HAMK OHUTLEVYKESKUS

ENERGY PERFORMANCE

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Contents

1. Introduction

This report has been prepared at the request of Ruukki Construction Oy regarding the energy performance of HAMK Ohutlevykeskus (Figure 1) located in Hämeenlinna. Results of energy simulations presented in this report consider two life cycle phases of HAMK Ohutlevykeskus building – design phase (simulations conducted in 2014) and "As Built" phase (simulations conducted in 2015). Energy simulations were conducted in IDA ICE version 4.5 with borehole extension version 0.3 simulation environment.

Aim of the design phase simulations was to correctly size the geothermal plant and assess the impact of its components and plant control strategies on the building's energy performance. Total of three design phase cases are presented in this report.

Aim of the "As Built" phase simulation was to assess the energy performance of as built design due to some differences in the envelope materials and lights control strategies compared to design phase simulations building model's initial data. In addition to actually built case scenario, simulations with different ground heat exchanger solutions (energy piles, heat wells, underground water storage tank) and thermal storage sources (solar, AHU exhaust heat) were conducted during the "As Built" phase and presented in this report. Total of five "As Built" phase cases are presented in this report.

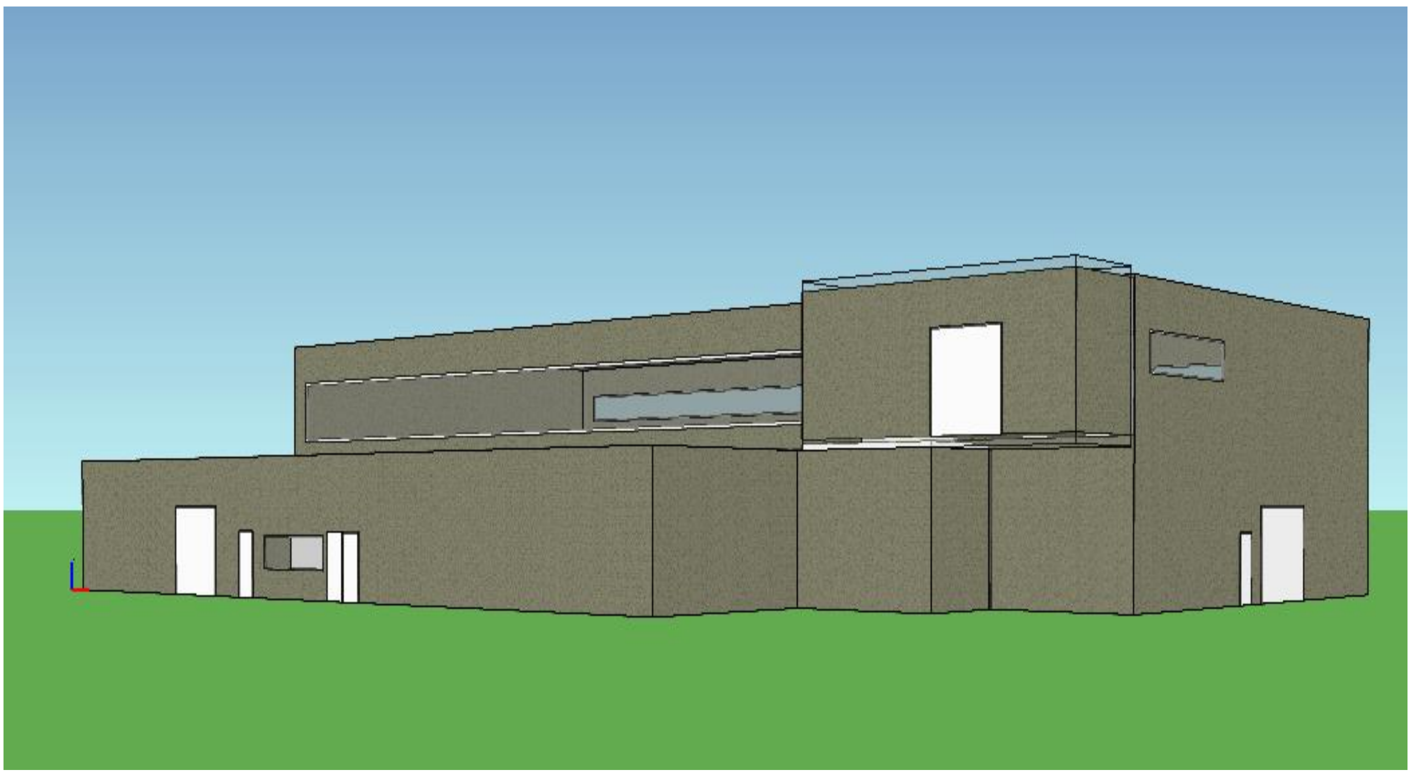


Figure 1. HAMK Ohutlevykeskus model in IDA-ICE

2. Initial data

Simulated cases initial data for building model and plant solution varied from case to case. In design phase simulations two different building model setups were applied. While in "As Built" phase, same building model setup was applied for all simulations. This sections only covers building model's initial data and more detailed plant solution description is presented further separately for each case in simulation results section.

2.1. Design phase building model description

For sake of comparison and assessment of geothermal plants energy performance a reference case with district heating was compiled. Therefore, two building models were setup according to initial data presented further. Marked as blue cells in initial data tables describe the parameters, that differ from the parameters presented in previous table.

2.1.1. Reference case with district heating

The following table presents the initial building model data applied in reference case with district heating (1 case).

Table 1. Reference case with district heating building model settings

Wall	0.17
Roof	0.09
Window	1.0 (SHGC = 0.55)
Floor	EPS 150, λ=0.034
Infiltration	4 m3/m2 h q50
AHU HR	50%
Lights	15 W/m2
DHW	68 l/m2 a
People	30
Fresh air (SFP=2.0)	1.5(2 overall) l/sm2
Setpoints	18/25
Energy source	District heating
Cooling EER	2.5
Schedule	8-17 (5 days a week)

2.1.2. Design phase cases with geothermal plants

The following table presents the initial building model data applied in design phase geothermal plant cases (total of 2 cases).

Table 2. Design phase building model settings

Wall	0.16
Roof	0.12
Window	1.0 (SHGC = 0.55)
Floor	EPS 150, λ=0.034
Infiltration	0.87 m3/m2 h q50
AHU HR	80%
Lights	10 W/m2
DHW	68 l/m2 a
People	30
Fresh air (SFP=2.0)	1.5
Setpoints	18/25
Energy source	GHSP
Cooling EER	free cooling
Schedule	8-17 (5 days a week)
Room units	Radiant heating/cooling panels (n=0.9)

2.2. “As Built” phase building model description

The following table presents the initial building model data applied in “As Built” phase geothermal plant cases (total of 6 cases).

Table 3. “As Built” phase building model settings

Wall	0.16
Roof	0.12
Window	Average U = 0.78 (SHGC = 0.43)
Floor	EPS 150, ʎ=0.034
Infiltration	Measured 0.76 m3/m2 h q50
AHU HR	80%
Lights	10 W/m^2 with daylight control 300 LUX
DHW	68 l/m2 a
People	30
Fresh air (SFP=2.0)	1.5
Setpoints	18/25
Energy source	GSHP
Cooling EER	free cooling
Schedule	8-17 (5 days a week)
Room units	Radiant heating/cooling panels (n=0.9)

3. Methods

Detailed energy simulation were conducted in Equa IDA-ICE version 4.5 software with borehole extension version 0.3. An ESBO plant was used as a template for creating a specific geothermal plant solutions (Figure 2).

