# Simulating with modulating heat pumps in GHEtool Cloud

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Today, a brand new feature has been released in GHEtool Cloud: simulating with modulating heat pumps. Instead of working with traditional constant heat pump efficiencies to convert the building load to a resulting ground load, you can now select a machine or a number of machines from our database, and GHEtool will calculate the resulting efficiency for you.

> ***!Note***
> *This article builds further on the research that was presented in an earlier article, which you can find here.*

## Towards more accurate borefield design: a three-step process

In the summer of last year, we presented our three-step roadmap to change the way geothermal borefields are designed forever. Today, with the implementation of heat pumps directly into GHEtool, this process is complete.

### Step 1: varying fluid properties

The first step, released right before the summer of 2025, was to get rid of the constant fluid properties that are traditionally used in borefield design. In GHEtool Cloud, the fluid properties such as viscosity and density are updated every hour, giving you a variable Reynolds number and borehole resistance. This was of particular importance for the accuracy of high cooling loads. More information can be found in our article on this topic.

### Step 2: variable flow rates

The next assumption we got rid of, just last month, was that of a constant flow rate. In reality, most borefields have a varying flow rate since the heat pump controls the pump speed to achieve a certain temperature difference across its evaporator. Although this change did not necessarily affect the design of your systems since the maximum flow rate remains unchanged, it better predicted the fluid temperatures in the mid seasons and paved the way for our third step.

You can read more about variable flow rates here.

### Step 3: modulating heat pumps

When you are designing borefields, you typically have a building load that you need to convert in one way or another to a ground load (that is, extraction and injection of heat). This is traditionally done by using an SCOP value that can be found in the technical data sheets. However, there are a couple of problems with this assumption.

1. By using the SCOP to convert the peak power heating to an extraction peak power, you overestimate the peak power, since the COP during peak conditions is typically lower than the SCOP. This can lead to an oversized borefield.

   ***!Note***
   *The SCOP is a measure of the seasonal efficiency of a heat pump, whereas the COP is a measure of the instantaneous efficiency. If you are not familiar with heat pump efficiencies, please read our article on this topic.*

2. By using an SCOP at B0/W35 to convert the heating and domestic hot water demand to a ground load, you are assuming that the ground temperature is at 0°C. However, in most designs this only occurs, if ever, after a couple of years, meaning that the average temperature is higher. This gives a higher SCOP, so using a B0/W35 value is an underestimation of the efficiency and therefore of the imbalance, which can result in undersizing (see for example our article on how to cope with imbalance).

3. The efficiency of a heat pump depends on the ground temperature and will therefore change depending on your design. However, since the SCOP is typically an input instead of an output of a borefield design, the SCOP does not vary when the design changes. This is rather counter intuitive.

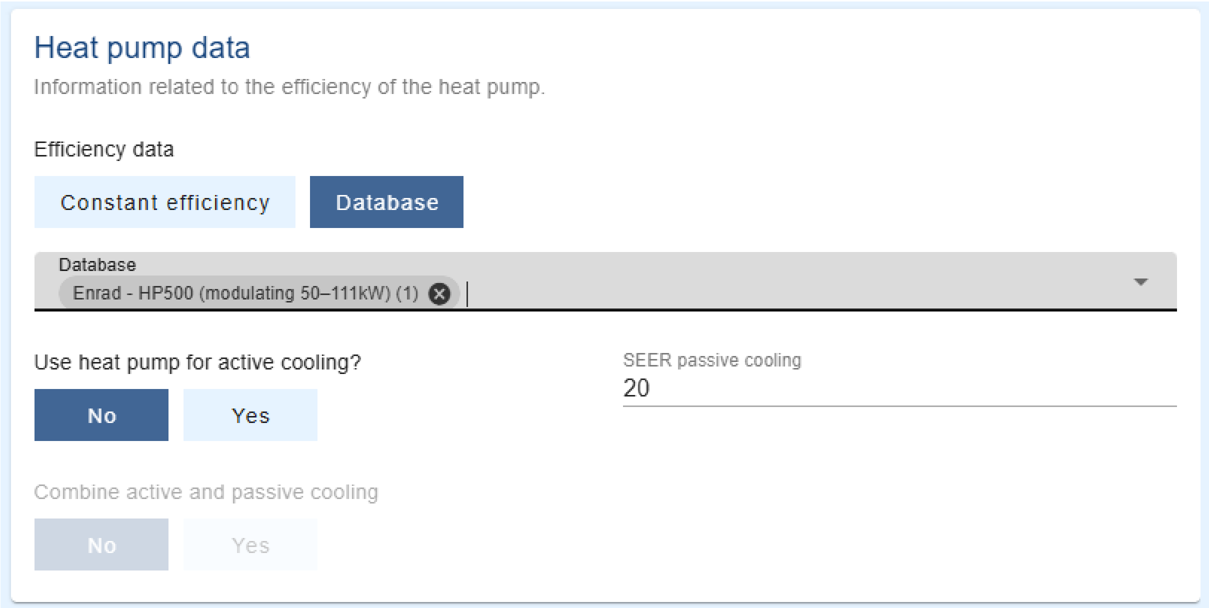
It should be clear that there are quite some challenges and uncertainties when using only an SCOP for borefield design. That is why, from today onwards, you can select your machines directly in GHEtool.

