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Are Rules of Thumb Misleading? The Complexity of Borefield Sizing and the Importance of Design Software

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Engineering firms, architects, drilling companies: everyone works with rules of thumb. We have simple rules for pressure drops in pipes, water usage in residential buildings and the sizing of geothermal borefields. Although all rules of thumb are a simplification of reality, the sizing of borefields is way too complex to be put into one rule. This article demonstrates that relying on rules of thumb for borefield sizing can easily result in a 50% over- or under-sizing of the borefield, potentially leading to infeasible projects, non-functioning systems, or even environmental harm.

Introduction

The building sector is responsible for 26% of the global CO2 emissions related to energy usage, mainly due to heating and cooling demand [1]. In order to decarbonise this sector, ground source heat pumps (GSHP) have gained a lot of attention over the years since they have a high efficiency, can provide free/passive cooling and require little maintenance. On the other hand, geothermal systems carry a high investment cost, so a correct sizing is important. When talking about closed geothermal systems (borefields) there are multiple ways to size them, ranging from using detailed geothermal design software (like GHEtool, EED, GLHEPro) to using a simple rule of thumb. This last option, however, although often used, requires some caution.

The importance of correct borefield sizing

Geothermal systems are not sustainable by nature but by design. It is, therefore, important that the borefield is sized in such a way that, over time, the ground temperature stays between certain temperature limits. This is important for the system itself, as too low temperatures can cause system failures, but also for the environment, as microbiological life in the underground can be impacted due to temperature fluctuations. On the other hand, borefields are rather expensive to drill, so in order to keep them economically attractive, you don't want to oversize them. So, how do you size them?

The blindness of rules of thumb

Within the field of engineering, rules of thumb are used everywhere, from pressure drops in pipes to water usage in residential buildings. They simplify and speed up the design process, but they give no insight into all the physics that lies underneath a certain rule. Such general guidelines are oftentimes created based on a certain scientific correlation or an extrapolation of some practical experience. But after time, we lose track of the exact assumptions behind a specific rule, and these rules become a truth in and of itself.

In the field of shallow geothermal borefields, such rules of thumb come in the form of the 'specific heat extraction x W/m borehole', making abstraction of all the parameters that determine the required size of a borefield: the building heating and cooling demand profile, the fluid regime and borehole internals, temperature limits.

In the next paragraphs, these design parameters are varied in order to show the sensitivity of the borefield size (expressed in total borehole length, i.e. the depth of the borehole multiplied by the number of boreholes in a borefield) and the correctness of a specific rule of thumb, for three different building cases: an office, an auditorium and a residential building complex. These three cases are based on real projects and were simulated on an hourly basis. Some characteristics of the heating and cooling profiles are given in Table 1. All buildings use rather slow emission systems (concrete core activation (CCA) and floor heating) but use the ventilation system for cooling, hence the small heating peak in comparison to the cooling peak.

Sensitivity to building demand

Figure 1 shows the required total borehole length of the three cases calculated using a rule of thumb of 30W/m applied to both the peak heating and peak cooling. This sizing is compared to an hourly sizing with GHEtool [2]. The relative difference between both rule-of-thumb sizings and the reference sizing is shown in Figure 2.

One can see that applying the rule of thumb of 30W/m to the peak heating value leads to under-sizing the borefield for all cases, even for the heating-dominated buildings like the auditorium and residential buildings. This can be explained by the fact that using slow emission systems requires only small peak powers and, hence, a smaller sizing, underestimating the effect of the yearly load imbalance.