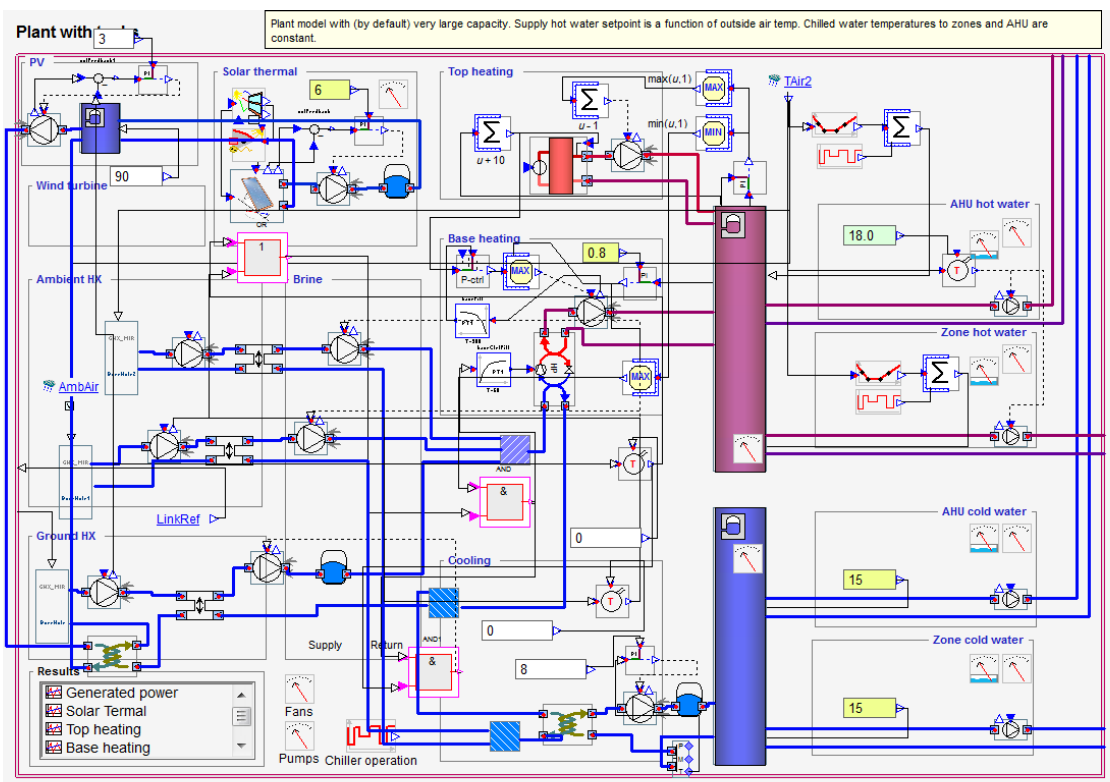


Figure 2. Geothermal plant solution in IDA-ICE (“As Built”)

In simulations with geothermal plants supply temperature depends on the outdoor air temperature value. The following supply temperature curve (Figure 3) is applied for radiant heating panels and AHU heating coil supply side.

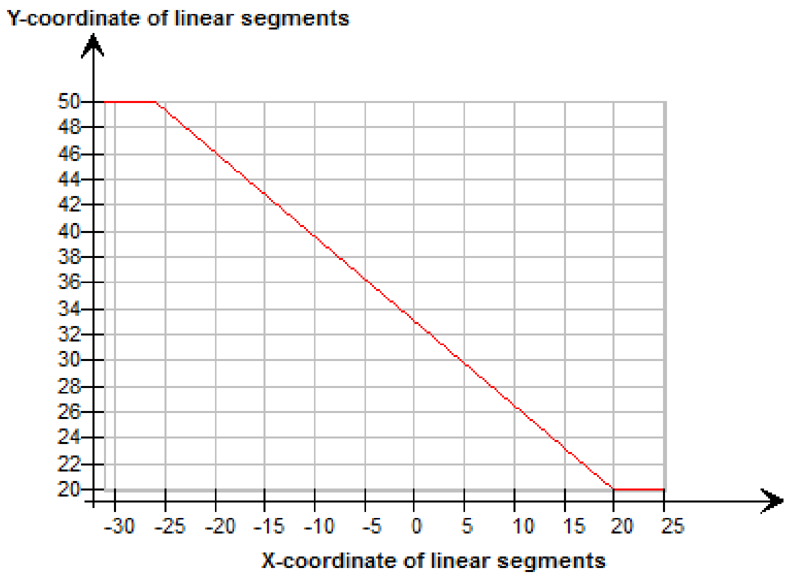


Figure 3. Secondary side (radiant heating panels, AHU heating coil) supply temperature schedule

3.1. Delivered energy calculation

Simulation results covered in section 4 are presented in table and graphical format. Table results are divided into two groups – energy need and delivered energy. Energy need represents the net energy, which does not include distribution losses, efficiency of heat generations systems etc. On the other hand, delivered energy accounts for efficiencies (distribution losses), conveyance and control, heat/cool generation coefficients of performances. Delivered energy value multiplied by energy source weighting factor results in energy performance value (EPV).

Delivered energy values in simulation results tables were calculated using the following initial data:

- Radiant heating/cooling panels efficiency n = 0.9;
- Heat pump coefficient of performance calculated by the dynamic heat pump model;
- Domestic hot water (DHW) generation efficiency n = 0.89;
- Heat pump DHW SCOP = 1.8.

Further an example of delivered energy calculation is presented based on the case 4.2 “Design phase: Energy piles and heat wells without thermal storage”:

- Top-up heating delivered energy = energy need / radiant panels efficiency;
    - Top=up heating delivered energy = 2793 : 0.9 = 3103 kWh;
- Heat pump delivered energy = energy need / radiant panels efficiency / heat pump SCOP;
    - SCOP is not given in the table, but can be back calculated: 57667 : 0.9 : 14074 = 4.55;
    - Heat pump delivered energy = 57667 : 0.9 : 4.55 = 14074 kWh;
- Domestic hot water delivered energy = energy need / generation efficiency / heat pump DHW SCOP;
    - Domestic hot water delivered energy = 5918 : 0.89 : 1.8 = 3694 kWh.

3.2. Geothermal loops control logics

There are two separate loops in the system, where one consists of 64[1] energy piles and other of two energy wells. Each of two loops is equipped with a separate pump. Temperature of outlet brine in each loop is measured.

