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Underground diurnal and seasonal energy storage for a cooling and heating system in a retail building in Jerez de la Frontera / Spain

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1. Introduction

In the southwest of Spain, an international company has projected and built a new retail outlet in Jerez de la Frontera. A little more than fifteen km from the Atlantic Ocean, Jerez is characterized by mild winters and very hot and dry summers, with 17.7 °C annual average. The extreme temperatures in August in a long-term average rise to 33.1 °C maximum and fall to 18.4 °C minimum, and the actual readings exceed 38 °C each year on several occasions. Thus cooling demand in this region exceeds any heating demand by far, in particular in commercial buildings with lot of internal heat sources. Designing a Borehole Thermal Energy Storage (BTES) for cooling under these conditions requires unconventional solutions; seasonal storage is hardly feasible, with mean temperatures in winter not lower than 10 °C (figure 1).

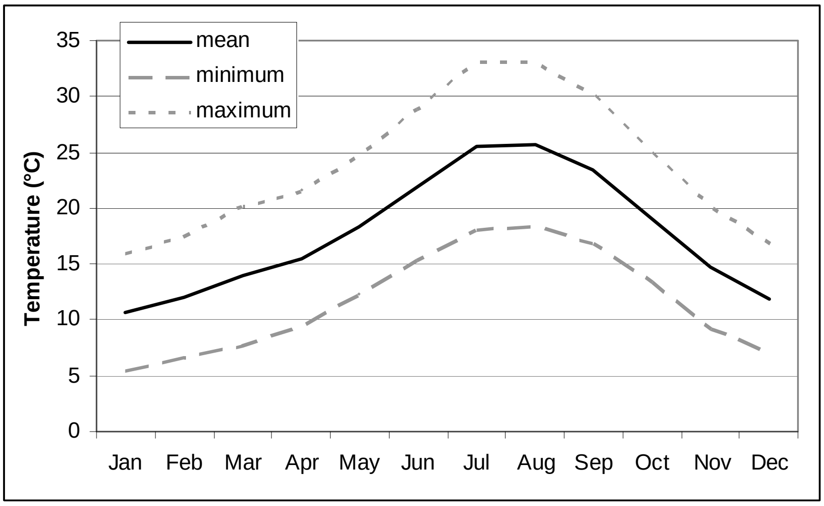

Figure 1: Average temperatures 1971-2000, after published data for Jerez Airport

2. Building demands

The company has equipped already a number of large stores in Northern Europe with Underground Thermal Energy Storage (UTES) systems (both with borehole heat exchangers as with groundwater wells), but the one in Jerez is quite different for the specific climatic conditions it has to deal with. Given the climate of Jerez and the building design and concept used for the retail building, there is a totally unbalanced thermal energy demand:

Heating demand: 75 MWh/a

Cooling demand: 4’104 MWh/a

Thus heat accounts for only 1.8% of the demand for cooling, i.e. the cooling takes 54 times more energy than heating. The monthly building loads are given in figure 2; even in winter, the monthly cooling demand is higher than heating demand!

