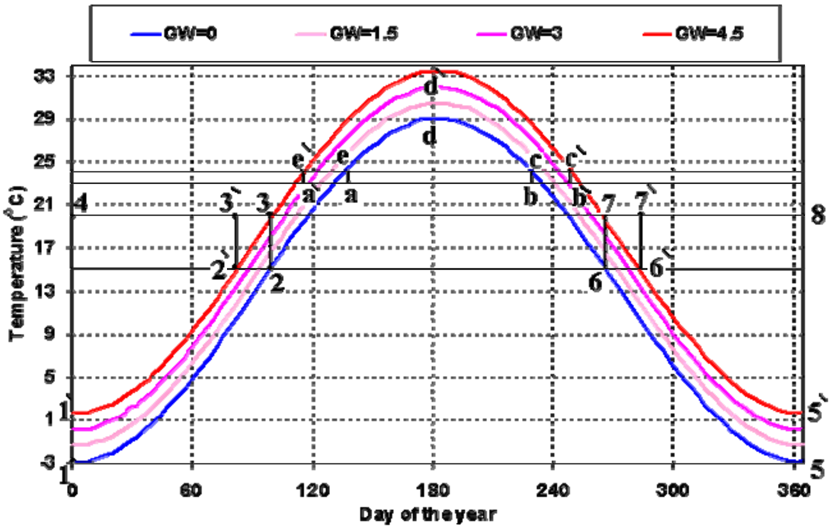


Fig. 5. The seasonal outdoor air temperature in the chosen region

Thus, using Eq.7, we can calculate the total heat loss coefficient of the chosen building, L (W/K) as follow

$$L = \frac{(\rho C_p)_{air} \cdot I \cdot V}{3600} + \sum U \cdot A \qquad (7)$$

Finally, seasonal energy requirements, Q (J), for heating is

$$Q_h = 3600 \cdot L \cdot DHh \qquad (8)$$

and for cooling is

$$Q_c = 3600 \cdot L \cdot DHc \qquad (9)$$

From Eq.7, 8 and 9 we see that required energy for a building is a function of DH, i.e. a function of the ambient air temperature. Fig 5 shows that with increasing ambient air temperature the total number of heating and cooling DH will decrease and increase, respectively. Thus, for the case of GW=4.5 ^oC, Eq.8 and Eq.9 show that the ratio of required energy for heating before and after GW is equivalent to the ratio between the two areas ($A_{1`2`3`41`}+A_{5`6`7`85`}$) and ($A_{12341}+A_{56785}$), see fig 5. For the cooling demand, the corresponding ratio is given by the two areas ($A_{a`b`c`d`e`a`}$) and (A_{abcdea}). This is expressed by Eq.10 and Eq.11;

$$\frac{Q_{ha}}{Q_{hb}} = \frac{A_{1`2`3`41`} + A_{5`6`7`85`}}{A_{12341} + A_{56785}} = \frac{DHha}{DHhb} \quad \text{for heating} \qquad (10)$$

$$\frac{Q_{ca}}{Q_{cb}} = \frac{A_{a`b`c`d`e`a`}}{A_{abcdea}} = \frac{DHca}{DHcb} \quad \text{for cooling} \qquad (11)$$

where Q_{hb} and Q_{ha} are the energy required for heating before and after GW, respectively. It should be noticed, when cooling is >0 the ratio between seasonal heating Q_{hb} and cooling Q_{cb} demands before GW has to be equal to the ratio between the area ($A_{12341}+A_{56785}$) and A_{abcdea} in fig 5

$$\frac{Q_{hb}}{Q_{cb}} = \frac{A_{12341} + A_{56785}}{A_{abcdea}} \qquad (12)$$

In this paper for the prototype building in the chosen region, and by use of Eq.6 and fig 5, this ratio was found to be $\frac{Q_{hb}}{Q_{cb}}$=7.95. Therefore, the heating and cooling demand for this study were assumed 32 and 4 MWh, respectively. Using Eq.10 and Eq.11 for each scenario of GW, we have calculated the heating and cooling demand after global warming, which is tabulated in table 1.

Fig 6 illustrates the change in heating/cooling energy requirements due to GW. As it is shown, heating demand is decreasing while cooling demand is reducing.

