Combined active cooling and passive cooling (part 1)

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With climate change, our building demand is shifting more towards cooling. With borefields, you can have passive cooling (also called free cooling), but sizing your borefield this way is rather expensive. Therefore, the option to use active cooling is sometimes proposed to reduce the investment cost. However, this increases electricity consumption compared to passive cooling. This article investigates whether and how it is possible to design a borefield for active cooling while maximising the use of passive cooling.

The design challenge

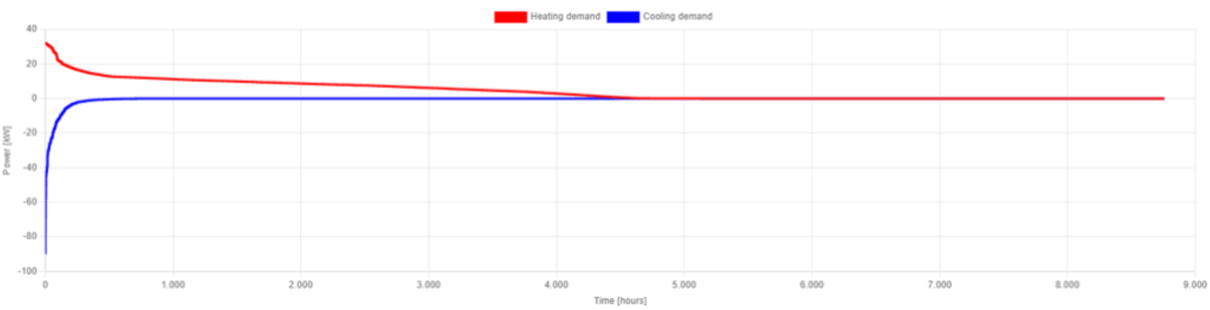
Geothermal systems have gained significant interest in the energy transition due to their ability to provide users with passive cooling. This means that no heat pump is required to cool the building, as we directly utilise the cold stored in the ground (hence the alternative term: 'free cooling'). To use this cold directly, we must ensure that our average fluid temperature does not exceed a certain limit, typically set between 16-18°C. Sizing borefields for passive cooling, therefore, requires adhering to very strict temperature limits, increasing the required borefield size for buildings with a high cooling demand.

The other traditional option is to forgo passive cooling and size the borefield to operate with active cooling instead, using a heat pump to cool the building. This consumes more electricity but removes the restriction of maintaining the 16-18°C range for passive cooling. Hence, active cooling results in a smaller borefield but with a higher operational cost.

To illustrate this difference, let us examine a typical example.

Example building: auditorium

An auditorium in the Belgian climate typically has a higher annual heating demand than cooling demand but often experiences a higher cooling peak than heating peak. This is due to the fact that heating is often delivered via a slow emission system like underfloor heating, whereas cooling is provided via an all-air system. Below is the load-duration curve of this building.

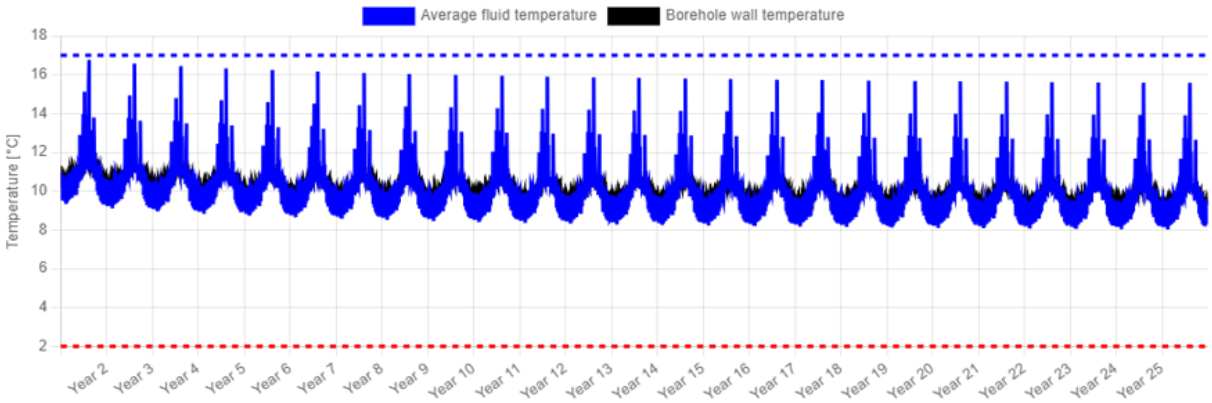


As shown, the auditorium has a heating peak of 32 kW and a cooling peak of 90 kW. However, the energy demand is 38.3 MWh/year and 3.86 MWh/year for heating and cooling, respectively. Let us now size this borefield for both passive and active cooling.