# Heat pumps in GHEtool Cloud

Working with temperature and part load dependent efficiency data is not trivial, as this information is not available in technical datasheets. That is why we collaborate directly with heat pump manufacturers to obtain highly detailed measurement data and create a digital twin of their machines. These digital twins are now available in the tool, so that whenever you are working with an hourly building load, the option will appear to select one or multiple modulating heat pumps from our heat pump database.

> ***!Note***
> *At the moment, four machines of Enrad are available in the tool, and other machines and manufacturers will be added in the coming months.*

> ***!Note***
> *At the moment, working with modulating heat pumps is only possible when you have an hourly load, since it is only at this resolution that we are able to calculate the fluid temperatures and the efficiency accurately. However, if you do not have this information, you can generate an hourly load directly in GHEtool, as explained here.*




*Modulating heat pumps in GHEtool Cloud.*

## Cascading heat pumps

One extra level of complexity is how you model multiple heat pumps working together. For example, instead of having one machine of 100 kW that is able to modulate between 30 and 100 kW, you can also work with two machines rated at 50 kW that are able to modulate between 15 and 50 kW. With this last option, your total modulation range will be 15 to 100 kW, giving you more flexibility than when you are working with a single machine.

Now, this implies that we need some cascading principles to determine when each heat pump will turn on. In GHEtool, the philosophy is that, for every power level, the maximum number of heat pumps is operating in order to keep the average modulation degree as well as the WAIR as low as possible, whilst improving the accuracy.

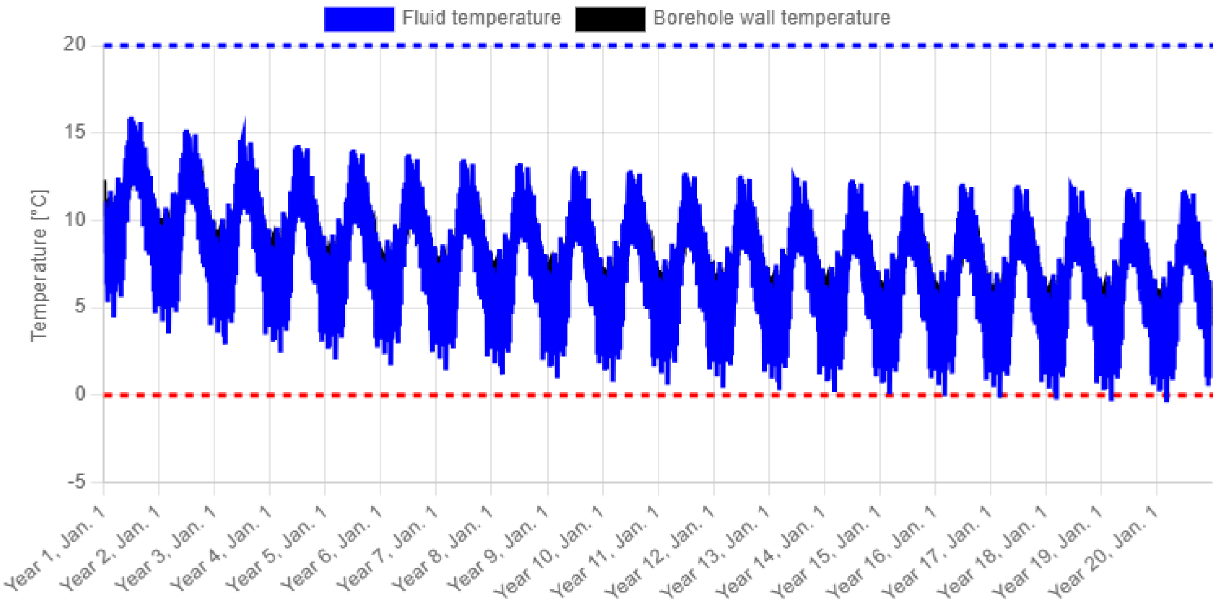
To illustrate this, imagine you have two machines of 50 kW and 30 kW is demanded. This could be achieved by letting one machine run at 30 kW or by letting both machines run at 15 kW. In GHEtool, the second option is always selected. For powers lower than 30 kW, only one machine is active.