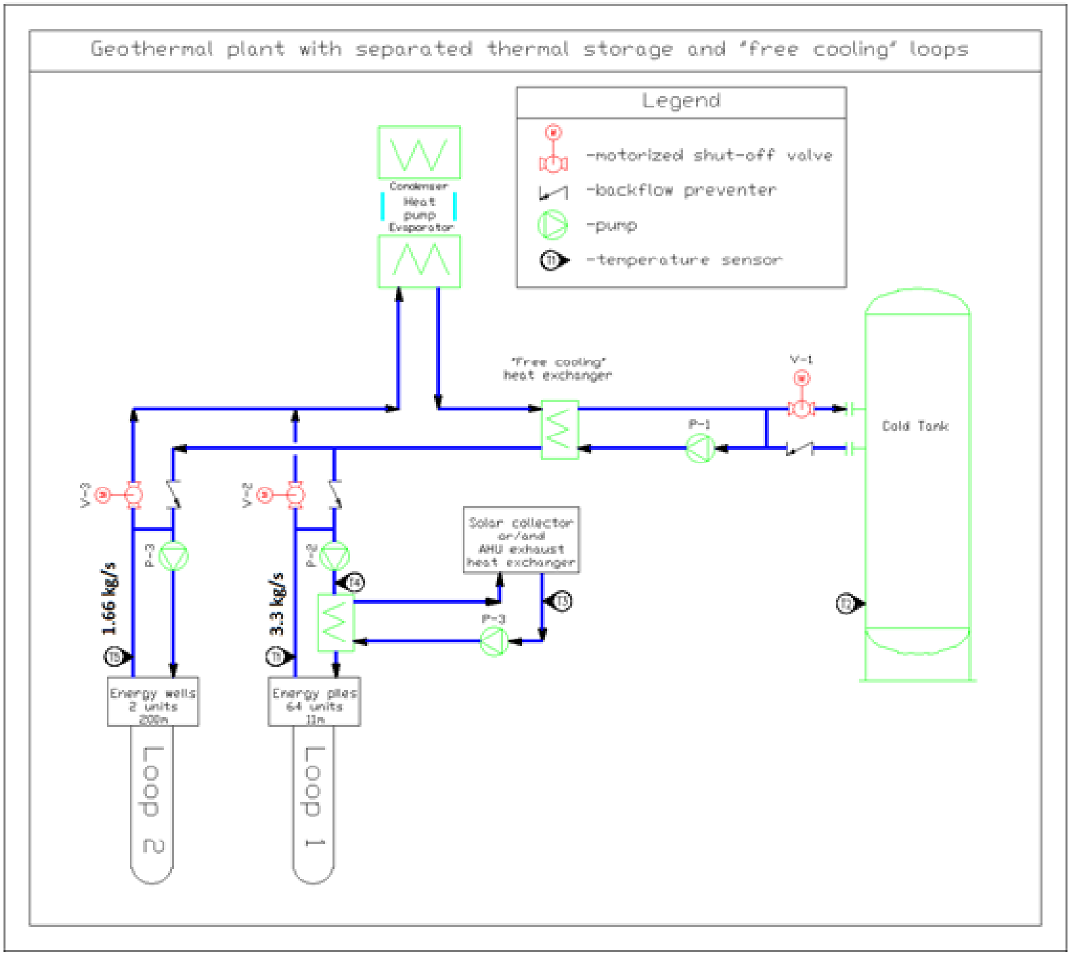


Figure 4. Geothermal plant with separated thermal storage and "free cooling" loops

Frost protection

In order to prevent the formation of the ice in the ground and possible frost heave, geothermal loops brine outlet temperature should not drop below 0…-1 °C. Therefore, circulation pumps in each loop should stop when the brine outlet temperature drops below the setpoint of 0…-1 °C.

Heating season operation

System consists of multiple loops with different design flows and physical properties (2x200m and 64[1]x11m). In energy piles loop (64[1]x11m) brine outlet temperature will be significantly higher, because of the application of thermal storage. The heat pump will operate whenever there is a heat demand and the following conditions are fulfilled.

During the heating season total design flow in the system is 4.95 dm^3/s. Energy wells outlet temperature will drop below the allowed setpoint (0…-1°C) earlier, than in energy piles loop. Therefore, circulation pump of energy wells will stop and the overall flow in the system will result in 3.3 dm^3/s. As the outlet temperature in energy piles loop is still above the setpoint, the heat pump has to operate to absorb the energy available in energy piles field.

At some point energy piles loop might be inactive and energy wells loop active. In this case the overall flow in the system will equal 1.65 dm^3/s and heat pump should operate.

Heat pump should be able to operate, whenever the temperature in one of the loops is above the setpoint. On the contrary, it should stop its operation when there is no flow in the system (both loops are below the setpoint). With this control logics all the available geothermal energy will be absorbed.

[1]There are 64 energy piles in reference cases and 60 in "As Built" cases

Cooling season operation

Whenever the cooling cycle starts, there is no heat demand in the system and heat pump will not operate. As the heat pump is inactive, energy piles loop should be separated by e.g. three-way valve from evaporator circuit. In this case only energy wells are active and 1.65 dm^3/s will flow through free cooling heat exchanger.

Thermal storage

For each of two loops there is a separate thermal storage. In case of energy wells, the required amount of heat is supplied during their free cooling operation.

Solar collector (with/without buffer tank) and/or AHU exhaust air is applied as a thermal storage source in energy piles loop. Thermal storage source(s) is (are) connected via heat exchanger to energy piles loop inlet pipe. Whenever the heap pump is inactive, energy piles loop should be separated by e.g. three-way valve. Flow of 3.3 dm^3/s is maintained and energy piles are loaded with heat separately from energy wells.

4. Simulation results

This section presents the simulation results of conducted simulations. Initial data regarding plant solution and plant components is described for each case individually.

4.1. Design phase: Reference case with district heating

Building model initial data is presented in Table 1. Default IDA-ICE heating plant solution is applied as a district heating source. Reference case can be used for feasibility assessment of further presented geothermal plant cases.

4.1.1. Results

The following table presents the results of energy performance simulation of reference case with district heating.

Table 4. Reference case with district heating results

	Energy need		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Heating	88272	59.0	88272	59.0
Cooling	8502	5.7	3401	2.3
Fans electricity (SFP=2.0)	18498	12.4	18498	12.4
Pumps electricity	79	0.1	79	0.1
Lighting	51178	34.2	51178	34.2
DHW	5918	4.0	5918	4.0
	Total electricity:		**73156**	**49**
	Total heat:		**94190**	**63**

4.2. Design phase: Energy piles and heat wells without thermal storage

Building model initial data is presented in Table 2. Total of 64x11m energy piles and 2x200m heat wells were applied in custom geothermal plant. Thermal storage due to floor heat loss is taken into an account, while no other additional sources of thermal storage persist. Heat pump capacity was 40 kW. Heat wells loop provide "free cooling", energy piles loop used only during heat pump operation.

4.2.1. Results

The following table presents the results of energy performance simulation of energy piles and heat wells without thermal storage.

Table 5. Energy piles and heat wells without thermal storage results

	Energy need		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Top-up heating	2793	1.9	3103	2.1
Heat pump	57667	38.5	14074	9.4
Cooling	8502	5.7	0	0.0
Fans electricity (SFP=2.0)	14302	9.6	14302	9.6
Pumps electricity	5378	3.6	5378	3.6
Lighting	34109	22.8	34109	22.8
DHW	5918	4.0	3694	2.5
	Total electricity:		**74661**	**49.9**

The following figures describe brine outlet temperature from energy piles and heat wells loops. It can be observed, that only heat wells loop is used for "free cooling". Which explains temperature rise during summer period.