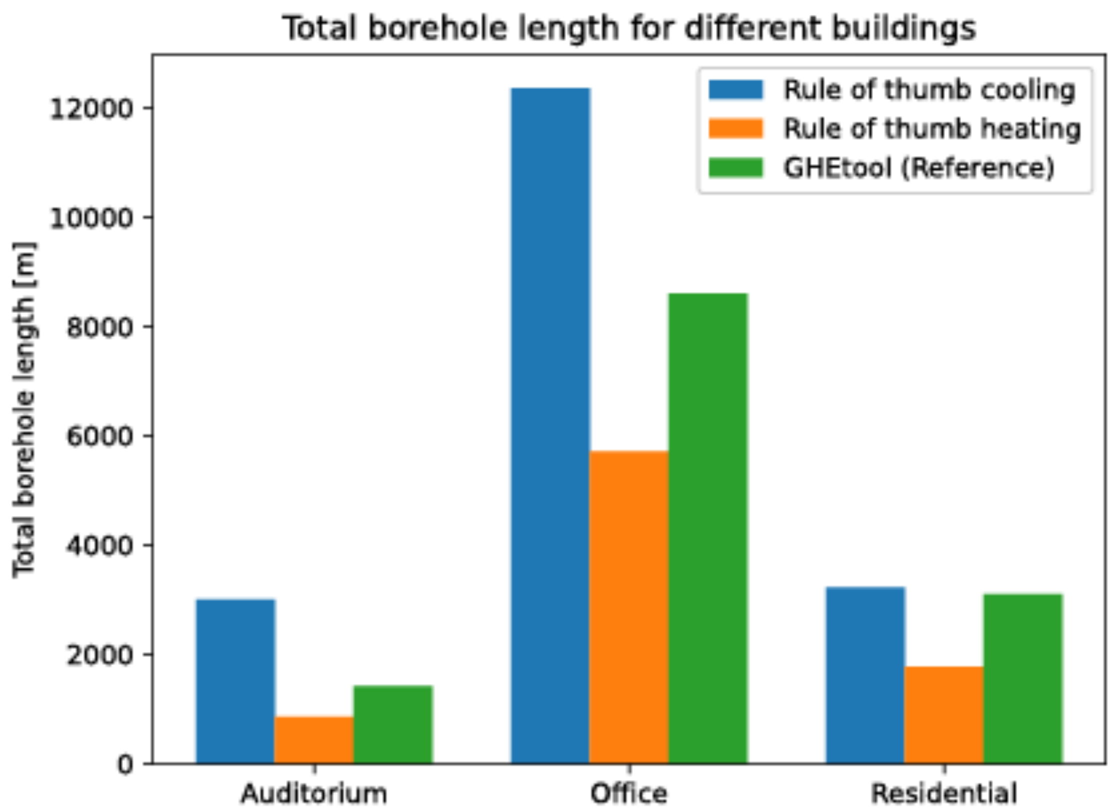

Figure 1: The total borehole length for three different buildings using a rule of thumb of 30W/m for both peak cooling and peak heating in reference to a borefield sized with GHEtool.

On the other hand, sizing according to a rule of thumb for peak cooling can give a very significant oversizing up to a factor of 2 in the case of the auditorium. This is due to the fact that the auditorium has a high peak cooling, but the yearly cooling demand is rather small. The effect of the peak is hence overestimated using the rule of thumb for cooling here. Rather coincidentally, sizing for peak cooling gives a very good result for the residential case.

