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Hokksund school – A plus energy school building with an innovative geothermal heat pump system

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Abstract

Hokksund School is a multi-building project comprising three school wings, a sports hall, and a swimming pool with a total heated area of 11,200 m². The school wing and sports hall are designed as plus-energy buildings according to the Futurebuilt definition, while the swimming pool uses best-available technology to minimize energy use. The thermal supply is based on the Lowex concept – low-temperature heating and high-temperature cooling – combined with a deep closed-loop borehole field (10 wells × 500 m) and six inverter-controlled heat pumps (total 258 kW). Simulations indicate that free cooling from the wells alone should meet cooling demands most of the summer season; however, there is still uncertainty about whether compressor-based cooling (reversal of the heat pumps) will have to be used at the end of the cooling season or under peak load conditions. The paper presents the Lowex system design, borehole field sizing based on in-situ thermal response test (TRT) results, and long-term Superposition Borehole Model (SBM) simulations for the 10-well field. The school was completed and occupied in August 2025; commissioning and tuning are ongoing, so measured verification of the simulated performance is pending.

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1. Introduction

In building projects with high energy ambitions, such as Nearly-Zero-Energy-Buildings or plus-energy buildings, optimizing all systems that affect the building's energy use is essential. These optimizations typically cover:

A. Passive building properties (U-values, thermal mass),
B. Technical systems (ventilation, lighting),
C. Thermal energy supply (heat pumps, boilers),
D. Local renewable electricity production (on-site PV).

A high-performance thermal energy supply is often necessary to achieve high overall energy performance. In this project we apply a Lowex approach [1] – low-temperature heating combined with high-temperature cooling – so that the ground (via boreholes) supplies relatively high source temperatures to the heat pumps while the building heat emittance system operates at low supply temperatures. The Lowex objective is to minimize the heat pump temperature lift in heating and to enable direct ground cooling in summer, avoiding mechanical cooling where possible.

A key factor for Lowex performance is the borehole field: the source temperature, thermal capacity, and long-term thermal balance of the ground directly determine the achievable supply temperatures for heating and

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the potential for direct ground cooling in summer. In Norway, practical constraints such as groundwater-filled boreholes and the need for casing to bedrock influence the economics and layout of the field; casing is expensive, so drilling fewer but deeper boreholes was found to be financially feasible for this project. These geological and economic constraints motivated the choice of deeper wells for Hokksund and directly informed the thermal response testing and long-term simulations presented below.

Several buildings employing Lowex principles have been reported in the literature [2] and practice (including projects using shallower boreholes), demonstrating high seasonal performance when heating and cooling emittance systems and heat-pump integration are optimized. Some of these projects report very high seasonal performance factors (SPF) and direct ground cooling operation; Annex 52 [3] documents multiple cases of direct ground cooling with reported SPFs above 30.

Hokksund Primary School, located approximately 50 km west of Oslo (Norway), is a multi-purpose building consisting of a school wing (7160 m²), a multi-purpose sports hall (1940 m²), and a swimming pool (2100 m²). The school wing and the multi-purpose sports hall are designed to the plus energy standard according to Futurebuilt's definition [4]. The Futurebuilt plus energy definition requires that the total energy use of the building is covered by renewable on-site electricity production, including 2 kWh/m² for electric mobility purposes. The school wing and the multi-purpose hall are designed according to the Lowex concept [1, 2], which is a comprehensive approach for low-temperature heating and high-temperature cooling using the floor construction. This concept can provide seasonal COP for heating above 5 and seasonal EER for cooling above 30, where COP and EER follow the European definitions – COP being the ratio of useful heating output (kW) to electrical input (kW), and EER the ratio of useful cooling output (kW) to electrical input (kW).

To provide low-temperature heating and high-temperature cooling, all floor structures are optimized to ensure low thermal resistance between the water in the PEX pipes and the floor surface. The self-leveling compound is gypsum-based (which has higher thermal conductivity than cement-based compounds), and the floor covering is typically made of thin vinyl and thin wood flooring, which provide low thermal resistance. Heat production in the building consists mainly of six inverter-controlled heat pumps, each with a capacity of 43 kW, designed to cover the entire heating demand in a normal year. Each heat pump unit has two independent circuits. The first compressor is inverter-controlled, while the second operates in on/off mode. The heat pumps are augmented with electric boilers under peak conditions. Two of the heat pumps are dedicated to the swimming pools, three are allocated to the school wing and the multi-purpose sports hall, and one heat pump is allocated to domestic hot water production for the school and the sports hall. The three heat pumps that cover the heating demand can be continuously regulated between 6 and 129 kW and can therefore operate almost without start-stop cycles throughout the heating season, which is beneficial both due to reduced part-load losses and improved system lifespan.