Table 1 effect of GW on DH and energy demand

	Global Warming ^{o}C			
	0	1.5	3	4.5
Q_{ha}/Q_{hb}	1	0.894	0.793	0.697
Q_{ca}/Q_{cb}	1	1.411	1.869	2.372
DHh (h)	77370	69170	61350	53920
DHc (h)	9735	13740	18200	23090
Cooling demand (MWh)	4	5.645	7.478	9.487
Heating demand (MWh)	32	28.608	25.374	22.301

To determine individual month heating share from seasonal heating demand, we have deduced the percentage of degree-hours for every heating month from the total number of heating degree-hours DHh Consequently, percentage of heating requirement for individual month from the total heating demand was found. Similarly was done for cooling season. The results are tabulated in table 2 and shown the fig 7

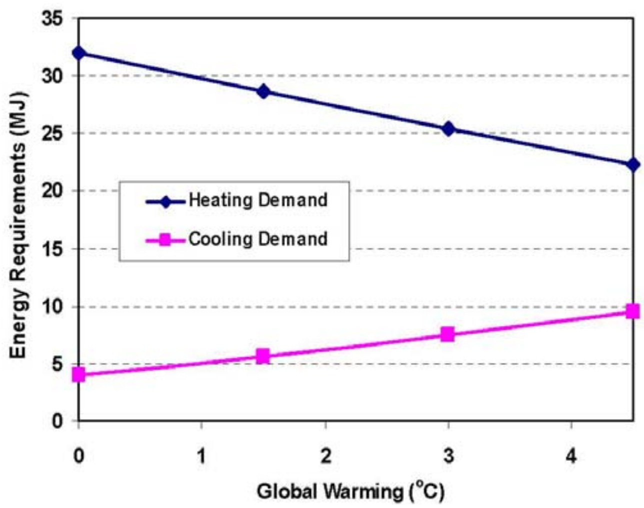


Fig. 6. Change in heating/cooling demand due to GW

4. Determination of Borehole Systems Change Due to GW

Using the assumptions shown in table 3, three types of simulations were made;

- Considering the ground temperature increase

- Considering the change in heating/cooling demand
- Considering both these two factors (ground temperature increase and the change in heating/cooling demand.

Table 2 individual month share from heating/cooling demand of the entire year

	Heating				Cooling			
Month	GW=0	GW=1.5	GW=3	GW=4.5	GW=0	GW=1.5	GW=3	GW=4.5
Jan	0.214	0.223	0.233	0.244	0	0	0	0
Feb	0.158	0.162	0.167	0.171	0	0	0	0
Mar	0.109	0.106	0.096	0.081	0	0	0	0
Apr	0.015	0.006	0	0	0	0	0	0.008
May	0	0	0	0	0.098	0.134	0.163	0.178
Jun	0	0	0	0	0.387	0.353	0.325	0.303
Jul	0	0	0	0	0.407	0.370	0.340	0.316
Aug	0	0	0	0	0.108	0.143	0.172	0.184
Sep	0.013	0.004	0	0	0	0	0	0.011
Oct	0.107	0.103	0.091	0.076	0	0	0	0
Nov	0.169	0.174	0.179	0.183	0	0	0	0
Dec	0.214	0.223	0.234	0.245	0	0	0	0

These simulations were computed, for each one of the four different scenarios of GW, using EED (EED, 2008) program in order to calculate total borehole length that is required to supply both heating and cooling energy requirement. Results are shown in table 4; and illustrated in fig 8 and 9.

For the filling material in the boreholes, it was assumed to have the same thermal properties as the ground, as it provides a better condition for heat transfer.

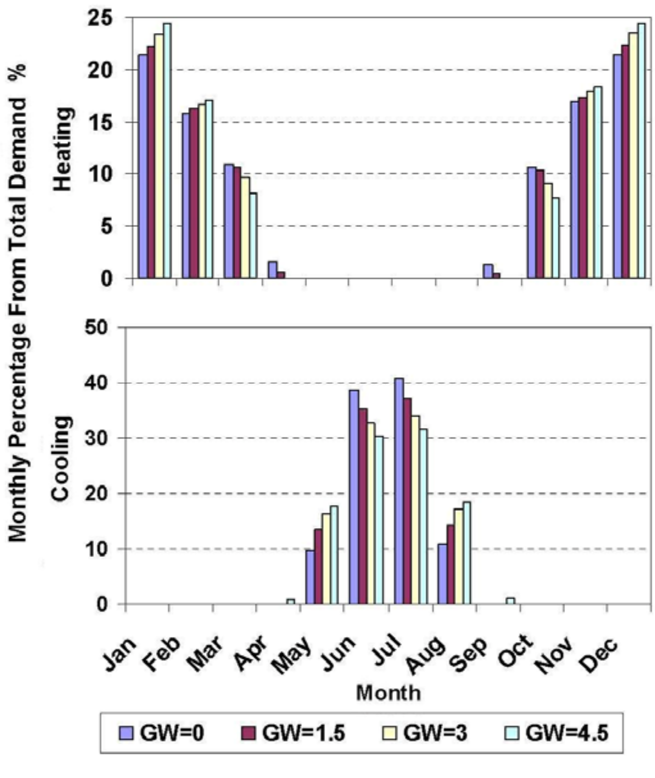


Fig. 7. Monthly share of total energy demand for heating and cooling

As seen in figure 8, increasing global temperature reduces the totally required borehole's length. It is also seen that the change in heating and cooling demand due to GW has a greater effect on borehole systems than the change in ground temperature, fig 8 and 9.