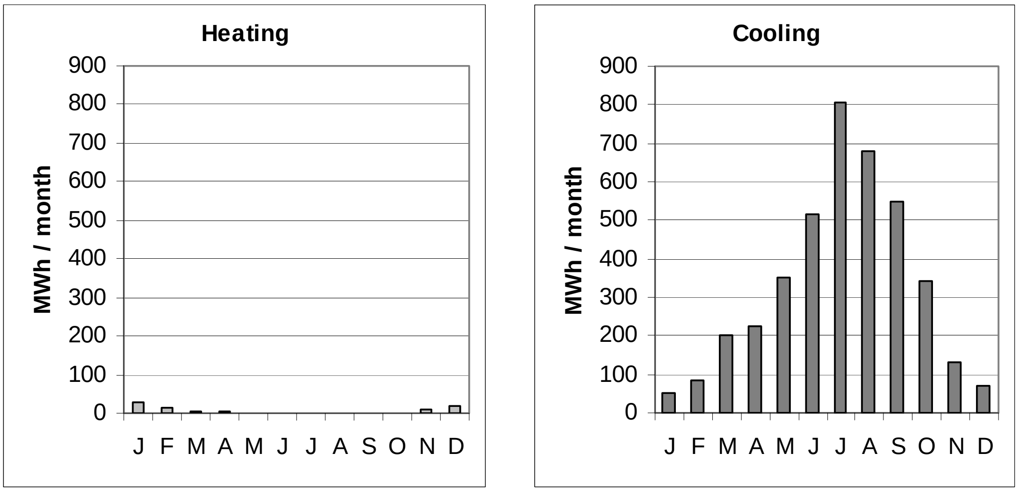

Figure 2: Monthly heating demand for retail building in Jerez de la Frontera

3. Design considerations and underground investigation

The design target under these conditions was to create a geothermal HVAC system that covers the full (small) heating demand and a part of the total cooling demand, in order to achieve the goal of at least 56 tons of reduction in CO_2 emissions, as compared with other energy sources.

For these extremely unbalanced demands, a substantial part of the cooling can only be covered if sufficient cold is stored in the underground, or in other terms, surplus heat is extracted from the underground. The final design hence did not only include cold storage in wintertime for a seasonal balancing, but also short-term cold storage during night in summer. A similar concept was already proposed for use in Egypt by Abbas & Sanner (1999). With using all time available for heat extraction, considering the periods when ambient air temperature is sufficiently lower than ground temperature, a maximum annual cooling supply of about 700 MWh/a might be achieved.

For the BHE design, a thermal response test (TRT) had been done in advance. The resulting value of the first TRT, 1.5 W/m/K, was lower than expected for the Tertiary rocks on site; however, the temperature curves and in particular the step-wise (sequential) evaluation (figure 3) gave no hints for errors. For confirmation, two more TRT were done during construction of the BHE field and yielded the same result. The undisturbed underground temperature was 19.8 °C, a rather high value compared to classical UTES countries like Sweden or the Netherlands. Figure 4 shows a map created by BGRM within the Geotrainet project, giving typical data for the undisturbed ground temperature (in the neutral zone, i.e. below the region of seasonal temperature influence), and the location of Jerez de la Frontera.

From their daily practice, the authors have experienced frequent misunderstandings when architects or HVAC-designers from one region are involved in projects in a different climatic zone. Obviously, climatic data will be different than at home; however, it is important to understand that not only the climate, but also the underground temperatures are different – and have a crucial impact on the UTES performance!