# Simulating with a modulating heat pump

In order to illustrate the extra insights you can obtain by working directly with a heat pump digital twin, different scenarios are simulated in GHEtool.

## Baseline

To illustrate the importance of working with modulating heat pumps, we simulated a geothermal system with a peak heating demand of 100 kW and 200 MWh per year, and 40 kW in cooling with 40 MWh per year, using an HP500 heat pump from Enrad rated at 111 kW. As a first step, we looked up the official SCOP B0/W35 of 3.41 and simulated our borefield using this value. The temperature profile, which will serve as the baseline case, is given below.

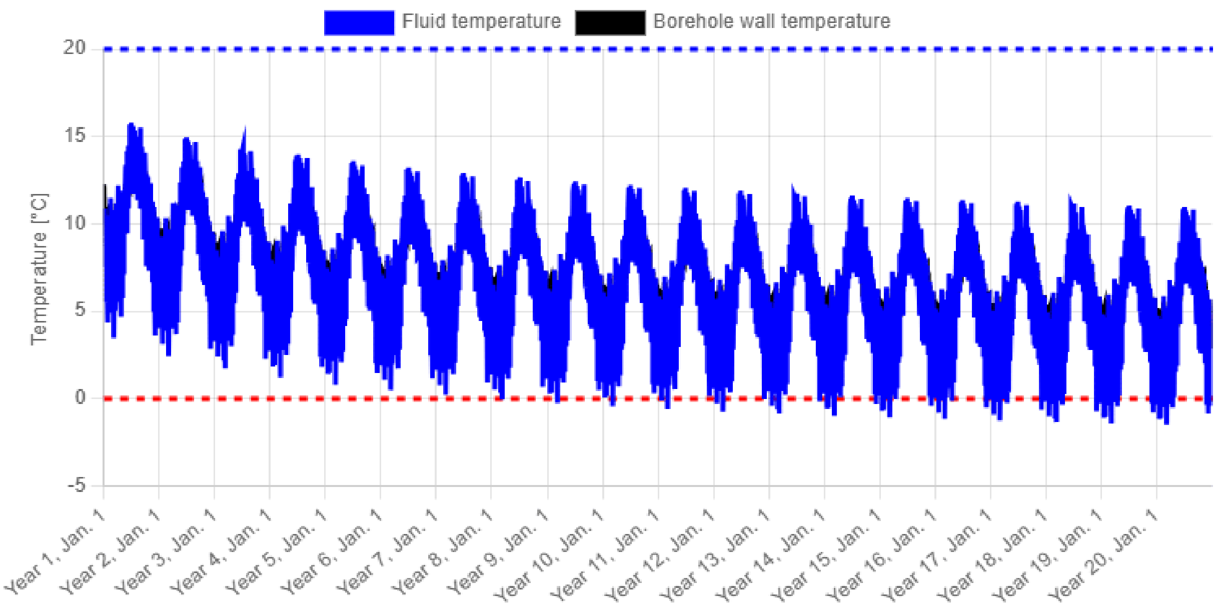



*Hourly temperature profile when working with a constant SCOP.*

The minimum average fluid temperature is −0.41°C and is ever so slightly below our design limit of 0°C.