Due to special ground conditions, with 100–110 meters down to the bedrock, it was decided to drill deep energy wells of approximately 500 meters. In total, ten closed-loop boreholes were installed, each equipped with a single U-pipe and arranged in a linear configuration with a minimum spacing of 10 meters. Two wells are allocated to the swimming pool, and eight wells are allocated to the school wing and the multi-purpose sports hall. The advantage of deep wells is that they provide significantly higher ground temperatures, which is highly favorable for achieving high COP values in the heat-pump system. However, deeper wells also increase the risk that free cooling cannot be maintained throughout the entire cooling season. If free cooling becomes insufficient, the system must switch to heat-pump reversal for cooling, which results in substantially higher energy use. This paper focuses primarily on the design and simulation results for the school wing and the sports hall.

2. Methods

Because borehole characteristics are decisive for Lowex operation, the modelling workflow couples building energy simulations with detailed borehole design: building loads set the thermal demand, the Lowex floor design sets heating and cooling emittance temperatures, and TRT-informed SBM simulations evaluate the borehole field's ability to supply and reject heat over seasonal and multi-year horizons.

The approach used to model and design the Lowex system for the buildings consisted of three main steps: (1) Building energy simulations using Simien [5], which provides detailed energy and power profiles for realistic system sizing; (2) Design of the Lowex thermal distribution system, based on simulation results from Simien and refined with a custom calculation sheet to determine heat pump supply temperature, loop dimensions, and practical control curves; and (3) Geothermal borehole field simulation using the Superposition Borehole Model, SBM, [6] to ensure stable operation during heating and cooling seasons, with SBM input parameters obtained from an in-situ thermal response test.

The buildings were simulated using Simien 7, the most widely used standard energy-simulation software for buildings in Norway. Simien is specifically designed to comply with the Norwegian building code and the national energy-labelling scheme, following the calculation methodology defined in the Norwegian standard for energy calculation NS 3031:2025 [7]. The software includes a built-in heat pump simulation model that calculates the coefficient of performance (COP) at each time step, considering the buildings' dynamic heating and cooling demand, the temperatures on both the condenser and evaporator sides of the heat pump, the part-load efficiency of inverter-controlled compressors, and the thermal storage volume. Distribution losses are also explicitly included.

The simulations provide detailed results, including the buildings' hourly and cumulative thermal and electrical energy consumption as well as instantaneous and peak power demands. These outputs allow for comprehensive evaluation of the energy system, assessment of load profiles, and estimation of overall system efficiency. The input values were based on the assumed actual use of the buildings, including occupancy schedules and the number of occupants, as far as this could be determined. This approach provides a more realistic system design compared to relying solely on standardized usage profiles.

The Lowex thermal system was modelled using a combination of Simien and a custom Lowex spreadsheet developed in an earlier research project [1]. The spreadsheet is based on the electric analogy model in ISO 11855-2 [8], which is a two-dimensional stationary model of the heat transfer between the water pipes and the floor surface. The required heat load for each room was determined by creating room models in Simien for typical and design-critical rooms. These room-level heat requirements were then used as input for the Lowex spreadsheet, which calculates the required floor loop lengths and pipe sizing based on the necessary floor surface temperature. The floor surface temperature is calculated by the floor's thermal resistance and the desired room temperature. Further, the heat pump supply temperature is determined by the room with the highest required water temperature in the PEX pipes. To take into account the thermal inertia of the building, the supply temperature is not a function of only the current outdoor temperature but is a weighted temperature that considers the forecasted temperature 48 hours in advance. Together, these results support both hydraulic dimensioning and system control design, ensuring that the underfloor heating system operates efficiently under varying external and internal conditions.

Each room shall, in theory, have its own outdoor-temperature-compensated control curve for the mass slab, based on the room's physical design and use. In practice, it is not practical from the viewpoint of the building operator to have many individual control curves. Thus, a simplified control scheme is provided by curve-fitting all the rooms into one single control curve, which is called the normal curve. For rooms which have a higher or lower heating load, two other curves are made by offsetting the normal curve by ±1-2°C. The appropriate control curve for each room is found during the commissioning phase when the room is in real use.