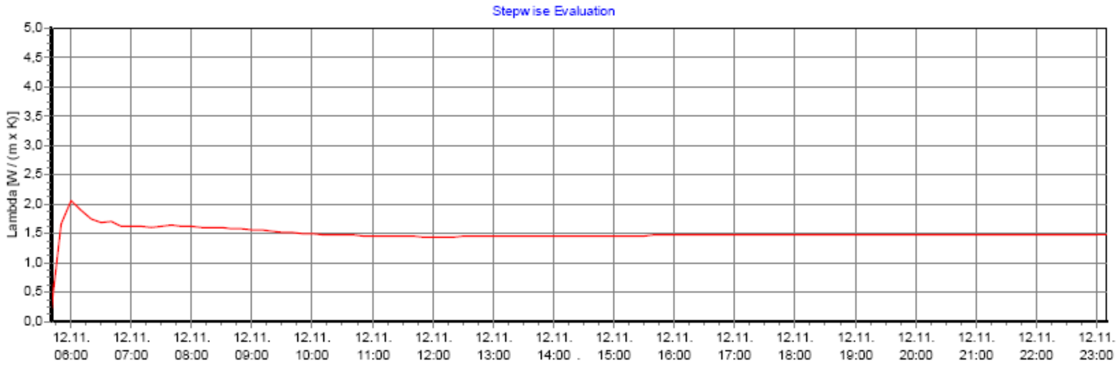

Figure 3: Step-wise evaluation of TRT in Jerez, Nov. 2009

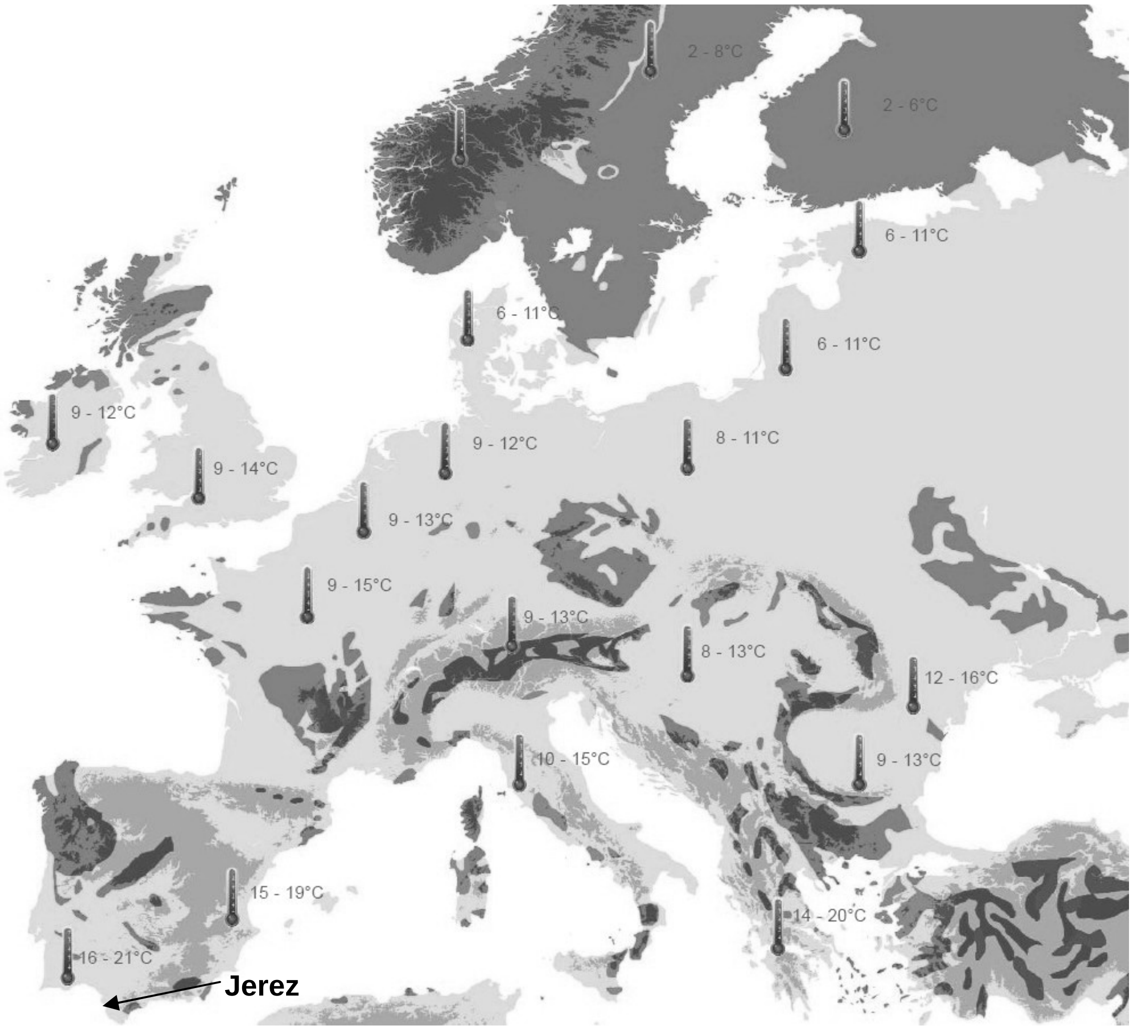

Figure 4: Map of typical underground temperatures in the neutral zone in Europe (BRGM, from www.geotrainet.eu)

4. Design calculations

From economic considerations, the maximum number of BHE was limited to 50, with a maximum distance of 8 m among each, and a maximum depth of 130 m. So the design task was more to check what would be the maximum cooling that could be provided by a BHE-field of this size. Calculations using a standard approach resulted in the possible loads given in table 1; of the annual cooling demand of >4 GWh, only about 7 % could be covered by BTES that way.