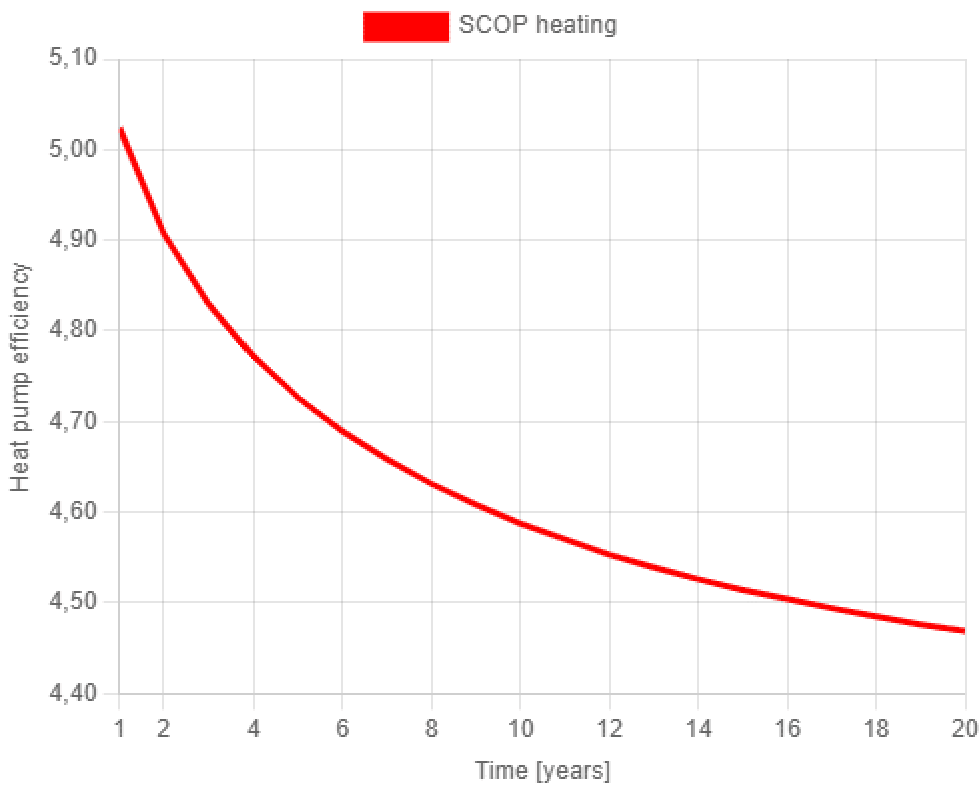
## Single heat pump

As a comparison, let us now select the HP500 heat pump directly from the list and simulate our borefield using it. The new temperature profile is shown below.




*Hourly temperature profile when working with the HP500 heat pump directly.*

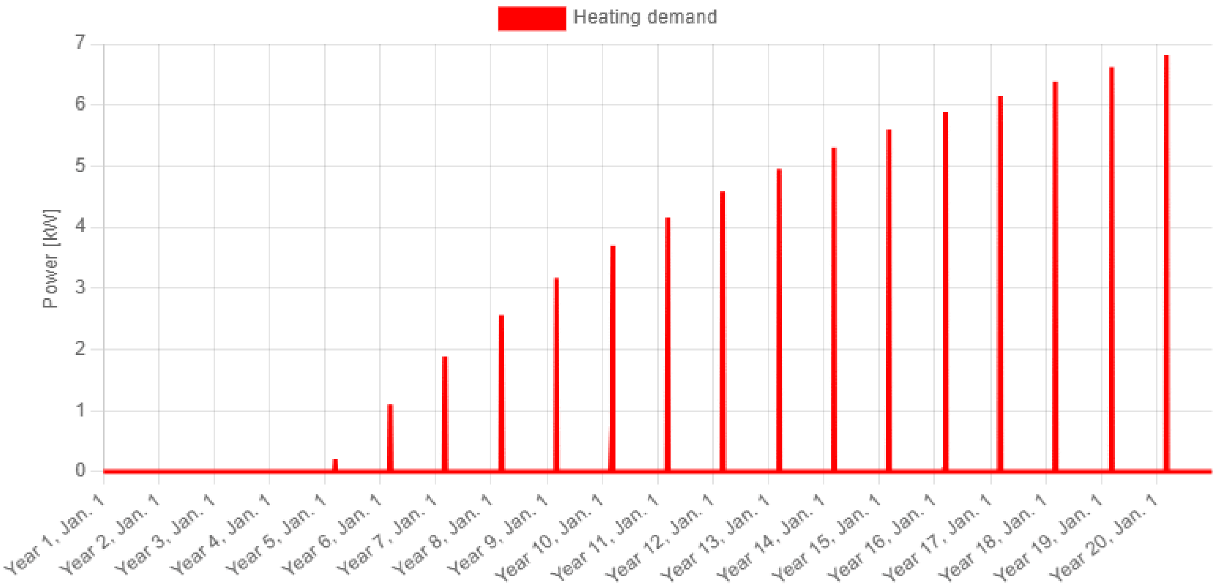
One thing that is immediately clear is that the temperature drops further to −1.47°C. This is because our calculated SCOP is not the official 3.41 but 4.62 in this case, an increase of 35%. This, of course, also has an influence on the imbalance, which increased from 99 MWh per year to 115 MWh per year of net extraction, leading to lower temperatures in the end. The impact of the decreasing temperature trend on the heat pump efficiency is also clearly visible in the graph below.