Table 3 Assumptions made for the borehole system design.

Ground temperature (^oC)	0	Pipe outer diameter of pipe (m)	0.032
Borehole type	Single-U	Pipe wall thickness (m)	0.003
Borehole Configuration		Thermal conductivity (W/m,K)	0.42
Borehole Spacing (m)	6	Pipe shank spacing (m)	0.07
Borehole Diameter (m)	0.11	Filling thermal conductivity (W/m,K)	3
Flow rate (m^3/s)	0.002	Minimum mean fluid temperature (^oC)	-5
Contact resistance (m,K/W)	0	Maximum mean fluid temperature (^oC)	2

Table 4 Total borehole length of the borehole system as a function of global warming.

	Required total borehole length					
	change in demand and ground temperature		Change in ground temperature		Change in the demand	
GW (^oC)	Total length (m)	Change %	Total length (m)	Change %	Total length (m)	Change %
0.0	414.7	0.0	414.7	0	414.7	0
1.5	337.0	18.7	374.5	9.7	374.9	9.6
3.0	263.0	36.6	340.0	18.0	323.9	21.9
4.5	206.0	50.3	310.6	25.1	282.0	32.0

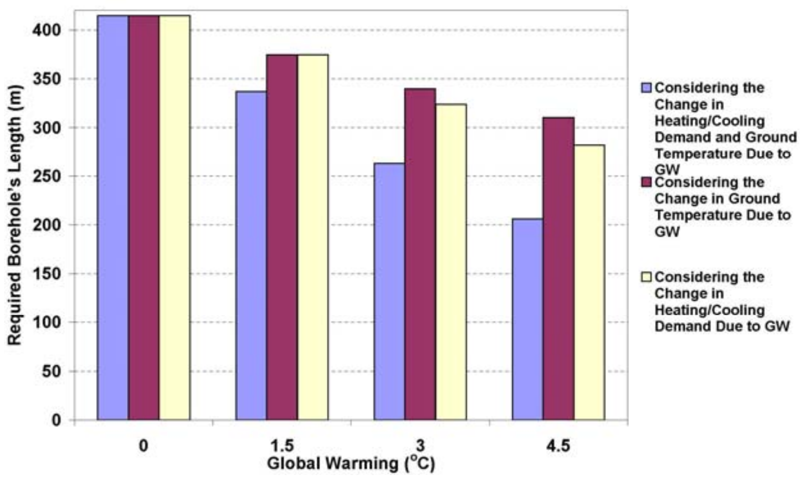


Fig. 8. Total required borehole length vs. GW.

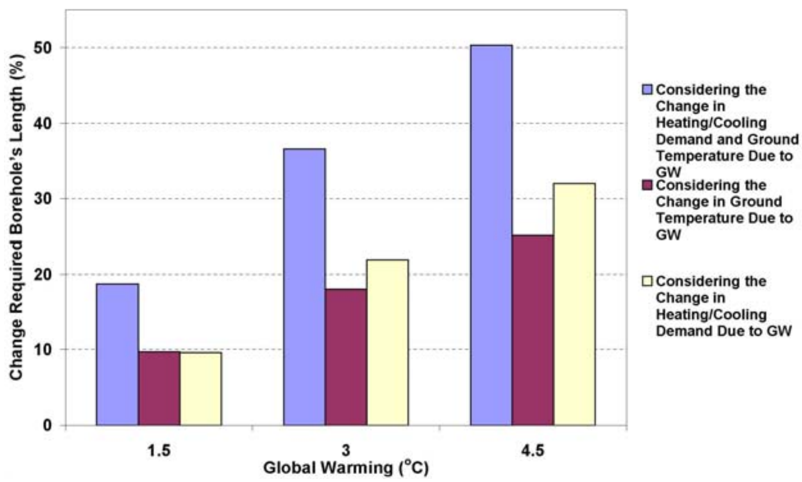


Fig. 9. Change required Borehole length as percentage of total length before GW.

5. Conclusion

- In a region where the ground has thermal properties similar to what were assumed in this study, the change of ground mean temperature almost equals 50% of the ambient air temperature change.
- The total number of heating and cooling degree-hours (DH) is suitable to study the effect of GW on the heating/cooling demand of a building.
- The cooling demand increases and heating demand decreases due to GW
- In the case that the heating demand is greater than the cooling demand, GW will make existing borehole systems more efficient, while future systems will be cheaper, since fewer boreholes are needed.

Performed study is made for a building with considerably greater heating demand than cooling demand. In continued work, the varying heating and cooling demand will be studied.

6. References

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