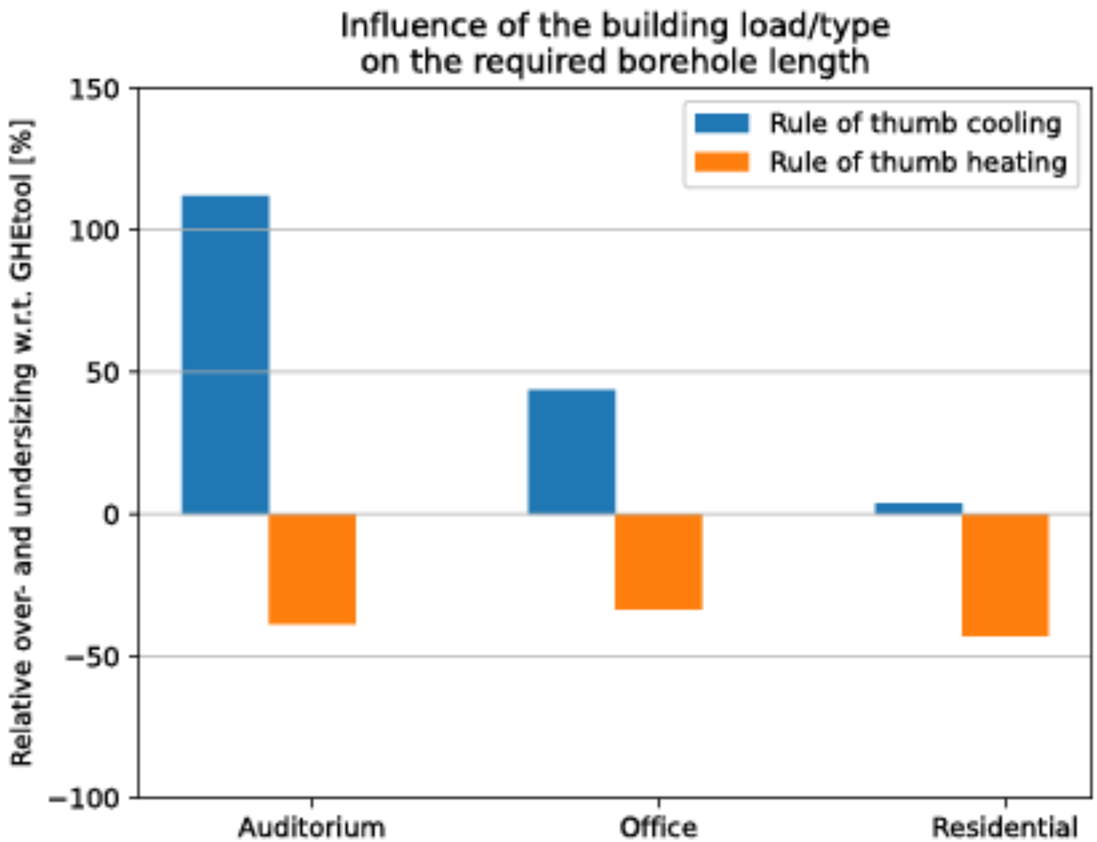

Figure 2: Relative over and undersizing when using rule of thumb sizing in reference to a borefield sizing with GHEtool.

Sensitivity to fluid regime and number of pipes

Not only can the building loads lead to significant under- and oversizing, but the internal design of the boreholes themselves can also be of great importance. In designing the borehole itself, typically, two parameters can be varied: the type of tubing (single or double U-pipes or even coaxial) and the fluid regime (laminar or turbulent). All these parameters have an effect on the equivalent borehole thermal resistance and, hence also the required total borehole length.

Figure 3 shows the influence of these design parameters in the over- and under-sizing of the borefield in reference to a sizing with GHEtool for the auditorium. The oversizing of Figure 2 (which was calculated with a turbulent flow and double U-pipe borehole) disappears when working with a single U-pipe, laminar flow borehole. This can be understood since the turbulent flow and double U-pipe case give the best borehole thermal resistance, making the influence of the peak power smaller, whereas a single U-pipe, laminar flow case, stresses the influence of the peak power. Therefore, the oversizing when using a rule of thumb for cooling is smaller in this latter case.