*Variation of the SCOP over the years when working with an HP500 heat pump.*

With the decreasing temperatures, the heat pump capacity also decreases. In this case, the heat pump is not able to fully meet the building demand in the last year, since at −1.47°C it can only deliver around 93 kW. In GHEtool, this is shown as a "power shortage".

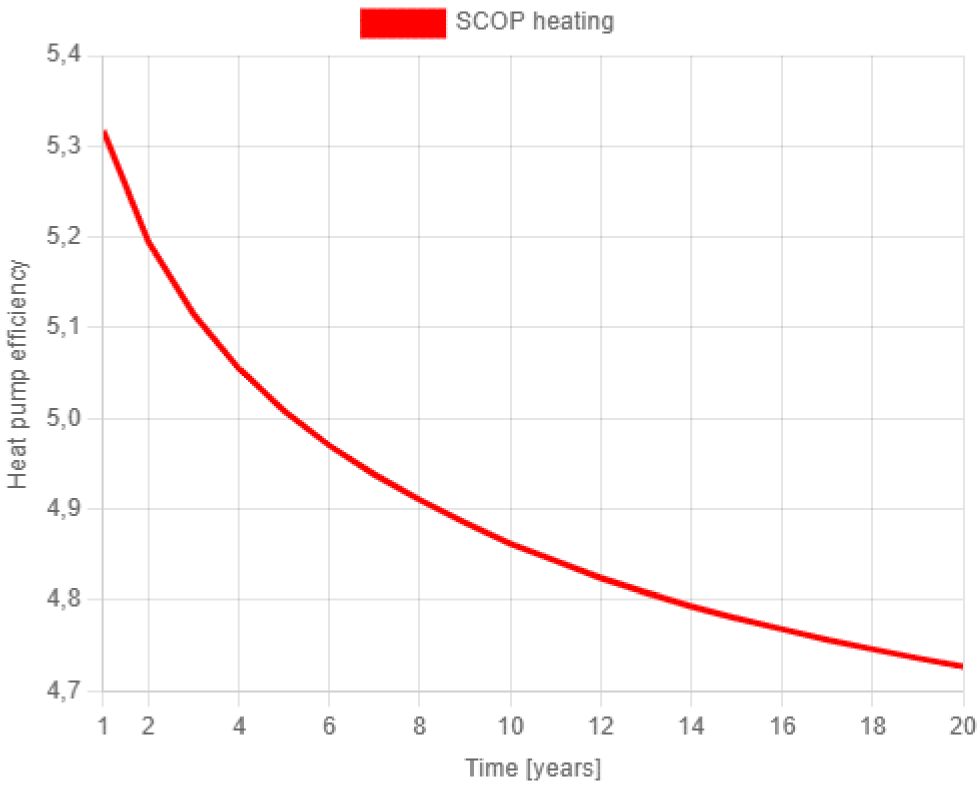
> ***!Note***
> *In this case, this is not really a problem since the missing 7 kW occurs during only one hour of the simulation period. However, since you are now limited to the maximum capacity of a machine, it can happen that the first time you try this method, you find that your heat pump selection is significantly too small or perhaps too conservative.*




Power shortage when working with a single HP500 heat pump.

## Two heat pumps in cascade

The simulation above was performed with a single HP500 heat pump, rated at 111 kW, which seemed to be sufficient, but perhaps slightly on the smaller side. In this second variation, we therefore selected two smaller HP300 machines, each rated at 60 kW, giving a total available power of 120 kW, which is slightly higher than in our previous case. When we simulate our borefield with these machines, the efficiency curve looks like this.