The geothermal borehole field has been sized and simulated using the Superposition Borehole Model (SBM). Heating and cooling loads have been taken from the building simulations. Ideally, the outlet temperature from the boreholes should be on average around 5°C during the significant part of the heating season, and below approximately 14°C during the cooling season. The design inputs to the SBM, including undisturbed ground temperature, ground thermal conductivity, and borehole thermal resistance, have been determined through an in-situ TRT.

In addition to the design steps described above, Hokksund school and swimming hall are instrumented with thermal and electrical meters to enable systematic monitoring and analysis of critical system parameters. Recorded data includes, for example, the inlet and outlet temperatures of the energy wells and the coefficient of performance (COP) of the heat pump system, facilitating comprehensive evaluation of system performance.

3. Results and Discussion

Table 1 shows the energy simulation results from Simien, with the energy flow table according to NS3031:2025. Net energy (column 2) is defined as the energy demand in the rooms of the building. The gross energy (column 4) considers the losses in the distribution and storage system (column 2). The supplied energy (column 6) also accounts for the production efficiency of the heating and cooling system, given by the seasonal performance factor (SPF) of the different systems, as shown below. The SPF of the heating systems (column 5) can be regarded as the annual mean of the whole heat pump system, including electric peak load energy. As can be seen, the SPF is above 5 for the heating system, and the cooling system SPF (annual average EER) is close to 30. High seasonal SPF values in the simulations result from the combination of low emittance temperatures to the Lowex floor system, elevated borehole source temperatures from deep wells, and inverter part-load behavior and low distribution losses. These numbers are in accordance with the goal of the project but must be verified with measured values when the systems are in normal operation.

Table 1. Energy simulation results of the school and sports hall.

Energy post	Net (A)	Distr./Acc.	Gross (B)	SPF	Supplied (C)
1a Space heating	19.3	2.5	21.9	5.14	4.3
1b Heating coils (ventilation)	1.2	0.2	1.3	5.14	0.3
2a Tap water	7.7	2.3	10.0	3.34	3.0
3a Space cooling	6.7	0.2	6.9	29.34	0.2
3b Coling coils (ventilation)	0.5	0.1	0.6	23.58	0.0
4a Fans	4.6	0.0	4.6	1.00	4.6
4b Pumps	0.7	0.0	0.7	1.00	0.7
Sum 1-4	40.8	5.3	46.1	68.55	13.1
5 Lighting	8.1	0.0	8.1	1.00	8.1
Sum 1-5	48.9	5.3	54.2	69.55	21.2
6 Equipment (appliances)	8.8	0.0	8.8	1.00	8.8
Total net energy usage, sum 1-6	57.7	5.3	63.0	2.10	30.0

Energy flow [kWh/m²]

Fig. 1 shows the downhole borehole temperature profile measured prior to conducting the thermal response test. The data illustrate a clear increase in temperature with depth, with values at 200 m significantly lower than those observed at 500 m. This gradient highlights a key advantage of deeper boreholes for heating applications: higher ground temperatures at greater depths improve heat pump efficiency and reduce the required borehole length for a given thermal load. The average undisturbed ground temperature measured and used as input in the Superposition Borehole Model (SBM) is 12.8 °C.

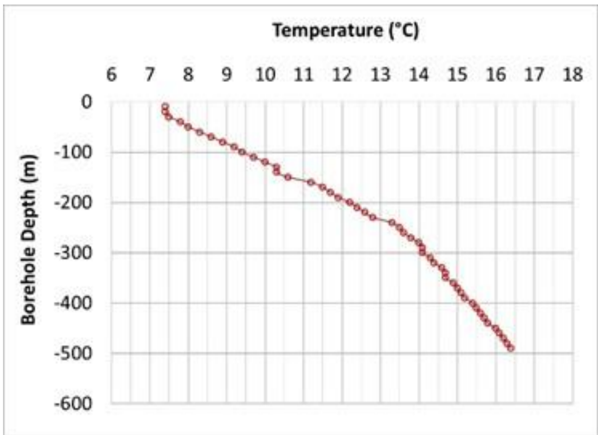

Figure 1. Downhole temperature profile measured before the thermal response test.