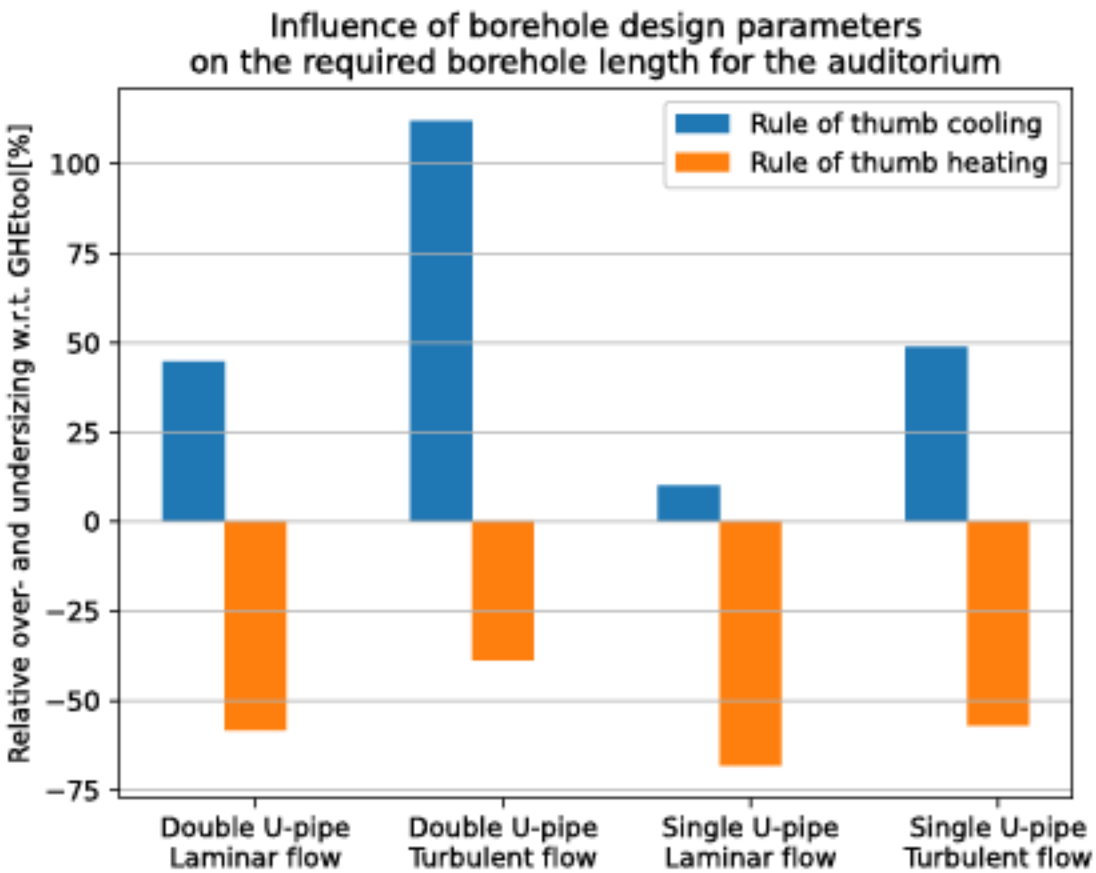

Figure 3: Influence of the fluid regime and the number of U-pipes in the borehole on the relative over- and under-sizing of the borefield in reference to a borefield sizing with GHEtool.

Sensitivity to temperature limits

Depending on the system design, other temperature limits can be set for the borefield. For example, when working with passive cooling, a maximum average fluid temperature of 17°C is typically used, which requires larger borefields for buildings with high cooling demand. When using a system with active cooling, 25°C can be used as a maximum temperature limit, relaxing the required total boreholelength. However, on the minimum temperature side, one can also work with different safety margins. 3°C for the average fluid temperature can be used as a safe margin to never get to negative fluid temperatures. This can, in practice, lead to oversizing; therefore, some people suggest using 1°C as a minimum average fluid temperature bound. This is a less safe solution, but it increases the economic viability of the borefield design. The effect of these temperatures on the relative over- and under-sizing is shown in Figure 4.

When going to active cooling (and using a maximum average fluid temperature limit of 25°C), sizing with a rule of thumb for cooling gives an extreme oversizing with a factor of 3 to 4. This is due to the fact that the borefield is now limited by the heating load, and hence, the peak cooling does not matter that much [3]. Notice how moving to active cooling also makes sizing with a rule of thumb for heating shift from under- to oversizing. This can be understood since the field is now limited by the heating peak, and therefore, this rule of thumb gives a more accurate estimation.