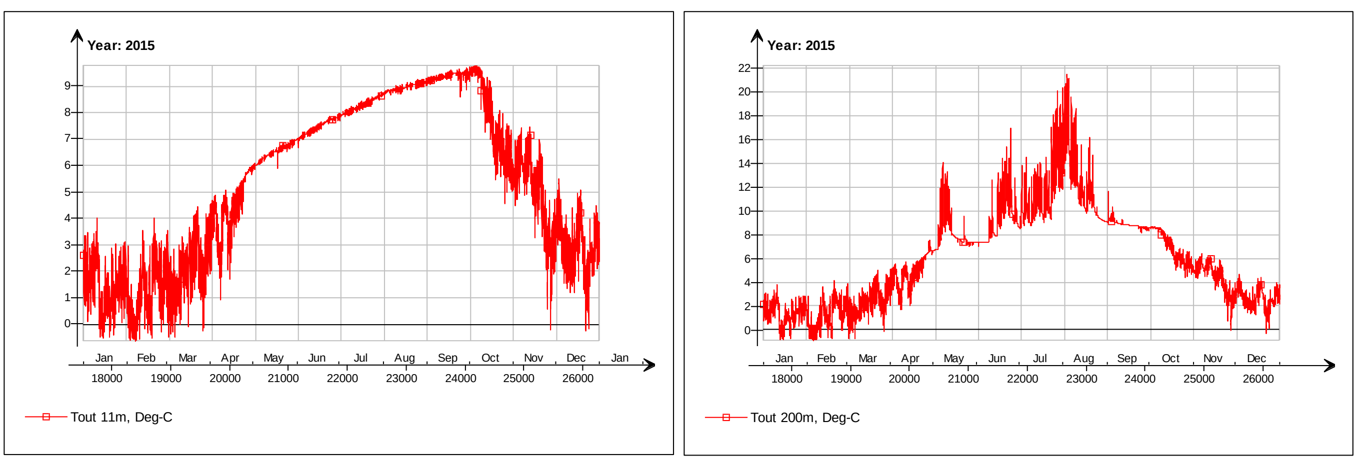


Figure 5. Energy piles brine outlet temperature (left), heat wells outlet temperature (right)

The following figures describe heat pump evaporator loop inlet temperature and indoor air temperature of hall zone. Most of the time indoor air temperature stays within the desired temperature setpoint of 25 °C.

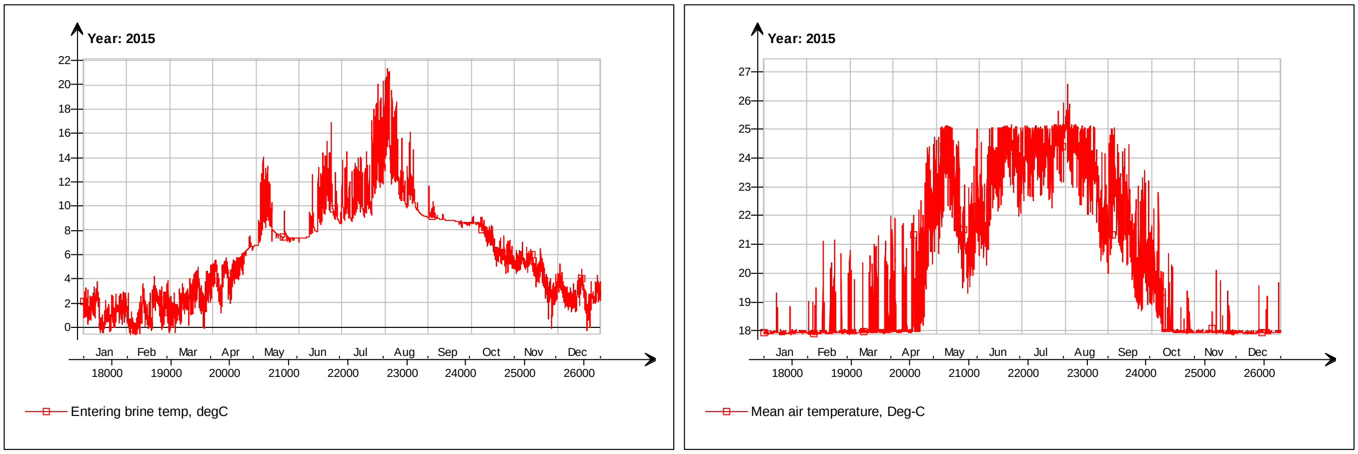


Figure 6. Heat pump evaporator/"free cooling" heat exchanger entering temperature (left), indoor air temperature (right)

4.3. Design phase: Energy piles and heat wells with solar thermal storage

Building model initial data is presented in Table 2. There are total of 64x11m energy piles and 2x200m heat wells applied in custom geothermal plant. Solar collectors of total area 24 m^2 with efficiency parameters of "Ruukki Classic" are applied as thermal storage source. Solar collectors are connected via heat exchanger to energy piles inlet side. Geothermal plant operates according to operation principles described in section 3.2. Thermal storage due to floor heat loss is taken into an account. Heat pump capacity was 40 kW.

4.3.1. Results

The following table presents the results of energy performance simulation of energy piles and heat wells with thermal storage.

Table 6. Energy piles and heat wells with thermal storage results

	Energy need		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Top-up heating	1998	1.3	2220	1.5
Heat pump	56500	37.8	13689	9.2
Cooling	8502	5.7	0	0.0
Fans electricity (SFP=2.0)	14302	9.6	14302	9.6
Pumps electricity	6254	4.2	6254	4.2
Lighting	34109	22.8	34109	22.8
DHW	5918	4.0	3694	2.5
	Total electricity:		**74268**	**49.6**

The following figures describe brine outlet temperature from energy piles and heat wells loops. It can be observed, that during summer period heat wells loop is used for “free cooling”. Meanwhile, energy piles loop is loaded with solar thermal storage system.

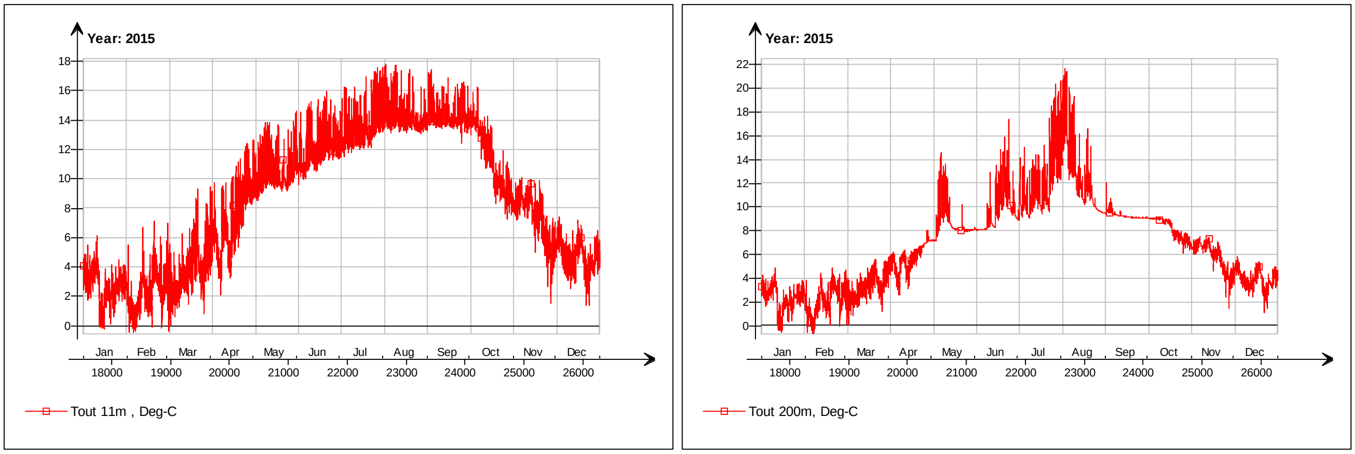


Figure 7. Energy piles brine outlet temperature (left), heat wells outlet temperature (right)

When compared to previous case, temperature in energy piles loop is noticeably higher due to applied solar thermal storage.