Sized for passive cooling

If we size our borefield for passive cooling, we must ensure our average fluid temperature remains below 17°C, as otherwise, our emission system cannot meet the cooling demand. This results in a required total borehole length of 2310 m and an electricity consumption of 193 kWh/year (using an SEER of 20). Below is the hourly temperature profile.

> ***!Note***
> *Although passive cooling is often called 'free', a circulation pump is always running for the borefield. Therefore, our cooling efficiency (SEER) is finite, typically around 20-25.*

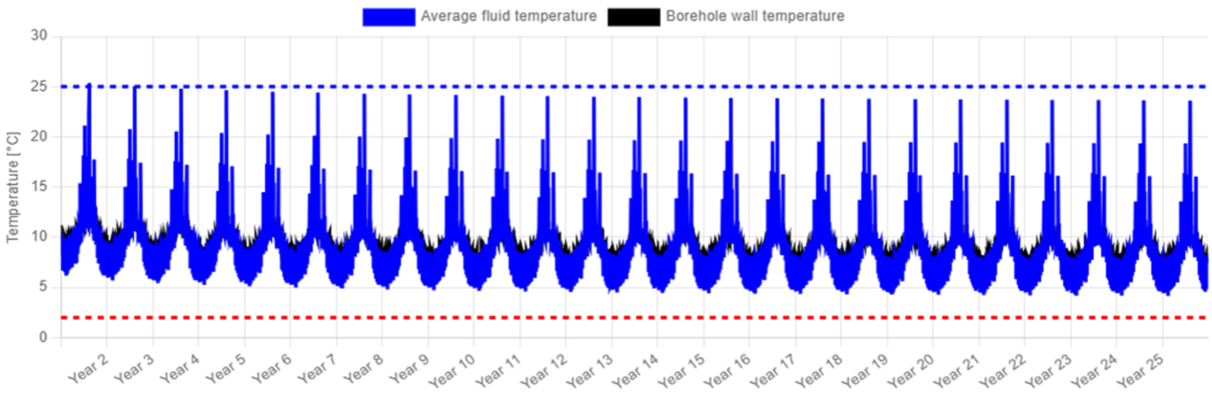


> ***!Note***
> *If you are unfamiliar with how to interpret such temperature profiles, you can visit our article on this topic here.*

Sized for active cooling

By removing the passive cooling restriction, we can increase our maximum average fluid temperature to, for example, 25°C. This significantly reduces our borefield size to 990 m of total borehole length, with an annual electricity consumption of 772 kWh/year (assuming an SEER of 5 in active cooling).

> ***!Caution***
> *Although there is no technical limitation to the maximum average fluid temperature, it is advisable to keep it under control to prevent environmental harm. Please check local legislation for any restrictions regarding fluid temperatures.*



As demonstrated, there is a significant difference in required total borehole length (2310 m for passive cooling versus only 990 m for active cooling) and electricity consumption (193 kWh/year compared to 772 kWh/year). This raises the design question: is it possible to maintain the design for active cooling while achieving the efficiency of passive cooling? Can we combine the best of both worlds?

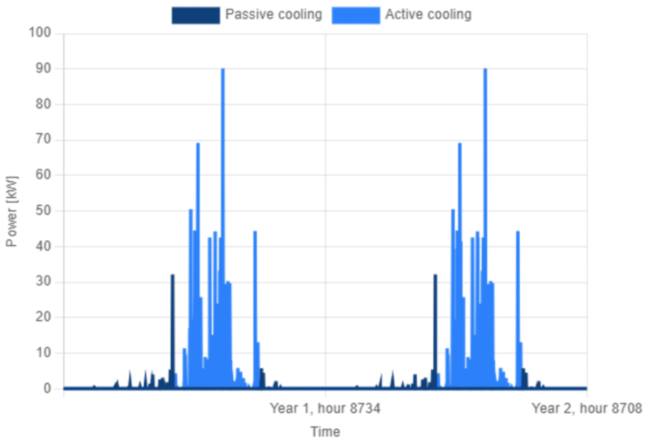
Design methodology

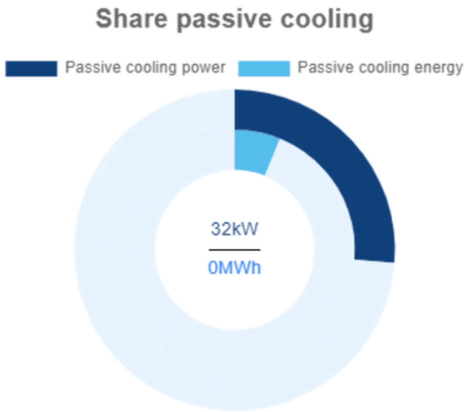
There are two ways to approach this design challenge: either defaulting to active cooling during certain months or switching to active cooling when a specific temperature threshold is exceeded, regardless of the time of year. Both methods are implemented in GHEtool Cloud and will be discussed below.