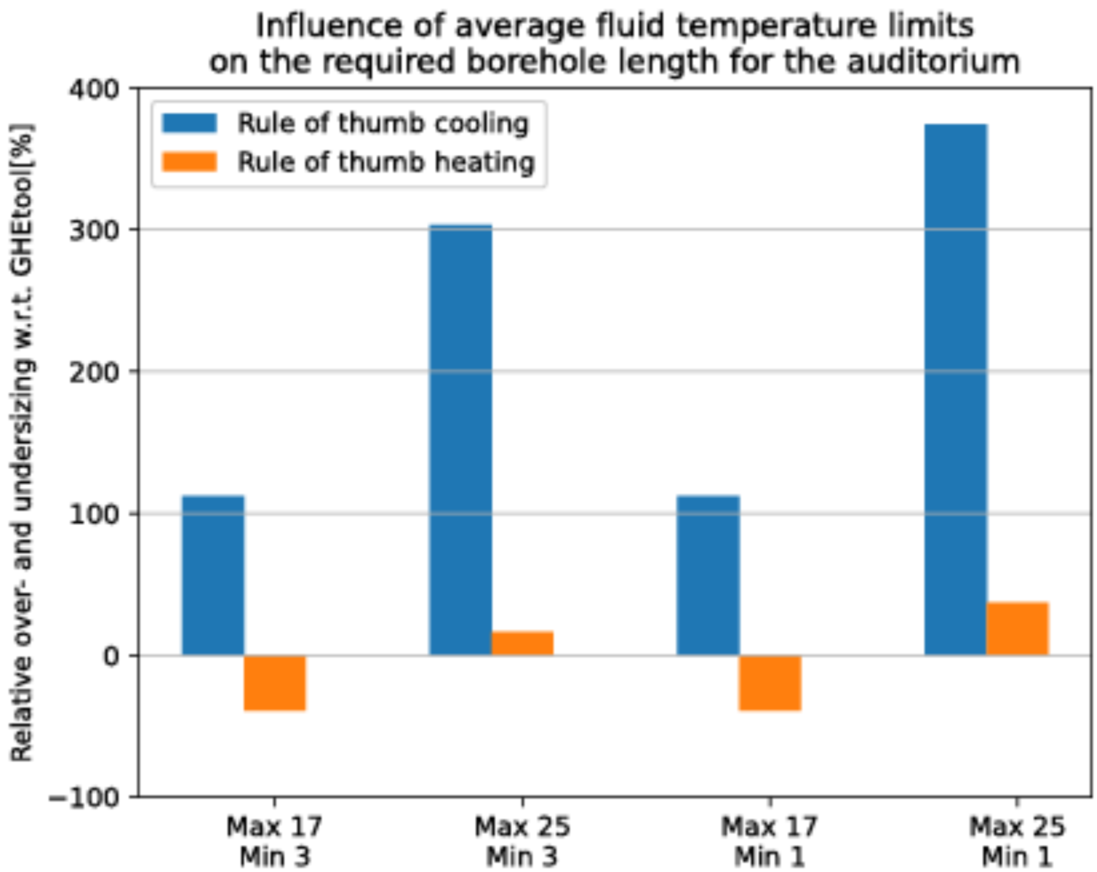

Figure 4: Influence of the average fluid temperature limits on the required borehole length in reference to a borefield sizing with GHEtool.

Overall sensitivity

The previous three paragraphs only showed a couple of parameters that influence the required total borehole length. The length/width ratio of the borefield, the simulation period (being 20 to 40 years), the ground thermal conductivity, the ground temperature gradient, the grout thermal conductivity, the peak duration, etc., all influence the required total borehole length. Figure 5 shows the total spread in the required total borehole length when varying all these parameters using a boxplot. It is clear that the one rule of thumb is nowhere near capable of capturing all variations in the required total borehole length when varying all the abovementioned parameters. The same conclusion can be drawn from Figure 6, where the rule of thumb value was reverse-engineered based on the calculated borefield size and the peak power. There is no one good and clear rule of thumb for all these cases and their variations.