Table 1: Load data on building and ground side for standard case (without active re-cooling of the ground)

	Building supply	BTES coverage	expected SPF	BTES inj./extr.
Heating	75 MWh/a	100 %	5	60 MWh/a
Cooling	300 MWh/a	7 %	3	450 MWh/a

For the BTES design, the software EED was used. Being around for quite some years (Hellström & Sanner, 1994), EED now is in version 3.16 from 2010, and can be considered one of the standard tools for design of borehole heat exchangers (BHE). The validity of EED calculations could be confirmed in several monitoring projects, the latest publication is Bohne et al (2012). For calculation with EED, the thermal loads have to be stated as monthly loads. As the geothermal coverage of the cooling load is so small, an almost steady operation over the whole year for the very base load can be assumed (figure 5). The heating in wintertime is only able to reduce the heat injection into the BHE field, but not to turn it into heat extraction. As a result, the operation would not be storage at all, but heat dissipation into the underground. In consequence, the temperature would rise constantly over the 25 years of operation calculated with EED, and further on (figure 6).

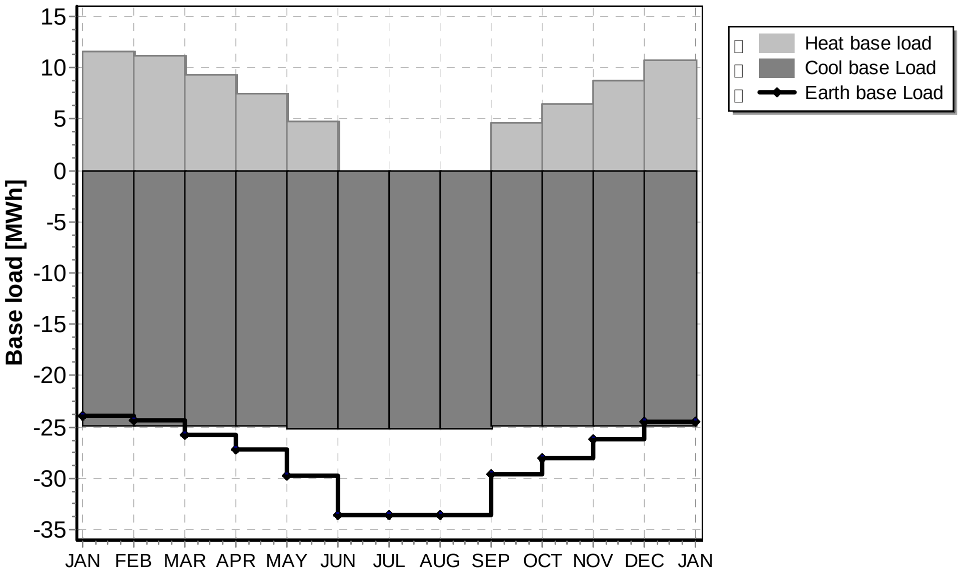

Figure 5: Monthly load distribution for standard case (without active re-cooling of the ground)

In order to increase the thermal output of the BHE field, active heat extraction from the underground (re-cooling) is required. While the standard case as shown in figures 5 and 6 does only use the heat extraction for heating in winter as cold source for the underground, optimum design would have to consider additional cold sources. Anything could be used as cold source as long as the temperature is sufficiently lower than the temperature in the underground. With annual average ground temperature of >19 °C, ambient air on cold winter days (below about 10-12 °C) can be used efficiently for re-cooling. This way a real storage operation (BTES) will be achieved. With rising ground temperature after several years of operation, air temperatures of 15 or more might be used for re-cooling. The time period for re-cooling in winter thus will increase over the years, and thus the amount of possible heat extraction from the BTES.

For the winter months, a monthly re-cooling of about 25 MWh could be achieved that way, in addition to the heat extracted while heating with the heat pump. However, re-cooling in winter only would be sufficient to increase the share of cooling from the BTES as desired. Again, additional cold sources for re-cooling need to be investigated.