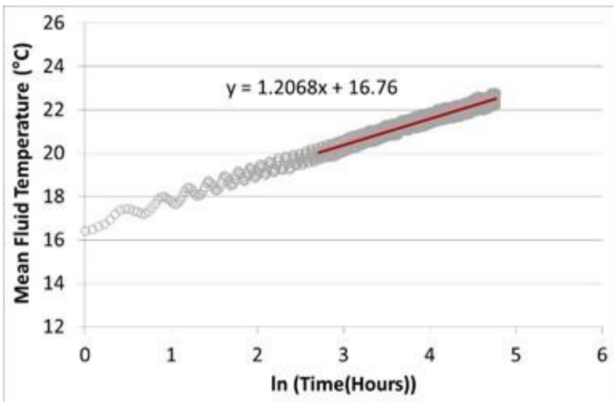

Figure 2. Line-source evaluation from the thermal response test.

Fig. 2 shows the line-source evaluation, where the mean fluid temperature measured during the thermal response test (TRT) is plotted against the natural logarithm of time. The TRT was conducted over a period of approximately 120 hours, with data from beyond 15 hours used for evaluation to minimize early transient effects. Based on this analysis, the estimated ground thermal conductivity is 2.5 W/(m·K), which was used as a design input in the Superposition Borehole Model (SBM). Borehole thermal resistance has been derived both from the TRT data and using the method proposed by Spitler et al. for groundwater-filled boreholes [9]. A value of 0.11 (m·K)/W is adopted for the design simulations.

Fig. 3 presents simulation results for eight energy wells, each 500 meters deep, supplying the school and the sports hall. The graphs show inlet and outlet borehole temperatures over a 25-year period, with clear annual fluctuations reflecting seasonal heating and cooling demands. The average outlet temperature remains well above 5 °C during the heating season, indicating stable thermal performance for heat extraction. During the cooling season, temperatures ideally stay below 14 °C, but the simulation reveals occasional peaks exceeding this threshold, particularly in the early years.

In reality, if free cooling from the boreholes proves insufficient during peak conditions or late in the cooling season, the system can operate the heat pumps in cooling (reversal) mode as a fallback; this operation increases electrical consumption and is therefore undesirable for sustained use, particularly beyond the first few seasons. Whether reversal is required will depend on measured cooling demands, ambient conditions, and the commissioning-adjusted control strategy.

Over time, both inlet and outlet temperatures exhibit a gradual downward trend, especially during the cooling season. This behavior reflects a developing thermal imbalance in the borehole field, where more heat is extracted during heating than is reinjected during cooling. As a result, the ground temperature slowly declines, which can increase cooling efficiency and decrease the risk of exceeding design limits in future years.

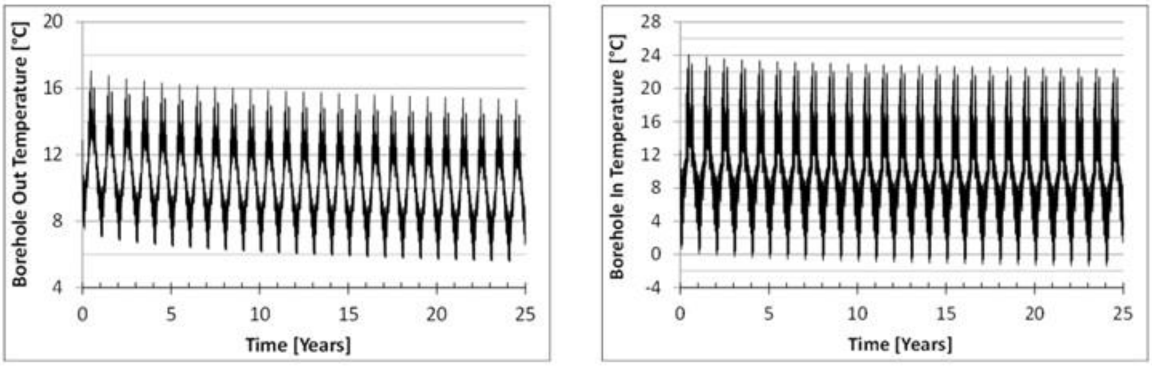

Figure 3. Left: Long-term simulation of borehole outlet temperatures showing annual cycles and gradual cooling. Right: Corresponding inlet temperature simulation over the same 25-year period.

Fig. 4 shows the calculated setpoint supply temperature from the heat pump system as a function of the outdoor temperature conditions. Even in the coldest periods of the year, the supply temperature does not need to exceed 30 °C. The high SPF of the heating system given in Table 1 can be explained by the high temperatures from the boreholes and the low temperature to the heating system.