Figures below present heat pump evaporator loop inlet temperature and solar collector outlet temperature.

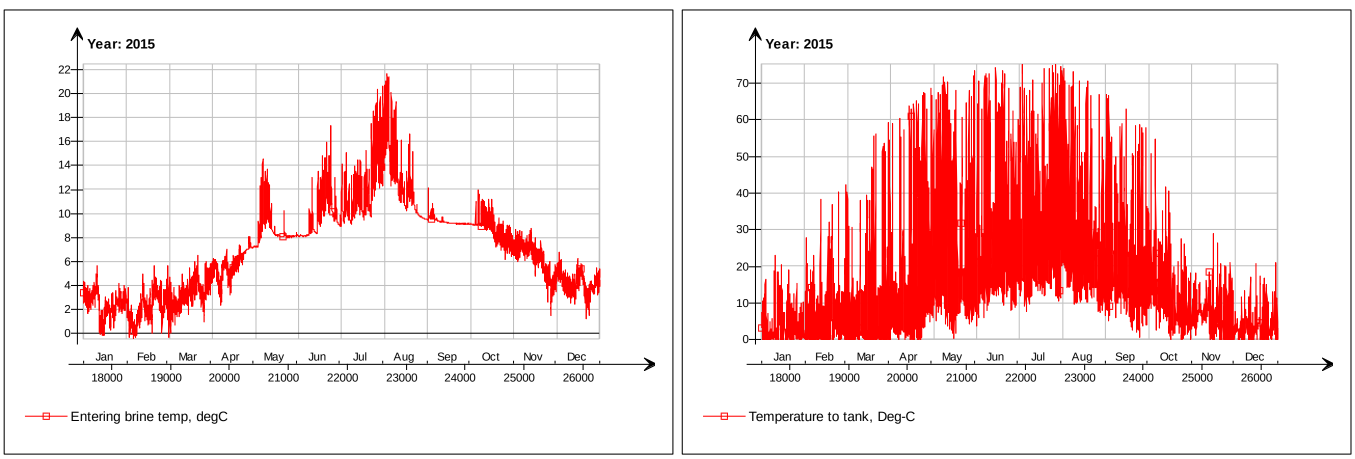


Figure 8. Heat pump evaporator/”free cooling” heat exchanger entering temperature (left), solar collector outlet temperature (right)

4.4. “As Built” phase: Energy piles and heat wells with solar thermal storage (“As Built” case)

Building model initial data is presented in Table 3. There are total of 60x11m energy piles and 2x200m heat wells applied in custom geothermal plant. Solar collectors of total area 24 m^2 with efficiency parameters of “Ruukki Classic” are applied as thermal storage source. Solar collectors are connected via heat exchanger to energy piles inlet side. Geothermal plant operates according to operation principles described in section 3.2. Thermal storage due to floor heat loss is taken into an account. Heat pump capacity was 30 kW.

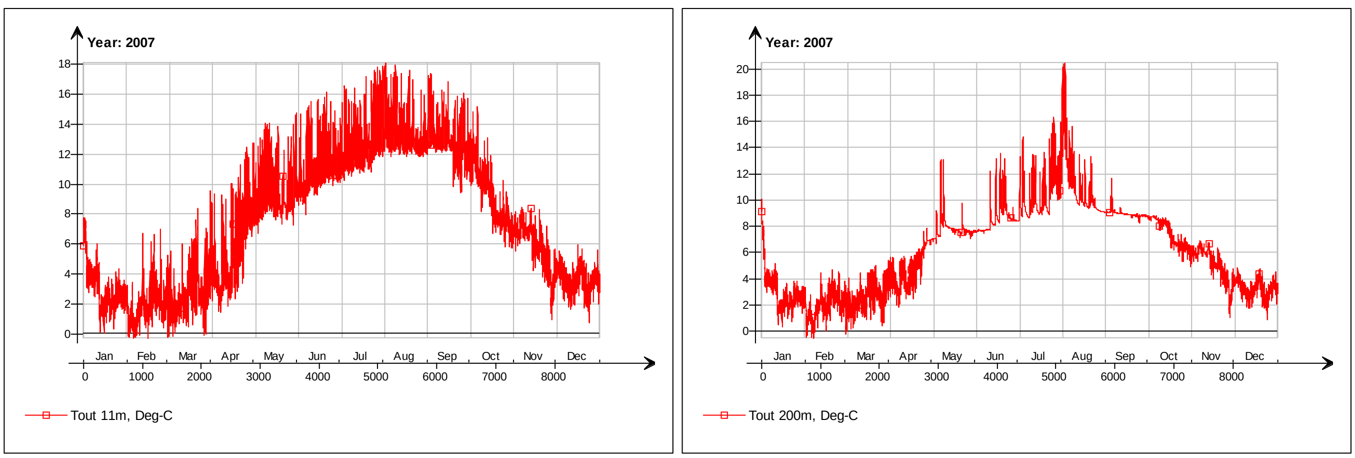
4.4.1. Results

The following table presents the results of energy performance simulation of “AS Built” HAMK Ohutlevykeskus building case.

Table 7. Energy piles and heat wells with thermal storage (“As Built”) results

	Energy need		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Top-up heating	3906	2.6	4340	2.9
Heat pump	61713	41.2	13490	9.0
Cooling	3353	2.2	0	0.0
Fans electricity (SFP=2.0)	14302	9.6	14302	9.6
Pumps electricity	6254	4.2	6254	4.2
Lighting	19498	13.0	19498	13.0
DHW	5918	4.0	3694	2.5
	Total electricity:		**61578**	**41.1**

The following figures describe brine outlet temperature from energy piles and heat wells loops.



Figures below present heat pump evaporator loop inlet temperature and solar collector outlet temperature.