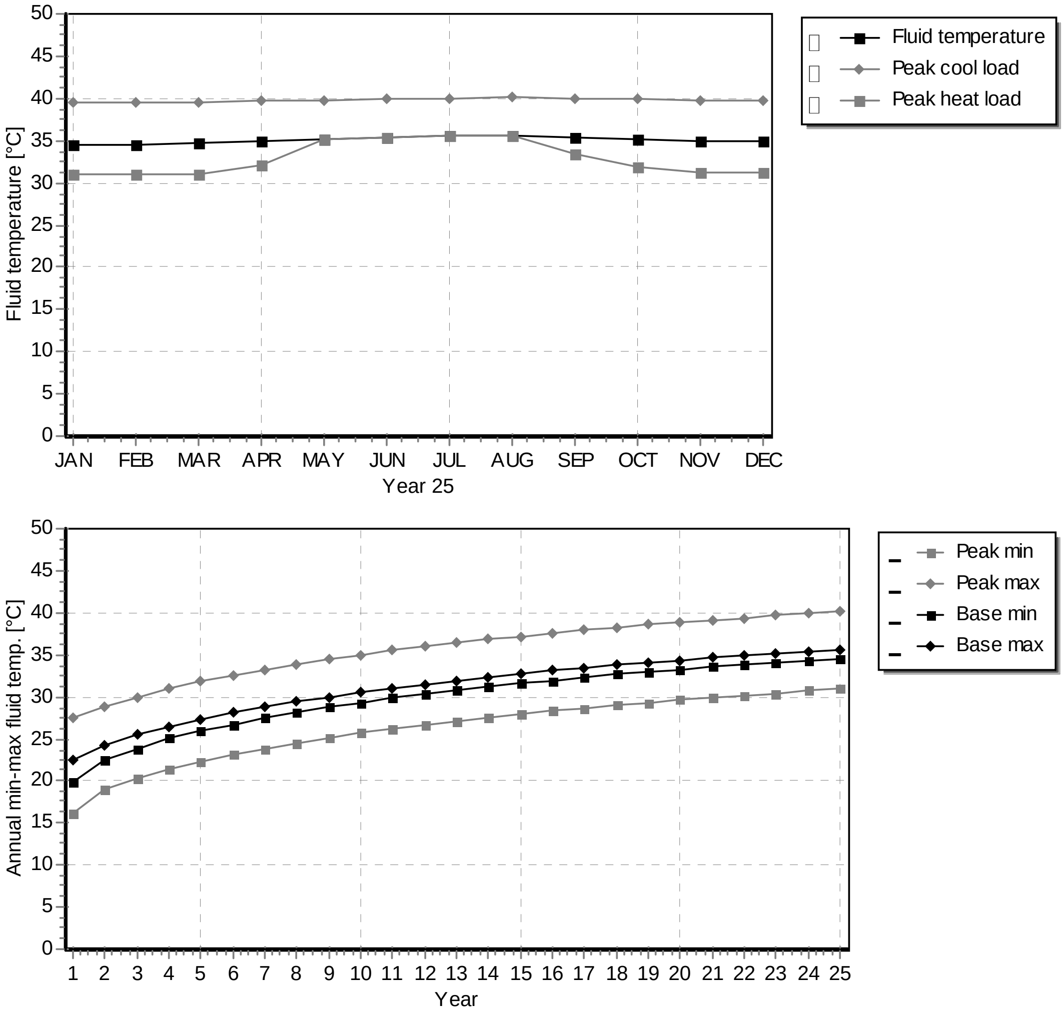

Figure 6: Results of EED-calculation for standard case (without active re-cooling of the ground), load data as shown in figure 5

Even in summertime, ambient air at night can be colder than the temperature in the BTES. The temperature in the underground will rise steadily over the years, not only in the standard case (fig. 6), but also when active re-cooling is done; in the latter case the increase will just be slower. So the opportunities for re-cooling with nighttime ambient air will improve over time. Weather data from nearby Cadiz (figure 7) were used to assess the amount of re-cooling that could be done during spring, summer and autumn. In order to use the cold from the ground efficiently, now no cooling from BTES was assumed, as the lower ambient air temperatures in wintertime will allow for efficient use of air coolers. Using the ground for cooling is more desirable in summer, when ground temperatures are much lower than cooling water from air coolers. Eventually, the monthly load curve as shown in figure 8 was deemed feasible, resulting in load data as given in table 2.