Fixed months

One way to combine active and passive cooling is to use active cooling exclusively during specific months. This approach is similar to a central change-over system where, depending on the cooling demand, you may need to resort to emission systems that require a lower fluid regime, which the borefield cannot provide. This method involves setting the efficiency for both active and passive cooling and determining the months in which active cooling will be used. Based on this information, the algorithm calculates the resulting ground load, generates the corresponding temperature profile, and returns an average SEER.

Applying this method to the auditorium case, using the same SEER values as before for both active and passive cooling and actively cooling from June to September, we obtain an average SEER of 5.24 and an annual electricity consumption of 737 kWh/year (which is nearly identical to the 100% active cooling case).





This outcome is understandable by analysing the graphs above. By defaulting to active cooling during the summer, almost all cooling demand is delivered actively, with only a negligible portion being passive, except for a passive cooling peak at the end of May. In this case, we need to install 32 kW for passive cooling and 90 kW for active cooling.

Temperature threshold

Another approach to combining active and passive cooling is based on the principle: "Passive when possible, active when necessary," aiming to maximise passive cooling. This method involves setting a temperature threshold: if the fluid temperature remains below this threshold, passive cooling is used; if it exceeds the threshold, active cooling is employed.

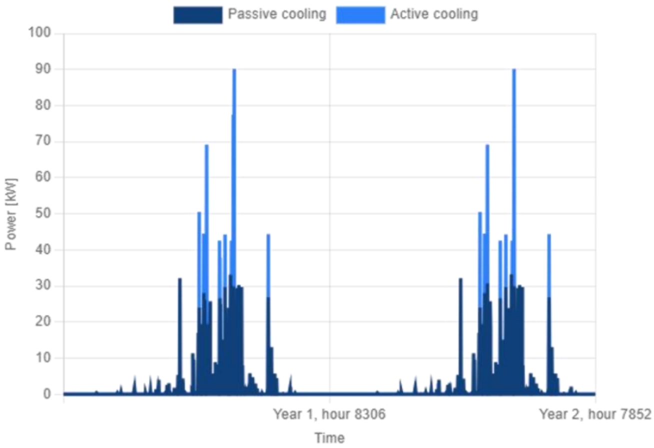
This method works as follows:

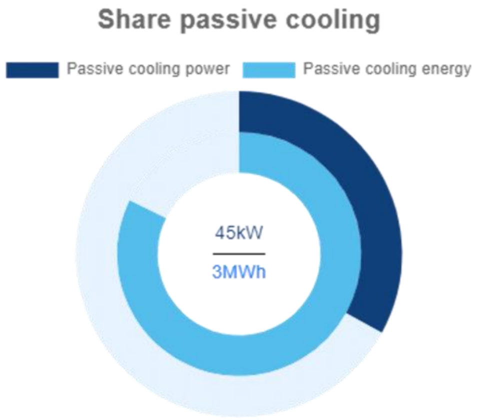
1. Set the efficiency in active and passive cooling
2. Set the temperature threshold above which there is active cooling
3. Calculate the resulting ground load, assuming only passive cooling
4. Calculate the temperature profile
5. Check if maximum average fluid temperature is above passive threshold
    1. If yes, then recalculate resulting ground load, with every hour at which the temperature is above the threshold, being active cooling.
    2. If no, then go to (7)
6. Recalculate temperature profile/size borefield
7. Return average SEER

Using this methodology, we achieve a geothermal system with an average SEER of 13.06 and an annual electricity consumption of 296 kWh, which is a significant improvement over the previous case.

!Note

When using the temperature threshold method, the average SEER is calculated over the entire simulation period. The energy in MWh in the passive cooling share diagram also represents the average annual energy for passive cooling. This is because, due to thermal imbalance, the ground conditions may change over time, potentially increasing or decreasing the share of passive cooling annually.