Figure 9. Energy piles brine outlet temperature (left), heat wells outlet temperature (right)

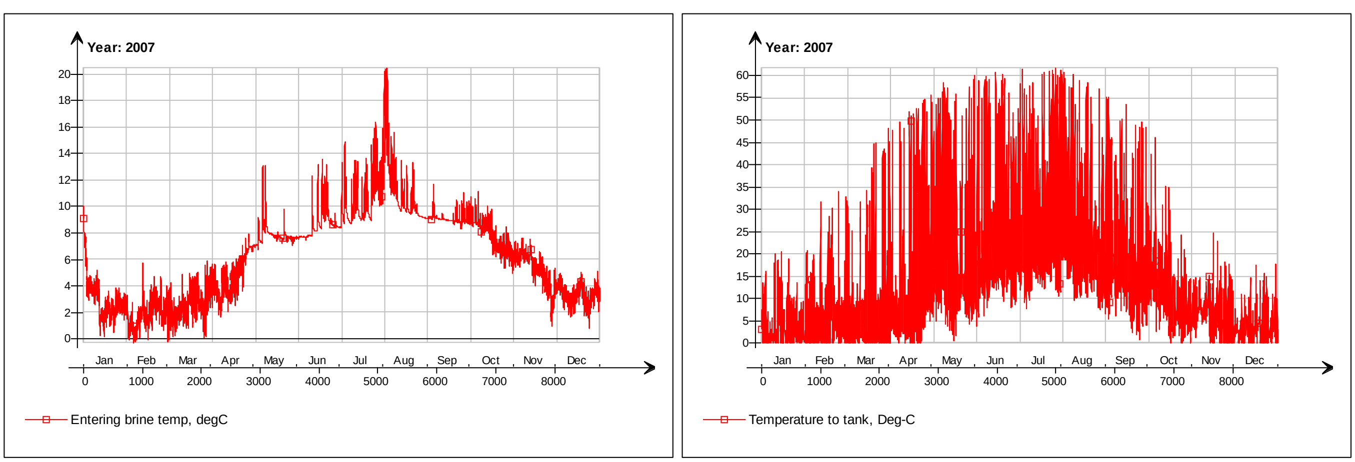
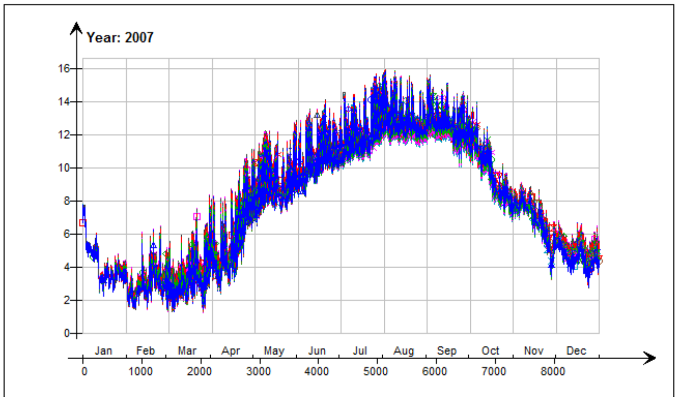


Figure 10. Heat pump evaporator/”free cooling” heat exchanger entering temperature (left), solar collector outlet temperature (right)

The following figures describe soil temperatures at energy piles and heat wells wall. Each pile and well is divided into 10 equal pieces in vertical direction.



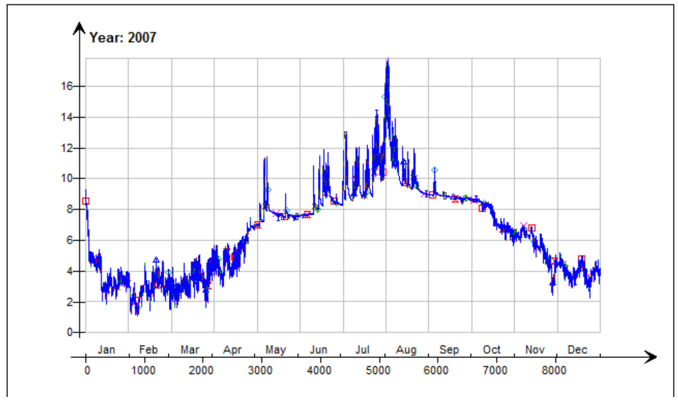


Figure 11. Soil temperatures at energy piles wall (left), soil temperatures at boreholes wall (right)

Energy piles soil temperature figure has 60x10 lines plotted, while heat well has only 10 lines plotted. Higher soil temperature during summer period can be observed in the center of the pile field located closer to surface.

4.5. "As Built" phase: Energy piles without heat wells and without thermal storage

Building model initial data is presented in Table 3. Total of 60x11m energy piles were applied in custom geothermal plant. Thermal storage due to floor heat loss is taken into an account, while no other additional sources of thermal storage persist. Heat pump capacity was 30 kW. Energy piles loop provides "free cooling".

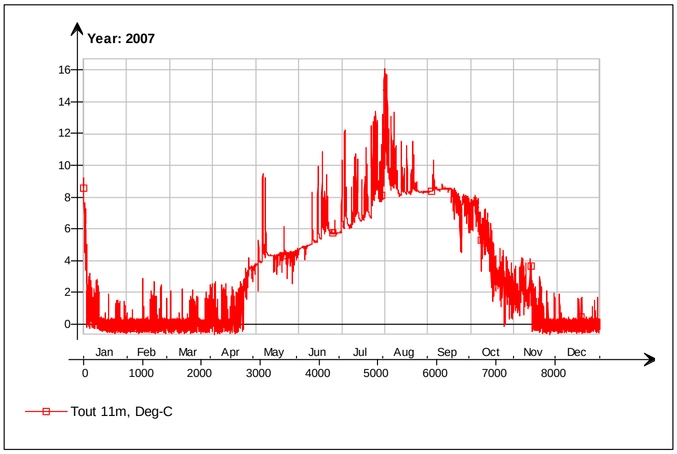
4.5.1. Results

The following table presents the results of energy performance simulation of energy piles without heat wells and without thermal storage.

Table 8. Energy piles without heat wells and without thermal storage results

	Energy need		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Top-up heating	22080	14.8	24534	16.4
Heat pump	41256	27.6	9945	6.6
Cooling	3293	2.2	0	0.0
Fans electricity (SFP=2.0)	14302	9.6	14302	9.6
Pumps electricity	3578	2.4	3578	2.4
Lighting	19521	13.0	19521	13.0
DHW	5918	4.0	3694	2.5
	Total electricity:		**75574**	**50.5**

The following figures describe heat pump evaporator loop inlet temperature and indoor air temperature of hall zone. Most of the time indoor air temperature stays within the desired temperature setpoint of 25 °C.



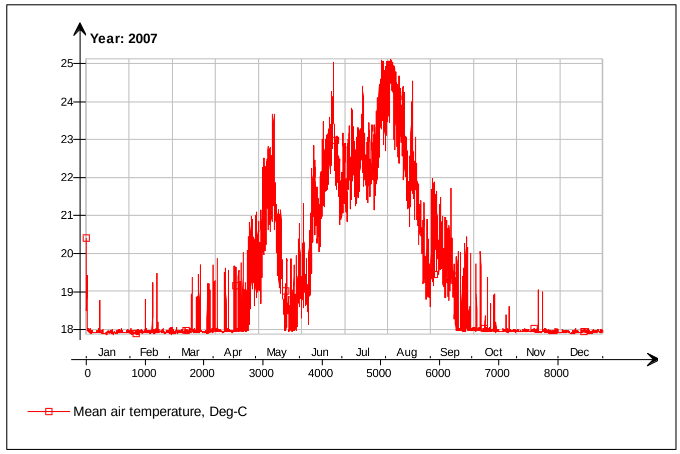


Figure 12. Energy piles brine outlet temperature (left), indoor air temperature (right)

The following figures describe soil temperatures at energy piles wall. Each pile and well is divided into 10 equal pieces in vertical direction. Total of 600 soil temperature lines are plotted.