Table 2: Load data on building and ground side for maximum re-cooling case

	Building supply	BTES coverage	expected SPF	BTES extr. heating	BTES extr. re-cooling	total BTES inj./extr.
Heating	75 MWh/a	100 %	5	60 MWh/a	420 MWh/a	480 MWh/a
Cooling	530 MWh/a	13 %	3	-	-	795 MWh/a

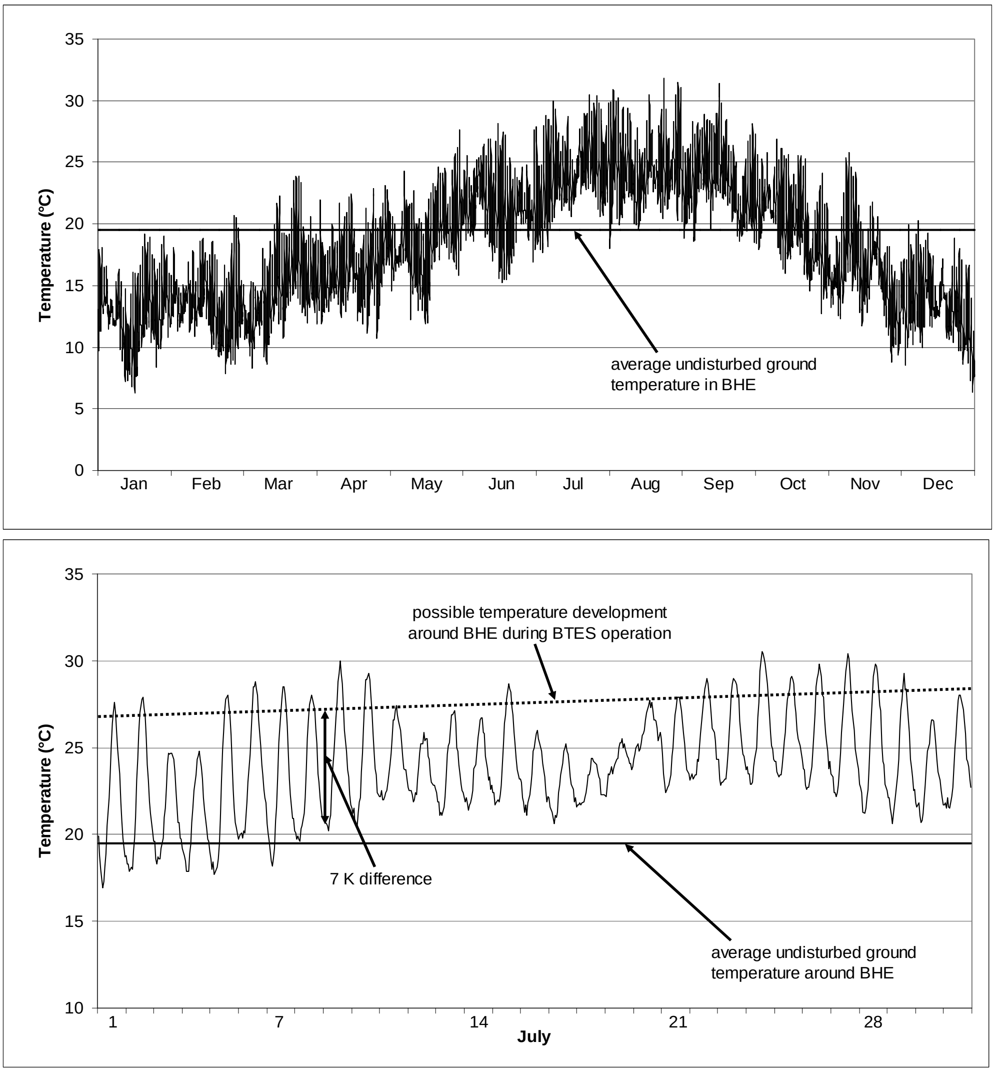

Figure 7: Hourly dry air temperature data for Cadiz (from Spanish Meteorological Service) and ground temperatures in undisturbed situation and during BTES operation