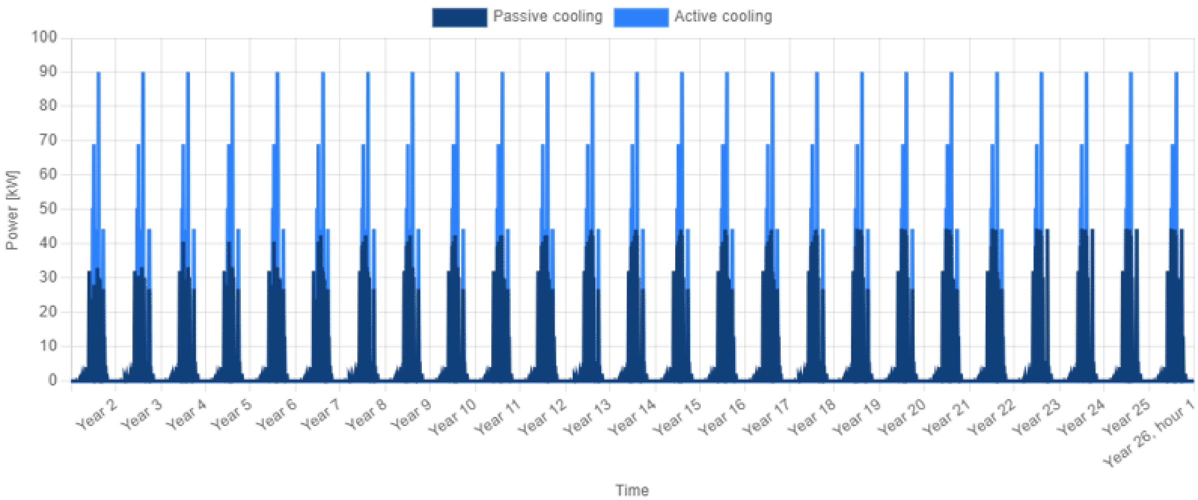




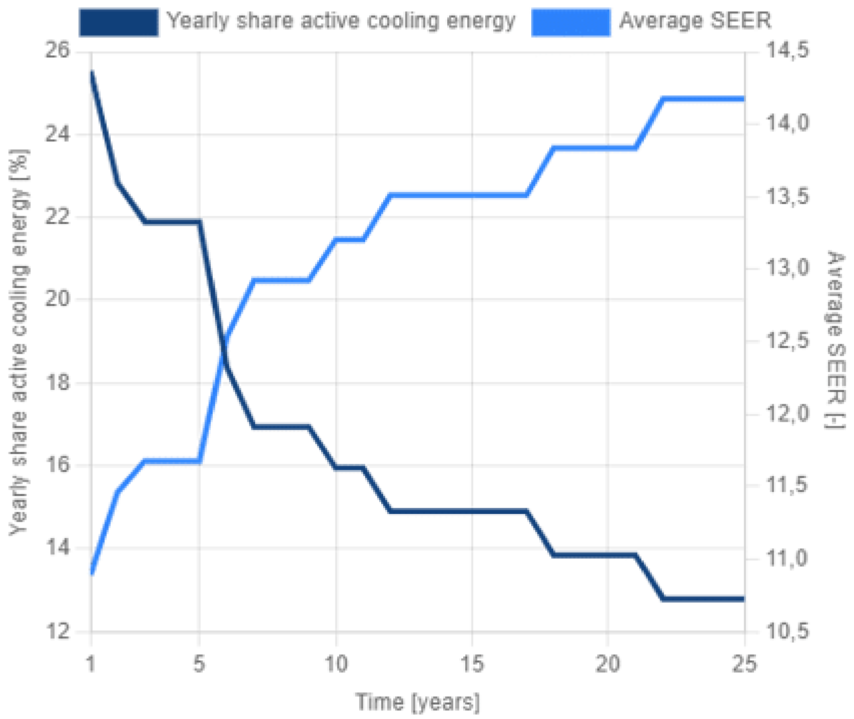
The primary reason for this improvement can be seen in the figure above, where there is still considerable passive cooling during the summer. This depends heavily on the cooling demand profile. For borefields that are thermally limited in the third or fourth quadrant, active cooling may make no difference.

!Note

If you have not read our article about borefield quadrants, you can check it out [here](#).



Analysing the cooling demand profile over the entire simulation period reveals that passive cooling increases year after year. This is due to the negative thermal imbalance of the auditorium (recall that its heating demand is almost ten times higher than its cooling demand). As a result, the ground cools over the simulation period, increasing the share of passive cooling annually and, consequently, raising the average SEER over time.



Conclusion

Active and passive cooling each have their advantages and disadvantages. Active cooling leads to significantly lower investment costs but higher electricity consumption, whereas passive cooling has the opposite effect. This article has demonstrated that by sizing your borefield for active cooling but ensuring passive cooling is utilised whenever possible, you can achieve an average SEER of 13! There is substantial potential for integrating active and passive cooling, and in the next article, we will show you how to calculate it using GHEtool Cloud. Stay tuned!

References

- Watch our video explanation over on our YouTube page by clicking here.
- More information on active and passive cooling can be found in (Coninx et al., 2024).

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