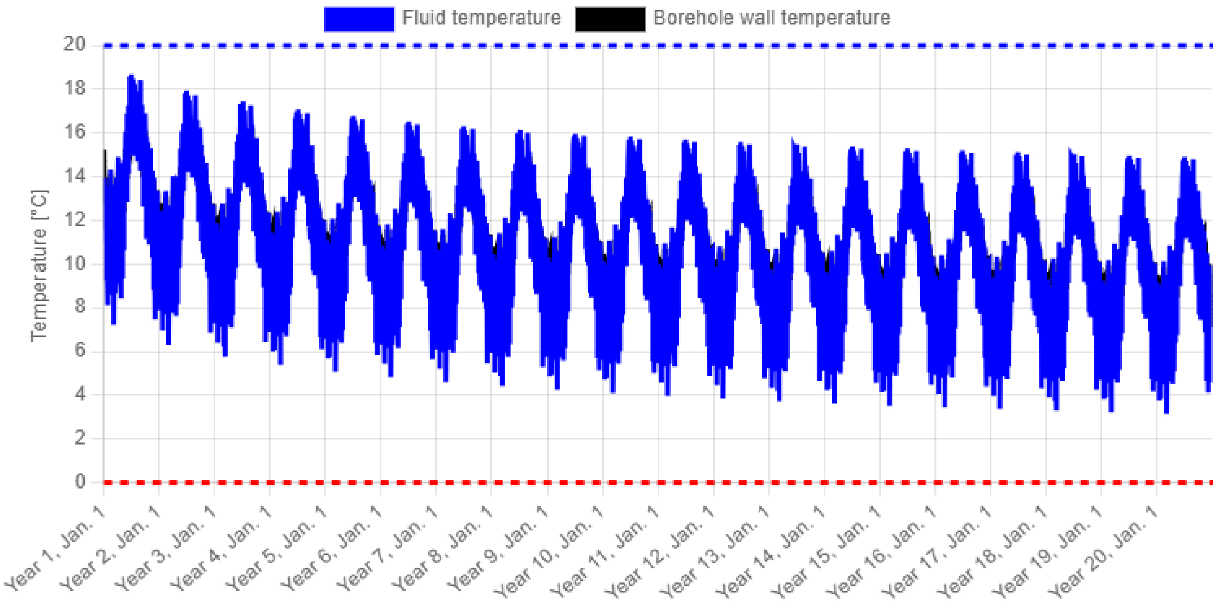



*Variation of the SCOP over the years when working with two HP300 heat pumps.*

We still see this downward sloping trend, but the overall efficiency of the system is now 4.9 instead of 4.62 with our single heat pump, an increase of 6% in efficiency. However, our temperatures are, again due to the higher efficiency, somewhat lower, now reaching −2.05°C.