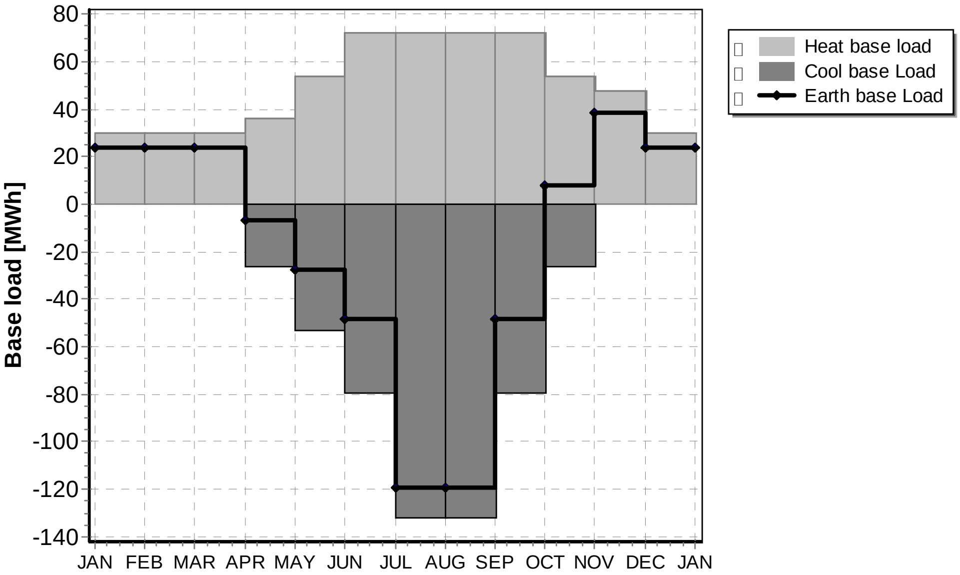

Figure 8: Monthly load distribution for maximum re-cooling case

Calculations with EED using the values in table 2 and figure 8 resulted in the temperature development shown in figure 9. The increase with operating years is not as steep as in the standard case (figure 6), and the temperature development over an individual year is much more pronounced. The storage effect can be seen more clearly here, with 20 °C in January and 35 °C in July after 5 years, and 25 °C in winter and 40 °C in summer after 25 years.