The (non)sense of rules of thumb in borefield sizing

By now, it should be clear that there is a lot of diversity in the required borefield size that is not captured with a simple rule of thumb, but we don't necessarily need to throw them all away. For very specific buildings with similar designs, in a similar region and for borefields constructed in the same way, the spread in Figures 5 and 6 can for sure be smaller, and hence, a rule of thumb can be found in that case. However, it is not easy (to near impossible) to predict when one will deviate from it. In general, therefore, it is better to double-check the calculated borefield size with specialized software like GHEtool, EED, GLHEPro, EWS. By doing so, one can be more certain of a correct borefield size and, hence, a more robust, durable, economical and viable system.

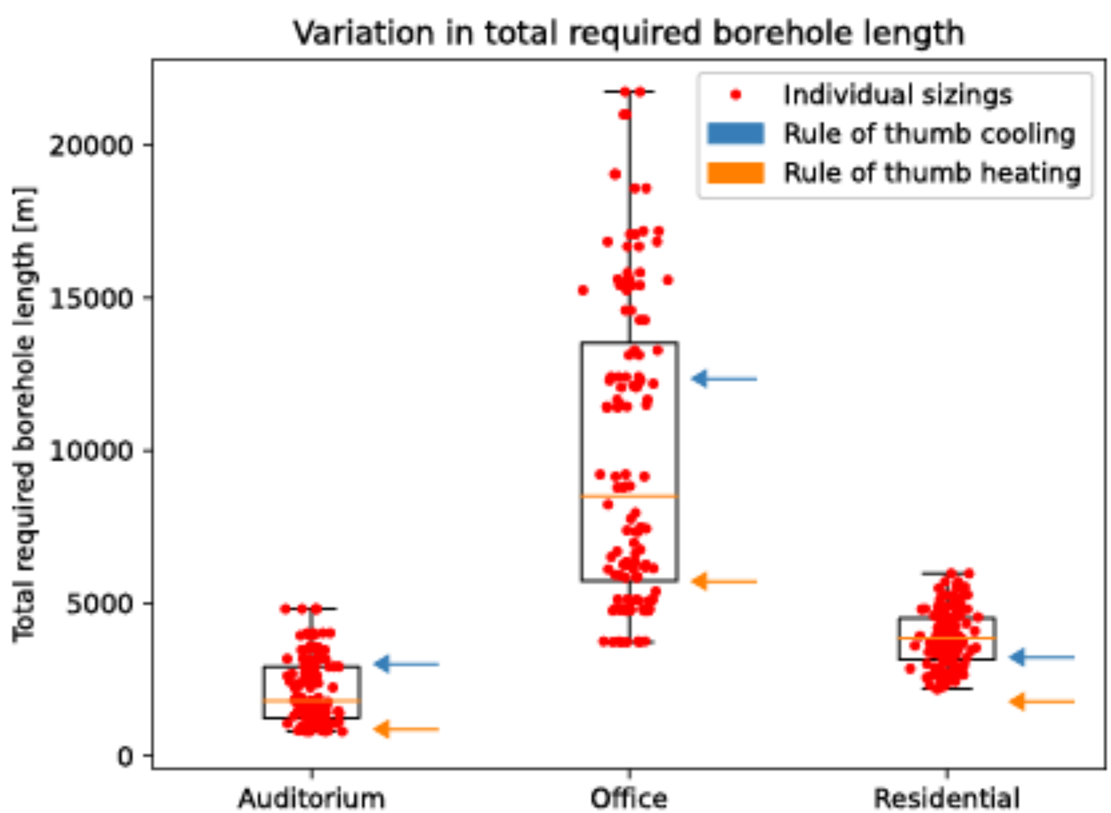

Figure 5: Variation in total required borehole length for three different buildings when varying the ground properties, grout properties, average fluid temperature limits, fluid regime, number of U-pipes and simulation period. The variation is shown in a box plot per building, indicating the sizings according to a rule of thumb.