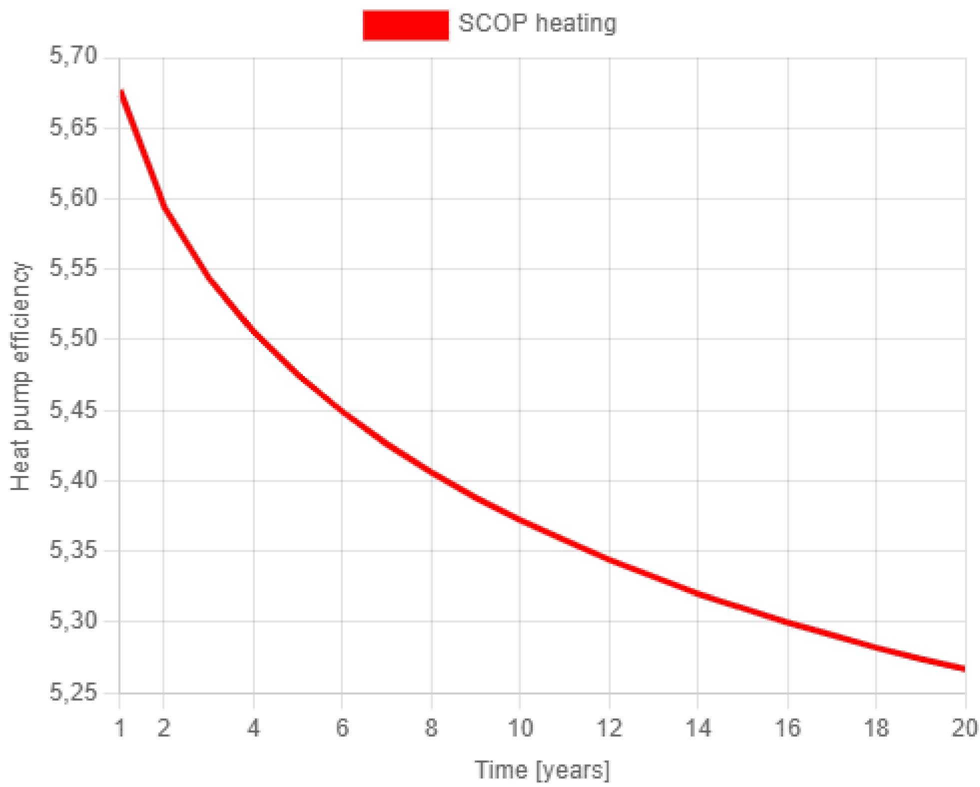
## Deeper borefield

As a third variation, we are going to change our borefield design to stay above our 0°C minimum threshold. Therefore, instead of working with 20 boreholes of 150 m, we are going to change this to 10 boreholes of 300 m, which will give us a significantly higher undisturbed ground temperature. With the same two HP300 machines selected, the temperature profile is shown below.




*Hourly temperature profile when working with two HP300 heat pumps and boreholes of 300 m deep.*

As you can see, the average fluid temperatures are now much higher, to the point that the borefield is actually oversized, with a minimum of 3.16°C. This higher temperature is also beneficial for the heat pump efficiency, which now has an average SCOP of 5.39 over the whole simulation period. So, by changing our design, our efficiency increased by 10% compared to the last scenario.




*Yearly SCOP when working with two HP300 heat pumps and boreholes of 300 m deep.*

# What is next?

However, although today marks the end of our three-step process of making GHEtool significantly more accurate for the design of shallow geothermal borefields anno 2026, this is not the end of the road. Many more accuracy improvements are planned in general, but related to modulating heat pumps, the following steps are already being taken.

- As mentioned, at the moment working with modulating heat pumps is only possible when you have an hourly load profile, since the model needs to know the power at each hour to calculate the respective efficiency and corresponding ground load. We are investigating whether this could be extended to working with purely monthly loads. In the meantime, you can use the built in feature of GHEtool to generate an hourly load profile yourself.
- At the moment, modulating heat pumps are not compatible with the optimise for power, energy, and balance methods because they follow a different strategy. On the one hand, you have optimisation methods that determine the required power of your ground source heat pump for you, and on the other hand, when working with modulating heat pumps, you select your machines directly. We are working on an improved method where you can select a number of machines and an algorithm will determine which one, or which combination of machines, you need.

- Another important key aspect is the condenser temperature. At the moment, heating is always supplied at 35°C and domestic hot water at 55°C, but of course there are also projects where 45°C is needed for heating or where this emission temperature varies over time. This will be implemented in another update so that you, our user, can design even more precisely.

Besides these model improvements, we are in discussions with multiple manufacturers to implement their machines into GHEtool as well. If you are a manufacturer yourself, please reach out to us via info@ghetool.eu.

# Conclusion

In this article, we introduced the new, groundbreaking feature of working with modulating heat pumps directly in GHEtool Cloud. This not only gives you more insight into the real efficiency of your system, in the example above an improvement of 58% compared to the official SCOP data was achieved, but also allows you to see the effect of design variations on the system performance, such as the drilling depth or the number of machines.

With this implementation, the final cornerstone of our three groundbreaking features, variable fluid properties, modulating flow rates, and modulating heat pumps, is complete. However, this was only the framework for further innovations. Subscribe to our newsletter if you do not want to miss out, or try GHEtool today.

# References

- Watch our video explanation over on our YouTube page by clicking here.
- Peere, W. (2025). Integrating Temperature and Part-Load Dependent COP in Shallow Geothermal Borefield Design. In *Proceedings of German Geothermal Congress DGK 2025*. Frankfurt (Germany), 18-20 November 2025.
- For more information about the modulating heat pumps from Enrad, click here.