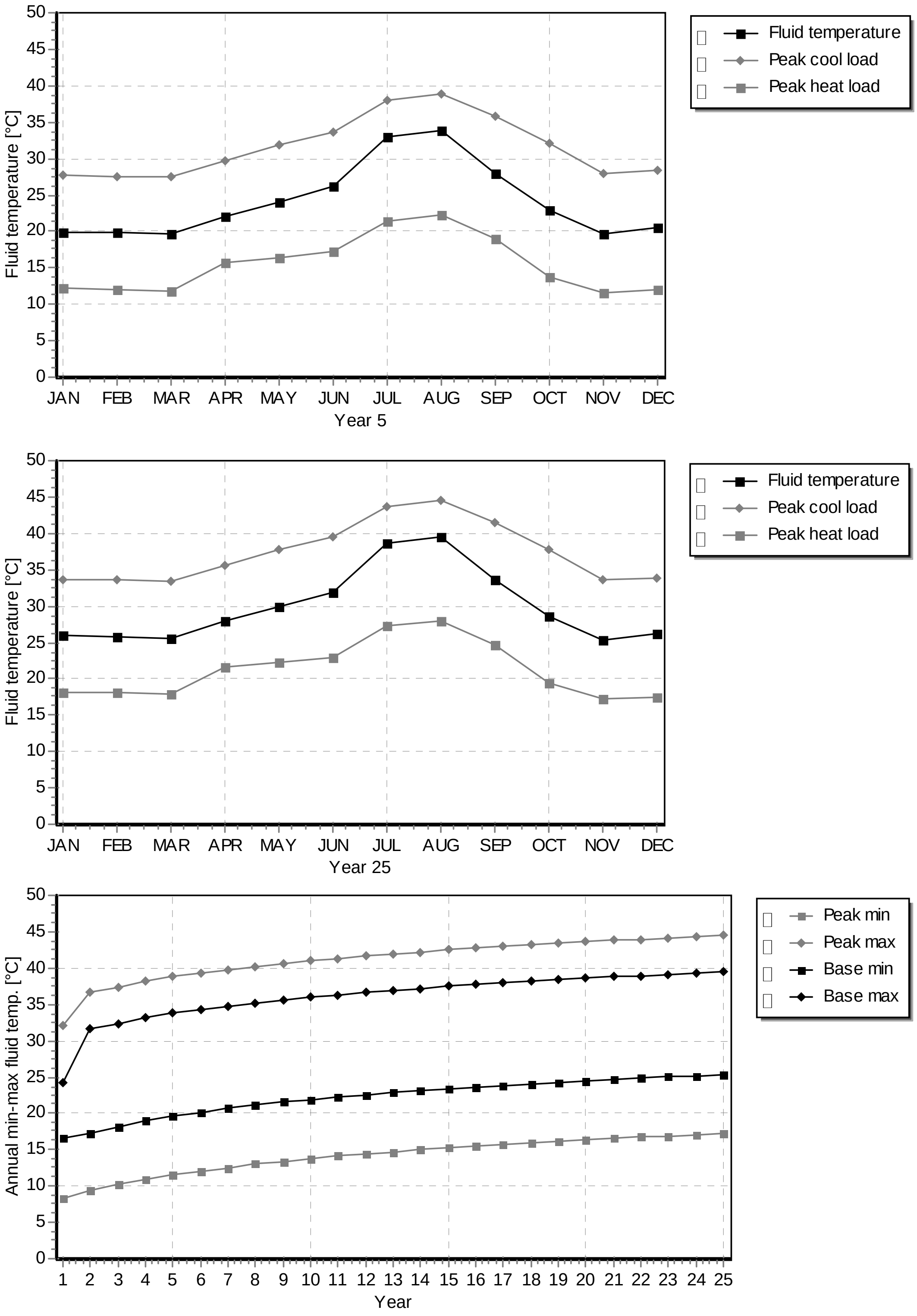

Figure 9: Results of EED-calculation for maximum re-cooling case, load data as shown in figure 8

The temperatures in summertime after 10 or more years do not need to rise as given in figure 9, as the higher the ground temperature, the better the opportunities for re-cooling in seasons other than winter. A design run was made checking how much cooling could be supplied from the BTES as to achieve the maximum admissible temperatures after just 5 years, and gradually increase re-cooling with rising temperatures in order to achieve some balance later on. With the same load data as given in table 2, but 700 MWh building cooling load (i.e. 17 % coverage by BTES), the temperature development will be as shown in figure 10 for the 5th year of operation.

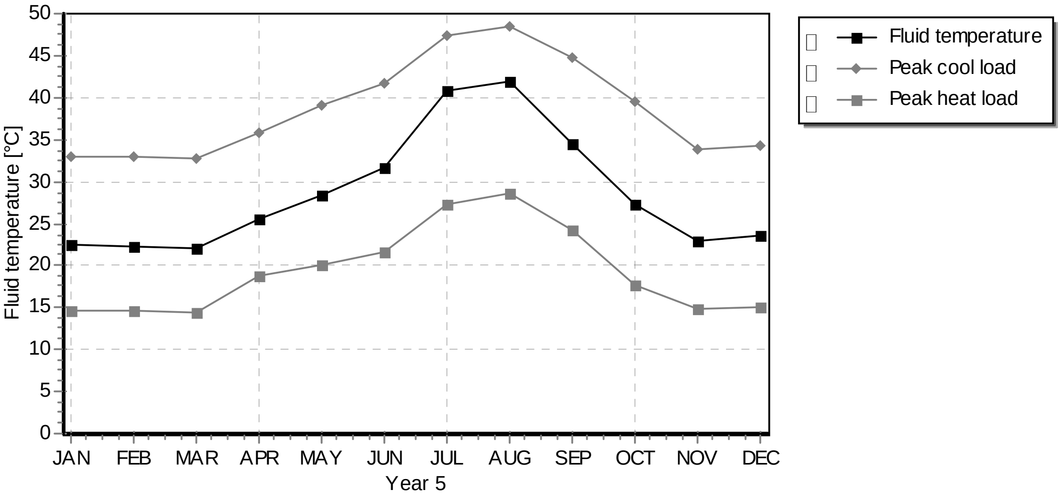

Figure 10: Results of EED-calculation for maximum re-cooling case, 5th year of operation, with increased cooling load (see text)

5. Conclusions

The geothermal system consists of borehole heat exchangers (BHE) in the underground, heat pump and dry cooler. The BTES extends to an overall volume of about 553’000 m^3 and was finished in 2010. Alas, by the time of writing, no monitoring data could be evaluated yet.

With this innovative design concept, adapted to Mediterranean climate and combining both diurnal and seasonal cold storage, the cooling output from UTES can be increased in a sustainable way. In summer, the underground works as a store of cold during the night and as a sink of heat during the day (diurnal storage). In wintertime, the regular operation of the heat pump delivers cold, and an additional cooling (or re-cooling) is done by dry cooler (seasonal cold storage).

6. References

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