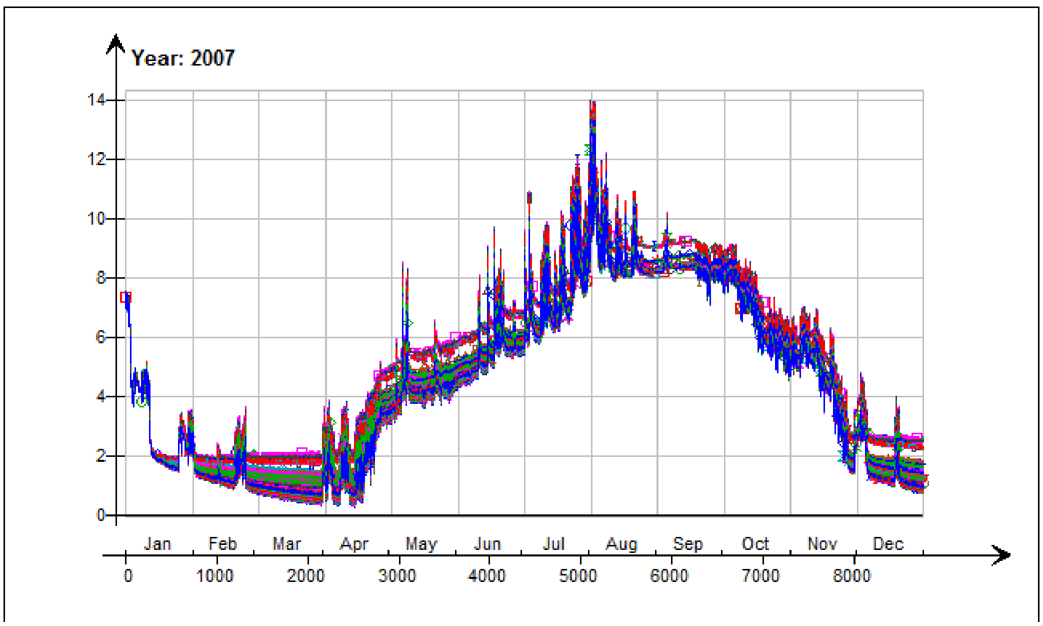


Figure 13. Soil temperatures at energy piles wall

4.6. "As Built" phase: Energy piles with AHU exhaust thermal storage

Building model initial data is presented in Table 3. There are total of 60x11m energy piles are applied in custom geothermal plant. AHU exhaust air heat exchanger is applied as thermal storage source. Thermal storage due to floor heat loss is taken into an account. Heat pump capacity was 30 kW. Energy piles loop also tries to provide "free cooling" when beneficial.

4.6.1. Results

The following table presents the results of energy performance simulation of energy piles with AHU exhaust thermal storage.

Table 9. Energy piles with AHU exhaust thermal storage

	Energy need		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Top-up heating	13595	9.1	15105	10.1
Heat pump	49325	33.0	11910	8.0
Cooling	2852	1.9	0	0.0
Fans electricity (SFP=2.0)	14302	9.6	14302	9.6
Pumps electricity	4454	3.0	4454	3.0
Lighting	19519	13.0	19519	13.0
DHW	5918	4.0	3694	2.5
	Total electricity:		**68984**	**46.1**

AHU exhaust thermal storage source managed to produce 17.04 MWh of thermal storage.

The following figures described energy piles loop outlet temperature and AHU exhaust thermal storage outlet temperature.

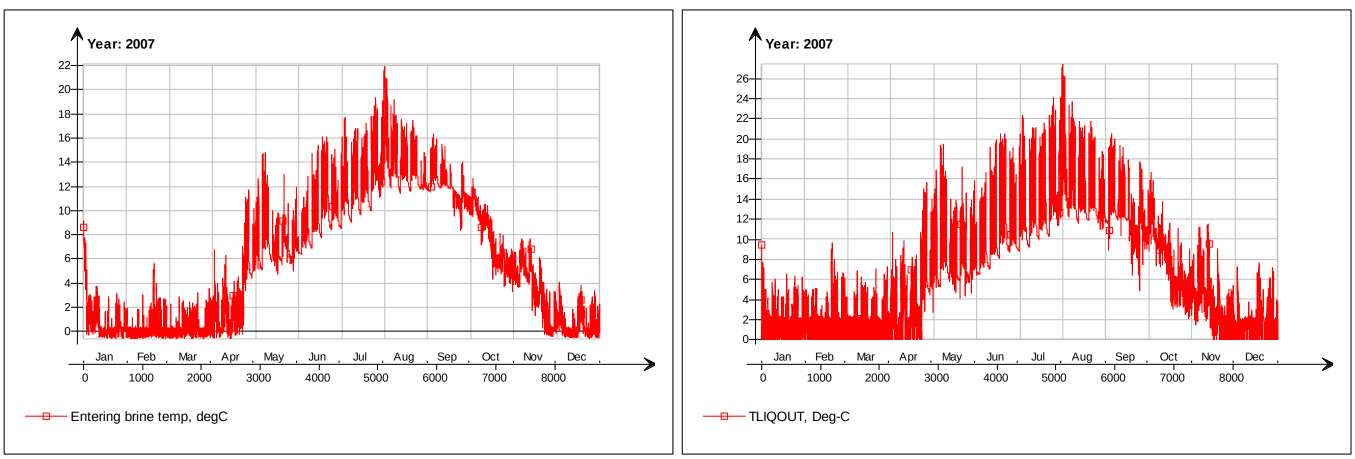


Figure 14. Energy piles brine outlet temperature (left), AHU HX inlet temperature (right)

4.7. "As Built" phase: Energy piles with AHU exhaust and solar thermal storage

Building model initial data is presented in Table 3. There are total of 60x11m energy piles are applied in custom geothermal plant. AHU exhaust air heat exchanger and solar thermal storage are applied as thermal storage source. Solar collectors of area 24 m^2 with efficiency parameters of "Ruukki Classic" are applied in simulation. Thermal storage due to floor heat loss is taken into an account. Heat pump capacity was 30 kW. Energy piles loop also tries to provide "free cooling" when beneficial.

4.7.1. Results

The following table presents the results of energy performance simulation of energy piles with AHU exhaust and solar thermal storage.

Table 10. Energy piles with AHU exhaust and solar thermal storage

	Energy need		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Top-up heating	9688	6.5	10764	7.2
Heat pump	52773	35.3	12696	8.5
Cooling	2107	1.4	0	0.0
Fans electricity (SFP=2.0)	14302	9.6	14302	9.6
Pumps electricity	5727	3.8	5727	3.8
Lighting	19518	13.0	19518	13.0
DHW	5918	4.0	3694	2.5
	Total electricity:		**66701**	**44.6**

AHU exhaust air loaded the energy piles loop with 8.1 MWh and solar storage loaded total of 17.95 MWh.