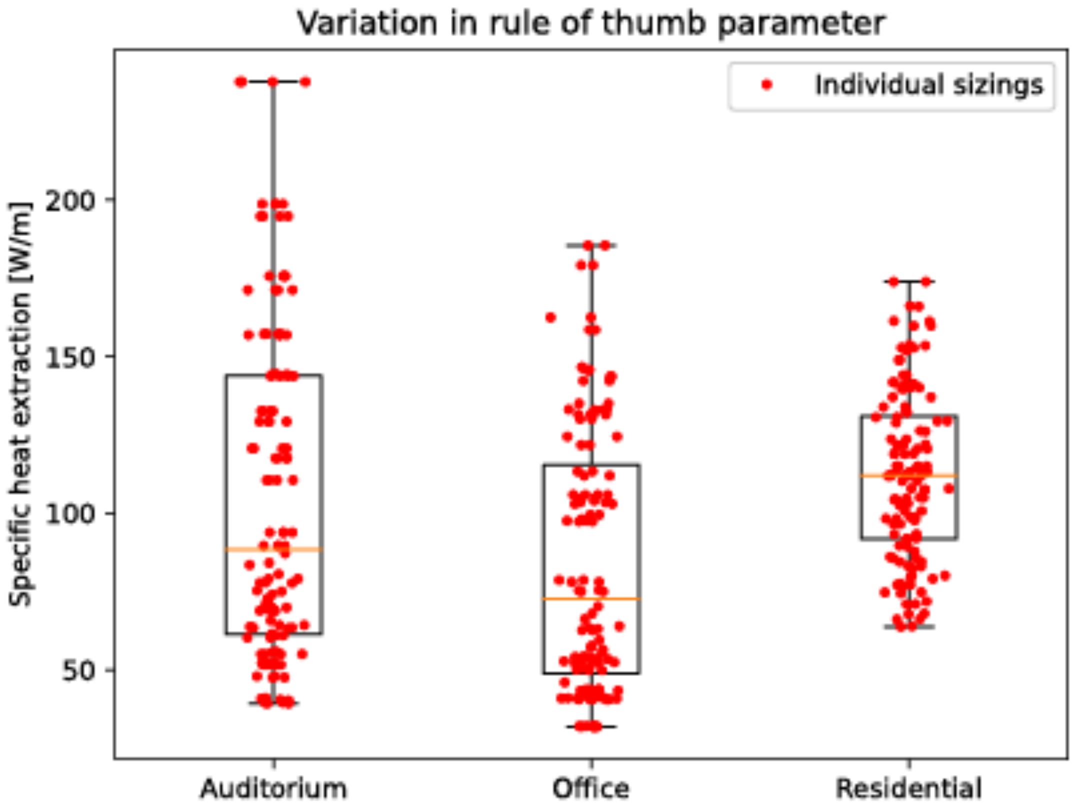

Figure 5: Variation in total required borehole length for three different buildings when varying the ground properties, grout properties, average fluid temperature limits, fluid regime, number of U-pipes and simulation period. The variation is shown in a box plot per building, indicating the sizings according to a rule of thumb.

Conclusions

This article shows the potential danger of using rules of thumb for borefield sizing. For three different buildings, it was shown that a simple rule of thumb can sometimes undersize the borefield or oversize it by up to 400%. The results from these simple rules are not, by definition, wrong, but they are covered with uncertainty. One cannot know for sure when these results can be trusted and therefore, the use of detailed borefield sizing tools is to be recommended in order to design borefields in such a way that they are both robust and financially viable.

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Table 1: Geothermal loads for the three building cases.

Building	Peak heating	Yearly heating demand	Peak cooling	Yearly cooling demand
Auditorium	26,0 kW	30,6 MWh	90,2 kW	3,86 MWh
Office	171 kW	94,0 MWh	370 kW	118 MWh
Residential	53,2 kW	122 MWh	96,7 kW	24,0 MWh

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