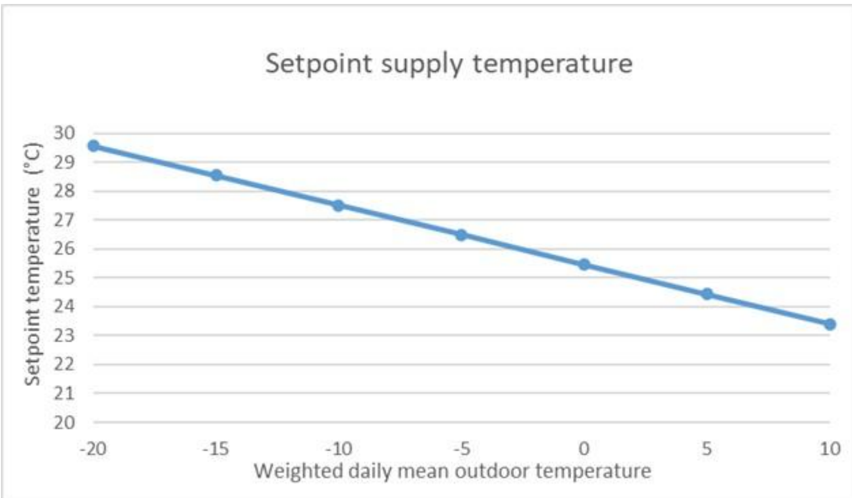

Figure 4. Control curve. X-axis shows the weighted outdoor temperature; Y-axis shows supply temperature from the heat pump system.

4. Conclusion

An innovative Lowex heating and cooling system combining deep geothermal boreholes and high-performance inverter heat pumps has been applied to a plus energy school. Key design and simulation outcomes are: a borehole field of 10 wells × 500 m with an average undisturbed ground temperature of 12.8°C (TRT input), a heat-pump plant sized at 258 kW (six units), and simulated seasonal performance factors for heating above 5 and annual cooling EERs on the order of 30. Long-term SBM simulations indicate outlet temperatures that remain above the 5 °C target during most of the heating season, while occasional summer peaks above the 14 °C cooling threshold appear in early years. These results underline two practical implications: (1) deeper boreholes raise source temperatures and reduce heat-pump temperature lift, improving simulated SPF, and (2) free ground cooling is expected to cover most of the cooling season but heat-pump reversal may be required under peak or late-season conditions, which is undesirable for long-term energy use. The choice to drill fewer, deeper boreholes was driven by Norwegian practice (groundwater-filled boreholes requiring casing to bedrock) and the relative cost of casing, making deeper but fewer boreholes financially feasible for this project. Finally, while the simulated performance is promising, measured verification is required; the paper therefore presents the design and simulation basis and highlights the need to compare measured hourly COP/SPF and borehole temperatures with the modelled projections during the commissioning and first years of operation.

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References

[1] Avantor. The LowEx concept [Internet]. Available from: https://www.avantor.no/aktuelt/forskningsprosjektet-lowex/
[2] Javed S, Ørnes IR, Myrup M, Dokka TH. Design optimization of the borehole system for a plus-energy kindergarten in Oslo, Norway. Archit Eng Des Manag. 2019;15(3):181–195.
[3] Gehlin S, Spitler JD. Case study summary report. IEA HPT Annex 52 – Long-term performance monitoring of GSHP systems serving commercial, institutional and multi-family buildings [Internet]. 2022. Available from: https://doi.org/10.23697/xsbr-xn83
[4] FutureBuilt. FutureBuilt plus energy criteria [Internet]. Available from: https://www.futurebuilt.no/FutureBuilt-kvalitetskriterier
[5] SIMIEN: Simulation of indoor climate and energy use [Internet]. Available from: https://simien.no/
[6] Eskilson P. Thermal analysis of heat extraction boreholes [dissertation]. Lund (Sweden): Department of Mathematical Physics, University of Lund; 1987. Available from: http://www.buildingphysics.com/Eskilson1987.pdf
[7] Standard Norway. NS 3031:2025 Energy performance of buildings – Calculation of energy and power demand. Oslo: Standard Norway; 2025.
[8] International Organization for Standardization. ISO 11855-2: Building environment design – Design, dimensioning, installation and control of embedded radiant heating and cooling systems – Part 2: Determination of the design heating and cooling capacity. Geneva: ISO.
[9] Spitler JD, Javed S, Ramstad RK. Natural convection in groundwater-filled boreholes used as ground heat exchangers. Appl Energy. 2016;164:352–365.