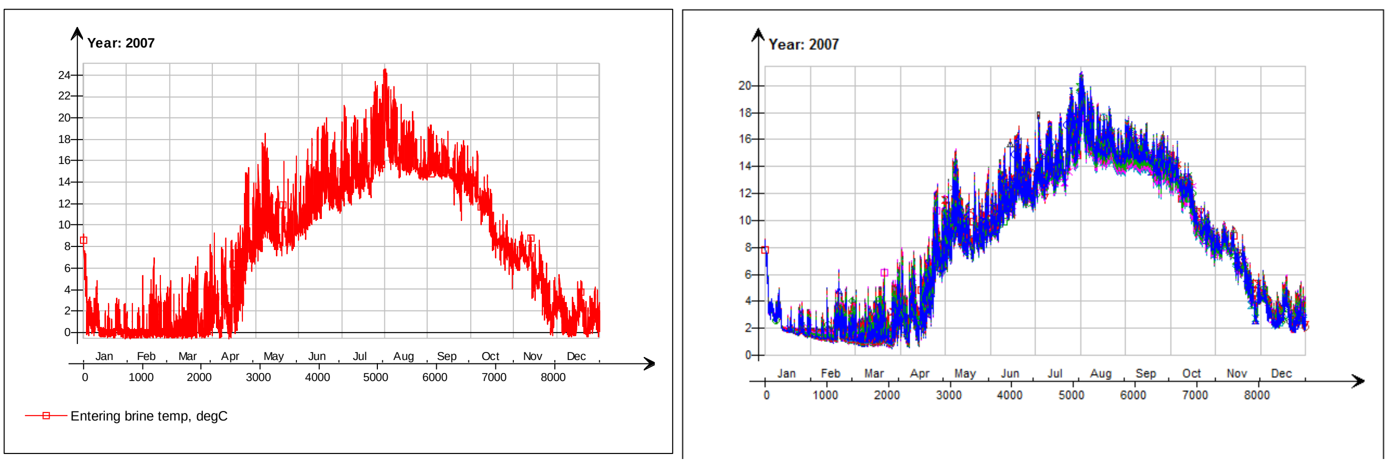


Figure 15. Energy piles brine outlet temperature (left), soil temperature at energy piles wall (right)

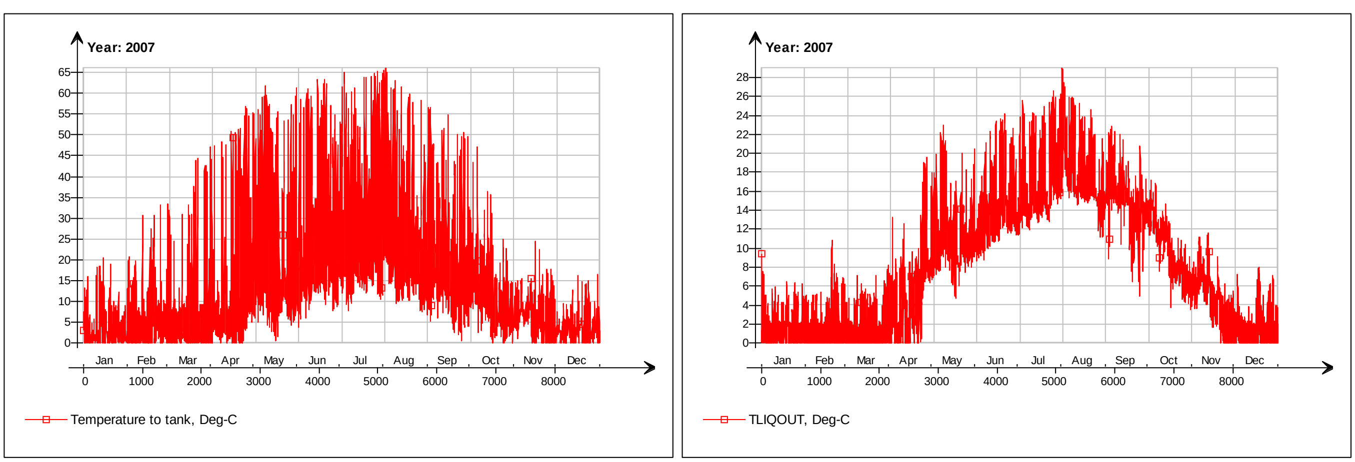


Figure 16. Solar collector outlet temperature (left), AHU HX inlet temperature (right)

4.8. “As Built” phase: Heat pump plant with underground water tank

Aim of this case was to size the underground water storage tank that will be able to guarantee evaporator yield of case 4.5: “As Built” phase: Energy piles without heat wells and without thermal storage.

A tank with total volume of 1548 m^3, surface area 3236 m^2 and wall U-value 0.3 W/m^2K (H = 971 W/K) managed to let the heat pump evaporator to absorb 35.9 MWh VS 35.8 MWh of absorbed evaporator heat in energy piles case with 60x11m energy piles.

The assumptions are, that there is a perfect mixing persists in the tank. Results are only comparable for first year of system operation.

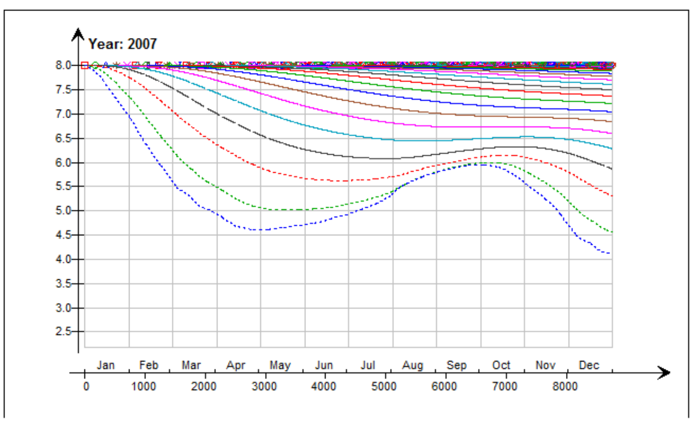
4.8.1. Results

The following table presents the results of energy performance simulation with underground water storage tank coupled with heat pump evaporator part.

Table 11. Heat pump plant with underground water tank

	Energy need		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Top-up heating	15488	10.3	17208	11.5
Heat pump	47319	31.6	11430	7.6
Cooling	3582	2.4	0	0.0
Fans electricity (SFP=2.0)	14302	9.6	14302	9.6
Pumps electricity	3578	2.4	3578	2.4
Lighting	19518	13.0	19518	13.0
DHW	5918	4.0	3694	2.5
	Total electricity:		**69730**	**46.6**

The following figures describe the soil temperatures at tank wall and tank outlet brine temperature.



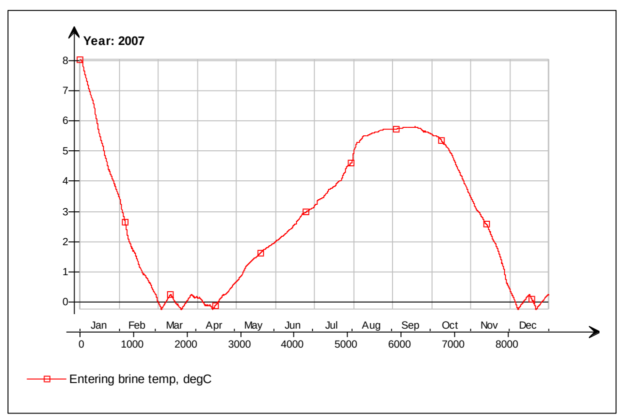


Figure 17. Soil temperature surrounding tank (left), tank outlet temperature (right)